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UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

SCINT 2024

17th International Conference on Scintillating Materials and their Application

University of Milano – Bicocca, Milan, Italy
July 8th - July 12th, 2024

2024 SCINT

Organizing Secretariat:
Promoest srl, Via G. B. Moroni 33, Milano (MI)
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The Local Organising Committee of the
17th International Conference on Scintillating Materials and their Applications
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Table of contents

Presentation letter

Dear colleagues,

We have the pleasure to invite you to attend the forth coming **17th International Conference on Scintillating Materials and their Applications (SCINT2024) that will be held at the University of Milano – Bicocca, Milano, Italy, from July 8th – July 12th, 2024**.

The conference is an international forum on scintillator materials spanning from fundamental aspects to technological applications. Topics include:

- **Mechanisms and theory of scintillation**
- **Characterizations of scintillators**
- **Crystals: growth and structural control**
- **Optical ceramics and glasses**
- **Nano- and metamaterials, hybrids, and other novel materials**
- **Scintillators for fast timing detection and imaging**
- **Scintillators for neutron detection and imaging**
- **Applications of scintillators: fundamental research, health, environment, energy, metrology, industrial controls.**
- **Plenary lectures, keynotes, orals, and poster sessions are planned during the whole week together with several social activities. In addition, a two-day summer school for young researchers on scintillation mechanisms and applications will be organized just before the starting of the conference.**

The submitted conference proceedings will be published on IEEE – Transactions on Nuclear Science after a regular peer-review process.

Abstract submission is now closed, but the registrations for the conference were closed on June 23rd, 2024. News concerning the conference will be posted in this website, which will be constantly updated.

We look forward to receiving your contributions and to building a very exciting scientific program.

See you soon in Milano,

Mauro Fasoli and *Anna Vedda*

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Mauro Fasoli and Anna Vedda

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Invited Speakers

Invited Speaker

VIVEK NAGARKAR

Radiation Monitoring Devices Inc. (USA)

MONDAY, JULY 8TH | 9:00 - 9:45

Scintillators for Neutron Detection and Imaging

Invited Speaker

MAKSYM KOVALENKO

ETH Zurich, Switzerland

TUESDAY, JULY 9TH | 8:45 - 9:30

Highly luminescent perovskite nanocrystals as scintillators: challenges and opportunities

Invited Speaker

YUNTAO WU

Shanghai Institute of Ceramics of the Chinese Academy of Sciences, China

WEDNESDAY, JULY 10TH | 8:45 - 9:30

Recent Advances in Halide Scintillators

Invited Speaker

BENOIT SABOT

Université Paris-Saclay, CEA, LIST (France)

THURSDAY, JULY 11TH | 8:45 - 9:30

Needs and trends in scintillation for radionuclide metrology

Invited Speaker

HAN LIMBURG

Medusa Radiometrics B.V. (Netherlands)

FRIDAY, JULY 12TH | 8:45 - 9:30

Scintillators in the wild – the present and future of gamma-ray sensing in geophysical applications

Sunday, July 7th, 2024

16:00/ 18:00	Registration

Monday, July 8th, 2024

08:00	Registration
08:45	Conference Opening Ceremony
09:00	Invited Speaker
09:45	Session 1: Applications of scintillators (Part 1)
10:15	Coffee Break
10:45	Session 2: Applications of scintillators (Part 2)
12:15	Lunch
13:45	Session 3: Characterizations of scintillators (Part 1)
15:30	Coffee Break
16:00	Session 4: Characterizations of scintillators (Part 2)
16:45	Session 5: TWISMA
18:15	Welcome cocktail

Tuesday, July 9th, 2024

08:45	Invited Speaker
09:30	Session 6: Nano- and metamaterials (Part 1)
10:30	Coffee Break
11:00	SESSION 7: Scintillators for fast timing detection and imaging (Part 1)
12:15	Lunch
13:45	SESSION 8: Mechanisms and theory of scintillation
15:45	Coffee Break
16:15	Poster session

Timetable Overview

Wednesday, July 10th, 2024

08:45	Invited Speaker
09:30	Session 9: Crystals: growth and structural control
10:45	Coffee Break
11:15	Session 10: Optical ceramics and glasses
12:45	Lunch and excursions

Thursday, July 11th, 2024

08:45	Invited Speaker
09:30	Session 11: Characterizations of scintillators (Part 3)
10:15	Coffee Break
10:45	Session 12: Scintillators for neutron detection and imaging
12:00	Lunch
13:30	Session 13: Scintillators for fast timing detection and imaging (Part 2)
15:30	Coffee Break
16:15	Session 14: Nano- and metamaterials (Part 2)
20:00	Gala dinner

Friday, July 12th, 2024

08:45	Invited Speaker
09:30	Session 15: Applications of scintillators (Part 3)
10:15	Coffee Break
10:45	Session 16: Applications of scintillators (Part 4)
12:00	Closing

Scientific Program

Sunday, July 7th, 2024

16:00-18:00 **Registration**

Monday, July 8th, 2024

8:00 **Registration**

8:45 OPENING

9:00 ***Invited speaker***
Scintillators for Neutron Detection and Imaging
Nagarkar V. - Radiation Monitoring Devices Inc. (USA)

SESSION 1: Applications of scintillators (Part 1)

9:45 **The PicoCal for the LHCb Upgrade II: Light-based ECAL Technologies with Picosecond Timing**
Martinazzoli L. - CERN (Switzerland)

10:00 **Ultrafast nanocomposite scintillators based on Cd-enhanced $CsPbCl_3$ nanocrystals in polymer matrix**
Carulli F. - University of Milano-Bicocca (Italy)

10:15 Coffee break

SESSION 2: Applications of scintillators (Part 2)

10:45 ***Keynote***
Cryogenic pure-CsI crystals for neutrino detection potential
Sun X. - Institute of High Energy Physics Beijing (China)

11:15 **The CMS MTD Barrel: design optimization, performance validation and detector construction**
Lucchini M.T. Toliman - INFN and University of Milano-Bicocca (Italy)

11:30 **New developments in the OMNISCINTI™ project: a multiple radiation discrimination with a unique scintillator**
Bertrand G. - Université Paris Saclay, CEA, List (France)

11:45 **Real-in-time dose measurements in brachytherapy procedure using scintillation detectors**
Witkiewicz-Lukaszek S. - Kazimierz Wielki University (Poland)

12:00 **Exploring Cherenkov and Scintillation emission in crystals arrays using Low-Noise High-Frequency electronics**
Terragni G. - Technical University of Vienna (Austria)

12:15 Lunch

SESSION 3: Characterizations of Scintillators (Part 1)

13:45 ***Keynote***
Facts and Fantasy on the organic-inorganic lead halide perovskite scintillators
Dorenbos P. - Delft University of Technology (Netherlands)

14:15 **Crystal Growth and Scintillation Properties of Eu^{2+}-doped $TlSr_2Br_5$**
van Loef E. - Radiation Monitoring Devices, Inc. (USA)

14:30 **Exploring the Scintillation Characteristics of CsCu2I3**
van Blaaderen J. - Delft University of Technology (Netherlands)

14:45 **Scintillation properties of the Cs_2ZrCl_6 crystal over a 5-300 K temperature range**
Nagorny S. - Queen's University (Canada)

15:00 **Magnesium Modified Cesium Lead Bromide**
Buryi M. - Institute of Plasma Physics of the Czech Academy of Sciences (Czech Republic)

15:15 **The PARIS array phoswich characterization with SiPM readout**
Giaz A. - INFN Milano (Italy)

15:30 Coffee break

SESSION 4: Characterizations of Scintillators (Part 2)

16:00 **Low Temperature Properties of Li_2MoO_4 and Na_2MoO_4 crystal for cryogenic phonon detectors**
Xue M. - University of Science and Technology of China (China)

16:15 **The role of Ce^{3+} Co-dopant on Luminescent Enhancement of Bi^{3+} Emission and $Bi^{3+}\rightarrow Bi^{2+}$ Conversion in $LiLaP_4O_{12}$ host**
Valerio M. - Federal University of Sergipe (Brazil)

16:30 **Chalcogenide Scintillators for Modern Cryogenic Detectors for Low Background Nuclear Spectrometry Systems**
Rybalka I. - Institute for Scintillation Materials of National Academy of Sciences of Ukraine (Ukraine)

SESSION 5: TWISMA

16:45 ***Keynote***
Optimization of Ce-doped garnet scintillators by complex codoping with divalent cations
Sidletskiy O. - Institute for Scintillation Materials NAS of Ukraine (Ukraine)

17:15 **Investigating scintillation kinetics of GAGG and YAG for HEP applications, from laboratory to particle beams**
Roux L. – CERN (Switzerland)

17:30 **Improving timing performance of BSO scintillator**
Viahin O. - Institute for Scintillation Materials NAS of Ukraine (Ukraine)

17:45 **Growth and characterization of multicomponent garnets grown under reducing atmosphere**
Kofanov D. - Institute for Scintillation Materials NAS of Ukraine (Ukraine)

18:00 **Impact of Ce, Mg concentrations on the scintillation performance of GAGG shaped single crystals**
Kononets V. - Université Claude Bernard Lyon1 (France)

18:15 - 20:00 Welcome cocktail

Tuesday, July 9th, 2024

8:45 ***Invited speaker***
Highly luminescent perovskite nanocrystals as scintillators: challenges and opportunities
Kovalenko M. – ETH Zurich (Switzerland)

SESSION 6: Nano- and Metamaterials (Part 1)

9:30 **Spectral Dynamics in GaN Photonic Crystal Scintillators: Elucidating Optical Responses Across UV, X-ray, and Alpha Radiation**
Yasar F. - Jet Propulsion Laboratory NASA, Caltech (USA)

9:45 **YAG:$Ce^{3+/4+}$ aerogels: efficiency, timing, diffusion and self-absorption**
Mai P. - Universite Claude Bernard Lyon 1 (France)

10:00 **Fast timing with highly loaded cesium lead halide perovskite nanocomposites**
Mihóková E. - Institute of Physics, Czech Academy of Sciences (Czech Republic)

10:15 **Nanoscintillators for biomedical applications: optimizing the functionalization to control biocompatibility**
Bulin A-L - Université Grenoble Alpes (France)

10:30 Coffee break

SESSION 7: Scintillators for fast timing detection and imaging (Part 1)

11:00 **A new class of plastic scintillators for fast timing detector and medical applications**
Traini M. - INFN National Institute for Nuclear Physics, Roma (Italy)

11:15 **Additive Manufacturing of Structural and Pixelated/Discriminating Scintillators**
Wolverton A. - Nevada National Security Sites (USA)

11:30 **Slow Excitation Transfer via Gadolinium Subsystem in Ce-doped Garnet-type Scintillators and Blocking the Transfer by Aliovalent Codoping**
Tamulaitis G. - Vilnius University (Lithuania)

11:45 **Neutron and Gamma-ray Imaging of Th-232 and Cm-244 using Organic Glass Scintillators**
Lopez R. - University of Michigan (USA)

12:00 **Growth and scintillation characteristics of ultrafast Cs_2ZnCl_4 crystal scintillators**
Shi Y. - Shanghai Institute of Ceramics, Chinese Academy of Sciences (China)

12:15 Lunch

SESSION 8: Mechanisms and theory of scintillation

13:45 ***Keynote***
The Decay of Ultrafast Cross-Luminescence in Binary and Ternary Scintillator Materials
Nagirnyi V. - University of Tartu (Estonia)

14:15 **Photoluminescence and scintillation characteristics of undoped and Ce-doped (Gd,Y)AlO_3 single crystals**
Kotykova M. - Institute of Physics of the Czech Academy of Sciences (Czech Republic)

14:30 **Simulation of Excitation Transfer via Gd Sublattice in Garnet-type Scintillators**
Talochka Y. - Vilnius University (Lithuania)

14:45 **Compositionally Disordered Crystalline Compounds for Novel Scintillation Materials**
Korzhik M. - Belarus State University (Belarus)

15:00 **Design criteria and fundamental limits of Sm2+-doped halide scintillators**
van Aarle C. - Delft University of Technology (Netherlands)

15:15 **Influence of partial substitution of aluminum and gallium by scandium ions on energy transfer proceses in garnet crystals**
Spassky D. - University of Tartu (Estonia)

15:30 **Unveiling Temperature-Dependent Scintillation Mechanisms in Toluene: Insights from X-ray and Optical Excitation Studies**
Wolszczak W.W. - Lawrence Berkeley National Laboratory (USA)

15:45 Coffee break

16:15 - 18:15 **Poster session**

Scientific Program

Wednesday, July 10th, 2024

8:45 ***Invited speaker***
Recent Advances in Halide Scintillators
Wu Y. - Shanghai Institute of Ceramics of the Chinese Academy of Sciences (China)

SESSION 9: Crystals: Growth and structural control

9:30 ***Keynote***
Flux growth of oxide scintillators for neutron detection
Kodama S. - Saitama University (Japan)

10:00 **Room Temperature-Grown $CsCu_2I_3$ Perovskite Crystal via Solution Processing: Unveiling Scintillation Properties**
Gourishetty A.K. - Indian Institute of Technology Roorkee (India)

10:15 **Oxide single crystals with high melting point grown by advanced micro-pulling-down method**
Yokota Y. - Tohoku University (Japan)

10:30 **Highly Efficient Solution Synthesis, Crystal Growth, and Scintillation Properties of Cs_2TeCl_6**
Lewis M. - Queen's University (Canada)

10:45 Coffee break

SESSION 10: Optical ceramics and glasses

11:15 ***Keynote***
Role of Cerium Concentration on Defect-driven Luminescence Phenomena in GAGG Ceramics Obtained by Reactive Sintering
Moretti F. - Lawrence Berkeley National Laboratory (USA)

11:45 **Structure-property relationship of scintillating garnet optical ceramics towards effective radiation detection schemes**
Cova F. - University of Milano-Bicocca (Italy)

12:00 **Online Radiation Induced Attenuation measurements of Radiophotoluminescence Dosimeters irradiated with X-rays: Dose rate dependence at high doses**
Raj Mandal A. - Université Jean Monnet (France)

12:15 **Temperature Dependence of Hafnate Scintillators**
Kurosawa S. - Tohoku University (Japan)

12:30 **Effects of Ce concentration on the structural and optical properties in Ce:GAGG ceramic scintillators**
Bowman W. - University of Central Florida (USA)

12:45 Lunch and excursions

Thursday, July 11th, 2024

8:45 ***Invited speaker***
Needs and trends in scintillation for radionuclide metrology
Sabot B. - Université Paris-Saclay, CEA, LIST (France)

SESSION 11: Characterizations of cintillators (Part 3)

9:30 **Influence of Dual-Organic-Cation on Optical and Scintillation Properties in Perovskite Single Crystal Scintillators**
Kuddus Sheikh M.A. - PORT Polish Center for Technology Development (Poland)

9:45 **Radiation resistance of the Muon Collider Crilin calorimeter prototype equipped with Cherenkov lead fluoride crystals**
Verna A. - ENEA Nuclear Department, Casaccia Research Center (Italy)

10:00 **Performance Characterization of Organic Glass Scintillators**
Maurer T. - University of Michigan (USA)

10:15 Coffee break

SESSION 12: Scintillators for neutron detection and imaging

10:45 ***Keynote***
Melt-Blended Organic Scintillators for High Efficiency Neutron Imaging
Myllenbeck N. - Sandia National Laboratories (USA)

11:15 **Design of Novel Capture-gated Neutron Spectrometer with a CLYC(Ce) scintillator**
Park H.W. - Korea Research Institute of Standards and Science (Republic of Korea)

11:30 **Enabling fast neutron spectroscopy in CLYC through advanced pulse shape discrimination**
Laplace T. - University of California (USA)

11:45 **Lithium-6 neutron scintillators**
Jongman J. - Scintacor (United Kingdom)

12:00 Lunch

SESSION 13: Scintillators for fast timing detection and imaging (Part 2)

13:30 ***Keynote***
Prospects for the use of scintillators in photon-counting CT scanners
Schaart D. - Delft University of Technology (Netherlands)

14:00 **Relaxation Processes Leading to Ultrafast Luminescence in K_2SiF_6 and Na_2SiF_6 Studied Under Synchrotron Radiation Excitation**
Kirm M. - University of Tartu (Estonia)

Scientific Program

14:15 **Cross-luminescence in cesium-based ternary fluorides**
Vanecek V. - JSPS International Research Fellow - Sendai (Japan)

14:30 **Investigation of Timing Properties of Tl_2LaCl_5:Ce crystal Scintillators for PET Applications**
Kim H.J. - Kyungpook National University (Republic of Korea)

14:45 **$(Gd,Lu,Y)_3Al_2Ga_3O_{12}$:Ce,Mg with optimized coincidence time resolution for PET-TOF scanners**
Novotny R. - Justus Liebig University (Germany)

15:00 **Metal-Loaded Organic Glass Scintillators for Gamma-Ray Spectroscopy**
Witzke R. - Sandia National Laboratories (USA)

15:15 **A novel scintillator detector for online high-resolution proton beam profiling**
Leccese V. - CSEM SA Neuchâtel (Switzerland)

15:30 Coffee break

SESSION 14: Nano- and metamaterials (Part 2)

16:00 ***Keynote***
A few recent developments in nanophotonic scintillators
Roques-Carmes C. - Stanford University (USA)

16:30 **Tailoring the Purcell enhancement in nanoplasmonic perovskite scintillators**
Kowal D. - PORT Polish Center for Technology Development (Poland)

16:45 **Improving the scintillating sensors properties: nanoparticles and nanocomposites**
de Oliveira Lima K. - CEA-Saclay (France)

17:00 **Halide- and oxide-based composite, nano and meta materials: comparison and luminescent properties**
Cuba V. - Czech Technical University in Prague (Czech Republic)

17:15 **Sensitized triplet-triplet annihilation in nanostructured polymeric scintillators allows for pulse shape discrimination**
Hu X. - Adolphe Merkle Institute at University of Fribourg (Switzerland)

17:30 **Latest Developments on Low-Dimensional Lead-Free Rb-based Metal Halides for Radiation Detection**
Mulholland R. - University of Surrey (United Kingdom)

17:45 **Reabsorption-free scintillating MOF crystals activated by ultrafast energy transfer**
Perego J. - University of Milano-Bicocca (Italy)

18:00 **Recent advancements in development of composite scintillators based on epitaxial structures of oxide compounds**
Zorenko Y. - Kazimierz Wielki University in Bydgoszcz (Poland)

20:00 *Gala dinner* - *Società Umanitaria - via San Barnaba 48 - Milano*

Friday, July 12th, 2024

8:45 ***Invited speaker***
Scintillators in the wild – the present and future of gamma-ray sensing in geophysical applications
Limburg H. - Medusa Radiometrics B.V. (Netherlands)

SESSION 15: Applications of scintillators (Part 3)

9:30 **The CUPID neutrinoless double-beta decay experiment**
Di Domizio S. – Università di Genova (Italy)

9:45 **A monocrystal based detection unit for semi-continuous determination of tritium in wastewater samples**
Fejgl M. - SÚRO, v.v.i. (Czech Republic)

10:00 **Multicomponent nanoscintillators in radiotherapy and Alzheimer's disease treatment**
Villa I. - University of Milano-Bicocca (Italy)

10:15 Coffee break

SESSION 16: Applications of scintillators (PART 4)

10:45 ***Keynote***
Potential of radioluminescence for phototherapy in the treatment of Parkinson's disease
Muñoz Velasco I. - Univ. Grenoble Alpes, CEA, Leti (France)

11:15 **An overview of the CMS High Granularity Calorimeter and its current status**
Yi-Mu Chen – University of Maryland (USA)

11:30 **Multi-energy imaging of SiPM-based photon-counting CT using Ce:YGAG scintillators compared with clinical dual-energy CT**
Sato D. - Tohoku University (Japan)

11:45 **Nanoparticle-based Scintillating Aerogels for Real-time Radioactive Gas Detection**
Cheref Y. – Université Claude Bernard (France)

12:00 CLOSING

Oral Sessions

Oral Sessions | Summary

Scintillators for Neutron Detection and Imaging

Vivek V Nagarkar
Radiation Monitoring Devices Inc., 44 Hunt Street, Watertown, MA 02472, USA

Unlike X-rays, which interact with electron clouds, neutrons interact with nuclei. Consequently, neutrons provide complementary information to that obtained using X-ray-based techniques. This unique interaction, along with their neutral charge and near-zero electric dipole moment, has been exploited by researchers in a wide variety of fields, from materials research to nondestructive testing. Traditional reactor-based and spallation neutron sources and compact neutron generators have made significant advances in recent years, enabling research in diverse areas, including chemistry, earth sciences, engineering, and solid-state physics. The high brilliance of these sources has even made dynamic imaging possible, a capability previously restricted to the X-ray domain.

The future of neutron sources is oriented towards making them more accessible, efficient, and powerful. Innovations in accelerator technology, target materials, and neutron detection are expected to drive new discoveries and expand the use of neutrons in diverse fields, from fundamental science to practical industrial applications. Collaboration between international research facilities and the development of next-generation sources will likely continue to enhance the capabilities and applications of neutron science. Consequently, our community now faces the challenge of developing efficient converters that can simultaneously provide fast response, wide dynamic range, effective gamma discrimination, high spatial resolution, and response uniformity across the sensitive area for thermal to fast neutron energies.

Research institutions and industry have been actively pursuing the development of semiconductor and scintillator detectors for gamma rays, X-rays, charged particles, and neutrons. Additionally, significant progress has been made in the development of advanced elpasolites, plastics, and organic glass scintillators capable of discriminating between neutron and gamma interactions based on pulse shape discrimination. This presentation will provide a summary of neutron detectors, highlighting RMD's contributions to the field over the past five decades as it celebrates 50 years of business in August 2024. It will cover the basics of neutron interactions with matter and neutron detection and outline recent developments in thermal and fast neutron scintillators and their applications. The presentation will also include details on crystal growth, film growth, and PSD/PHD characterization of various materials, as well as examples of systems developed using advanced scintillators.

SESSION 1: APPLICATIONS OF SCINTILLATORS (PART 1)

M-AP1 The PicoCal for the LHCb Upgrade II: Light-based ECAL Technologies with Picosecond Timing

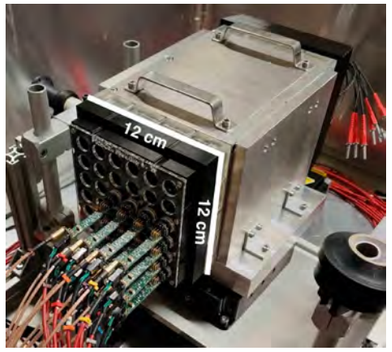
Loris Martinazzoli[1], *On behalf of the LHCb ECAL Upgrade II R&D group*
[1]European Organization for the Nuclear Research (CERN), Geneva, Switzerland

Corresponding Author Email: loris.martinazzoli@cern.ch

The aim of the LHCb Upgrade II at the LHC is to operate at a luminosity of 1.5 x 10^{34} cm^{-2} s^{-1} to collect a data set of 300 fb^{-1}. This will require a substantial modification of the current LHCb ECAL due to high radiation doses in the central region and increased particle densities [1].

Spaghetti calorimeter (SpaCal) and Shashlik technologies based on scintillation light are currently being investigated.

The baseline design includes both organic and inorganic scintillators: the region facing up to 1 MGy of radiation dose will be equipped with inorganic crystal garnets, whereas the region with radiation doses up to 200 kGy with organic scintillators. An intense R&D campaign is ongoing to identify and optimize the scintillators. This includes accelerating the scintillation of the garnets to cope with the high particle rate, and developing radiation-tolerant plastics, for instance with organic dyes or nanomaterials embedded in polysiloxane hosts.



Picture of the SpaCal prototype with 3D-printed Tungsten absorber and polystyrene scintillanting fibres

Calorimeter prototypes with cast lead and 3D-printed tungsten absorbers were produced and tested, comparing different scintillators, studying optical couplings, and testing multiple readout configurations with fast photodetectors.

Energy resolutions showed sampling and constant terms of about 10% / sqrt(E) and 1%, respectively, while the time resolution reached 10 ps [2, 3]. The results are in agreement with detailed Monte Carlo simulations.

The prototypes successfully reach the target performance, but further optimisation of the scintillating materials is mandatory to cope with the Upgrade II environment. This contribution presents the latest testbeam results and gives an overview of the ongoing R&D for the organic and inorganic scintillators.

1. The LHCb Collaboration, Framework TDR for the LHCb Upgrade II: Opportunities in flavour physics, and beyond, in the HL-LHC era, 2021, LHCB-TDR-023, https://cds.cern.ch/record/2776420

2. An L. et al., Performance of a spaghetti calorimeter prototype with tungsten absorber and garnet crystal fibres, NIM A, 2023, 1045, 167629, https://doi.org/10.1016/j.nima.2022.167629

3. The LHCb Collaboration, LHCb Particle Identification Enhancement Technical Design Report, 2023, LHCB-TDR-024-001, http://dx.doi.org/10.17181/CERN.LAZM.F5OH

Oral Sessions | Monday, July 8th 2024

M-AP2 Ultrafast nanocomposite scintillators based on Cd-enhanced CsPbCl3 nanocrystals in polymer matrix

Francesco Carulli[1], Andrea Erroi[1], Francesca Cova[1], Isabel Frank[2,7], Matteo L. Zaffalon[1], Jordi Llusar[3], Sara Mecca[1], Alessia Cemmi[4], Ilaria Di Sarcina[4], Francesca Rossi[5], Anna Vedda[1], Luca Beverina[1], Francesco Meinardi[1], Ivan Infante[3,6], Etiennette Auffray[2] and Sergio Brovelli[1]

[1]*Dipartimento di Scienza dei Materiali, Università degli Studi Milano-Bicocca, via R. Cozzi 55, 20125, Milano, Italy*
[2]*CERN, Esplanade des Particules 1, 1211 Meyrin, Switzerland*
[3]*Basque Center for Materials, Applications, and Nanostructures, UPV/EHU Science Park, Leioa 48940, Spain*
[4]*ENEA Fusion and Technology for Nuclear Safety Department, Casaccia, Via Anguillarese 301, 00123 Rome, Italy.*
[5]*IMEM-CNR Institute, Parco Area delle Scienze 37/A, 43124 Parma, Italy.*
[6]*Ikerbasque Basque Foundation for Science, Bilbao 48009, Spain*
[7]*Ludwig Maximilian University, 80539 Munich, Germany*

Corresponding Author Email: francesco.carulli@unimib.it

Lead halide perovskite nanocrystals (LHP-NCs) in polymeric matrices are gaining attention for next-, generation radiation detectors that combine the high efficiency of inorganic crystals with the scalability of plastic composites[1]. Despite notable progress on green-emitting $CsPbBr_3$ NCs[2,3], no study to date has addressed the scintillation properties of $CsPbCl_3$ NCs, which exhibit size-tunable ultrafast emission in the UV-blue region (~415 nm), matching the peak efficiency of ultrafast photodetectors and offering a valuable alternative to conventional fast scintillators based on Cherenkov emission or cross-luminescence. Here, we investigate the scintillation properties of $CsPbCl_3$ NCs synthesized via a scalable route and resurfaced with $CdCl_2$, resulting in >90% emission efficiency and improved stability towards polymerization of polyacrylate nanocomposites. Spectroscopic and radiometric experiments complemented by density functional theory calculations reveal the presence of deep hole trap states arising from surface undercoordinated chloride ions, which are completely eliminated by a Pb to Cd substitution. Radiation hardness studies reveal exceptional stability to high gamma doses and time-resolved radioluminescence experiments show excitonic scintillation with average lifetime as short as 1.7 ns arising from ultrafast multiexciton decay. These results extend our understanding of the scintillation properties of LHP NCs and make $CsPbCl_3$ a potential candidate for highly scalable ultrafast scintillator nanocomposites.

1. A. Anand, M. L. Zaffalon, A. Erroi, F. Cova, F. Carulli, S. Brovelli, "Advances in Perovskite Nanocrystals and Nanocomposites for Scintillation Applications", ACS Energy Letters, 9, 3 (2024).

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F. Rossi, F. Cova, K. Pauwels, M. Mauri, J. Perego, V. Pinchetti, A. Comotti, F. Meinardi, A. Vedda,
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This work was funded by Horizon Europe EIC Pathfinder program through project 101098649 – UNICORN, by the PRIN program of the Italian Ministry of University and Research (IRONSIDE project), by the European Union—NextGenerationEU through the Italian Ministry of University and Research under PNRR—M4C2-I1.3 Project PE_00000019 "HEAL ITALIA"

SESSION 2: APPLICATIONS OF SCINTILLATORS (PART 2)

M-AP3 Cryogenic pure-CsI crystals for neutrino detection potential

Xilei Sun[1]

[1]*Institute of High Energy Physics, CAS, Beijing, China*

Corresponding Author Email: sunxl@ihep.ac.cn

This report will detail a leading scintillation light yield among inorganic crystals, as measured from a 0.5 kg pure-CsI detector operating at 77 Kelvin[1]. Detection of scintillation photons was achieved using two 2-inch Hamamatsu SiPM arrays outfitted with cryogenic front-end electronics. The combination of pure-CsI's enhanced light yield at low temperatures and SiPM's high photon detection efficiency enabled a light yield of 30 photoelectrons per keV energy deposit for X-rays and γ–rays ranging from 5.9 keV to 60 keV. The report will thoroughly analyze both instrumental and physical effects impacting the light yield measurement. This marks the first stable cryogenic operation of a kg-scale pure-CsI crystal, read by SiPM arrays, at liquid nitrogen temperatures over several days. The exceptional light yield achieved positions pure-CsI crystal for diverse applications, especially in detecting coherent elastic neutrino-nucleus scattering from reactor neutrinos. This report will discuss the potential applications of pure-CsI crystals in neutrino physics.

1. L. Wang, G. d. Li, Z. Y. Yu, X. H. Liang, T. A. Wang, F. Liu, X. L. Sun, C. Guo, X. Zhang, "Reactor neutrino physics potentials of cryogenic pure-CsI crystal," arXiv:2212.11515 [physics.ins- det].

Acknowledgments

The study is supported in part by the National Natural Science Foundation of China (Grant No. 11975257 and Grant No. 12275289), the State Key Laboratory of Particle Detection and Electronics (SKLPDE-ZZ-202116), and the Youth Innovation Promotion Association of Chinese Academy of Sciences.

M-AP4 The CMS MTD Barrel: design optimization, performance validation and detector construction

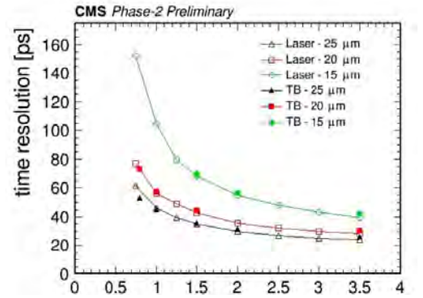
Marco Toliman Lucchini[1,2] *on behalf of the CMS Collaboration*
[1]*University of Milano-Bicocca, Milano, Italy*
[2]*INFN Sezione di Milano-Bicocca, Milano, Italy*

Corresponding Author Email: marco.toliman.lucchini@cern.ch

The High Luminosity phase of the Large Hadron Collider (HL-LHC), scheduled to start in 2029, will provide an unprecedented integrated luminosity of about 3000 fb-1 over 10 years of operations, and will constitute a unique opportunity for the experiments to perform precision measurements and search for rare processes. Such a large proton-proton collision dataset will be collected at the price of harsh experimental conditions, namely a large number of interactions per bunch crossing - up to 200 - and extremely high radiation levels, posing a challenge for the detectors' operation.

To mitigate the adverse effects of pileup, the CMS Experiment Upgrade will include a novel detector, the Mip Timing Detector (MTD), to facilitate the association of each particle with its interaction vertex through precision timing measurements. Its barrel section, the Barrel Timing Layer (BTL), will make use of about 166,000 scintillating LYSO:Ce crystals coupled to about 332,000 custom developed Silicon Photomultipliers. The key design features of the BTL detector, exploiting such a technology for the first time in such a harsh radiation environment and for a large area detector, will be presented.

The optimization and validation of the detector time resolution in measuring charged particles with a precision of ~30 ps at startup, degrading to ~60 ps at the end of operation due to the SiPMs radiation damage (neutron fluence of 2E14 1 MeV n_{eq}/cm^2) has been achieved with dedicated test beam campaigns on final module prototypes. A report on the status of the crystal and SiPM production and qualification along with the ongoing detector assembly, which has started in early 2024, will be presented.



M-AP5 New developments in the OMNISCINTI™ project: a multiple radiation discrimination with a unique scintillator.

Guillaume H.V. Bertrand[1], Pauline Vergnory[1], Matthieu Hamel[1], Camille Frangville[1], Victor Buridon[1], Dominique Tromson[1]
[1]*Université Paris Saclay, CEA, List, F-91120 PALAISEAU, FRANCE*

Corresponding Author Email: Guillaume.bertrand@cea.fr

When facing unknown sources of radiation, first responders are often confronted to the problem of choosing an apparatus to evaluate the nature of the contamination. Multiple detection solutions exist, but each of them are specific and assume previous knowledge of the radiation nature. The Omniscinti™ technology developed in CEA/LCIM answer this challenge by performing efficient separation of the five types of ionizing radiation that can be encounter (α, β, γ, n_{fast}, $n_{thermal}$).

Omniscinti™ is a triple layer fully organic phoswich with each layer designed for optimal detection and separation of radiation type. This conception step implies optimization of the thickness, chemical composition and photophysics properties of each scintillating layer. α, β contribution signals are mainly separated using differences in penetration power hence using an ultra-thin (α), and a thin layer (β) to separate this contributions. γ, n_{fast}, $n_{thermal}$ are separate in the third and thickest layer using our home made, 6 lithium doped, triple discriminating plastic scintillator. Each layer is designed with a specific scintillation decay time and a specific thickness that enable simultaneous detection and separation of the five emitter contributions using Pulse Shape Discrimination (PSD) method.

We present here a concise overview of the Omniscinti™ principle as well as an in depth discussion of the key design choices to achieve quintuple discrimination. Plastic scintillator compositions and thickness were optimized, especially concentration of fluorophores were tuned to adapt decay time in a range from 2.5 ns to 90 ns. We present our recent characterization of a pre-prototype set-up with several radiations sources and different emitters. We especially investigate the challenge of optical isolation and the tradeoff it induces on alpha detection. Our main goal is to quantify the detection limits for all radiations and a possible multi-radiation calibration.

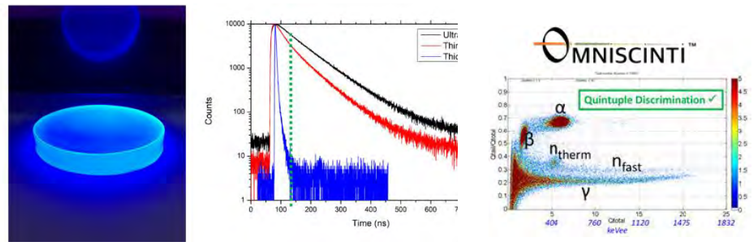


Figure 1: Left: photo of an Omniscinti™; Center TCSPC decay time of individual layer; Right: Bidimentional PSD graph that shows quintuple discrimination

Acknowledgments:

This project has received funding from the French NRBC-E research program.

Oral Sessions | Monday, July 8th 2024

M-AP6 Real-in-time dose measurements in brachytherapy procedure using scintillation detectors

Sandra Witkiewicz-Lukaszek[1*], Bogna Sobiech[2], Janusz Winiecki[2,3], Yuriy Zorenko[1,2]

[1]Physical Faculty of Kazimierz Wielki University, 85-090 Bydgoszcz, Poland
[2]Oncology Center, Medical Physics Department, 85-796 Bydgoszcz, Poland
[3]Collegium Medicum of Nicolaus Copernicus University, 85-067 Bydgoszcz,Poland

Corresponding author email: sanwit@ukw.edu.pl

Conventional detectors based on ionization chambers, semiconductors or thermoluminescent (TL) materials in principle cannot be used for in vivo verification of the dose delivered in brachytherapy procedures with γ–rays sources. The first approach to solve this problem is to use dosimetric materials that can be placed in the patient's body to record the delivered radiation dose using the OSL detectors [1]. Recently, we consider testing of well-known dosimetric TL/OSL Al_2O_3:C, Al_2O_3:C,Mg and BeO crystals to measure the radiation dose during brachytherapy treatment [2]. Meanwhile, the complication of OSL detector is the use of two optical pathways in the fiber to stimulate and record OSL light. However, we found also that not only the OSL modes of the efficient OSL materials (Al_2O_3:C and BeO), but also their scintillation properties, such as intensity and emission spectra of radioluminescence (RL), can also be used for in situ dose determination [3]. This measurement method can be performed in real time, absolutely non- invasively, using very sensitive compact spectrometers equipped with a long optical fiber terminated with scintillation crystals located intracavitary next to the tumour.

In this work, the scintillation detectors based on the YAG:Ce (ρ=4.5g/cm^3; Z_{eff}=35), LuAG:Ce (ρ=6.75 g/cm^3; Z_{eff}=63) and GAGG:Ce (ρ=6.63 g/cm^3; Z_{eff}=54.4) garnet crystals with different density and effective atomic number Z_{eff} as well as tissue-equivalent Al_2O_3:C and Al_2O_3:C,Mg crystals (ρ=3.95 g/cm^3; Z_{eff}=10.2) with 2*2*1mm size were tested. The measurements were performed in the clinical conditions of the Oncology Center in Bydgoszcz for in-situ measurement of applied dose in the 0.05-8 Gy range at brachytherapy treatment procedure with of ^{192}Ir source (392 keV).

The obtained results are very promising. We observed a very good linear correlation between the dose and signal registered by detector based on the GAGG:Ce crystal. Close to linear dependence between the dose and intensity of scintillation response was obtained also for tissue equivalent Al_2O_3:C crystals. However, due to low density and Z_{eff} for this material the scintillation signal is significantly lower than that for GAGG:Ce crystals.

The proposed method is fully non-invasive and safe. The crystal with close-to tissue density can be used in any location, including the respiratory ways, because they do not interfere with dose distribution. However, there are many cases of radiation therapy where the detector can be located behind the target. In this case, the use of heavy, high-density and high-Z_{eff} scintillators is strongly preferred.

Acknowledgement

This work was performed in the frame of Polish NCN 2022/47/I/ST8/02600 project. References

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M-AP7 Exploring Cherenkov and Scintillation emission in crystals arrays using Low-Noise High-Frequency electronics

Giulia Terragni[1,2], Elena Tribbia[1,3], Carsten Lowis[1,4], Fiammetta Pagano[5], Joshua W. Cates[6], Marco Pizzichemi[1,3], Johann Marton[2], Etiennette Auffray[1]

[1]CERN, Geneva, Switzerland
[2]Technical University of Vienna, Vienna, Austria
[3]University of Milano-Bicocca, Milano, Italy
[4]RWTH Aachen University, Aachen, Germany
[5]Instituto de Instrumentación para Imagen Molecular (I3M), Valencia, Spain
[6]Lawrence Berkeley National Laboratory CA, USA.

Corresponding Author Email: giulia.terragni@cern.ch

BGO offers a compelling solution to increase the sensitivity and decrease the cost of time-of-flight positron emission tomography (TOF-PET) detectors. On the other side, the timing is affected by its slow decay time compared to LYSO. By layering BGO and plastic in a heterostructured concept, the detector benefits from the properties of both materials: the high stopping power of BGO and the fast timing of plastic.

In order to identify and exploit the fast light production of these materials, Cherenkov radiation of BGO and scintillation of plastic, high-frequency and low-noise electronics is needed. It enables fast signal processing, by lowering the leading edge detection threshold, using the first photons produced in the crystals.

Up to now, only single-pixels of BGO and heterostructured scintillators have been studied using high-frequency electronics. In this work, we measure the energy and time resolutions of 4x4 matrices of BGO and heterostructures (made of alternating layers of 250 µm of BGO and plastic), investigating the potential of using low-noise low-power high-frequency electronics to process the signals from matrices of scintillators with different light production mechanisms.

Despite the layering structure decreasing the light output, light attenuation is correlated to the depth-of-interaction (DOI) of the gamma and can be exploited to extract the information on the DOI. Therefore, the next steps include the application of a light guide on top of the matrix to extract the DOI information by means of the light-sharing mechanism. The timing performance will be evaluated and the improvement using the information on the DOI of the gamma estimated.

This work is carried out in the framework of the Crystal Clear Collaboration and supported by CERN Austrian and Gentner (grant no. 13E18CHA) Doctoral Programmes and Knowledge Transfer budget. The development of the readout boards was supported by the National Institute of Biomedical Imaging and Bioengineering under award 5TR01EB028286.

Oral Sessions | Monday, July 8th 2024

SESSION 3: CHARACTERIZATIONS OF SCINTILLATORS (PART 1)

M-CA1 Facts and Fantasy on the organic-inorganic lead halide perovskite scintillators

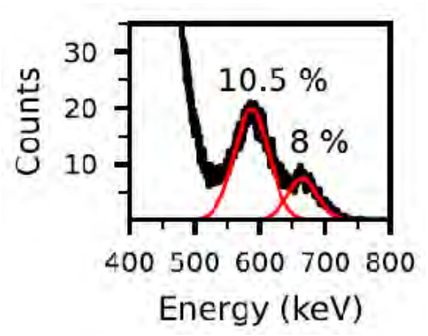
Pieter Dorenbos and Jasper. J. van Blaaderen

Delft University of Technology, Faculty of Applied Sciences, Dept. Radiation Science and Technology, Mekelweg 15, 2629JB Delft, The Netherlands

Corresponding Author Email: p.dorenbos@tudelft.nl

The genuine 3-dimensional perovskites $CsPbX_3$ (X=Cl, Br, I) and (MA)PbX_3 (MA=methyl ammonium CH_3-NH^{3+}) have generated a surge of scientific studies since 2013 because of their small band gaps and long diffusion length of free charge carriers. Ideal properties for photovoltaic applications and for solid state detection of ionizing radiation. The studies soon broadened to a wider class of materials consisting of 2-dimensional sheets of corner connected PbX_6-octahedra separated by organic layers; the so-called 2D perovskite lead halides. The intrinsic exciton type luminescence tends to be very fast, i.e., on the several or even sub-nanosecond time scale. Such ultrafast decay when combined with a high scintillation light yield are ideal for various scintillation application.

In this contribution, we will review the status of the 3D and 2D perovskite lead halide family of compounds in terms of scintillation performance, and compare it with results from own work [1-3] Scintillation light yields reported for the same composition by independent researchers may differ a factor of ten. Are the methods to evaluate light yields always just, and to what extend are reported scintillation yields well above 100.000 photons/MeV then fact or fantasy? There appears more consensus on the scintillation decay time which remains very fast for the lead halide perovskite family of compounds. Potential applications for photon-counting computed tomography detectors will be addressed [1]. Finally, interesting new developments and future prospects will be highlighted.



Part of the 662 keV pulse height spectrum of 0.5 mm thick $(BZA)_2PbBr_4$ single crystal from [1] showing the full energy peak and well-resolved Pb-escape peak.

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3. J.J. van Blaaderen et al., "The Temperature Dependent Optical and Scintillation Characterisation of Bridgman Grown $CsPbX_3$ (X = Br, Cl) Single Crystals," to be submitted.

M-CA2 Crystal Growth and Scintillation Properties of Eu^{2+}-doped $TlSr_2Br_5$

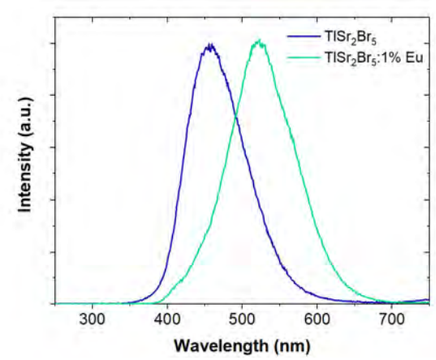
Edgar van Loef,[1] Myles Innis,[1] Jared Schott,[1] Kimberly Pestovich,[2] Luis Stand,[2] Mariya Zhuravleva,[2] Charles Melcher,[2] Lakshmi Soundara Pandian,[1] Jarek Glodo[1]

[1] Radiation Monitoring Devices Inc., 44 Hunt Street, Watertown, MA 02472, USA
[2]Scintillation Materials Research Center, University of Tennessee, Knoxville, TN 37996, USA

Corresponding Author Email: EvanLoef@RMDInc.com

Over the last seven years, novel thallium-based scintillators such as Tl_2LaCl_5 [1,2] and Tl_2LiYCl_6 [3,4] have emerged as promising radiation detection materials for numerous applications, including nuclear non-proliferation and homeland security. This is due in part to the high density, high effective atomic number (Z_{eff}) constituents, and often higher light yields and better energy resolution of these thallium- based scintillators compared to their alkali-containing analogs (e.g. Cs_2LiYCl_6).

As a follow up on our previous research into $TlSr_2Cl_5$ and $TlSr_2Br_5$, in this paper we report on the crystal growth and scintillation properties of Eu^{2+}-doped $TlSr_2Br_5$. Crystals of up to 16 mm in diameter were grown by the Vertical Bridgman method up to 50 mm in length. $TlSr_2Br_5$ has the monoclinic crystal structure with space group P21/c. Its density and Z_{eff} are 5.03 g/cm^3 and 58.6, respectively. Radioluminescence spectra of pure and Eu^{2+}-doped $TlSr_2Br_5$ feature a broad emission band peaking at 455 nm for undoped and 520 nm for Eu^{2+}-doped crystals (see figure). We attribute this shift towards longer wavelengths for Eu^{2+}-doped crystals to an energy transfer from the host (Tl^+ related) to Eu^{2+}. The light yield of undoped $TlSr_2Br_5$ is 44,000 ph/MeV, which increases to 60,000 ph/MeV for Eu^{2+}- doped crystals. The energy resolution at 662 keV (^{137}Cs) is about 5 – 6% (FWHM). The scintillation decay of undoped $TlSr_2Br_5$ can be described by an intermediate decay component of approximately 400 ns and a long decay component of approximately 2 µs. For Eu^{2+}-doped crystals, the lifetime of these components increases to approximately 600 ns and 2.7 µs, respectively.



Radioluminescence spectra of undoped and Eu^{2+}-doped $TlSr_2Br_5$.

In summary, Eu^{2+}-doped $TlSr_2Br_5$ exhibits promising performance and physical properties suitable for radiation detection applications. However, more research is needed to mitigate the high afterglow of the scintillator.

1. R..Hawrami et al., "Tl_2LaCl_5:Ce, high performance scintillator for gamma-ray detectors," Nucl. Instr. Meth. Phys. Res. A, 869, 107 (2017).

2. Edgar van Loef et al., "Crystal growth and scintillation properties of Thallium-based halide scintillators," J. Crystal Growth, 532, 1225438 (2020).

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4. Gul Rooh et al., "Crystal growth and scintillation characterizations of Tl_2LiYCl_6: Ce^{3+}," J. Crystal Growth, 459, 163 (2017).

This material is based upon work supported by the U.S. Department of Homeland Security under Grant Award Number 20CWDARI00036-01-00. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

Oral Sessions | Monday, July 8th 2024

M-CA3 Exploring the Scintillation Characteristics of $CsCu_2I_3$

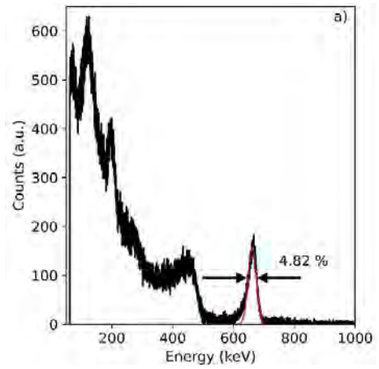
J.Jasper van Blaaderen*,[1], Karl W. Kämer[2], Pieter Dorenbos[1]

[1]FacultyofAppliedsciences,DepartmentofRadiationScienceandTechnology,DelftUniversityof Technology. Delft, The Netherlands
[2]DepartmentofChemistry,BiochemistryandPharmacy,UniversityofBern,Bern,Switzerland

*CorrespondingAuthor: J.J.vanBlaaderen@tudelft.nl

Small band-gap intrinsic scintillators have gained significant attention in recent years. Examples of such compounds are cesium hafnium based halides like Cs_2HfI_6, and hybrid lead based halides like $(PEA)_2PbBr_4$. Another material that has gained attention for its interesting properties is $CsCu_2I_3$. It has a band gap of 3.55 eV, is non-hygroscopic, non-toxic, melts congruently,has an extremely low after glow,and has a density of 5.01g/cm^3 and effective atomic number of 50.6.

In this contribution we will discuss the characterization of $CsCu_2I_3$ between 10 and 400 K [1]. The mean emission wavelength of 560 nm makes $CsCu_2I_3$ very suitable for readout with silicon based photodetectors. Figure 1 shows the ^{137}Cs pulse height spectrum of $CsCu_2I_3$ using an avalanche photo diode. From this pulse height spectrum the light yield and energy resolution are determined to be 36,000 photons/MeV and 4.82% at 662 keV. It was also found that the proportionality of $CsCu_2I_3$ is on par with that of SrI_2:Eu. One of the main problems of this material however is that it starts to quench at 200 K. This behavior is investigated based on emission and decay measurements. The light yield of $CsCu_2I_3$ is determined to be 60,000 photons/MeV at 200 K using temperature dependent pulse height measurements. $CsCu_2I_3$ can be a very interesting scintillator when we can engineer the quenching temperature towards higher temperatures by means of co-doping strategies. First results of that strategy will be presented.



Pulse height spectrum of a $CsCu_2I_3$ single crystal (10mm x 3mm x 3mm) measured on an avalanche photo diode (APD) using a ^{137}Cs γ–source. The red line in the plot shows a fitted Gaussian function used to obtain the energy resolution and light yield.

[1]: J. Jasper van Blaaderen, Liselotte A. van den Brekel, Karl W. Krämer, Pieter Dorenbos, Scintillation and Optical Characterisation of CsCu2I3 Single Crystals from 10 to 400 K, Chemistry of Materials 35 (2023) 9623-9631, https://doi.org/10.1021/acs.chemmater.3c01810

M-CA4 Scintillation properties of the Cs_2ZrCl_6 crystal over a 5–300 K temperature range

F. Cappella[1,2], P.C.F. Di Stefano[3], E. Ellingwood[3,4], J. Hucker[3,4], T. Leroy[5], S.S. Nagorny[3,4], V.V. Nahorna[6], L. Pagnanini[3,7,8], P. Skensved[3,4], N. Swidinsky[3,4], and P. Wang[6]

[1]INFN, sezione di Roma, I-00185 Rome, RM, Italy
[2]Dipartimento di Fisica, Università di Roma "La Sapienza", I-00185 Rome, RM, Italy
[3]Department of Physics, Engineering Physics and Astronomy, Queen's University, K7L 3N6 Kingston, ON, Canada
[4]Arthur B. McDonald Canadian Astroparticle Physics Research Institute, K7L 3N6 Kingston, ON, Canada
[5]Université de Lyon, F-69361 Lyon, ARA, France
[6]Department of Chemistry, Queen's University, K7L 3N6 Kingston, ON, Canada
[7]Gran Sasso Science Institute, I-67100 L'Aquila, AQ, Italy
[8]INFN – Laboratori Nazionali del Gran Sasso, I-67100 Assergi, AQ, Italy

Corresponding Author Email: sn65@queensu.ca

The Cs_2ZrCl_6 (CZC) crystals have recently emerged as promising detectors to study rare nuclear processes in natural Zr isotopes, namely the neutrinoless double beta decay of ^{94,96}Zr and strongly forbidden single beta decay of ^{96}Zr. In this work, we investigated the scintillation properties of the CZC crystal in a broad temperature range from 5 to 300 K. The room temperature scintillation light yield of CZC excited with a 662 keV γ–quanta of ^{137}Cs source is measured to be 45.8(3.2)×10^3 photons per MeV resulting in the energy resolution of 5.3%. As the crystal temperature decreased, the light yield values reached a maximum at temperatures around 135 K for α-particles and 165 K for γ–quanta, respectively. As the crystal continued to cool down, the light yield dropped sharply and reached a minimum of light emission in the temperature range 5–70 K, with light yield values even lower than those measured at room temperature. Such unusual behavior of the scintillating light intensity could be explained by a negative thermal quenching over the 80–160 K temperature range caused by thermal activation of trapped carriers.

The Quenching Factor (QF) measured with an external 4.7 MeV α-particles from ^{241}Am source, exhibits a slight increase from QF = 0.30(2) value determined at room temperature up to QF = 0.37(3) obtained at 135 K.

The measurements of scintillation decay curves revealed complex kinetics due to delayed recombination processes. The average pulse profile could be well described by three exponential components for α-particles (0.3, 2.5, 11.8 μs) and by two components for γ–quanta (1.3, 11.5 μs) at room temperature. As the crystal temperature decreased, the decay constants smoothly increased to temperature around 135 K for α–particles and 160 K for γ–quanta, then on the temperature interval 80–160 K occur an abrupt rising of their values, followed by almost constant decay components over the 4–70 K temperature interval. Even more complex dynamics is observed for relative amplitudes of corresponding decay components. Over the temperature interval 80–160 K the abrupt re-distribution of the relative amplitudes occurs resulting in a significant elongation of the scintillation pulse both for α-particles and γ–quanta. The pulse-shape discrimination ability stays the same from room temperature to 180 K with a quick deterioration at lower temperatures.

The optimal experimental conditions to achieve the best CZC-based detector performance and the ultimate sensitivity in experiments to search for rare decays of Zr isotopes are also discussed.

Oral Sessions | Monday, July 8th 2024

M-CA5 Magnesium Modified Cesium Lead Bromide

Maksym Buryi[1], Tomáš Hostinský[1], Shelja Sharma[1], Zdeněk Remeš[2], Andriy Prokhorov[1,2], Lucie Landová[2,3], Sergii Chertopalov[2], Kateřina Aubrechtová Dragounová[3]

[1]*Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[2]*FZU – Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[3]*Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, Prague, Czech Republic*

Corresponding Author Email: buryi@ipp.cas.cz

Cesium-lead bromide ($CsPbBr_3$, CPB) is a promising material for optoelectronic [1] and time-of- flight (TOF) applications, especially in positron emission tomography (PET) [2]. One of the most important effects regulating the mechanism of scintillation are charge trapping processes. These can appear at the shallow and deep states, and the role of material size in this case is significant. There is still lack of fundamental understanding of these aspects, especially, combined. The recent study partly answers the questions related to the described phenomena [3]. There, the CPB nanocubes, nanowires, nanosheets and bulk crystals of different scale were investigated to find out that small defects participate in the charge distribution processes thus having the consequence of delayed intragap emission. This mechanism becomes active due to the de-trapping through thermal tunneling.

To be applied as scintillating detector in TOFPET – the radiation hardness should also be taken into account. It was found for γ radiation doses of 1 MGy imparted to the nanocrystalline form of the CPB to be peculiar [4]. Due to narrow bandgap, in general, CPB does not suffer from deep defect levels. At the same time electron trapping occurs at the surface of the CPB nanocrystals, which can be removed by surface treatment, for example, post-growth fluorination [4].

It is well-known, that, in general, dopants affect the properties of materials. Therefore, electron paramagnetic resonance (EPR) and thermally stimulated luminescence (TSL) were combined to reveal the role of different Mg contents in the defects and trapping states in $CsPbBr_3$. In addition, the photo- and radioluminescence and optical properties of the synthesized CPB particles were studied.

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Acknowledgements

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M-CA6 The PARIS array phoswich characterization with SiPM readout

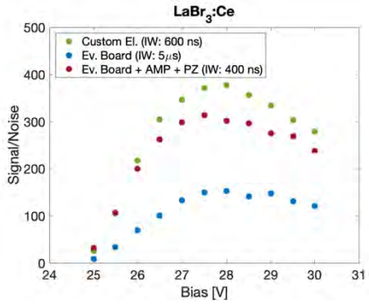
Agnese Giaz[1], Sergio Brambilla[1], Stefano Riboldi[1,2], Ciro Boiano[1], Benedicte Million[1]

[1]*INFN sez. di Milano, Via celoria, 16, 20133 Milano, Italy*
[2]*Università degli studi di Milano, Via celoria, 16, 20133 Milano, Italy*

Corresponding Author Email: agnese.giaz@infn.mi.it

In nuclear physics experiments, where the aim is the measurement of high-energy y-rays (from 100 keV up to 20 MeV), large-volume scintillators are employed due to their energy resolution (from 3% at 662 keV), time resolution (<1ns) and efficiency. The high-energy y-ray measurement is fundamental for nuclear structure studies through collective modes in excite nuclei, such as resonances. Several arrays of large-volume scintillator detectors were built, such as the PARIS ($LaBr_3$:Ce/NaI or $CeBr_3$/NaI phoswich clusters) [1] and HECTOR+ (large-volume $LaBr_3$:Ce) arrays.

The readout of the light of PARIS phoswich is commonly performed with photomultiplier tubes (PMTs). However, in several experimental campaigns, the arrays were coupled to magnetic spectrometers, thus compromising the performance of the PMT. Moreover, in cases where relativistic beams are involved, the interaction position can help to correct for the Doppler broadening of the peaks. The SiPMs performances are improving and becoming comparable and or better than that of commonly used PMTs, opening the possibility of replacing PMTs with SiPMs for large-volume scintillators.



The signal-to-noise ratio obtained from $LaBr_3$:Ce coupled to the SensL matrix and custom electronics (green points), evaluation board (blue points) and evaluation board plus PZ circuit (red points).

We performed preliminary measurements with a cubic 2”x2”x2” LaBr3:Ce coupled to a SensL matrix (64 SiPM of 6x6 mm2) and a HAMAMATSU R6233-100sel spectroscopic PMT. The LaBr3:Ce is a good candidate for testing the different electronics solutions and SiPMs performances due to its fast signal and energy resolution. For example, Fig. 1 reports the signal-to-noise ratio obtained from LaBr3:Ce coupled to the SiPM matrix and different electronics solutions. Afterward, we compared the performance of the PARIS phoswich coupled with a HAMAMATSU R13089-100 PMT and the SiPM matrix. We measured and compared the energy, time resolution, and linearity of the detectors coupled to the PMTs and the SiPM matrixes. The LaBr3:Ce coupled with the PMT has identical energy resolution (3.1% at 662 keV) as the SiPMs. The PARIS phoswich energy resolution is slightly better with the SiPM matrix (5% at 662 keV) than with the PMT, thanks to the geometry. The energy resolution for the LaBr3:Ce and the PARIS phoswiches at 9 MeV is better with the SiPM matrix (~0.7%), but there is non-linearity. In general, the PMTs show a better non-linearity, but it changes from PMT to PMT, and it is not easy to model it, whereas the SiMPs linearity depends on the number of cells in each SiPM matrix, and we can model it. We measured a time resolution of FWHM~600 ps through the coincidence between the PARIS phoswich coupled with SiPMs and a small LaBr3:Ce coupled with the PMT with the 60Co source, comparable with the one obtained with PMTs.

The results demonstrate that the performances with the SiPMs are comparable to or better than the PMTs. Finally, these results show the possibility of coupling PARIS phoswich with SiPM matrices for nuclear physics measurements.

1. http://paris.ifj.edu.pl/

Oral Sessions | Monday, July 8th 2024

SESSION 4: CHARACTERIZATIONS OF SCINTILLATORS (PART 2)

M-CA7 Low Temperature Properties of Li_2MoO_4 and Na_2MoO_4 crystal for cryogenic phonon detectors

Mingxuan Xue[1,2]

[1]State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei 230026, China
[2]Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China

Corresponding Author Email: xuemx@ustc.edu.cn

The novel molybdate crystals, Li_2MoO_4 and Na_2MoO_4, are popular used as absorbers in cryogenic phonon scintillating bolometers for 100Mo neutrinoless double beta decay search [1, 2]. The low temperature properties, including specific heat and scintillation characteristics, are important detector research and design parameters. In this work, the heat capacity of these two crystals are measured at O(500) mK, and the results are found to be consistent with the prediction of Debye model. The excitation spectrum and light yield are measured ranging from 20 K to room temperature. Consequently, a Li_2MoO_4 bolometer and a Na_2MoO_4 bolometer are setup and running at ultra-low temperature mK-level with light-heat double readout.

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2. B. Mailyan et al., "Light Collection of Some Molybdate Crystal Absorbers for Cryogenic Calorimeters at Millikelvin Temperatures," IEEE Transactions on Nuclear Science, 70. 7(2023).

Acknowledgments
This work is supported by "the Fundamental Research Funds for the Central Universities".

M-CA8 The role of Ce^{3+} Co-dopant on Luminescent Enhancement of Bi^{3+} Emission and Bi^{3+}→Bi^{2+} Conversion in $LiLaP_4O_{12}$ host

José Henrique M. de Azevedo[1], Adriano B. Andrade[1,2], Giordano F. C. Bispo[1,2], Thaíse de J. Monteiro[1], Zélia S. Macedo[1,2] and Mário E. G. Valerio[1,2]

[1]Physics Department, Federal University of Sergipe, São Cristóvão, SE, Brazil
[2]Materials Science and Engineering Department, Federal University of Sergipe, São Cristóvão, SE, Brazil

Corresponding Author Email: mvalerio@academico.ufs.br

Red light-emitting scintillators have been extensively investigated in recent years for applications in detectors with maximum efficiency at this region of electromagnetic spectrum[1]. X-ray excitation of some bismuth doped phosphates can induce a valence change from Bi^{3+} to Bi^{2+}, accompanied by an efficient red emission from divalent bismuth ions. Literature presents $LiLaP^4O^{12}$ host as a useful scintillator material when doped with rare earth or bismuth ions[2], however, no co-dopant systems using lanthanide and transition metals ions are discussed for $LiLaP^4O^{12}$, neither its charge transfer mechanisms.

Charge transfer from host to dopants, combined to the capability in accommodating high concentrations of dopants without quenching effects, make $LiLaP^4O^{12}$ host useful for luminescent applications[2]. However, the process involved in X-rays induced change of the bismuth valence is not fully explained up to the moment. Additionally, charge transfer from rare earth to bismuth and its role on the enhancing of bismuth emission are still open fields in this area[3].

In this sense, the present work brings a study of the mechanism of interaction between the Ce^{3+} and Bi^{3+} ions in $LiLaP^4O^{12}$ host. The luminescent properties were studied via photoluminescence in emission and excitation modes, and via radioluminescence spectra. The results indicates that energy transfer from Ce^{3+} to Bi^{3+} occurs for samples excited at 5.2 eV, which improves their overall emission. On the other hand, for samples exposed to X- rays, an enhancement of the red emission, ascribed to Bi^{2+}, was observed, indicating a valence change Bi^{3+}→Bi^{2+} caused by charge transfer from Ce^{3+} to Bi^{3+} ions, as can be observed in the figure. Based on these results, an energy level diagram including energy transfer mechanism and charge transfer from Ce to Bi ions is proposed.

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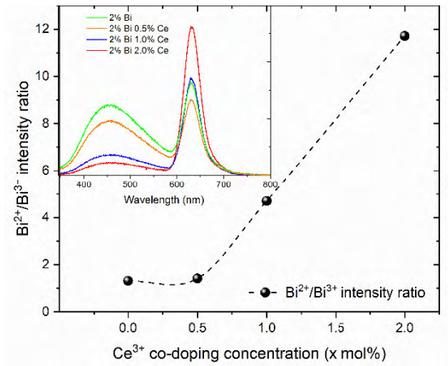
The author gratefully acknowledges CNPq, Brazilian funding agency for the grants under project number 317283/2021-9 and LNLS for the facilities under research proposal 20190096.



X. ray excited optical luminescence for Bi^{3+}-doped $LiLaP^4O^{12}$ and Ce3+-co-doped $LiLaP^4O^{12}$:Bi^{3+} (inset), Bi^{2+}/Bi^{3+} ratio of emission intensity as a function of Ce^{3+} doping concentration (main figure).

Oral Sessions | Monday, July 8th 2024

M-CA9 Chalcogenide Scintillators for Modern Cryogenic Detectors for Low Background Nuclear Spectrometry Systems

I. Rybalka[1], S. Galkin[1], O. Lalayants[1], L. Sidelnikova[1], A. Boyarintsev[1], V. Vistovskyy[2], V. Mykhaylyk[3]

[1]*Institute for Scintillation Materials, National Academy of Sciences of Ukraine, Kharkiv, Ukraine*
[2]*Ivan Franko National University of Lviv, Department of Physics, Lviv, Ukraine*
[3]*Diamond Light Source, Didcot, UK*

Corresponding Author Email: iren.rybalka@gmail.com

The creation of modern cryogenic phonon-scintillation detectors stimulates the search for new and optimization of obtaining conditions for well-known scintillation materials. The most important general requirements for scintillators for cryogenic detectors are an extremely low level of radioactive contamination (less than 0.01 mBq/kg), high light output at low temperatures, the presence of specific nuclei, as well as high optical quality and perfect crystal structure. Scintillation crystals of chalcogenides (ZnSe, ZnTe, ZnSe(Te), ZnSe-ZnS) meet the above requirements, their chemical composition does not contain elements with natural radioactive isotopes, and so they are promising for studying rare experiments of nuclear processes, such as neutrinoless double beta-decay (0νDBD). In the work, we present the results of a R&D aimed at the development and improvement of scintillation crystals based on ZnSe, ZnTe and mixed ZnSe-ZnS compounds for low-background cryogenic detectors. Techniques for the synthesis of high-purity raw materials were developed and optimal growing modes of ZnSe, ZnSe-ZnS, ZnTe crystals from the melt using the vertical Bridgman method under high inert gas pressure were worked out.

When studying the formation conditions of intrinsic and impurity point defects in ZnSe crystals, the doping effect with di- (Ca, Sr, Ba) and tri- (Al, Ga, In, Bi) valence elements on the optical- luminescence characteristics: absorption coefficient, fundamental absorption edge, X-ray luminescence spectra, light output and decay time at room temperature was determined. Low- temperature measurements have shown that the course of temperature dependence of radioluminescence intensity and decay time of doped ZnSe crystals is radically different in two temperature ranges: low-temperature 4÷160 K and high-temperature 160÷300 K, which indicates a different composition of luminescence centers, and therefore a different luminescence mechanism. Measurement of phonon thermal conductivity in low-background ZnSe crystals in the temperature range of 5÷298 K has shown that the length of the free path of phonons at low temperatures is about 20 μm, which is comparable to the distance between the twins' boundaries contained in crystals.

For the CUPID-0 project aimed at the search for 0νDBD, we obtained 24 pcs of $Zn^{82}Se$ bolometric elements (enriched in the 82Se isotope). The light output of the elements was 5 keV/MeV for β/γ– and 10 keV/MeV for α- excitation, which guarantees the identification of the nature of the interacting particle. The cryogenic test performed in conditions similar to the 0νDBD experiment showed a radioactive contamination of the crystals of the order of few μBq/kg for the most critical isotopes, which is compatible with the requirements of 0νDBD experiments [1].

Studies of mixed ZnSe-ZnS crystals have shown that samples cooled to low temperatures (T=150 K and below) demonstrate a significant improvement in scintillation characteristics due to an increase in light output and a decrease in the decay time to the level of the known ZnSe(Al), and therefore are promising for use as scintillation bolometers for the search for 0νDBD in the ^{82}Se isotope.

Studies of ZnTe crystals have shown that upon cooling below 150 K the luminescence intensity increases with the characteristic kinetics of decay, the maximum position shifts to the long- wavelength region from 2.17 eV to 2.14 eV, and therefore zinc telluride is a promising scintillator for cryogenic applications, in particular for the search for 0νDBD in the ^{130}Te isotope.

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SESSION 5: TWISMA

M-FT1 Optimization of Ce-doped garnet scintillators by complex codoping with divalent cations

Oleg Sidletskiy[1,2*], Iaroslav Gerasymov[1], Daniil Kurtsev[1], Oleh Viahin[1], Sofiia Sadivnycha[1], Roberto Cala'[3,4], Loris Martinazzoli[3], Louis Roux[3,5], Etiennette Auffray[3]

[1]*Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine*
[2]*Centre of Excellence ENSEMBLE3 Sp. z o.o., Warsaw, Poland*
[3]*European Organization for Nuclear Research (CERN), Geneva, Switzerland*
[4]*Università degli Studi di Milano-Bicocca, Milan, Italy*
[5]*Université Claude Bernard Lyon1, UMR5306 CNRS, Institut Lumière Matière, Lyon, France*

**Corresponding Author Email: sidletskiy@isma.kharkov.ua*

The application of Ce-doped garnets in high-rate scenarios faces limitations due to the extended radiation lifetime of Ce^{3+} within these hosts. Efforts to reduce scintillation rise/decay times primarily rely on codoping with divalent alkali metals, commonly Mg^{2+}, to facilitate partial Ce^{3+} transfer to Ce^{4+} and mitigate carrier trapping [1]. However, this causes a considerable reduction in light yield due to thermal ionization of electrons from Ce^{4+} excited levels to the conduction band. Meanwhile, our recent investigation into the divalent codoping of $Y_3Al_5O_{12}$:Ce (YAG:Ce) has revealed the efficacy of Ca^{2+} in eliminating slow components, while the main decay time persisted at a slow rate of 55 ns [2].

This work addresses the double codoping of YAG:Ce with Ca^{2+} and Mg^{2+} cations. A similar approach was recently proposed for GAGG:Ce ceramics [3], resulting in effective decay time (τ_{eff}) of 38 ns and a high light yield of 27400 phot/MeV, albeit without optimized doping concentrations. With tuned dopant concentrations, YAG:Ce,Ca,Mg obtains a better decay time to light yield ratio (Fig. 1) than that of present GAGG:Ce,Mg crystals [1], with a light yield of 21600 phot/MeV, rise/decay times of 30 ps/26 ns, respectively. The synergistic effect of Ca^{2+} and Mg^{2+} codopants is discussed, leading to enhanced timing parameters while maintaining a high light yield.

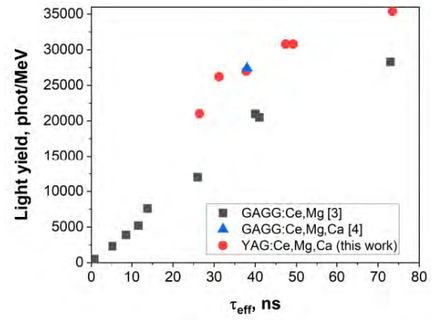

Fig. 1. Correlation between light yield and τ_{eff} in YAG:Ce,Ca,Mg and GAGG-based scintillators.

Furthermore, YAG:Ce,Mg,Ca crystals were successfully grown in this work by the Czochralski using cheap W crucibles, ensuring a lower cost compared to Ga-containing crystals grown in large sizes exclusively in Ir crucibles. Therefore, our approach offers a compelling alternative to GAGG:Ce- based scintillators in fast-timing applications.

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2. I. Gerasymov et al, Effects of Codoping With Divalent Cations on Performance of YAG:Ce,C Scintillator, IEEE Trans. Nucl. Sci., 70, 362 (2023).
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Oral Sessions | Monday, July 8th 2024

M-AP8 Investigating scintillation kinetics of GAGG and YAG for HEP applications, from laboratory to particle beams

L. Roux[1,2], L. Martinazzoli[1], R. Cala'[1,3], O. Sidletskiy[4], I. Gerasymov[4], M. Nikl[5], P. Bohacek[5], K. Lebbou[2], V. Kononets[2], A. Nehari[2], C. Dujardin[2,6] and E. Auffray[1]

[1] *European Organization for Nuclear Research (CERN), Geneva, Switzerland*
[2] *Université Claude Bernard Lyon1, UMR5306 CNRS, Institut Lumière Matière, Lyon, France*
[3] *INFN & Università degli Studi di Milano-Bicocca, Milan, Italy*
[4] *Institute for Scintillation Materials NAS of Ukraine, 60 Nauky Ave., Kharkiv, Ukraine*
[5] *Institute of Physics of the Czech Academy of Sciences, 16200 Prague, Czech Republic*
[6] *Institut Universitaire de France (IUF)*

Corresponding Author Email: Louis.Roux@cern.ch

In the design of future calorimeters for High-Energy Physics (HEP) experiments with high rates of events, fast timing detection emerges as a crucial consideration. The rapid succession of events demands the use of fast scintillating materials to prevent spillover and guarantee accurate particle identification as well as energy measurement.

Among the possible candidates, garnet scintillators such as GAGG:Ce,Mg or YAG:Ce,Mg,Ca are potential candidates and R&D effort is ongoing in several groups to develop material that will meet the requirements of future detectors in terms of time, energy resolution, radiation hardness and production scalability.

Translating laboratory measurements with X-rays and gamma sources into real measurements in the calorimeter presents a major challenge. This involves the determination of the useful kinetic parameters of scintillation emission required for detector timing performance and adapting them into practical parameters tailored for HEP applications.

Our work explores how to derive the best and easiest way to measure experimental useful estimators for accurate simulations and find a compromise between the optimal effective decay time values and light output. We hereby present tests of measurement methods with the standard YAG:Ce,Mg,Ca and GAGG:Ce,Mg garnet samples produced to support our simulations, opening new perspectives into the field of calorimeters in high-energy physics.

Acknowledgment

This work is carried out within the framework of the Crystal Clear Collaboration and has received support from the Twinning European project (TWISMA, grant agreement 101078960), CERN EP-R&D and the ScintLab IRP CNRS project.

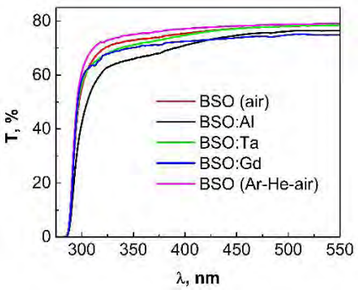
M-FT2 Improving timing performance of BSO scintillator

Serhii Tkachenko[1], Oleh Viahin[1*], Iaroslav Gerasymov[1], Daniil Kurtsev[1], Olga Zelenskaya[1], Louis Roux[2,5], Roberto Cala'[2,4], Loris Martinazzoli[2,4], Etiennette Auffray[2], Oleg Sidletskiy[1,3]

[1]*Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine*
[2]*European Organization for Nuclear Research (CERN),Geneva, Switzerland*
[3]*Centre of Excellence ENSEMBLE3 Sp. z o.o., Warsaw, Poland*
[4]*INFN & Università degli Studi di Milano-Bicocca, Milan, Italy*
[5]*Université Claude Bernard Lyon1,UMR5306 CNRS, InstitutLumière Matière, Lyon,France*

**Corresponding Author Email: viagin.oleg@gmail.com*

$Bi_4Ge_3O_{12}$ (BGO) scintillator has been widely used in particle physics experiments because of its high density, short radiation length, and relatively high light output. However, this crystal has a slow decay time of 300 ns and moderate radiation hardness, which limits its application, especially in high energy physics where fast timing or high radiation hardness are crucial. On the other hand, bismuth silicate, $Bi_4Si_3O_{12}$ (BSO) seems to be a possible alternative, because of its shorter decay time of 100 ns, and wider transmission range in UV-band that enhances the registration efficiency of fast Cherenkov light [1]. As the BSO light output is rather low (ca. 1600 ph/MeV),improving light output would enable to enhance Coincidence Time Resolution (CTR) of this scintillator. According to some papers, there were attempts to increase light output by doping with Ta [2], Dy [3], Gd [4].



Transmission spectra of the BSO crystals.

A series of large BSO crystals were grown in ISMA. The growth was carried out from Pt crucibles in air and Ar-He-air environment. The scintillation characteristics (light output, scintillation decay and coincidence time resolution) of the crystals were studied in CERN. It was shown that the addition of dopants (Ta, Gd, Al) has not improved scintillation parameters but worsened crystallization conditions, resulting in larger quantity of inclusions. Meanwhile, CTR of undoped BSO was improved to 125ps by tuning growth atmosphere composition that provides minimization of SiO2 evaporation and reducing amount of Pt dissolving into the melt and, consequently, decrease the numberofinclusionsincrystals. Theenhancement inCTRcorrelateswiththereduced absorptionin UV-band that reflects decrease in concentration of color centers. As BSO is a non-congruent composition crystallized from Bi2O3-enriched melt-solution, further optimization of growth conditions, as well as clarifying the nature of involved color centers is necessary to get large-size crystals with acceptable optical quality.

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This work was carried out in the framework of the Horizon Europe ERA Widening Project no. 101078960 "TWISMA". The authors also thank to Crystal Clear team at CERN for help with the measurements.

M-CA10 Growth and characterization of multicomponent garnets grown under reducing atmosphere

Denys Kofanov, Iaroslav Gerasymov, Sergii Tkachenko, Daniil Kurtsev, Pavlo Maksimchuk, Liudmyla Zavora, Oleg Sidletskiy

Institute for Scintillation Materials NAS of Ukraine, 60 Nauky Ave., 61072 Kharkiv, Ukraine

Corresponding Author Email: Phkofanov@gmail.com

Garnet-based scintillators are widely used in various fields, including scintillation detectors engineering, emission diodes engineering, etc. $Y_3Al_5O_{12}$:Ce (YAG:Ce) is one of the most popular composition among them, due to its low cost, developed production technologies and the possibility to grow it from cheap W crucibles [1]. Recent studies [2,3] indicate the improvement in light yield up to 26000-30000 phot/MeV in YAG:Ce and LuAG:Ce grown in CO-containing reducing atmosphere. However, slow luminescence rise/decay is one of disadvantages related in part to a long diffusion length to luminescence centers of electrons and holes generated by ionizing particle due to a low Ce distribution coefficient and, hence, Ce concentration in crystals. Conversely, GAGG:Ce crystals possess much higher Ce distribution coefficient of ~0.3 due to loosening of garnet lattice by substitution of Al^{3+} with larger Ga^{3+} cations. Apart of that, there is a tendency to the enhancement of light yield in two- or multicomponent systems as comparted to their constituents [4].

In this work, we present the approach to enhancement of activator distribution coefficient and scintillation performance in YAG:Ce by substituting Y^{3+} with smaller (Lu^{3+}) and larger (Gd^{3+}) heavy lanthanide ions. A series of $(Lu,Y,Gd)_3Al_5O_{12}$:Ce mixed crystals with the length up to 9 cm and different Lu+Gd/Y ratios were grown by the Czochralski technique in reducing atmosphere from W crucibles with graphite heat insulation. Structure, optical and luminescent parameters of crystals were studied. Ce^{3+} emission spectra of the $(Lu,Y,Gd)_3Al_5O_{12}$:Ce shift to the short-wavelength side indicating the increase in crystalline field strength with cation substitution. Meanwhile, as heavier Gd^{3+} and Lu^{3+} ions are introduced into the lattice, the density of obtained crystals from 4.4 g/cm^3 in YAG to 6 g/cm^3, making this material more attractive for registration of high energy particles.

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Oral Sessions | Monday, July 8th 2024

M-CR1 Impact of Ce, Mg concentrations on the scintillation performance of GAGG shaped single crystals

Valerii Kononets[1*], Pavlo Mai[1], Abdeldjelil Nehari[1], Christophe Dujardin[1], Kheirreddine Lebbou[1], Louis Roux[1,2], Roberto Gala[2,3], Loris Martinazzoli[2], Etiennette Auffray[2], Iaroslav Gerasymov[4], Oleg Sidletskiy[4,5]

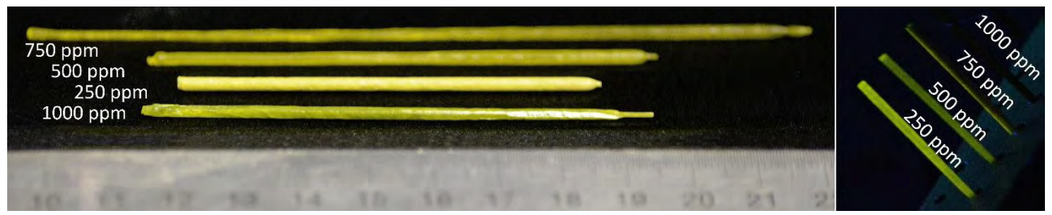
[1]Université Claude Bernard Lyon1, UMR5306 CNRS, Institut Lumière Matière, Villeurbanne, France,
[2]European Organization for Nuclear Research (CERN), Geneva, Switzerland
[3]Universita´ degli Studi di Milano-Bicocca, Milano, Italy
[4]Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine
[5]Centre of Excellence ENSEMBLE3 Sp. z o.o., Warsaw, Poland

**Corresponding Author Email: valerii.kononets@univ-lyon1.fr*

Currently, garnets-type materials are considered as potential candidates for fast-timing detectors future high-energy colliders at CERN. The performance of calorimeters strongly depends on the scintillation performance of built-in single crystals, which should combine a fast lifetime (≤15 ns), medium light yield (≥15000 Ph/MeV), good radiation hardness, and ability to scale up reproducible fabrication of single crystals. $Gd_3Ga_{5-x}Al_xO_{12}$:Ce (GAGG:Ce) is a promising crystal for such application with a high light yield, but not fast enough scintillation decay which may be accelerated by codoping with divalent alkali ions. The Mg^{2+} codoping demonstrated promising improvement in decay time, but further tuning of dopant concentrations is necessary to meet the target specifications.

The presented work consists of two stages: solid-state synthesis and subsequent crystallization from the melt by micro-pulling down technique of Ce, Mg-codoped GAGG crystals. The growth of fibers was carried out in RF heated Ir crucible (<2000°C) in Ar/0.5%O2 gas flow to suppress the evaporation of Ga-oxide. To optimize the composition and provide Ce and Mg concentrations were tuned in the ranges of 750 - 2500 ppm and 250 - 1000 ppm, respectively.

The average decay time, τ_{eff} is in the 1.2-7 ns range. On the other hand, the light output measured in the fiber-shaped crystals (2 mm dia x 5 mm length) is low <2000 Ph/MeV. In the frame of this project, we are working to develop performed Ce,Mg codoped GAGG crystals through technology growth process controlling and mass production.



Fibers of GAGG with 1500 ppm Ce and different Mg content at daylight (right), under 365 nm excitation (left).

This work was made in the frame of Crystal Clear collaboration and support Horizon Europe ERA Widening Project no. 101078960 "TWISMA" and the CNRS IRP project (ScintLab).

Highly luminescent perovskite nanocrystals as scintillators: challenges and opportunities

Maksym V. Kovalenko

[1]Swiss Federal Insittute of Technilogy Zurich (ETH Zurich), 8093, Switzerland
[2]Empa-Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland

Corresponding Author Email: mvkovalenko@ethz.ch

Perovskite nanocrystals (NCs) offer distinct opportunities owing to their native colloidal state, engineerable composition, and unique photophysics. For instance, Fast neutron imaging with colloidal nanocrystals (NCs) was demonstrated to eliminate light scattering and afterglow [1], issues that are inherent to conventional phosphors (typically microcrystalline ZnS:Cu). On the other hand, perovskite NCs inherently suffer from re-absorption (small Stokes shift). Towards this goal, the Mn^{2+}-doped $CsPb(BrCl)_3$ NCs with oleyl ligands offered higher resolution because of a large apparent Stokes shift but suffered from insufficient concentration for high light yield. We then demonstrated [2] a NC scintillator that features simultaneously high quantum yields, high concentrations, and a large apparent Stokes shift using long-chain zwitterionic ligand affording stable colloids of Mn^{2+}-doped $CsPb(BrCl)_3$ NCs at very high concentrations (>100 mg/mL). Mn^{2+}:$CsPb(BrCl)_3$ NCs have the potential to displace ZnS:Cu as the leading scintillator for fast neutron imaging. We also systematically compared NC scintillators with molecular ionic liquid-type of Pb-based scintillators, finding that the ionic liquids are superior in spatial resolution but inferior in light yield [3]. One unique opportunity for devising scintillators, at low temperatures, stems from the record-fast radiative rates attainable with perovskite NCs, owing to the giant oscillator strength effect [4].

1. K. McCall, K. Sakhatskyi, E.H. Lehmann, B. Walfort, A. Losko, F. Montanarella, M.I. Bodnarchuk, F. Krieg, Y. Kelestemur, D. Mannes, Y. Shynkarenko, S. Yakunin, and M.V. Kovalenko ACS Nano, 2020, 14, 11, 14686–14697

2. F. Montanarella, K.M. McCall, K. Sakhatskyi, S. Yakunin, P. Trtik, C. Bernasconi, I. Cherniukh, D. Mannes, M.I. Bodnarchuk, M. Strobl, B. Walfort, and M.V. Kovalenko CS Energy Lett., 2021, 6, 4365–4373

3. V. Morad, K.M. McCall, K. Sakhatskyi, E. Lehmann, E. Lehmann, B. Walfort, A.S. Losko, P. Trtik, M. Strobl, S. Yakunin, and M.V. Kovalenko ACS Photonics, 2021, 8, 11, 3357–3364

4. C. Zhu, S.C. Boehme, L.G. Feld, A. Moskalenko, D.N. Dirin, R.F. Mahrt, T. Stöferle, M.I. Bodnarchuk, A.L. Efros, P.C. Sercel, M.V. Kovalenko, G. Rainò Nature, 2024, 626, 535–541

SESSION 6: NANO- AND METAMATERIALS (PART 1)

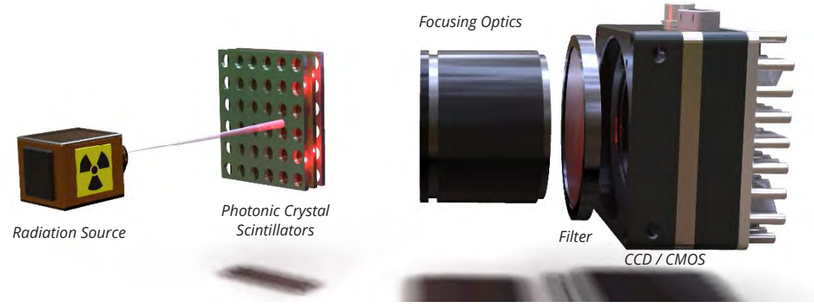
T-NA1 Spectral Dynamics in GaN Photonic Crystal Scintillators: Optical Insights Across UV, X-ray, Alpha Radiation

Firat Yasar[1], Noriaki Kawaguchi[2], Takayuki Yanagida[2], and Sam Keo[1]

[1]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA
[2]Nara Institute of Science and Technology (NAIST), 8916-5 Takayama, Ikoma, Nara 630-0192, Japan

Corresponding Author Email: firat.yasar@jpl.nasa.gov

Our work encompasses the careful design of a photonic crystal structure integrated into a robust material (GaN) to optimize the guidance of scintillation light [1]. The successful fabrication of the chip within a challenging cleanroom environment, coupled with a diverse array of intricate metrology and characterization techniques, has been executed. Our results, carefully examined through both computational models and experimental data, unequivocally showcase a substantial enhancement in spectral performance specifically at the 550 nm scintillation wavelength. This enhancement notably surpasses efficiency at other wavelengths, particularly around 400 nm [2].



The figure shows an experimental setup for measurements of the collimated scintillation. The objective lens with a specific X-ray filter is focused on the sides of the active layer where the collimated in-plane scintillation

The observed improvement is not confined solely to X-ray-induced scintillation; the photonic crystal GaN exhibits vigorous performance under diverse radiation sources, including UV and alpha particles. This versatility broadens its potential applications, establishing it as an adaptable solution for a variety of radiation detection scenarios. The advancements presented in this study contribute to the realm of photonics, not just in terms of technological innovation but also by unveiling new possibilities for practical applications. These applications span a spectrum from medical imaging to environmental monitoring, demonstrating the broader societal impact of this research.

The incorporation of this approach not only deepens our comprehension of the capabilities of photonic crystal GaN but also establishes it as a significant advancement in the field of radiation detection technologies. This work serves as a stepping stone toward more efficient and versatile detectors, paving the way for continued progress in the broader landscape of radiation detection and its diverse applications.

1. F. Yasar, M. Kilin, S. Dehdashti, et al., "Spatially resolved x-ray detection with photonic crystal scintillators," J. Appl. Phys. 130 (2021).
2. T. Yanagida, T. Kato, D. Nakauchi, et al., "Photoluminescence and scintillation properties gan," Appl. Phys. Express 14, 082006 (2021).

Oral Sessions | Tuesday, July 9th 2024

T-NA2 YAG:Ce$^{3+/4+}$ aerogels: efficiency, timing, diffusion and self-absorption

Pavlo Mai[1], Yannis Cheref [1,2], Raphael Marie-Luce[2], Frederic Lerouge[2], Sylvie Pierre[3], Benoit Sabot[3], Frederic Chaput[2] and Christophe Dujardin[1,4]

[1]*Universite Claude Bernard Lyon1, CNRS, ILM UMR5306, Villeurbanne, France*
[2]*Laboratoire de Chimie, Ecole Normale Supérieure de Lyon, Université Claude Bernard Lyon1, CNRS UMR 5182, Lyon, France*
[3]*Université Paris-Saclay, CEA, LIST, Laboratoire National Henri Becquerel, Palaiseau, France*
[4]*Institut Universitaire de France (IUF), Paris, France*

Corresponding Author Email: pavlo.mai@univ-lyon1.fr

Detection of radionuclides that decay directly to the ground state in the atmosphere requires to detect the beta or alpha radiation directly, which is very challenging due to their short mean free path in air at normal pressure. This suggests that the highest detection efficiency is obtained when the radionuclide is incorporated in the sensing part of the detector, which is applied with different gas radionuclides in ionisation chambers (gas-gas mixing) and for liquid solution in the liquid scintillation counting (LSC) technique (gas-liquid mixing). We hereby introduce the concept of gas-solid mixing to design an efficient detector, wherein the radioactive gas is introduced into a highly porous transparent inorganic scintillator. In this frame we have prepared YAG:Ce aerogels from sol-gel nanoparticle dispersion.

Post-synthesis thermal treatment (sintering/calcination) at several temperatures was applied to the aerogels demonstrating a significant impact on the cerium oxidation state and transparency (figure 1). The focus of this work is also the investigation of the aerogel optical properties after being altered by sub-calcination/sintering temperature treatments in H_2 or air ambient gases. This low-temperature (400°C) treatment has managed to significantly change the ratio of Ce$^{3+/4+}$ population in the sample, thus introducing a novel, easy and reversible approach to change scintillating properties of YAG:Ce aerogel.

In this presentation, the effect of the thermal treatment on the transparency, diffusion, self-absorption, photoluminescence and scintillation efficiency and timing will be discussed in the frame of their use as sensor in the Triple to Double Ratio method, the standard technique used for liquid scintillation and the metrology of radionuclides.

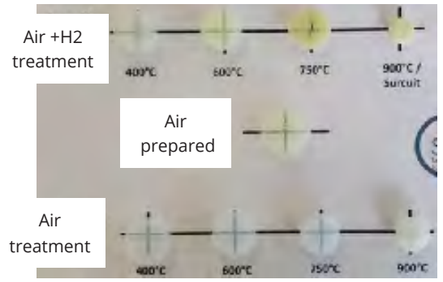


Figure 1: YAG:Ce aerogels under various thermal treatments

Acknowledgement

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T-NA3 Fast timing with highly loaded cesium lead halide perovskite nanocomposites

Eva Mihóková[1,2], Jan Král[1,2], Vojtěch Zabloudil[2,3], Fiammetta Pagano[3,4], Kateřina Děcká[1,2], Etiennette Auffray[3], Václav Čuba[2]

[1]*Institute of Physics, Czech Academy of Sciences, Prague, 162 00, Czech Republic*
[2]*FNSPE Czech Technical University in Prague, 115 19, Czech Republic*
[3]*European Organization for Nuclear Research (CERN), Meyrin, 1211, Switzerland*
[4]*Department of Physics, University of Milano-Bicocca, Milano, 20 126, Italy (now at I3M, Valencia)*

Corresponding Author Email: mihokova@fzu.cz

In recent years cesium lead halide perovskite nanocrystals have attracted attention in many application fields, among which that of radiation detection. Thanks to quantum confinement effect they feature ultrafast scintillation decays [1]. Therefore, they have been identified as promising fast emitters in scintillating metamaterials intended to build up novel detectors requiring fast timing [2]. Such detectors are particularly needed in the time-of-flight (TOF) techniques in medical imaging as well as high energy physics. However, the practical usage of nanocrystals requires dealing with two major issues. Poor chemical stability can be overcome by their incorporation in a suitable, e.g. polymer, matrix to form nanocomposite. Low stopping power calls for fabrication of nanocomposites with the highest possible nanocrystalline loading keeping their reasonable level of transparency.

In this work we study synthesis, structural and optical characteristics including the timing performance of cesium lead bromide and cesium lead bromo-chloride nanocrystals embedded in the polystyrene matrix. We focus on synthesis routes for nanocomposites with high nanocrystalline loading up to 40%. However, with higher loading favourable luminescent properties of nanocrystals can be compromised by their agglomeration leading to reduced transparency and consequently the reduced light extraction from prepared nanocomposites. To limit this effect, we use advanced polymerization techniques and copolymerizable ligands. The level of nanoparticle agglomeration is studied by confocal microscopy. We also study scintillation characteristics of prepared nanocomposites, especially scintillation decays. We assess the nanocomposite time resolution using a setup described in [3]. Prepared nanocomposites feature significantly better time resolution with respect to the currently used standalone conventional scintillators, such as LYSO:Ce crystal.

1. K. Děcká, J. Král, F. Hájek, P. Průša, V. Babin, E. Mihóková, V. Čuba "Scintillation response enhancement in nanocrystalline lead halide perovskite thin films on scintillating wafers," Nanomaterials, 12, 14 (2021).

2. G. Konstantinou, P. Lecoq, J.M. Benlloch, A.J. Gonzalez "Metascintillators for ultrafast gamma detectors" A review of current state and future perspectives," IEEE Trans. Radiat. Plasma Med. Sci., 6, 510 (2021).

3. F. Pagano, N. Kratochwil, M. Salomoni, I. Frank, S. Gundacker, M. Pizzichemi, M. Paganoni, E. Auffray "A new method to characterize low stopping power and ultra-fast scintillators using pulsed X-rays," Front. Phys., 10, 1 (2022).

This work was carried out in the frame of crystal clear collaboration. Financial support of projects: GAČR 23-05 615, SenDiSo, Reg.No. CZ.02.01.01/00/22_008/0004596 and European Pathfinder project Unicorn (GA: 101098649) is gratefully acknowledged.

Oral Sessions | Tuesday, July 9th 2024

T-NA4 Nanoscintillators for biomedical applications: optimizing the functionalization to control biocompatibility

Clémentine Aubrun Fulbert [1, 2], Sarah Stelse-Masson [1, 2], Frédéric Chaput [3], Hélène Elleaume [2], Anne-Laure Bulin [1]

[1] *Université Grenoble Alpes, Inserm U1209, CNRS UMR 5309, Institute for Advanced Biosciences, Grenoble, France*
[2] *Université Grenoble Alpes, Inserm UA7, Synchrotron Radiation for Biomedicine, Grenoble, France*
[3] *École Normale Supérieure de Lyon, Department of Chemistry, Lyon, France*

Corresponding Author Email: anne-laure.bulin@inserm.fr

More than 50% of cancer patients undergo radiation therapy in the course of their treatment. However, because of a lack of specificity for tumor tissues, delivering therapeutically effective doses of X-rays with tolerable toxicity on healthy surrounding tissues remains a challenge. To enhance the therapeutic window of radiotherapy and lead to a better prognosis for difficult-to-treat cancers, innovative nanoscintillators have been proposed to activate various radiotherapeutic effects including radiation dose enhancement [1], X-ray activated photodynamic therapy [2] or UV-C induced specific DNA damage [3], [4]. Such approaches are of particular interest for cancers such as glioblastoma or pancreatic cancer that remain at a therapeutic impasse. When designing nanoscintillators for biomedical applications, several properties need to be optimized. In addition to selecting suitable scintillating properties, appropriate sizes and shapes, the nanoparticles need to be tailored to achieve biocompatibility and proper *in vitro* and *in vivo* behavior. Amongst the parameters influencing these aspects, we identified the functionalization. In this work, we focused on the nanoparticles coating and compared two systems made of LaF3:Ce coated either with tripolyphosphate (TPP) molecules or with polyethylene glycol (PEG) chains.

After characterizing the chemical properties of these two systems, we first investigated the impact of the nanoscintillators coating *in vitro* on pancreatic cancer models grown in 2D or 3D cultures. 3D cultures have been proposed as a more physiological alternative to 2D cultures, which traditionnally provide high-throughput data but lack biological relevance. *In vitro*, we focused on cellular uptake and intracellular localization in 2D cultures, intra-spheroid uptake (3D cultures), as well as therapeutic efficacy evaluated in both 2D and 3D models. Because *in vitro* and *in vivo* behavior may strongly differ, we then investigated parameters such as biocompatibility and pharmacokinetics in healthy mice, as well as biodistribution in mice bearing pancreatic tumors orthotopically implanted.

1. Bulin et al. "Radiation Dose-Enhancement Is a Potent Radiotherapeutic Effect of Rare-Earth Composite Nanoscintillators in Preclinical Models of Glioblastoma" Advanced Science, 7, 2020

2. Sun et al. "Nanoscintillator-Mediated X-Ray Induced Photodynamic Therapy for Deep-Seated Tumors: From Concept to Biomedical Applications" Theranostics, 10, 2020

3. Squillante et al. "Fabrication and characterization of UV-emitting nanoparticles as novel radiation sensitizers targeting hypoxic tumor cells" Opt Mater, 80, 2018.

4. Espinoza et al., "Characterization of Micro- and Nanoscale $LuPO_4$:Pr^{3+}, Nd^{3+} with Strong UV- C Emission to Reduce X-Ray Doses in Radiation Therapy" Part Part Syst Char, 36, 2019

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SESSION 7: SCINTILLATORS FOR FAST TIMING DETECTION AND IMAGING (PART 1)

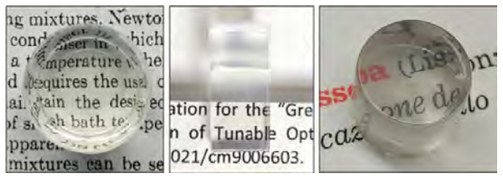
T-FT3 A new class of plastic scintillators for fast timing detector and medical applications

Michela Marafini[e,b], Alessandro Belardini[d], Alberto Burattini[c,d], Marta David[e], Angelica De Gregorio[a,b], Gaia Franciosini[a,b], Marco Magi[d,b], Annalisa Muscato[c,b], Vincenzo Patera[d,b], Flaminia Quattrini[a,b], Daniele Rocco[d], Alessio Sarti[d,b], Angelo Schiavi[d,b], Marco Toppi[d,b], Giacomo Traini[b], Leonardo Mattiello[d]

[a] *Sapienza University of Rome, Department of Physics, Rome, Italy*
[b] *INFN National Institute for Nuclear Physics, Roma I Section, Rome, Italy*
[c] *Sapienza University of Rome, Post-graduate School in Medical Physics, Rome, Italy*
[d] *Sapienza University of Rome, Department SBAI, Rome, Italy*
[e] *CREF Centro Ricerche Enrico Fermi, Rome, Italy*

Corresponding Author Email: michela.marafini@cref.it

Plastic scintillators consist principally of a fluorophore, responsible for the absorption and conversion of the kinetic energy of the particles into lower-energy light radiation and, sometimes, a wavelength shifter dissolved in a plastic polymer matrix. Obtaining homogeneous, light, machinable, transparent and high-performance plastic objects is one of the main challenges of this research line. The scintillation time of these currently available plastic scintillators (EJ-232 - Eljen Technology and BC- 422 - Saint Gobain) is 350 ps of rise time, 1600 ps of decay time and a pulse width of 1300 ps, against a light yield quoted at about 55% compared to anthracene. These characteristics place an intrinsic limit on the possibility of creating more performing time detectors.



The TOPS - *Time Of flight Plastic Scintillator* - project concerns the synthesis of a new series of organic molecules which can be used as fluorophores in plastic scintillators [1]. Comparing the light output and the time properties of new samples, a selection of the most promising scintillators has been investigated and characterized (redout with commercial PMTs - Hamamatsu H10721-20). The performance achieved with TOPS samples are extremely promising: a time resolution improvement from 10 up to 35% with respect to the EJ-232 commercial scintillator has been demonstrated. In addition, an increase of light output has been obtained for all samples with a consequent potential improvement in energy resolution measurements of a factor up to 35% [2].

Exploiting the 3D printer technique and integrating the scintillator inside resin we also demonstrate the feasibility of producing scintillator samples dissolving the new fluorophores in *VeroClear* (www.stratasys.com/it/materials/search/veroclear).

As for the commercial EJ-256 (clear plastic scintillator in which lead is incorporated by means of organometallic chemistry), we produced samples enriched with Bismuth. In commercial samples typical lead loading ranges from 1% to 5% by weight, loadings up to 10% have been made but are not recommended by Eljen, while with the increasing of lead loading, a corresponding loss is verified, and the scintillation efficiency dresses together with the optical clarity of the final plastic. In our test with 2N and Bismuth samples have been realized from 2 up to 10% obtained promising results and have been compared with commercial samples of EJ-256.

In this contribution, the performances of the different samples in the several experimental setups will be presented together with an overview of the possible application in medical physics.

1. Mattiello L;, Patera V.; Belardini A.; Rocco D.; Marafini M.; Organic Scintillator. Patent WO2023156957A1, 2023.

2. D.Rocco et al., "TOPS fast timing plastic scintillators: Time and light output performances". NIM A 1052, 168277 (2023); doi: 10.1016/j.nima.2023.168277

Oral Sessions | Tuesday, July 9th 2024

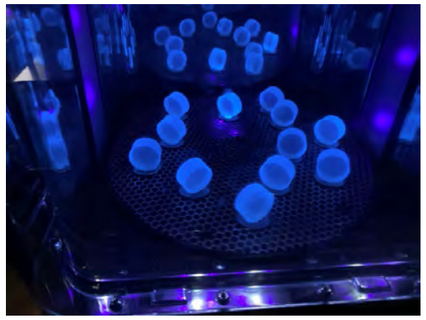
T-FT4 Additive Manufacturing of Structural and Pixelated/Discriminating Scintillators

Adam J. Wolverton[1], Matthew Staska[1], John DiBenedetto[1], Robert Buckles[1], James Tinsley[1]

[1]Nevada National Security Sites, North Las Vegas, NV, USA

Corresponding Author Email: Wolveraj@nv.doe.gov

Plastic Scintillators are commonly used in radiation detection devices throughout the world. The Nevada National Security Sites (NNSS) use scintillators for prompt radiation detection in high energy experiments that generate large fluxes of pulsed radiation. Increased light output and faster decay times are desired. These attributes are directly affected by the formulation of the scintillator, machining, polishing, and coatings on not only the scintillator, but also light guides in the optical path. Additive Manufacturing (AM) of plastic scintillators has been recently shown to produce performance comparable to cast materials. Resolution at micron levels allows us to rapidly prototype new formulations, shapes, and sizes of scintillators without the cost and machining associated with it.



3D-printed witness pieces of Anthracene and PPO/BBOT doped resins for test/characterization

This work examines the use of commercially off-the-shelf clear resins as a medium for mixing various concentration levels of dopants such as Anthracene, 2,5-Diphenyloxazole (PPO), and 2,5-Bis(5-tert-butyl-benzoxazol-2-yl)thiophene (BBOT). We printed several witness pieces as test articles to measure optical transmission, fluorescence spectrum, and fluor decay time. We compared our test articles to the EJ-232 scintillator, which we readily use in many detector designs. These AM scintillators were placed in a detector test fixture for gamma calibrations, allowing us to measure scintillator sensitivity to Co^{60} gamma radiation.

We will present results from increased dopant concentrations and their effect on gamma sensitivity, fluorescence decay time, and optical transmission. Further improvements in performance of the resins will reduce costs associated with machining and polishing, and speed up the development time of new and interesting scintillators. The fine detail found in current state-of-the-art AM systems allows for truly mixed materials and engineered structures not available by other means. We are extending these rather nascent advances into the engineering of shapes that function as structural components, gradients in material index (by composition) to improve optical coupling, and combinations of spatial and spectral aspects to increase discrimination.

This work was conducted with guidance from Chris Crowley at Formlabs, Inc., Capt. Brad Baker at the US Naval Academy, and Chuck Hurlbut from Eljen Technology. Their assistance and guidance aided us in beta testing new resins and developing new additive mixture concentrations for testing.

This work was done by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624 with the U.S. Department of Energy, the NNSA Office of Defense Programs, and supported by the Site-Directed Research and Development Program. DOE/NV/03624--1870.

3D-printed witness pieces of Anthracene and PPO/BBOT doped resins for test/characterization.

T-FT5 Slow Excitation Transfer via Gadolinium Subsystem in Ce-doped Garnet-type Scintillators and Blocking the Transfer by Aliovalent Codoping

G. Tamulaitis[1], Y. Talochka[1], S. Nargelas[1], Ž. Podlipskas[1], M. Kucera[2], Z. Lucenicova[2]

[1]Institute of Photonics and Nanotechnology, Vilnius University, Vilnius, Lithuania
[2]Faculty Math & Physics, Charles University, Prague, Czech Republic

Corresponding Author Email: gintautas.tamulaitis@ff.vu.lt

One of the key problems in the development of fast scintillators based on Ce-doped multicomponent garnets having convenient flexibility for composition engineering is the trade-off between their scintillation decay time and efficiency. Gadolinium is usually introduced in such scintillators to increase the luminescence efficiency by increasing the energy barrier for the thermal depopulation of emitting level 5d1 of Ce^{3+} ion. However, the Gd ions build a sublattice, so that a part of excitations might reach the Ce^{3+} ions via that sublattice with a delay deteriorating the timing properties of Ce- doped Gd-containing garnet scintillators. To test the importance of this mechanism, we compared the luminescence decay at the excitation with high-energy electrons and at photoexcitation resonantly to the emitting level 5d1 of Ce^{3+} to exclude the excitation transfer through the matrix. As illustrated in the figure, in $Lu_3Al_5O_{12}$:Ce (LuAG:Ce) containing no Gd in the matrix, cathodoluminescence (CL) and photoluminescence (PL) decay kinetics coincide, whereas the decay of CL is substantially slower than that of PL in Gd-containing $Lu_{0.75}Gd_{2.25}Ga_{2.5}Al_{2.5}O_{12}$:Ce (LuGAGG:Ce).

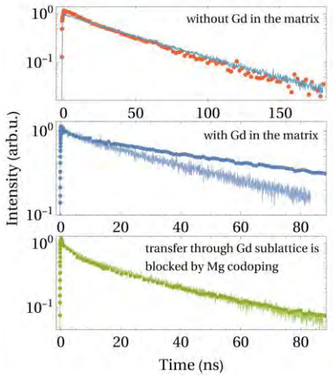
Normalized luminescence decay in Ce- doped garnet-type scintillator without Gd in its matrix LuAG:Ce and Gd-containing LuGAGG:Ce without and with Mg cooping at excitation by 10 keV electrons (points) and resonant photoexcitation to the emitting 5d1 level of Ce^{3+} (lines).

We interpret this effect by the delayed excitation transfer via the Gd sublattice and quantitatively characterize the transfer by the Monte Carlo simulation of excitation transfer with the dipole-dipole and Dexter transfer mechanisms taken into account to evaluate the rate of energy transfer between Gd^{3+} ions and from a Gd^{3+} ions to a Ce^{3+} ions, respectively. We revealed that two Gd^{3+} multiplets, ^6P and ^6I, are important in the excitation transfer to emitting Ce^{3+}.

The simulations show that the excitation transfer via the Gd sublattice results in a substantial slowing down of the luminescence decay within the first 100 ns after excitation.

Our study of LuGAGG:Ce codoped by Mg at different levels revealed that the deteriorating influence of Gd in the scintillator lattice on the luminescence decay can be blocked by Mg codoping, so that the slow excitation transfer is channeled via nonradiative recombination due to the spectral overlap of optical transitions in Gd^{3+} ions and the codoping-related absorption band. Thus, blocking of the excitation transfer via the Gd subsystem is an important mechanism of luminescence decay acceleration, in addition to the transformation of cerium ions from Ce^{3+} to Ce^{4+}, the elimination of the influence of electron traps, and the formation of Ce^{3+}+Mg^{2+} pairs.

In conclusion, the energy transfer via ^6P and ^6I multiplets of Gd^{3+} ions in Ce-doped garnet-type scintillators substantially slows down the scintillation decay. This effect might be suppressed by aliovalent codoping, although, at the expense of the light yield.



Normalized luminescence decay in Ce-doped garnet-type scintillator without Gd in its matrix LuAG:Ce and Gd-containing LuGAGG:Ce without and with Mg cooping at excitation by 10 keV electrons (points) and resonant photoexcitation to the emitting 5d1 level of Ce^{3+} (lines).

Oral Sessions | Tuesday, July 9th 2024

T-FT6 Neutron and Gamma-ray Imaging of Th-232 and Cm-244 using Organic Glass Scintillators

R. Lopez[1], P. Kerr[2], V. V. Mozin[2], S. D. Clarke[1], S. A. Pozzi[1]

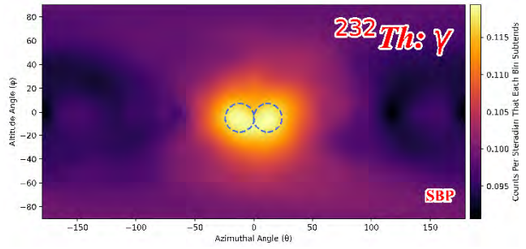
[1]Nuclear Engineering and Radiological Sciences - University of Michigan, Ann Arbor, MI, USA
[2]Lawrence Livermore National Laboratory, Livermore, CA, USA

Corresponding Author Email: rlopezle@umich.edu

Nuclear safeguards and nonproliferation constantly develop new tools and techniques to detect and characterize nuclear materials and other radiation sources. Organic glass scintillator (OGS) is a recent scintillator of interest, developed by Sandia National Laboratories that has high light output compared to stilbene scintillators, good timing resolution and is pulse shape discrimination capable [1].

Our group at the University of Michigan has developed a handheld dual-particle imaging system (H2DPI) composed of OGS bars (6x6x50 mm) and $CeBr^3$ cylinders (6x6 mm) [2]. Particle imaging is performed using the locations, times, and energy deposition from coincident events. These measured quantities are used to create conical projections that are then reconstructed using simple back projection to determine the most likely source location in angular space.

This work presents new results from two experiments that demonstrate the dual-particle imaging capabilities of the OGS system. Dual- particle imaging was performed on a pair of Th- 232 hemishells (outer diameter 13 cm and mass 590g each). The shells were placed side-by-side, approximately 35 cm in front of the imager. An energy gate of 200-300 keV was used for the gamma-ray imaging to isolate the 238 keV emission. Dual-particle imaging was performed on a single unshielded Cm-244 source placed approximately 37 cm in front of the imager. Fast neutrons from the Cm-244 source were measured and shown to enable accurate source imaging. The final paper will include neutron and gamma-ray spectroscopy results from these experiments. We will also use a LM- MLEM converging algorithm on the SBP images to better converge on the source locations. Ultimately, this work shows the dual particle capability of the H2DPI for new experiments on two unique radiation sources: Th-232 and Cm-244.



Simple back projection (SBP) images generated from data collected using the organic glass imaging system. Gamma image of Th-232 with an energy gate of 200-300 keV. Neutron image of Cm-244. Source locations represented with the dashed outlines.

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Acknowledgments

We thank Dr. Vladimir Mozin and Dr. Phil Kerr for providing use of sources and facilities at LLNL. This work was funded in-part by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration, United States of America award number DE-NA0003920.

T-FT7 Growth and scintillation characteristics of ultrafast Cs_2ZnCl_4 crystal scintillators

Yun Shi[1], *, Xiaoyi Zuo[1, 2], Shaohan Wang[1], Mingxue Deng[1], Sancan Han[2], Dong Wang[1], Junfeng Chen[1],*

[1]R&D center for novel materials, Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China
[2]School of Materials and Chemistry, University of Shanghai for Science and Technology, Shanghai, China

Corresponding Author Email: shiyun@mail.sic.ac.cn; jfchen@mail.sic.ac.cn

Recently, there is a rising R&D trends toward ultrafast scintillators for high energy physics (HEP), time of flight (TOF) measurements, GHz hard X-ray imaging, and other high count rate applications[1]. Besides the commercially available BaF_2 crystals, Cs_2ZnCl_4 has become one of the most promising candidates due to their recently reported ultrafast decay time (~1.66 ns) component and low ratio of slow decay components [2,3].

In this work, a series of large size Cs_2ZnCl_4 single crystals with high optical quality were grown via the vertical Bridgman method. Their structural, thermal physical, and transmittance properties were systematically investigated by X-ray diffraction (XRD), Differential Scanning Calorimetry (DSC), and UV-VIS spectrophotometry. The photoluminescence (PL) and radioluminescence (RL) properties of these crystals were characterized by the PL spectrum and X-ray excited luminescence (XEL) spectra, including their temperature-dependent characteristics. More importantly, we investigated systematically their scintillation performance under the different gammar ray excitation. The mechamism of the ultrafast decay, as well as the effect of the defects in the crystal were discusssed according to the experimental results.

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Acknowledgments

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Oral Sessions | Tuesday, July 9th 2024

SESSION 8: MECHANISMS AND THEORY OF SCINTILLATION

T-TH1 The Decay of Ultrafast Cross-Luminescence in Binary and Ternary Scintillator Materials

Vitali Nagirnyi[1], Marco Kirm[1], Sergey I. Omelkov[1], Ivo Romet[1], Juhan Saaring[2], Irina Kudryavtseva[1], Alexander Vanetsev[1]

[1]*Institute of Physics, University of Tartu, Tartu, Estonia*
[2]*Tartu University Hospital, Tartu, Estonia*

Corresponding Author Email: vitali.nagirnoi@ut.ee

Recent search for novel solutions in time-of-flight positron emission tomography, allowing the discovery of early stages of altered health conditions at relatively low exposure doses, have renewed interest to scintillators possessing ultrafast luminescence, despite the light yield of such luminescence is generally very low in comparison to that in widely used rare earth doped wide gap scintillators [1]. Currently, two main candidates of intrinsic luminescence processes can mainly be considered for such applications of wide gap materials. These are cross-luminescence (CL), originating from the radiative recombination of electrons from the valence band with holes in the outermost core band [2], and intraband luminescence (IBL) arising due to charge carrier radiative transitions within the conduction or valence band [3]. The IBL decay times lay in the sub-ps range, but its yield is extremely low spanning to 30 ph/MeV [4]. The yield of CL reaches 2000 ph/MeV at sub-ns decay times [5], but the processes defining the decay time depending, e.g., on impurity composition or morphology of the compound are not well studied because of insufficient experimental time resolution available. In recent years we have developed the setups for time-resolved luminescence spectroscopy studies at pulsed X-ray excitation at the FemtoMAX beamline of MAX IV Lab (Lund, Sweden) [6], and pulsed cathodoluminescence at the Institute of Physics (Tartu, Estonia) [4] with time resolution 30 and 50 ps, respectively. Benefitting from these experimental advancements, we report on the studies of the dynamics of ultrafast CL in classical binary cross-luminescent crystals as BaF_2, pure and doped by La or Y, and CsCl as well as in a series of ternary hexafluorides such as $BaGeF_6$ (see also [7]), K_2GeF_6, etc. The achieved time resolution allowed to discover more complicated CL decay kinetics, demonstrating in some cases several decay components, and to get insight into its temperature. A special attention is paid to the distinguishing of classical CL from IBL transitions in ternary materials, in which the IBL spectrum is remarkably complex due to the hybridized flouro-anion states forming a split structure of the valence band. The branching of relaxation processes in binary and ternary fluorides leading to different emissions will be analysed based on electronic band structure calculations and time-resolved luminescence spectroscopy results. Application prospects of the studied compounds as ultrafast scintillators will be considered.

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T-TH2 Photoluminescence and scintillation characteristics of undoped and Ce-doped $(Gd,Y)AlO_3$ single crystals

Monika Kotyková[1,2], Romana Kučerková[1], Alena Beitlerová[1], Vladimir Babin[1], Jan Touš[2], Jan Polák[2], Karel Blažek[2], Martin Nikl[1]

[1]*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[2]*CRYTUR spol. s r. o., Turnov, Czech Republic*

Corresponding Author Email: kotykova@fzu.cz

The Ce-doped aluminium perovskite $YAlO_3$ (YAP:Ce) is a well known scintillator applied in several fields. Especially high light yield over 18 000 ph/MeV, energy resolution of 4 %@662 keV, and fast response dominated by 25–30 ns decay time are among its practical advantages. However, due to its low density of 5.37 g/cm^3, this material is not suitable for detection of high-energy gamma radiation. In order to develop a higher density, fast and efficient bulk single crystal, Lu and Gd admixture was reported in literature. The addition of a component with higher atomic number increases the stopping power and density of the crystal. The optical properties of $LuAlO_3$ are very similar to those of YAP:Ce, but there are complications related to the stability of the perovskite phase and the frequent appearance of the garnet phase in the growth process. Also, its LY at room temperature is of about one half of YAP:Ce. Yttrium admixture stabilises the growth process (1). The addition of Gd to LuAP:Ce raises the LY to 21 000 ph/MeV, reducing the effect of traps in LuAP (2). Another effect is the acceleration of the transport of free carriers to Ce^{3+}. GdAP suffers from the back energy transfer from Ce^{3+} to Gd^{3+} (3), therefore the LY is lower (9 000 ph/MeV) (4).

A set of single crystals of $(Gd,Y)AlO_3$:Ce (GdYAP:Ce) with a varying ratio of Gd to Y was prepared in CRYTUR (5). This material has promising properties with light yield (LY) of up to 25 000 ph/MeV, that is superior to YAP:Ce and resolution of 5 %@662 keV measured on a polished sample of 1 mm thickness. The slower decay components in scintillation response due to energy migration inside the Gd sublattice are of the order of few hundreds of ns which are well captured by shaping time of 1–2 µs in LY measurement. In order to understand the luminescence and scintillation process in GdYAP:Ce, an undoped sample $(Gd_{0.40}Y_{0.60})AlO_3$ was also prepared and tested. The absorption spectrum, radio- and photoluminescence spectra and decay will be presented. Temperature dependence of the intensity of photoluminescence and decay time will be discussed to describe the energy migration in Gd^{3+} sublattice and the process will be compared with that in undoped Gd-rich aluminium garnets (6).

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Oral Sessions | Tuesday, July 9th 2024

T-TH3 Simulation of Excitation Transfer via Gd Sublattice in Garnet-type Scintillators

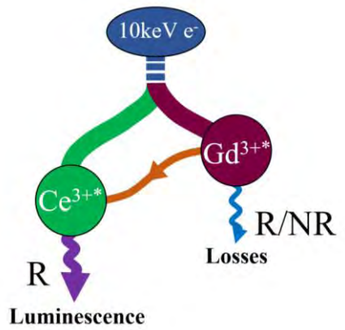
Y. Talochka, Z. Podlipskas, G. Tamulaitis

Institute of Photonics and Nanotechnology, Vilnius University, Sauletekio al. 3, LT-10257, Vilnius, Lithuania

Corresponding Author Email: yauheni.talochka@ff.vu.lt

Applications of scintillator-based radiation detectors in high energy physics experiments and for medical imaging require improvement in the response time of the scintillators. Fast scintillation decay is demanded to avoid the piling-up effect in the coming high-luminosity experiments at CERN High-Luminosity Large Hadron Collider [1]. To quantitatively reveal the mechanisms governing the scintillation decay kinetics of Ce-doped multicomponent scintillators containing gadolinium, a kinetic Monte Carlo model of excitation transfer via the gadolinium subsystem in quaternary garnet-type scintillator was developed and tested by the comparison of the luminescence decay kinetics simulated and measured using time-resolved cathodoluminescence technique in $Lu_{0.75}Gd_{2.25}Ga_{2.5}Al_{2.5}O_{12}$:Ce (LuGAGG:Ce) crystal as one of the most prospective fast scintillators.

The thermodynamic approach was used to simulate the spatial distribution of gadolinium, lutetium and cerium cations in LuGAGG crystal host [2]. The excitation transport through gadolinium subsystem and from gadolinium subsystem to emitting Ce^{3+} ions was simulated using the Monte Carlo technique. The dipole-dipole and Dexter transfer mechanisms were taken into account to evaluate the energy transfer rate between Gd^{3+} ions and from a Gd^{3+} ion to a Ce^{3+} ion, respectively. The cathodoluminescence decay kinetics in LuGAGG:Ce compound scintillator excited by 10 keV electron beam was described by taking into account the contributions of directly excited Ce^{3+} ions and Ce^{3+} ions excited due to the excitation transfer from gadolinium subsystem (see the relaxation path diagram in the figure). Fitting of the simulated and measured cathodoluminescence kinetics enabled us to extract parameters of excitation transfer via the Gd subsystem. We showed that the involvement of two gadolinium multiplets, ^6P and ^6I, in the excitation transfer to emitting Ce^{3+} ions has to be taken into account for an appropriate description of the cathodoluminescence decay. We showed that the excitation transfer via the Gd sublattice substantially decreases the luminescence decay rate within the first 100 ns after excitation.



Relaxation paths for excitations in LuGAGG:Ce scintillator.

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This research has been carried out in the framework of Crystal Clear Collaboration at CERN, was performed under the „Universities` Excellence Initiative" programme by the Ministry of Education, Science and Sport of the Republic of Lithuania and received funding via the HORIZON 2020 RIA project AIDAinnova.

T-TH4 Compositionally Disordered Crystalline Compounds for Novel Scintillation Materials

Mikhail Korzhik[1], Andrei Vasil'ev[2]

[1]Institute for Nuclear Problems of Belarus State University, Minsk, Belarus
[2]Skobeltsin Institute for Nuclear Physics of Moscow State University, Moscow, Russia

Corresponding Author Email: mikhail.korjik@cern.ch

The report summarizes evidence of the compositional disordering of the crystalline matrixes of the scintillation materials, activated and selfactivated, to improve their scintillation parameters. The advantages of complicating the crystal matrices, both anionic and cationic, of a variety of inorganic activated scintillation compounds have been summarized in [1]. A few effects of the compositional disorder in the crystalline system have been underlined. First is a change in the landscape of the top and bottom regions of the valence and conduction bands, which are adjacent to the bandgap. Second, a change of the positions inside the bandgap of the energy levels of fn-and mixed configurations fn-1d1 of Ce^{3+}, Pr^{3+}, Tb^{3+}, and Gd^{3+} ions allows to optimize the thermolyzed electronic excitations transfer efficiency.

This approach was generalized for activated and self-activated inorganic scintillators and supported by the results on the scintillation properties obtained with scintillation crystalline compounds of the garnet and scheelite structural types. It is shown that this way of engineering the compound's composition may result in an increase in the yield of scintillation, a shortening in the kinetics of scintillation, or a combination of both. This is due to the increasing role of geminate pairs of nonequilibrium carriers in the transfer of electronic excitations to luminescent centers, as well as the increasing role of exchange interaction, which reduces the role of long-range electronic excitation transport. The results on the scintillation properties of the complication of the crystal composition— from binary to quintuple cation garnet type compounds, containing Gd, Y, Lu, Tb, and Yb matrix- forming ions—and from binary to ternary tungstate crystals are discussed in support of the developed approach. The set of activating ions applied is enlarged to include Ce^{3+}, Pr^{3+}, Tb^{3+}, Eu^{3+}, and Yb^{3+}.

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Oral Sessions | Tuesday, July 9th 2024

T-TH5 Design criteria and fundamental limits of Sm^{2+}-doped halide scintillators

Casper van Aarle[1], Karl W. Krämer[2], Pieter Dorenbos[1]

[1]*Delft University of Technology, Faculty of Applied Sciences, Department of Radiation Science and Technology, Mekelweg 15, 2629JB, Delft, the Netherlands*
[2]*University of Bern, Department of Chemistry and Biochemistry, Freiestrasse 3, CH-3012, Bern, Switzerland*

Corresponding Author Email: c.vanaarle@tudelft.nl

The development of scintillation detectors with energy resolution below 2% runs into the fundamental limitation of Poisson statistics in the number of detected photons. Further improvement of the energy resolution therefore requires an increase in the number of detected scintillation photons. This can be achieved using silicon based photodetectors, with which a two times higher detection efficiency compared to a photomultiplier tube can be reached. These silicon based photodetectors can efficiently detect wavelengths up to 800 nm, making the near-infrared emitting Sm^{2+} an attractive alternative dopant to the conventionally used Ce^{3+} and Eu^{2+}. The main benefit of Sm^{2+} scintillation is the inherent low probability of self-absorption, a problem that is primarily present in Eu^{2+}-doped scintillators.

In order to find the ideal Sm^{2+}-doped scintillator, properties such as emission wavelength, decay time and light yield are of key importance. This work will demonstrate that the first two are closely related due to the Boltzmann distribution between the $4f^55d$ and $4f^6[^5D_0]$ excited state population. It is found that the optimal emission wavelength falls within the sensitivity window of silicon based photodetectors. It will be discussed what type of host compounds have this optimal Sm^{2+} emission wavelength. Furthermore, the maximum attainable light yield of Sm^{2+}-doped halide scintillators will be compared to that of Eu^{2+} and Ce^{3+}-doped halides. From this, the design criteria for Sm^{2+}-doped halide scintillators are formulated.

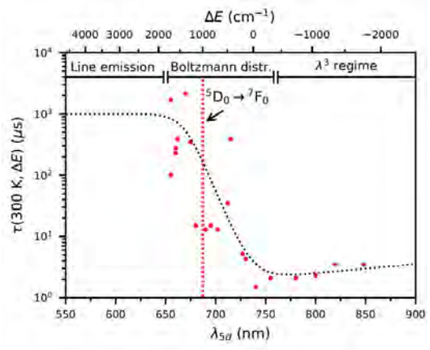

Figure 1: Photoluminescence decay time of the Sm^{2+} $4f^55d \rightarrow 4f^6$ emission as a function of emission wavelength λ_{5d} in various compounds. The dotted line is the expected behavior based on a Boltzmann distribution between the population of the $4f^55d$ and $4f^6[^5D_0]$ states. The shortest decay time is found around λ_{5d} = 750 nm.

T-TH6 Influence of partial substitution of aluminum and gallium by scandium ions on energy transfer processes in garnet crystals

Dmitry Spassky[1,2], Andrey Vasil'ev[2], Fedor Fedunin[3], Oleg Buzanov[4], Vitali Nagirnyi[1]

[1]*Institute of Physics, University of Tartu, 50411 Tartu, Estonia*
[2]*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119991 Moscow, Russia*
[3]*Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia*
[4]*FOMOS-Materials, Moscow, Russia*

e-mail: dmitry.spasskiy@ut.ee

$Gd_3Al_{5-x}Ga_xO_{12}$ garnets crystals doped with Ce^{3+} ions are promising scintillation materials for application in high-energy physics experiments, space research and medicine [1-3]. These crystals attract attention due to the combination of such properties as high density and light output, good energy resolution, radiation resistance and chemical stability. In particular, $Gd_3Al_3Ga_2O_{12}$:Ce crystals demonstrate the light output up to 60,000 photons/MeV that is the highest value for oxide scintillators [4,5]. A significant obstacle for GAGG:Ce application is the presence of slow components in the luminescence decay kinetics of cerium (τ > 100 ns), which negatively affects the scintillation properties of this material. These components originate from the intermediate localization of charge carriers at shallow traps as well as from the energy transfer to the Ce^{3+} luminescence centers through the 4f states of the Gd^{3+} sublattice. The purpose of this work is to study the effect of partial substitution of aluminum and gallium ions with scandium on the processes of energy transfer to Ce^{3+} luminescence centers.

Single crystals with nominal compositions $Gd_3Ga_3Al_2O_{12}$ (GAGG), $Gd_{2.97}Ce_{0.03}Ga_3Al_2O_{12}$ (GAGG:Ce) and $Gd_{2.97}Ce_{0.03}Ga_{2.5}Sc_1Al_{1.5}O_{12}$ (GASGG:Ce) were grown at Fomos Materials by the Czochralski method in iridium crucibles in an Ar+1%O_2 atmosphere. Luminescence excitation spectra were measured in a wide energy range 2.5-45 eV, thus allowing the analysis of different stages of excitation energy conversion into luminescence, such as direct excitation of luminescence centers, ionization of luminescence centers, creation of excitons, creation of separated electron-hole pairs, multiplication of electronic excitations and excitation of electrons from core levels.

It is shown that electronic states of Sc participate in the formation of the bottom of the conduction band and form an additional channel of energy transfer to luminescence centers. The relaxation of excitations via Sc states results in a redistribution of the efficiency of energy transfer to the Ce^{3+} and Gd^{3+} luminescence centers and an increase in the relative intensity of the Ce^{3+} luminescence.

The simulation of energy relaxation processes in garnet crystals was carried out as well. Based on the densities of states available in the literature, the effective masses and relaxation rates of electrons and holes were calculated. The distribution of secondary electronic excitations during inelastic scattering of electrons created by photons in the region of the multiplication of electronic excitations was estimated. A model was created that describes the formation of luminescence excitation spectra of Gd^{3+} in GAGG as well as Ce^{3+} in GAGG:Ce and GASGG:Ce.

Fedyunin F. is grateful to the support from the Theoretical Physics and Mathematics Advancement Foundation «BASIS».

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T-TH7 Unveiling Temperature-Dependent Scintillation Mechanisms in Toluene: Insights from X-ray and Optical Excitation Studies

Weronika W. Wolszczak[1], Gabriel D. Orebi Gann[1,2], Federico Moretti[1]

[1]*Lawrence Berkeley National Laboratory, Berkeley, CA, USA*
[2]*University of California Berkeley, Berkeley, CA, USA*

Corresponding Author Email: wwols@lbl.gov

Molecular materials encompassing organic, plastic, liquid, and water-based scintillators play a crucial role in various applications, yet their scintillation mechanisms remain inadequately understood, hindering the development of predictive models for their properties. Previous research [1] has underscored the pivotal role of phenyl rings in achieving high light yield in molecular materials. In this study, we investigate toluene as a model material, probing its properties through x-ray and optical excitation across a temperature range of 20-300 K. Our results reveal a notable enhancement in light yield at cryogenic temperatures when toluene is in its solid state.

Contrary to conventional statistical considerations postulating a fixed 1:3 ratio between singlet and triplet state populations, we observe a temperature-dependent variation in singlet to triplet intensity ratio with nearly complete quenching of triplet emission at 170 K. Fig. 1 shows an exemplary plot at 80 K showing singlet to triplet intensity ratio Φ = 0.71. Upon transitioning from a solid to a liquid state, we observe a substantial decrease in light yield attributed to the formation of a transient excimer state enabled by motion of excited toluene molecules [2].

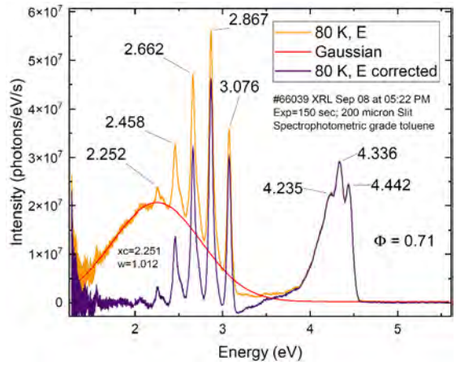

Figure 1. X-ray excited luminescence of toluene sample at 80 K. The orange curve shows raw data, the red curve is a gaussian fit of quartz cuvette scintillation. The purple line shows toluene scintillation spectrum corrected for cuvette scintillation. The peaks at 4.2-4.4 eV are identifies as singlet emission, while the series of vibration replicas between 2.2 and 3.1 eV corresponds to triplet emission. The integrated triplet to singlet intensity ratio is Φ=0.71.

Furthermore, as temperature increases, there is a discernible shift in the equilibrium between excimer and singlet emission with singlet emission dominating x-ray excited emission spectrum at 300 K. These insights elucidate the intricate temperature-dependent scintillation mechanisms in toluene, paving the way for a deeper understanding of molecular scintillators and their applications. The identification of the excimer formation process as one of the quenching mechanisms opens a possibility to design new molecular scintillators with increased light yield. The significant increase of the light yield at 20 K vs 300 K indicates that the theoretical limit for the maximum light yield has not been achieved in organic materials yet.

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Recent Advances in Halide Scintillators

Yun-Tao Wu

Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China

Corresponding Author Email: ytwu@mail.sic.ac.cn

Low-dimensional halides (LDHs) have drawn tremendous attention for scintillation detection applications due to decent radioluminescence efficiency, among which ternary-copper(I) halides are the most studied ones. We report a series of novel copper(I)-based halide scintillators with strong self-trapping exciton (STE) emission, such as $Cs_3Cu_2I_5$ and $Cs_5Cu_3Cl_6I_2$ [1,2]. Nonetheless, Figure 1 shows that the scintillation yields of most LDHs are far lower than the theoretical limit, despite possessing a high photoluminescence quantum yield. The exciton-exciton interaction, also known as Auger recombination, is a major quenching channel for halides under ionizing radiation. We propose exciton-harvesting and exciton confinement structural modulation strategies, to enhance scintillation yield [3]. For example, after Tl doping, the scintillation yield of $Cs_3Cu_2I_5$ increased by 300%, to about 90,000 photons/MeV under ^{137}Cs irradiation [4-6]. We also demonstrate the potential of radiation detectors based on copper(I)-based LDHs, such as all-solid-state radiation dose detectors and nuclear battery devices. Overall, due to a combination of non-hygroscopic properties, high effective atomic number (Zeff), high scintillation yield, and high energy resolution characteristics, copper(I)-based LDHs are uniquely positioned among scintillator materials, serving as versatile scintillator materials covering a wide range of radiation energies for various applications.

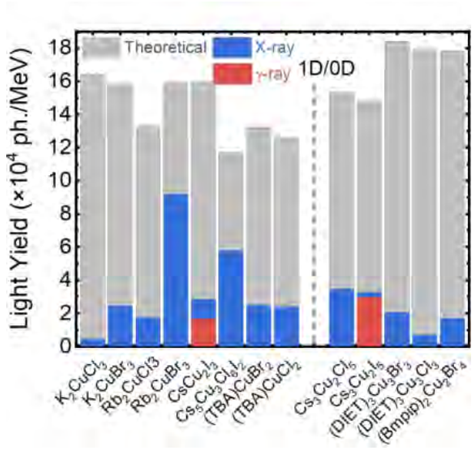

Figure 1. Theoretical and measured light yields of low-dimensional copper(I)-based halide scintillators.

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Oral Sessions | Wednesday, July 10th 2024

SESSION 9: CRYSTALS: GROWTH AND STRUCTURAL CONTROL

W-CR2 Flux growth of oxide scintillators for neutron detection

Shohei Kodama[1], Taiga Nishii[1], Miki Sodeno[1], Shunsuke Kurosawa[2,3,4], Akira Yoshikawa[2,3], Ikuo Yanase[1], Hiroaki Takeda[1]

[1] Graduate school of Science and Engineering, Saitama University, Saitama, Japan
[2] Institute for Materials Research, Tohoku University, Miyagi, Japan
[3] New Industry Creation Hatchery Center, Tohoku University, Miyagi, Japan
[4] Institute of Laser Engineering, Osaka University, Osaka, Japan

Corresponding Author Email: shokodama@apc.saitama-u.ac.jp

Inorganic compounds containing ^{6}Li have been actively developed such as LiI or $LiCaAlF_6$. We focused on Li_2CaSiO_4, an oxide compound composed of lightweight elements that is stable in air and has a low effective atomic number of 15 and density of 2.86 g/cm3, which is similar to that of $LiCaAlF_6$ (effective atomic number 14 and density 2.99 g/cm3). Li_2CaSiO_4 has a low sensitivity to gamma rays and is a promising host for novel Li-containing neutron scintillators.

$Ce:Li_2CaSiO_4$ and $Eu:Li_2CaSiO_4$ have been reported as UV-blue phosphors [1,2]. In our previous study, $Eu:Li_2CaSiO_4$ ceramics showed bright blue emission at approximately 480 nm [2]. Komendo et al. also reported that the pulse height spectra of translucent ceramics $Eu:Li_2CaSiO_4$, and the optimal $Eu:Li_2CaSiO_4$ crystal should be a promising neutron scintillator expected to show a high light output of up to ~100,000 photons/MeV [3]. However, Li_2CaSiO_4 undergoes a phase transition at 963 °C, which is located at a melting point of 1,053 °C. Consequently, melt growth of single- crystalline Li_2CaSiO_4 is quite difficult.

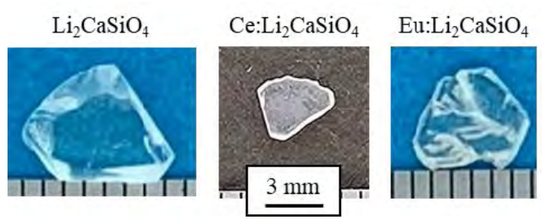

Figure 1. Obtained crystals of non-doped Li_2CaSiO_4, $Ce:Li_2CaSiO_4$ and $Eu:Li_2CaSiO_4$

In this study, single-crystalline $Ce:Li_2CaSiO_4$ and $Eu:Li_2CaSiO_4$ were obtained via the flux method, and their optical properties were evaluated for application as scintillators. A LiF-LiCl eutectic mixture and Li2MoO4 were used as the fluxes. The optimal flux-to-crystal weight ratio for flux growth was determined by thermal analysis. Crystals of undoped Li_2CaSiO_4, $Ce:Li_2CaSiO_4$, and $Eu:Li_2CaSiO_4$ were grown. The crystal phases and crystal habits were identified using X-ray diffraction. Finally, the scintillation decay curve and pulse height spectra were measured for feasibility study as a novel oxide neutron scintillator.

Figure 1 shows the obtained crystals of non-doped Li_2CaSiO_4 and $Eu:Li_2CaSiO_4$. All crystals exhibited a planar shape, which was determined to correspond to the (202) plane. The pulse height spectra of $Ce:Li_2CaSiO_4$ and $Eu:Li_2CaSiO_4$ were successfully measured under alpha-ray irradiation from Am^{241}. The detailed scintillation properties are presented in our presentation.

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2. S. Kodama et al., "Synthesis and photoluminescence properties of divalent rare-earth-doped Li2CaSiO4," Journal of the Ceramic Society of Japan, 131, 258 (2023)
3. I. Komendo et al., "Effect of the Synthesis Conditions on the Morphology, Luminescence and Scintillation Properties of a New Light Scintillation Material Li2CaSiO4:Eu2+ for Neutron and Charged Particle Detection," Crystals, 10, 127 (2020)

W-CR3 Room Temperature-Grown $CsCu_2I_3$ Perovskite Crystal via Solution Processing: Unveiling Scintillation Properties

Bhavika[1], V. Anand[1], G. Anil Kumar[1], Naveen Kumar Tailor[1], V. Ranga[1], Soumitra Satapathi[1], P. J. Sellin[2]

[1]Department of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, India
[2]Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, U.K.

Corresponding Author Email: bhavika1@ph.iitr.ac.in

Inorganic Single Crystals (SC) have been conventionally used as scintillators due to their high light output and good energy resolution. However, most of them are hygroscopic and very costly. Solution Growth (SG) of perovskite SCs offers a cost-effective alternative to these inorganic scintillators. Lead-free halide perovskites, such as Rb_2CuCl_3, $Cs_3Cu_2I_5$ and $CsCu_2I_3$ are emerging SCs having high stability, non-hygroscopic nature, and low cost. $CsCu_2I_3$ SC can be grown through various SG methods. The photodetection, optoelectronic performance data have been reported for 1D $CsCu_2I_3$ SC grown using the SG method [1], and scintillation properties have been reported for the Bridgman-grown crystal in the literature [2]. In this work, we present the scintillation properties of 1D $CsCu_2I_3$ grown using the Room-Temperature Solvent Evaporation Crystallization (RTSEC) method.

The $CsCu_2I_3$ solution was prepared using 5 millimoles of CsI, 10 millimoles of CuI in DMF and Oleic acid. The mixture was stirred for 60 min. After filtration, the solution was poured into a petri dish and covered with aluminium foil with holes having equal diameter. Crystals were extracted from the solution after 24 hours. Crystal appears colourless in ambient light and yellowish under 254 nm Ultraviolet (UV) illumination, as shown in the inset of the figure. Powder X-ray Diffraction (XRD) shows peaks corresponding to the orthorhombic structure with space group *Cmcm* [JCPDF No. 45-0076]. The Photoluminescence (PL) spectrum of the grown crystal exhibits a broad emission peak centered at 575 nm. The absorption and emission spectra indicate a large stokes shift of 230 nm, which is desirable in a scintillator. The atomic percentages of Cs, Cu and I atoms are 16.42%, 33.86% and 49.73% as given by Energy Dispersive Spectroscopy (EDS), which is in good agreement with the stoichiometry of $CsCu_2I_3$.

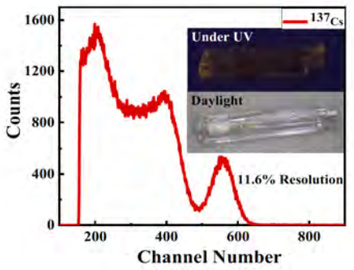

Figure: Pulse height spectra of 4mm x 1mm x 1mm $CsCu_2I_3$ SC under ^{137}Cs γ–ray irradiation.

Gamma radiation detection studies were performed with the SG $CsCu_2I_3$ perovskite scintillator mounted on a SiPM considering ^{133}Ba, ^{22}Na, and ^{137}Cs gamma sources. We present the pulse height spectra, the energy resolution, and the light output. The γ–rays response of the crystal is found to be linear for an energy range of 200-1300 keV. The measured energy resolution is found to be 11.6 % at 662 keV. The light output is found to be around 41000 photons/MeV, which is superior than the $CsCu_2I_3$ grown using the Bridgman method and coupled to a PMT [2] in which the authors reported an energy resolution of 20 % and a light output around 10000 photons/MeV.

As the SiPM used in this work has a maximum Photon Detection Efficiency (PDE) at 450 nm, the energy resolution of the RTSEC grown crystal is, therefore, expected to improve when coupled to photo-sensors having better PDE around 575 nm. Detailed characterization of the CsCu2I3 crystal such as decay profile, XPS, pulse height spectra, and energy-dependent resolution will be presented and discussed.

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Oral Sessions | Wednesday, July 10th 2024

W-CR4 Oxide single crystals with high melting point grown by advanced micro-pulling-down method

Yuui Yokota[1], Takahiko Horiai[2], Masao Yoshino[2], Akira Yoshikawa[1,2]

[1]Institute for Materials Research, Tohoku University, Sendai, Miyagi, Japan
[2]New Industry Creation Hatchery Center, Tohoku University, Sendai, Miyagi, Japan

Corresponding Author Email: yui.yokota.a5@tohoku.ac.jp

Many oxide scintillator single crystals have been grown by the Czochralski (Cz) and micro-pulling- down (μ-PD) methods using Iridium (Ir) and Platinum (Pt) crucibles. Ir, Pt and their alloy crucibles are used the crystal growths on commertial and research fields because of the stability at high temperature. However, single crystals with higher melting point (m.p.) than ~2100°C couldn't be grown by the conventional Cz and μ-PD methods using the Ir and Pt crucibles due to the usage limitation of Ir (m.p. 2446°C) and Pt (m.p. 1768°C). As a result, material researches and produces by the Cz and μ-PD methods are limited under 2100°C. Therefore, we developed an advanced μ-PD method using a tungsten (W, m.p. 3422°C) crucible and deoxygenated insulators to grow single crystals with high m.p. [Fig. (a)]. In this study, $La_2Zr_2O_7$ [LZO](m.p. 2283°C), $La_2Hf_2O_7$ [LHO](m.p. 2418°C) and Lu_3TaO_7 [LTO](m.p. 2380°C) are selected for target materials with high m.p., and crystal growth and evaluations of optical and scintillation properties were perforemed.

Crystal growths of oxide materials with high m.p. were performed by the advanced μ-PD method using a W crucible. The W crucible was surrounded by the deoxygenated ZrO2 insulators to keep warm and prevent oxidization of the W crucible. LZO, LHO and LTO powders were prepared by mixing starting materials of La_2O_3, ZrO_2, HfO_2 and Ta_2O_5 (>99.9%) with the stoichiometric composition and they were sintered at 1600°C in air. The sintered powders in the W crucible were melted by the high- frequency induction heating, and crystal growth was performed by pulling down the melt using a W seed. Growth crystals were cut and polished for measurements of optical and scintillation properties. Figure (b) is LZO, LHO and LTO single crystals grown by the μ-PD method using the W crucible [1,2]. Polished specimens indicated high transparency after post-annealing in air while as- grown crystals indicated black color. The black color is attributable to the oxygen defects generated during the crystal growth. Eu-doped LZO and LHO single crystals indicated emission peaks around 600 nm originated from 4f-4f transition of Eu3+ ion in photoluminecence and X-ray radioluminecence spectra. The details of crystal growth and properties for grown crystals will be reported.

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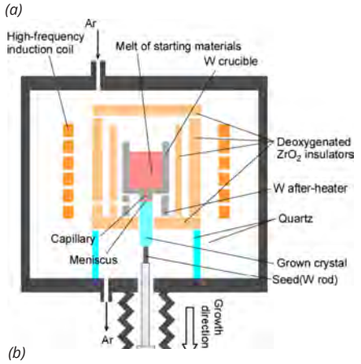

Fig. (a) Schematic diagram of advanced μ-PD method using W crucible. (b) As-grown LZO, LHO and LTO single crystals grown by advanced μ-PD method using W crucible and polished specimens after post-annealing.

W-CR5 Highly Efficient Solution Synthesis, Crystal Growth, and Scintillation Properties of Cs_2TeCl_6

Michael Lewis[1*], Serge Nagorny[1], and Peng Wang[1]

[1]First Affiliation Information: Queen's University, Kingston, Ontario, Canada

Corresponding Author Email: 16mpl7@queensu.ca

Scintillator materials are room-temperature radiation detectors that convert ionizing radiation into low-energy photons. Scintillators are desirable in fields such as medical imaging [1], homeland security [1,4], and in fundamental research areas. The search for scintillators with good conversion efficiency, high light yield, good energy resolution, fast decay times, and tunability of the structure allows for these materials to reach a wider range of applications. The anti-fluorite Cs_2TeCl_6 structured crystal is a fluorescent material that shows promise as a new scintillator detector with excellent structural stability in ambient conditions with promising optical (absorption coefficient ~ 105 cm-1) [2] and luminescence properties. Cs_2TeCl_6 can also find its application as a highly effective detector for a rare process that can occur in Te isotopes, namely the electron capture of ^{123}Te with a transition energy of just 53 keV [3], due to its high linearity of the scintillation response.

The Cs_2TeCl_6 compound was synthesized in an HCl (38.0% w/w) solution using low-purity reagents (TeO_2 (>99%) and Cs_2CO_3 (99%)) with a yield of 95.4%. The experimental powder X-ray diffraction pattern (p-XRD) of Cs_2TeCl_6 matches the theoretical p-XRD, indicating the high phase purity of the synthesized compound. Then Cs_2TeCl_6 powder was sealed in a quartz ampoule followed by crystal growth in a 2-zone vertical Bridgman furnace with a pulling rate of 12 mm day^{-1} and a temperature gradient of 35°C cm^{-1}. A high-purity Cs_2TeCl_6 crystal that's 40 mm in length and 10 mm in diameter was grown with no bubbling or inclusions with a final yield of 90.7%

from the initial theoretical yield. The structure and chemical purity of Cs_2TeCl_6 were examined through single-crystal XRD and ICP-MS methods. The optical and scintillation behaviors of Cs_2TeCl_6 were explored in terms of its relative light yield, energy resolution, and pulse height spectroscopy analysis.

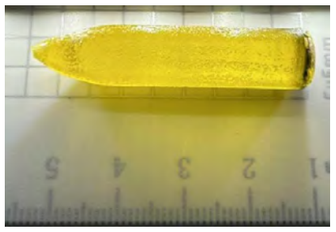

Figure 1: Bulk single crystal Cs_2TeCl_6 grown through vertical Bridgman.

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Acknowledgments

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Oral Sessions | Wednesday, July 10th 2024

SESSION 10: OPTICAL CERAMICS AND GLASSES

W-CE1 Role of Cerium Concentration on Defect-driven Luminescence Phenomena in GAGG Ceramics Obtained by Reactive Sintering

Federico Moretti[1], Weronika Wolszczak[1], William Bowman[2], Steven Lass[2], Romain Gaume[2,3,4]

[1]*Lawrence Berkeley National Laboratory, Berkeley, CA, USA*
[2]*CREOL, The College of Optics and Photonics, University of Central Florida, Orlando, FL, USA*
[3]*Department of Materials Science and Engineering, University of Central Florida, Orlando, FL, USA*
[4]*NanoScience Technology Center, University of Central Florida, Orlando, FL, USA*

Corresponding Author Email: fmoretti@lbl.gov

The optimization of scintillation properties in materials, achieved through single-crystal growth from the melt, faces limitations stemming from constraints posed by growth technology and inherent thermodynamic factors, such as dopant solubility within the crystals. Some of these limitations can be circumvented by employing alternative synthesis methods. Notably, the manufacturing of optical ceramics of cubic compounds enables exploration of dopant concentration ranges that are otherwise challenging to attain through melt-grown processing routes. Among these materials, optical ceramics of cerium-doped gadolinium aluminum gallium garnet (Ce:GAGG) are being considered as replacements for $CdWO_4$ single crystals in high-energy radiography systems, aiming to enhance both light yield and timing performance while minimizing overall afterglow. While studies on optimizing the scintillation properties of Ce:GAGG single crystals have been reported, a similar investigation for optical ceramics remains outstanding. In this study, we explore the impact of cerium concentration, in a wide range 0.1 to 10 at%, on the scintillation properties of GAGG optical ceramics synthesized via reactive sintering, focusing on the interplay between charge carrier trapping and radiative recombination phenomena. The accompanying figure demonstrates the effectiveness of high cerium doping concentrations in reducing the afterglow phenomenon by comparing samples prepared under identical conditions with different doping levels.

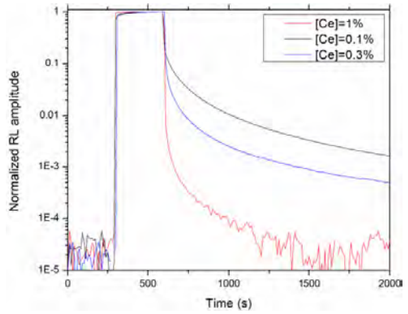

Figure: Normalized radioluminescence sensitization and afterglow of Ce-doped GAGG optical ceramics for various Ce contents. The optical ceramics have been fabricated by reactive sintering of raw oxides.

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2. T. Wu et al. "Fast (Ce,Gd)$_3$Ga$_2$Al$_3$O$_{12}$ scintillators grown by the optical floating zone method" Cryst. Growth Des. 22 180-190 (2022)

Acknowledgments:

This material is based upon work supported by the U.S. Department of Homeland Security under Grant Award Number 20CWDARI00038-01-00. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

Figure: Normalized radioluminescence sensitization and afterglow of Ce-doped GAGG optical ceramics for various Ce contents. The optical ceramics have been fabricated by reactive sintering of raw oxides.

W-CE2 Structure-property relationship of scintillating garnet optical ceramics towards effective radiation detection schemes

F. Cova[1], J. Hostasa[2], M. Colucci[3], A. Piancastelli[2], L. Esposito[2], V. Biasini[2], F. Picelli[2], I. Veronese[3], A. Paleari[1], A. Vedda[1], and R. Lorenzi[1]

[1]*Department of Materials Science, University of Milano – Bicocca, Via Cozzi 55, 20125 Milan, Italy*
[2]*CNR ISSMC, Institute of Science, Technology and Sustainability for Ceramics, Via Granarolo 64, 48018 Faenza, Italy*
[3]*Department of Physics, University of Milano, Via Celoria 16, 20133 Milano, Italy*

Corresponding Author Email: francesca.cova@unimib.it

Efficient detection of ionizing radiation plays a key role in several tools developed for X-ray-based security, particle identification, and medical diagnostics, from conventional X-ray imaging to computed tomography and nuclear medicine. Very active research is driven by the need to push the performances of current detectors to improve their sensitivity and timing response. A very fast luminescence response, an excellent light output and energy resolution are essential to achieve a good image-to-noise reduction and optimize the spatial accuracy. To this scope, garnet single crystals are promising candidates, thanks to their high density, good luminosity, and relatively short decay time. Novel complex compositions are emerging, among which $Gd_3(Ga,Al)_5O_{12}$ (GGAG) recently appeared as very attracting because of light yield higher than 104 photons/MeV and short scintillation lifetime of few tens of ns when doped with Cerium.

However, the limitations imposed by the production of bulk crystals have brought to the search of alternative and more easily workable media. In this framework, the advancements in the sintering technique of crystalline nano- or micro-grains into bulk ceramics with high optical quality led optical ceramics to achieve a powerful competitiveness over single crystals thanks to the relative easiness of production, which implies lower costs, the possibility to uniformly incorporate high activator concentrations, and the shaping versatility that allows to realize complex geometries in one piece without mechanical post-processing or bonding.

Our recent investigations led to the development of fully densified Ce:GGAG polycrystalline transparent ceramics by reaction sintering from commercial oxide powders [1]. We optimized the synthesis process to eliminate porosity and achieve an excellent optical quality, by developing a combined approach of a conventional pressureless sintering in air followed by hot isostatic pressing, with the use of sintering aids. In this work, we demonstrate a positive role of a sintering aid, such as TEOS, in the improvement of the timing response and in the enhancement of the scintillation efficiency. We study the correlation between sintering aids and the presence of point defects acting as traps in the scintillation mechanism to optimize their role according to the targeted application. We also explore unconventional geometries by coupling two layers of different garnets (Ce:GGAG and Pr:YAG) in order to find a scintillation response strongly dependent on the material architecture, extending the potential of layered optical ceramics for advanced energy- and direction-sensitive X- ray detectors [2].

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We acknowledge the Italian Ministry of Research under project Luminance of the PRIN2022 program.

Oral Sessions | Wednesday, July 10th 2024

W-CE3 Online Radiation Induced Attenuation measurements of Radiophotoluminescence Dosimeters irradiated with X-rays: Dose rate dependence at high doses

A. Raj Mandal[1], M. Ferrari[1], A. Morana[1], Y. Q. Aguiar[1,2], R. García Alía[2], S. Girard[1,3]

[1]*Laboratoire Hubert Curien : Université Jean Monnet, Saint-Etienne, France*
[2]*European Organization for Nuclear Research (CERN): CH-1211 Geneva, Switzerland 3Institut Universitaire de France (IUF) F-75005 Paris, France.*

Email: aditya.raj@univ-st-etienne.fr

One of the challenges working with ionizing radiation is to ensure protection and safety of personnel and of opto-electronics devices and components possibly susceptible of radiation damage. The monitoring of radiation levels using accurate dosimetry is accordingly of paramount importance in high radiation environments like the ones produced by particle accelerators, radioisotopes production facilities etc. Despite the increasing needs for dose monitoring in the kGy-MGy range, most dosimetry techniques are not reliable at these dose levels.

With this motivation, studies are ongoing using the X-ray irradiation facilities of the Hubert Curien Laboratory to characterize the response of radiophotoluminescent dosimeters (RPLDs) and to extend their range of use. The studied samples are commercial FD7 glass dosimeters, in the form of rods (1.5mm×8mm) employed of Silver-doped Phosphate glass, currently in use at the European Organization for Nuclear Research (CERN) to passively measure dose level in several locations of interest of the accelerator complex. Radiation induced RPL centers in the glass emit orange light (RPL signal) when excited with UV light. The emitted light is proportional to absorbed dose (up to 500 Gy, as indicated by the manufacturer) and it is exploited for dosimetry. In addition, radiation induces additional point defects in RPLDs causing radiation induced attenuation (RIA) of the light transmitted through sample. Dose levels in the kGy to MGy range can be measured combining RPL and RIA measurements at selected wavelengths.

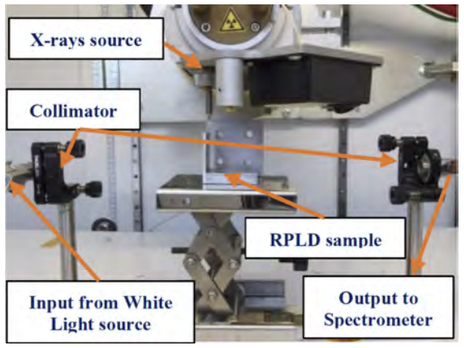


Fig 1. In-home made set-up to measure transmitted light under X-rays irradiator.

In this context a dedicated setup (Fig 1), has been developed to measure the spectral RIA, which is crucial for extending the dosimeter sensing range. The validated setup allows online (during irradiation) and offline characterizations of the RPLDs in a free-space configuration. In the initial irradiation campaign online RIA was measured varying the dose rate from 12 mGy[H_2O]/s to 0.48 Gy[H_2O]/s for total doses ranging from 0.5 to 75 kGy. RIA might decrease when radiation exposure terminates and this phenomenon is referred to as recovery. The RIA recovery was measured for 3 h after the irradiation conclusion. Preliminary investigations highlight the dependency of RIA growth and recovery kinetics on wavelength, dose rate and total dose. RIA recovered up to 7% and 33% for 0.5 and 15 kGy respectively at 800 nm wavelength. Investigating RIA recovery within few hours as well as after several days provides significant information about the evolution of active defects at room temperature. This information is crucial for the use of RPL dosimeters in different conditions, and especially when the readout is performed after several days of irradiation, which commonly happens in CERN applications associated with high-radiation areas. The set of collected results provides information on irradiation conditions and parameters that were never investigated in these dosimeters at high doses, and pave the way for an extension of the methodologies currently used to measure doses in the MGy range. Successful online RIA measurements confirm the possibility of using an adapted version of the current setup for time-resolved analysis of the RPL light as well. Future studies, to be presented at the conference, include the dependency of RIA, recovery and RPL signal on dose, dose rate and temperature over a wide range of wavelengths.

W-CE4 Temperature Dependence of Hafnate Scintillators

Shunsuke Kurosawa[1,2,3], Daichi Sato[1], Yusuke Urano[2,4], Akihiro Yamaji[1,2], Akira Yoshikawa[1,2,3], Koichi Harata[2], Kana Fujioka[3]

[1]*New Industry Creation Hatchery Center (NICHe), Tohoku University, Sendai, Miyagi, Japan*
[2]*Institute for Materials Research (IMR), Tohoku University, Sendai, Miyagi, Japan*
[3]*Institute of Laser Engineering, Osaka University, Suita, Osaka, Japan*
[4]*Graduate School of Engineering, Tohoku University, Sendai, Miyagi, Japan*

Corresponding Author Email: kurosawa@imr.tohoku.ac.jp

High gamma-ray sopping power and timing resolution are required for the scintillation materials in a positron emission tomography (PET) camera. Hafnium has a high atomic number of 72, and the intrinsic background is negligible. $SrHfO_3$ doped with Ce (Ce:SHO) are attractive scintillation material due to a high effective atomic number of around 60, no intrinsic background and faster scintillation decay time (21.6 ± 0.9 ns) compared to Ce:$(Lu,Y)_2SiO_5$ [1]. Moreover, Ce:$MHfO_3$ (Ce:MHO) group is also attractive material due to an effective atomic number of around 60 and no intrinsic background, where M is Ca or Ba. Thus, we performed a comprehensive material search for $AHfO_3$ (A=Ca, Sr, Ba) in this study.

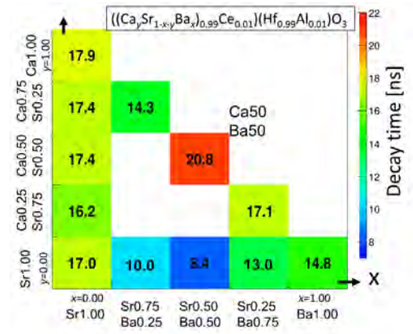


Fig.1 photo-luminesce decay map (only primary decay constant) for Ce/Al:AHO. (error width: ±~0.5 ns)

Since some Hf-containing materials have high melting temperatures of over 2500°C, we prepared transparent ceramics by the spark plasma sintering (SPS) process. We investigated optical and scintillation properties for $(A_{0.99}Ce_{0.01})(Hf_{0.99}A_{0.01})O_3$ (Ce/Al:$AHfO_3$) ceramics prepared by the SPS method using a SPS chamber (Fuji Denpa, DR.SINTER). Here, sintering temperatures were operated up to 1,700°C.

We succeeded in obtaining transparent hafnate-type ceramics. Ce/Al:$BaHfO_3$ and Ce/Mg/Al:$BaHfO_3$ samples had the shortest emission wavelength than others, and Ce/Al:$BaHfO_3$ had a maximum emission wavelength at 380 nm. All samples can be fitted by a single exponential curve except two samples: A = ($Sr_{0.75}$, $Ba_{0.25}$) and ($Sr_{0.50}$, $Ba_{0.50}$) which had secondary time constants around 20 ns as shown in Fig. 1. On the other hand, the light outputs for the all samples had less than 10,000 photons/MeV, and we investigated its temperature dependence at synchrotron facility,

Ultraviolet Synchrotron Orbital Radiation Facility (UVSOR), of Institute for Molecular Science, National Institutes of Natural Sciences. The result shows that thermal quenching was found above around 200K. In addition, at low

temperature, we observed some emission bands originating from not only Ce^{3+} 5d-4f transition, also other emission, which would be charge transfer: O-Hf. In this paper, we show the scintillation properties and their temperature dependence.

1. S. Kurosawa et al., "Optical Properties and Radiation Response of Ce:$SrHfO_3$ Prepared by the Spark Plasma Sintering Method" Radiat. Meas., 56 155 (2013)

W-CE5 Effects of Ce concentration on the structural and optical properties in Ce:GAGG ceramic scintillators

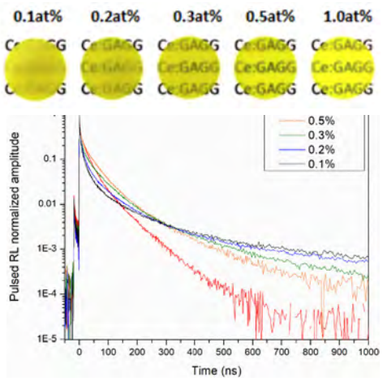
William Bowman[1], Steven Lass[1], Federico Moretti[2], Weronika Wolszczak[2], Romain Gaume[1,3]

[1]CREOL, The College of Optics and Photonics, University of Central Florida, Orlando, FL, USA
[2]Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[3]Department of Materials Science and Engineering, University of Central Florida, Orlando, FL, USA

Corresponding Author Email: William.Bowman@ucf.edu

Fast scintillation kinetics and optical quality are necessary scintillator attributes for applications such as CT and x-ray radiography of rapidly moving subjects. It has been shown in other garnet hosts such as Ce:YAG and Ce:LuAG that Ce concentration alters both scintillation and optical properties of the materials [1,2]. In the case of Ce:GAGG single crystals and Ce concentrations lower than 1 at%, radioluminescence decay constants decrease by increasing the Ce concentration [3] while light yield reaches a maximum at 0.3 at% [4]. For Ce:GAGG ceramics, the effect of Ce concentration on these properties has not been systematically investigated. There is at current no work on determining the solid solubility limit of Ce in GAGG, which is critical in controlling the development of secondary phases and subsequent optical quality.

This study aims to investigate the effects of Ce concentration on the structural, optical, and scintillation properties of GAGG optical ceramics with dopant concentrations in the 0.1at% to 10at% range. Transmission of the material increases with increasing Ce concentration up to 5.0at%. At the same time, the optical and scintillation properties of these samples show a complex evolution upon Ce concentration, highlighting the complex interplay among optical characteristics of the samples, concentration-related luminescence quenching phenomena, and charge carrier trapping defects.



(Above) Photographs of Ce:GAGG ceramics with varying concentrations of Ce. (Below) Corresponding pulsed RL decay curves.

1. G. Singh et al., "Effect of cerium doping on optical and scintillation properties of transparent YAG ceramic," Ceram. Int. 43, 9032–9040 (2017).

2. X. Chen et al., "Influence of cerium doping concentration on the optical properties of Ce,Mg:LuAG scintillation ceramics," J. Eur. Ceram. Soc. 38, 3246–3254 (2018).

3. L. Martinazzoli, et al. "Compositional engineering of multicomponent garnet scintillators: towards an ultra-accelerated scintillation response," Mater Adv 3, 6842–6852 (2022).

4. T. Wu et al., "Fast $(Ce,Gd)_3Ga_2Al_3O_{12}$ Scintillators Grown by the Optical Floating Zone Method," Cryst Growth Des 22, 180–190 (2022).

Acknowledgments:

This material is based upon work supported by the U.S. Department of Homeland Security under Grant Award Number 20CWDARI00038-01-00. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

Needs and trends in scintillation for radionuclide metrology

B. Sabot

CEA, LIST, Laboratoire National Henri Becquerel (LNE-LNHB), Université Paris-Saclay, 91120, Palaiseau, France

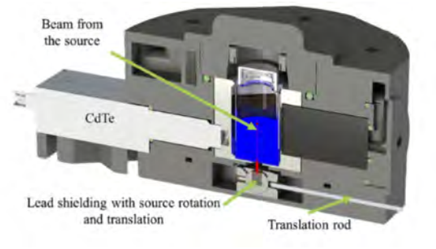
Corresponding Author Email: benoit.sabot@cea.fr

Radionuclide metrology is a wide-ranging discipline with an impact on many fields, including health, industry and even the military. Throughout the world, it is developed and carried out by the national metrology institutes of each country. It involves developing radioactive standards and associated methods, which must be adapted to the radionuclide itself.

One of these methods is based on liquid scintillation with the Triple to Double Coincidence Ratio (TDCR) technique, adapted for pure beta emitters and low-energy electron capture. The goal is to mix an aliquot of the aqueous radioactive solution into the liquid scintillation cocktail and use the model to determine the free parameters (i.e., scintillation yield) using Birks' formula. There are limitations to this technique, the first being the need to deal with organic liquid scintillators and mixed waste, and the second being that it is not always suitable, especially for field applications, even though portable devices have now been developed [1]. Source preparation remains a problem. With the help of plastic scintillators, we could find some solutions, for example, for on-site calibration of some radiopharmaceuticals. However, we still face many limitations especially for volatiles and specific application. Thus, recently, we developed two approaches: the use of other scintillator materials such compound for radioactive gas detection with and the development of methods for the absolute measurement of scintillation yield of any scintillator (Compton-TDCR).

Thus, recently, we decide to work on different approaches. One is the use of other scintillator materials, such as porous materials with aerogels of polymers, aerogels of YAG:Ce, CeF_3, and Metal Organic framework small crystals. These material offers porosity needed to detect radioactive gases, and the development of new reference methods that are closer to on-site needs. Even if all are not working the same way the results start to show a great interest and thus could be a game changer for the radionuclide metrology, especially when in this case liquid scintillation is not useful. However, for all these techniques, scintillation models remain either limited (Birks) or unknown. That is the reason why we work on methods for the absolute measurement of scintillation yield of any scintillator, as recently published and still under development [2].

In this talk, we will present some of the results of these examples of new concept in order to conclude where we plan to go and where we need some help from specific communities such as the people present here in SCINT.



The Compton-TDCR device developed to obtain absolute yield and time properties of scintillator in order to apply it to radionuclide metrology.

1. B Sabot, C. Dutsov, P. Cassette, K. Mitev, Performance of portable TDCR systems developed at LNE-LNHB, NIM-A 1034, 166721 (2022)

2. B. Sabot, C. Dutsov, P. Cassette, K. Mitev, M. Hamel, G.H.V. Bertrand, K. Lebbou, C. Dujardin, "A compact detector system for simultaneous measurements of the light yield non-linearity and timing properties of scintillators" Nature Scientific Report, 14, 6960 (2024).

We acknowledge support from the European Community through the grant no. 899293, HORIZON 2020—SPARTE FET OPEN

Oral Sessions | Thursday, July 11th 2024

SESSION 11: CHARACTERIZATIONS OF SCINTILLATORS (PART 3)

TH-CA11 Influence of Dual-Organic-Cation on Optical and Scintillation Properties in Perovskite Single Crystal Scintillators

Md Abdul Kuddus Sheikh[1,*], Michal Makowski[1], Dominik Kowal[1], Francesco Maddalena[2], Somnath Mahato[1], Marcin Eugeniusz Witkowski[3], Cuong Dang[2], Winicjusz Drozdowski[3], Daniele Cortecchia[4], Christophe Dujardin[5], Muhammad Danang Birowosuto[1]

[1] *Łukasiewicz Research Network-PORT, Wrocław, Poland;*
[2] *Nanyang Technological University & CINTRA UMI CNRS/NTU/THALES, Singapore;*
[3] *Nicolaus Copernicus University, Toruń, Poland;*
[4] *Dipartimento di Chimica Industriale "Toso Montanari,", Universitaì di Bologna, Bologna, Italy;*
[5] *Institut Lumière Matière, UMR5306, Université Claude Bernard Lyon1 and CNRS Lyon, Villeurbanne, France.*

Corresponding Author Email: abdul.kuddus-sheikh@ port.lukasiewicz.gov.pl

Hybrid organic-inorganic perovskite (HOIP) single crystals have captured significant attention due to their remarkable luminescent features, excellent photo-absorption capabilities, high exciton binding energy, and environmental stability [1]. Current research focus on halide perovskites incorporating phenethylammonium (PEA), butylammonium (BA), and benzylammonium (BZA), methylammonium (MA), generating considerable interest within the scientific community. Despite notable advantages such as high light yield (> 10 photons/keV) and faster photoluminescence decay time (< 3 ns) [1-3], challenges such as the fast component of decay, high mass density, and efficiency of electron-hole transfer persist, limiting their suitability for timing applications. Thus, enhancing structural, optical, and scintillation properties requires a comprehensive exploration of crystal growth optimization through the incorporation of dual-organic cations.

This study investigates the impact of structural variations on the optical and scintillating properties of HOIP crystals using a low-temperature solution process. Our investigation employs various techniques, including X-ray diffraction, photoluminescence (PL), time-resolved PL, radioluminescence, thermoluminescence, and scintillation measurements. The first approach involves introducing dual-aromatic organic cations, resulting in an enhancement of the fast component of scintillation decay and electron-hole charge transfer efficiency. The second approach incorporates dual-aliphatic organic cations, leading to an improvement in light yield. The final approach involves incorporating three-dimensional HOIP into two-dimensional HOIP structures, resulting in new perovskite crystal structures with higher mass density over 3.0 g/cm^3 and timing response as fast as 0.5 ns. This work emphasizes the significant role of dual-organic cations in advancing scintillating materials, paving the way for applications such as positron emission and photon-counting computed tomography.

1. Md A. K. Sheikh et al. "$A_2Bn_{-1}PbnI_{3n+1}$ (A = BA, PEA; B = MA; n = 1, 2): Engineering Quantum-Well Crystals for High Mass Density and Fast Scintillators" J. Phys. Chem. C, 127, 22, 10737-10747 (2023).

2. Md A. K. Sheikh et al. "Solution-Processable A_2XY_4 (A=PEA, BA; X= Pb, Sn, Cu, Mn; Y=Cl, Br, I) Crystals for High Light Yield and Ultrafast Scintillators" IEEE Transactions on Nuclear Science, 70, 7, 1384-1391 (2023).

3. D. Kowal et al. "PEA_2PbI_4: Fast Two-Dimensional Lead Iodide Perovskite Scintillator with Green and Red Emission" Mater. Today Chem., 29, 101455 (2023).

TH-CA12 Radiation resistance of the Muon Collider Crilin calorimeter prototype equipped with Cherenkov lead fluoride crystals

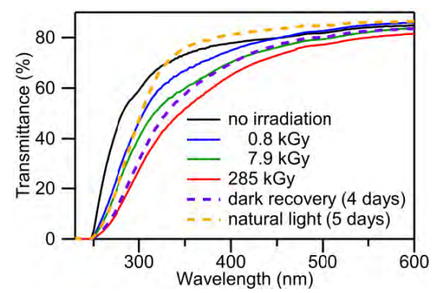
Adriano Verna[1], Rocco Carcione[1], Alessia Cemmi[1], Ilaria Di Sarcina[1], Beatrice D'Orsi[2], Jessica Scifo[1], Vittoria Ciccarella[3], Elisa Di Meco[3], Eleonora Diociaiuti[3], Ivano Sarra[3]

[1] *ENEA Nuclear Department, Casaccia Research Center, Via Anguillarese, 301, 00123 Rome, Italy*
[2] *Sapienza University of Rome, Physics Dept., Piazzale Aldo Moro 5, 00185 Rome, Italy*
[3] *INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 54, 00054 Frascati, Italy*

Corresponding Author Email: adriano.verna@enea.it

The Crilin calorimeter instantiates a semi-homogeneous calorimetric system incorporating lead fluoride (PbF_2) crystals interfaced with surface-mounted UV-extended Silicon Photomultipliers (SiPMs). This innovative design is proposed as the electromagnetic calorimeter for the prospective Muon Collider. Considering the need to discriminate signal particles from background noise and address substructures critical for jet identification, a high level of granularity is deemed necessary. Anticipating substantial occupancy due to beam-induced backgrounds, simulations indicate a photon flux with an average energy of 1.7 MeV and approximately 4.5 MHz/cm^2 fluence. Prioritizing time- of-arrival measurements within the calorimeter is crucial for associating clusters with interaction vertices. The calorimeter's energy resolution is vital for determining jet kinematics.

Operation within a challenging radiation environment is a crucial consideration, with exposure levels reaching 10 kGy/year total ionizing dose (TID) and a 1 MeV neutron equivalent fluence of 10^{14}/cm^2/year. Accurate testing of radiation hardness was carried out on PbF_2 crystals and on SiPMs to verify the system's capability to function under these extreme conditions. Effects of TID were evaluated through gamma irradiation tests that simulate the damage expected in operational conditions. Tests were carried out at the Calliope gamma irradiation facility [1] using a 60Co source (γ photon energies of 1.17 and 1.33 MeV). PbF_2 crystals (1 cm × 1 cm × 4 cm) were irradiated with a dose rate of 3.2 kGy/h at different values of absorbed dose up to 285 kGy. Gamma radiation induced the formation of color centers [2] that severely decreases the longitudinal transmittance of the crystals, a key parameter in determining the effectiveness of the calorimeter, as evidenced by the spectra reported in figure. Transmittance is partially recovered in a few days after the treatment by just keeping the samples at room temperature and in the dark, indicating a recombination of the point defects. Exposure to natural light improves transmittance to levels even higher than the pristine values in the operating spectral region of the calorimeter (> 320 nm). The stability of the optical response is verified by measurements repeated over a period of many months.



Transmittance of a PbF_2 crystal before and after the irradiation at the indicated doses and with the subsequent recovery in the dark and in natural light.

Gamma irradiation tests will be performed on a prototype of the calorimeter consisting of two layers of 3×3 PbF_2 crystals each and the operation of the devices before and after the radiation treatment will be analysed using 450 MeV electrons at the LNF Beam Test Facility.

1. S. Baccaro, A. Cemmi, I. Di Sarcina, G. Ferrara, "Gamma Irradiation Calliope Facility", ENEA Technical Report, 2019, RT/2019/4/ENEA.

2. X. Qu, L. Zhang, R. Zhu, "Radiation Induced Color Centers and Light Monitoring for Lead Tungstate Crystals", The Compact Muon Solenoid Experiment, 1999, CMS NOTE 1999/069.

Oral Sessions | Thursday, July 11th 2024

TH-CA13 Performance Characterization of Organic Glass Scintillators

T. E. Maurer[1], E. A. Schneider[1], E. R. Neely[2], K. L. Meagher[3], S. D. Clarke[1], P. L. Feng[4], S. A. Pozzi[1]

[1]*Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI, USA*
[2]*Program of Applied Physics, University of Michigan, Ann Arbor, MI, USA*
[3]*Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI, USA*
[4]*Sandia National Laboratories, Livermore, CA, USA*

Corresponding Author Email: tessam@umich.edu

Organic scintillators are a good candidate detector for nonproliferation applications such as imaging and nondestructive assay because they are sensitive to both fast neutrons and gamma rays and have a fast detector response time. Organic glass scintillators (OGS) are newly developed organic scintillators from Sandia National Laboratories (SNL) [1, 2]. We have developed an in-house system to melt and degas bulk OGS material at 200 °C and pour samples into custom silicone molds to produce a myriad of geometries and sizes. We characterized 6-mm edge OGS cubes for pulse shape discrimination (PSD) capabilities and neutron detection efficiency. To date, two manufacturers, BlueShift Optics and Radiation Monitoring Devices (RMD), have produced and distributed OGS. In this work, we characterize the performance of OGS samples from these manufacturers and compare it to the performance of OGS received directly from SNL and melt-cast in our U-M laboratory. Additionally, we explore performance variability across numerous cubes that were cast from the same OGS material obtained from BlueShift Optics, SNL, and RMD.

Using the same H3178-51 3.81-cm diameter Hamamatsu photomultiplier tube and a DT5730S CAEN digitizer, we first calibrated each scintillator using a ^{137}Cs source. We then measured PSD capabilities with ^{252}Cf. Fig. 1 shows the PSD performance for a BlueShift Optics 6-mm cube, showing measured neutron and gamma ray bands. Initial results indicate that for similar volume and a 0.070 MeVee threshold, the intrinsic neutron efficiency generally agrees within 10 percent for cubes cast from a given supplier's material. Comparing similar volume SNL and BlueShift Optics cubes, energy resolution is generally within 95 percent MATLAB reported confidence bounds. Currently there is no discernable trend across manufacturers for PSD capabilities. Our full submission will include characterization of cubes manufactured using RMD OGS.

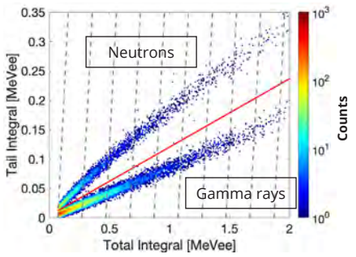


Fig. 1: The PSD performance for 252Cf with a 6-mm OGS cube sourced from BlueShift Optics. Note the red line of discrimination and the gray dashed lines representing total integral 'slices'

1. J. S. Carlson, et al., "Taking Advantage of Disorder: Small-Molecule Organic Glasses for Radiation Detection and Particle Discrimination," Journal of the American Chemical Society, 139 (28), 9621-9626, (2017), DOI: 10.1021/jacs.7b03989

2. T. H. Shin, et al., "Measured neutron light-output response for trans-stilbene and small- molecule organic glass scintillators," Nucl. Instr. Meth. A, Vol. 939, (2019), Pages 36-45, ISSN 0168-9002, DOI: 10.1016/j.nima.2019.05.036.

This work was funded in-part by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920

SESSION 12: SCINTILLATORS FOR NEUTRON DETECTION AND IMAGING

TH-NE1 Melt-Blended Organic Scintillators for High Efficiency Neutron Imaging

Nicholas R. Myllenbeck[1], Annabelle I. Benin[1], Gail Frances H. Garcia[1], Ryan J. Witzke[1], Patrick L. Feng[1]

[1]*Sandia National Laboratories, Livermore, CA, USA*

Corresponding Author Email: nrmylle@sandia.gov

Plastic scintillators (PSs) are widely used as radiation detection media in homeland security, medical imaging and nuclear physics applications. Their advantages include facile compositional tuning, mechanical durability, low cost and scalability. Chemical curing (CC) of PSs at kg scale has been practiced since the 1950s, but involves specialized equipment, chemical hazards and long reaction times to achieve sufficient conversion. [1]

An alternative method for PS synthesis called ***melt blending*** was recently demonstrated by our group [2], and involves co-melting thermoplastic polymers with high efficiency fluorophores, such as organic glass scintillator (OGS). Since the polymer matrix is pre-cured, the hazards, difficulties and time limitations associated with monomer conversion in CC are alleviated. Melt blended scintillators exceed benchmark formulations in scintillation light yield and fast neutron-gamma ray discrimination, but are synthesized in a fraction of the time, and permit incorporation of chemical functionality such as phenols (e.g. antioxidants) and active methylene groups (e.g. fluorene) not tolerated by CC.

We discuss the ease of melt blending in generating near net shape scintillator pieces at kilogram scale, using metal or glass molds, with total cycle time under four days. Applications to fast neutron radiography and neutron associated particle imaging experiments will be described.

Finally, melt blend-able scintillator formulations are compatible with widely practiced thermoplastic processing methods such as extrusion and three-dimensional printing. Production of scintillating filament and additively manufactured scintillator parts will be shown.

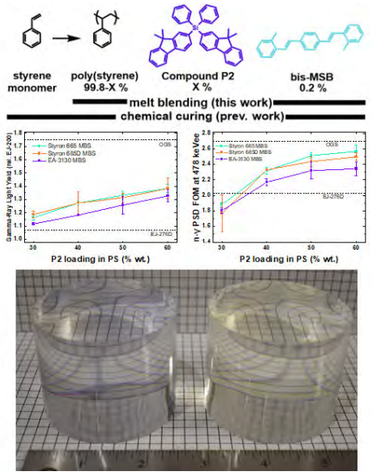


Figure 1. Top: Composition of melt blended scintillators. Middle: Radiation detection performance of 1" melt blended scintillators. Bottom: 2.5" diameter x 2" tall melt blended scintillators.

1. N. Myllenbeck, N. McIntyre, A. Long, et al, Nano-segmented optical fibers containing molecular organic glass scintillator for fast neutron imaging, SPIE, 2021.

2. N. R. Myllenbeck, A. I. Benin, G. F. H. Garcia, H. M. Tran, R. J. Witzke and P. L. Feng, "Melt Blending: A Tool to Simplify Plastic Scintillator Synthesis," in IEEE Transactions on Nuclear Science, vol. 70, no. 7, pp. 1398-1403, July 2023, doi: 10.1109/TNS.2023.3279800

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Oral Sessions | Thursday, July 11th 2024

TH-NE2 Design of Novel Capture-gated Neutron Spectrometer with a CLYC(Ce) scintillator

Hyeoung Woo Park[1], Sinchul Kang[1], Jungho Kim[1], Joong Hyun Kim[1], Hyeonseo Park[1], Young SooYoon[1]

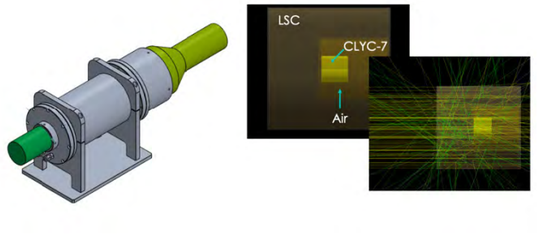
[1]*Korea Research Institute of Standards and Science, Daejeon, Korea*

Corresponding Author Email: hyeoungwoopark@gmail.com and ysy@kriss.re.kr

A capture-gated neutron spectrometer with a CLYC ($Cs_2LiYCl_6:Ce^{3+}$) scintillator and liquid scintillator is designed for fast neutron measurements and cosmic neutron spectrum measurements. Capture-gate neutron spectroscopy utilizes a liquid or plastic scintillator that generates signals along with deceleration through scattering with a thermal neutron detector containing nuclei with relatively high thermal neutron cross-section such as ^{6}Li, ^{10}Boron, and ^{3}He [1]. Recently, fast neutron measurements with CLYC scintillators using ^{35}Cl(n,p) reaction have reported, but they are effective below 8 MeV [2]. In this study, we developed a novel capture-gated neutron spectrometer consisting of a liquid scintillator and a CLYC scintillator.

Instead of ultimately capturing thermal neutrons in a traditional neutron spectrometer, a new concept was introduced that finally the detector captures fast neutrons with a ^{7}Li enriched CLYC scintillator. Geant4 simulation results of the designed neutron spectrometer show that the neutron spectrometer has a capability to measure neutrons with energy above 8 MeV.

A prototype capture-gated neutron spectrometer as shown in the figure was fabricated with reference to the simulation results. Liquid scintillators and CLYC scintillators were characterized by 2.5 MeV and 14.8 MeV monoenergetic neutron fields built at the Korea Research Institute of Standards and Science, respectively. This prototype spectrometer was able to selectively analyze neutrons coincidence signal as a result of the quenching factor and PSD obtained through characterization. We present the results of a new capture-gated neutron spectrometer composed of scintillators, and further introduce a multi-layered the neutron spectrometer for neutron spectrum measurements generated from cosmic-rays to be developed in the future.



Prototype capture-gated neutron spectrometer 3D CAD design drawing (left) and spectrometer geometry for Geant4 simulation (right)

1. J.H. Kim et al., "Neutron Spectrometer with a Capture-Gated Liquid Scintillator", Journal of the Korean Physical Society, 56, 1 (2010).

2. W. Zhou et al., "Measurement of wide energy range neutrons with a CLYC(Ce) scintillator", Journal of Instrumentation, 18, 02 (2023).

Acknowledgments

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TH-NE3 Enabling fast neutron spectroscopy in CLYC through advanced pulse shape discrimination

T.A. Laplace[1], B.L. Goldblum[1,2], J.A. Brown[1], J.M. Gordon[1], A. Venkatraman[1]

[1]*University of California Berkeley, Berkeley, California, USA*

[2]*Lawrence Berkeley National Laboratory, Berkeley, California, USA*

Corresponding Author Email: lapthi@berkeley.edu

$Cs_2LiYCl_6:Ce^{3+}$ (CLYC) has been a scintillator of interest for its ability to detect both fast and slow neutrons along with gamma rays. Neutrons are detected through ^{6}Li(n,αt) (slow neutrons) and ^{35}Cl(n,p) and ^{35}Cl(n,α) (fast neutrons). Efforts to use this material as a neutron spectrometer or multimodal detector have been frustrated by the inability to separate signals originating from proton and alpha recoils using the traditional charge integration method to perform pulse shape discrimination.

A measurement using a tagged time-of-flight setup was performed at Lawrence Berkeley National Laboratory. A ^{252}Cf source was surrounded in close proximity by 12 EJ-309 scintillators used to obtain a start signal by detecting gamma rays from fission. A 1-inch right cylinder of

CLYC6 was positioned at 1 m and used as a stop detector. Data were acquired using a CAEN V1730 500MS/s 14-bit digitizer. Separation of the different reactions is possible using the measured neutron time of flight along with the pulse integral in the CLYC6 detector. The waveforms for the isolated reaction channels were used to construct average waveforms for the individual reactions, which were normalized and are shown in Figure 1. The prompt component (~ns or less decay time) is attributed to core-valence- luminescence (CVL) [1] and is more pronounced for protons than alpha particles. This difference in the shape of the waveforms allows for improved pulse shape discrimination and isolation of the signals from ^{35}Cl(n,p). Fast digitization and sensitivity to the ~300 nm light from CVL are paramount to achieving this separation.

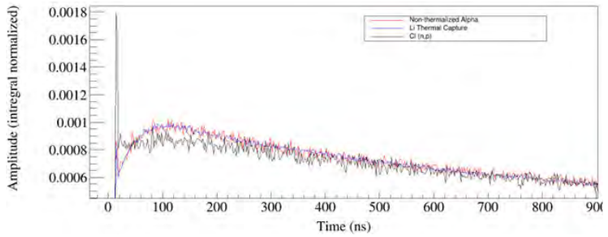

Figure 1. Integral normalized average waveforms for ^{35}Cl(n,p) and ^{6}Li(n,α) reactions in CLYC

Isolation of the ^{35}Cl(n,p) signals allows for the use of CLYC as a neutron spectrometer for >1 MeV neutrons, of interest for basic nuclear physics and nuclear security applications. Simultaneous detection of slow and fast neutrons using signals originating from reactions on both ^{6}Li and ^{35}Cl further allows for the extraction of a metric indicative of neutron downscattering in the environment. Progress towards the development of a multimodal fast neutron spectrometer will also be discussed.

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Oral Sessions | Thursday, July 11th 2024

TH-NE4 Lithium-6 neutron scintillators

Jan Jongman[1], Andrew Lee[1]

[1]*Scintacor: Cambridge, U.K.*

j.jongman@scintacor.com

Neutron detectors are used in a wide range of applications, using the unique properties of how they interact with matter. Neutrons have no charge and only interact with matter via the nuclear force, unlike x-rays, electrons and proton beams, which interact via the electro-magnetic force.

Neutron detection is applied in a variety of applications ranging across nuclear experiments, material research, medical and biological studies, homeland security and nuclear energy and nuclear waste management.

Lithium-6 is highly suitable element for neutron detection, with a neutron cross section of 940mb combined with the fact that it can be incorporated into solid scintillating materials enabling a high atomic density in contrast with the widely used Helium-3 isotope, which is a gas with low density.

Lithium can be incorporated into different glasses. Glass has the benefits of chemical robustness and stability against environmental conditions such as humidity and temperature. Glasses with different amounts of Lithium-6 can be manufactured resulting in high neutron cross sections (see figure 1). A 4mm thick GS20 neutron glass has a thermal neutron detection efficiency of 99.8%.

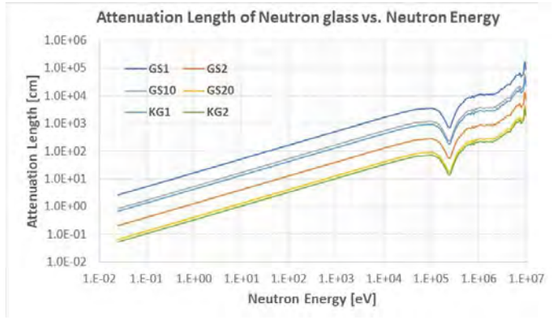

Figure 1. Neutron attenuation length for different types of Lithium-6 glass as function of neutron energy.

When large area neutron detection is required, Neutron Detection (ND) screens consisting of ^{6}LiF embedded in a powder scintillator are ideal. The detection requirements can be optimized for the required application, ZnS for high light output, and ZnO when high counting rates of up to 100,000 Hz are required. The neutron detection screens are manufactured with sizes up to ~1m^2 and can be cut into different shapes. The neutron screens are not rigid, and can be formed into curved shapes. Neutron screens cannot be made as thick as Lithium glass since the coating is not transparent to light. Screen thicknesses up to 450µm are available with a thermal neutron capture efficiency of 49%.

In our contribution an overview will be given of the different applications of Lithium glass and neutron screens. We will discuss the working principles and key properties of the Lithium-6 scintillating materials.

SESSION 13: SCINTILLATORS FOR FAST TIMING DETECTION AND IMAGING (PART 2)

TH-FT8 Prospects for the use of scintillators in photon-counting CT scanners

J. Jasper van Blaaderen[1], David Leibold[1], Casper van Aarle[1], Pieter Dorenbos[1], Dennis R. Schaart[1,2]

[1]*Delft University of Technology, Delft, The Netherlands*
[2]*Holland Proton Therapy Center, Delft, The Netherlands*

Corresponding Author Email: d.r.schaart@tudelft.nl

The development of photon-counting computed tomography (PCCT) is among the most significant technological innovations currently taking place in medical imaging [1]. PCCT promises to deliver higher-quality images at lower dose and, by utilizing the spectral information acquired using X-ray photon-counting detectors (PCDs), makes it possible to convert CT imaging from a mostly anatomical imaging modality into a quantitative one. A main challenge in the development of PCDs is that they must be able to count up to several hundreds of Mcps/mm^2 without suffering from pulse pile-up, as this gives rise to non-linear distortions of the measured count rate and spectral information. Current clinical PCCT scanners utilize PCDs based on CdTe, CZT, or Si semiconductor detectors that directly convert X-ray photons into electrical pulses. The cost of such detectors tend to make PCCT scanners expensive, and their long-term stability remains a point of attention. Scintillation detectors, on the other hand, have proven to be cost-effective and reliable in a wide variety of medical imaging applications. It has recently been shown that detectors based on ultrafast scintillators and silicon photomultipliers (SiPM) can meet the count rate requirements of PCCT [2], opening a new roadmap for the development of PCDs with potentially better cost-effectiveness.

The purpose of this presentation is to shed light on the requirements that must be met by a scintillator- based PCD and to propose a method that can be used to identify and compare suitable scintillators for PCCT. We present a simple model that takes basic SiPM and scintillator characteristics as input and allows the calculation of two performance metrics that jointly determine the ability to accurately count X-ray photons at high fluence rates. The first metric is the *pulse duration*, which determines the maximum count rate that can be handled without excessive pile-up. The second metric is denoted *pulse quality*; the larger its value, the smaller the statistical fluctuations on the measured pulses. Such fluctuations are due to the stochastic emission of scintillation photons and affect both counting and spectroscopic performance. Fluctuations can be suppressed by pulse shaping, but this leads to pulse elongation. Pulse quality can thus be seen as a measure of how closely the theoretical pulse duration can be approximated in practice.

Based on these and other metrics, the suitability for PCCT of different classes of scintillator will be discussed. These include doped scintillators (e.g. Eu^{2+}, Ce^{3+}, Pr^{3+}, Yb^{2+}, Sm^{2+}, and Tl^{+}) and intrinsic scintillators (e.g. near-bandgap excitons, self-trapped excitons, core-valence luminescence, intraband luminescence, Cherenkov radiators, and plastic scintillators). The results indicate that some scintillators previously considered suboptimal for medical imaging applications may be candidates for PCCT. At the same time, it appears that certain novel types of scintillator, such as low-dimensional perovskites, show promise for this application.

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This work was funded in part by: EU-IHI project IMAGIO, grant no. 101112053; Varian, a Siemens Healthineers company, grant no. 2018016; and the Dutch Research Council (NWO), grant no. 18040.

Oral Sessions | Thursday, July 11th 2024

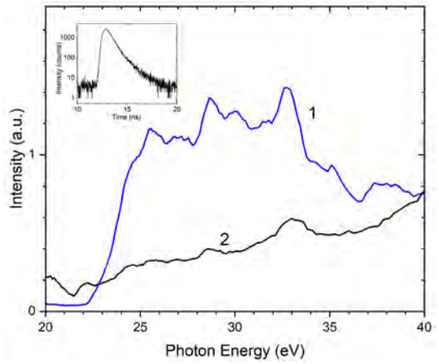
TH-FT9 Relaxation Processes Leading to Ultrafast Luminescence in K_2SiF_6 and Na_2SiF_6 Studied Under Synchrotron Radiation Excitation

Marco Kirm[1], Sergey I. Omelkov[1], Alexander Vanetsev[1], Eduard Feldbach[1], Kirill Chernenko[2], Aleksei Kotlov[3], Irina Kudryavtseva[1], Nataliya Krutyak[1], Sanu B. Maji[1], Ivo Romet[1], Juhan Saaring[4], Arslan R. Safdar[1], Dmitry Spasskiy[1], and Vitali Nagirnyi[1]

[1]*Institute of Physics, University of Tartu, Tartu, Estonia*
[2]*MAX IV Laboratory, Lund University, Lund, Sweden*
[3]*DESY Photon Science, Hamburg, Germany*
[4]*Tartu University Hospital, Tartu, Estonia*

marco.kirm@ut.ee

Scintillator materials have a wide range of application from simple ionizing radiation detection to sophisticated medical and scientific solutions, where superior time-resolution is required. Some intrinsic emissions revealed in wide-gap materials can help fulfilling this requirement. Namely, cross- luminescence (CL) and intraband luminescence (IBL) are among the emissions, which alongside with Cherenkov radiation have potential for achieving sub-nanosecond time-resolution. CL is observed only in compounds with a limited number of cations (K, Rb, Cs, Ba) providing elevated core levels. IBL is ultrafast because of severe quenching due to the competition with phonon relaxation of excited charge carriers. It has been shown that ternary hexafluorides possess electronic band structure, which facilitates the appearance of a rich luminescence spectrum due to fast CL and IBL transitions [1]. The energy gaps introduced in the density of states of the hybridized valence band result in IBL transitions with decay times in tens and hundreds of ps contrary to few ps known for binary compounds.



The current study reports on luminescence properties of K_2SiF_6 and Na_2SiF_6 powders, assessed by advanced time-resolved luminescence spectroscopy. The experiments were carried out at the FinEstBeAMS and FemtoMAX beamlines of the MAX IV Lab and at the P66 beamline of the DESY Photon Science [2]. K_2SiF_6 has a rich emission spectrum covering the VUV-visible spectral range [3]. In this spectrum, fast CL and IBL transitions are observed alongside with slower intrinsic emissions. Curve 1 in the figure shows the excitation spectrum for the 5.3 eV emission with a distinct onset above 22.1 eV, which is assigned to the K 3p core states. Obviously, the corresponding emission characterized by a short ~0.8 ns lifetime (see the inset in Fig.) is related to the transitions between the K 3p and hybridized valence band states (Si 3s, 3p; F 2p). The excitation for the 4.1 eV emission (curve 2) has less pronounced features without any thresholds. The energy gap value Eg for K_2SiF_6 was estimated to ~10.6 eV based on the excitation spectra recorded at 7 K. For Na_2SiF_6, the Na 2p core level was revealed as a dip at 34 eV, and the value of Eg > 10.7 eV was estimated from the recorded excitation spectra at 7 K. Thus, such electronic configuration excludes the appearance of CL in this compound but allows a convenient study of other intrinsic emissions, including IBL. The peculiarities of relaxation processes of intrinsic emissions in the studied ternary hexafluorides possessing substantially different electronic structure will be discussed.

1. J. Saaring, A. Vanetsev, K. Chernenko, et al., J. Alloys Compd. 883, 160916 (2021).
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TH-FT10 Cross-luminescence in cesium-based ternary fluorides

Vojtěch Vaněček[1,2], Takahiko Horiai[3], Masao Yoshino[3], Akihiro Yamaji[3], Akira Yoshikawa[1,3,4]

[1]*IMR, Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai, Miyagi, 980-8577 Japan*
[2] *SPS International Research Fellow*
[3]*NICHe, Tohoku University, 6-6-10 Aza-Aoba, Aoba-ku, Sendai, Miyagi, 980-8579 Japan*
[4]*C&A corporation, 6-6-40 Aza-Aoba, Aramaki, Aoba-ku, Sendai, Miyagi, 980-8579 Japan*

Corresponding Author Email: vanecekv@fzu.cz

Several application fields of scintillation detectors require very fast timing performance of the detector e. g. high energy physics or medical imaging. Due to the development in the technology of photodetectors and processing electronics, the temporal profile of scintillation light became a bottleneck for the achievement of so-called “ultrafast scintillation detectors”. Requirements on the time resolution of the detector (coincidence time resolution – CTR or detector time resolution DTR) depend on the application. However, the requirement can be as low as 10 ps [1]. Such technological challenge motivated the development of novel scintillators based on fast phenomena e. g. free exciton emission, Cherenkov radiation, hot intraband luminescence, and cross-luminescence (CL). In contrast to other candidates listed above, CL single crystal scintillators possess several important advantages: absence of reabsorption of the scintillation light, availability of large-volume optically homogenous elements, and facile industrialization due to well-established crystal growth technology. Despite these advantages, a successful application of CL scintillators is impeded by three main obstacles: poor spectral matching with photodetector, low attenuation for high-energy photons, and poor chemical stability. In the case of the CL scintillator paired with SiPM, good spectral matching can be achieved through the redshift of the CL emission. Such a redshift of the CL emission (compared to BaF_2) can be utilized in materials based on CsCl of CsF. A study of CsCl based scintillators by Vanecek et al. [2] showed the potential of $ABCl_3$ (A = alkali metal, B = alkaline earth metal) CL scintillators. However, the redshift was insufficient, and the crystals were hygroscopic. Both problems could be solved in fluoride homologs. This motivated research of cesium based ternary fluoride scintillators[3]. We have grown several crystals from the family of ternary fluorides with the general formula Cs_xByF_{x+2y} by micro pulling down method (mPD). Due to the nature of the mPD method and thermodynamic constraints (incongruent melting, CsF evaporation from melt) a flux growth had to be utilized for some of the crystals. Their structural and optical properties were thoroughly investigated using X-ray diffraction, absorption spectroscopy, photoluminescence, and radioluminescence as well as photoluminescence and scintillation decay kinetics. This work gives an insight into the potential of ternary fluoride CL scintillators for fast-timing applications.

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2. V. Vaněček et al., (INVITED) Ultraviolet cross-luminescence in ternary chlorides of alkali and alkaline-earth metals, Optical Materials: X 12 (2021) 100103.
3. V. Vaněček, et al., Scintillation properties of Cs4Mg3F10 crystal grown by micro-pulling-down method, Journal of Crystal Growth 629 (2024) 127568.

Acknowledgments

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TH-FT11 Investigation of Timing Properties of Tl_2LaCl_5:Ce crystal Scintillators for PET Applications

Hong Joo Kim[1, *], Dongwoo Jeong[1], Nguyen Thanh Luan[1], Arshad Khan[2]
[1] *Department of Physics, Kyungpook National University, Daegu 41566, Korea*
[2] *Department of Physics, Faculty of Arts and Sciences, Najran University, Najran, Saudi Arabia*

Corresponding Author Email: hongjoo@knu.ac.kr

Thallium-based inorganic halide scintillators draw considerable attention due to the high Z- number of thallium ions, offering enhanced detection efficiency for X- and γ–rays in various applications. Among these, Cerium-doped or co-doped with divalent ions Tl_2LaCl_5 (TLC) scintillator shows excellent scintillation performance including high light yield, good energy resolution and fast decay time [1,2,3]. The combination of high γ-ray detection efficiency, high light output and fast decay time makes TLC suitable for the positron emission tomography (PET) or time-of-flight PET (TOF-PET) applications.

In this study, we investigate the timing properties of Ce or Ce,Sr co-doped TLC scintillators and their timing resolution using a coincidence technique. The TLC crystals were grown using two- zone Bridgman furnaces. Two fast time response Hamamatsu H6610 PMTs and Co-60 and Na- 22 radioactive sources were used for the coincidence measurement study with a BaF2 and LaBr3:Ce reference crystals. The rising time and timing resolution characteristics of TLC:Ce and TLC:Ce,Sr crystals were analyzed and will be presented in this talk, along with comparison with the LYSO crystal.

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Oral Sessions | Thursday, July 11th 2024

TH-FT12 $(Gd,Lu,Y)_3Al_2Ga_3O_{12}$:Ce,Mg with optimized coincidence time resolution for PET-TOF scanners

Valerii Dormenev, Kai-Thomas Brinkmann, Dzmitry Kazlou, Rainer W. Novotny and Hans-Georg Zaunick
2nd Physics Institute Justus-Liebig-University Giessen, Germany

Corresponding Author Email: valery.dormenev@exp2.physik.uni-giessen.de

Positron emission tomography (PET) is presently in a phase of development towards whole-body scanners. A necessary enlargement of the active detection area demands cheaper scintillation materials. A prospective option is a transparent scintillation ceramics $(Gd,Lu,Y)_3Al_2Ga_3O_{12}$:Ce. It is manufactured according to the well-known ceramics production technology, but without applying pressure at the sintering stage. This production technology allows for an increase of the production rate of the crystalline mass. The scintillator shows a light yield at the level of 32 000 ph/MeV, which demonstrates a spectacular enhancement in a temperature range from 20 down to -40 oC. The effective decay constant is below 36 ns and only slightly dependent on the temperature down to -40 oC. The obtained features suggest that the material is quite promising for PET utilizing time-of-flight (TOF) techniques for the registration of annihilation γ–quanta. The figure of merit for applying any scintillation material for PET-TOF is a sufficient coincidence time resolution (CTR) in combination with an appropriate photo receiver.

In this report, we focus on the characterization of the material properties with respect to the achievable coincidence time resolution at different operating temperatures. A Tektronix MSO66B40 oscilloscope was used as the data acquisition system (DAQ) for CTR measurements with a ^{22}Na annihilation gamma source in combination with a Broadcom AFBR-S4E001 evaluation board and Broadcom FBR-S4N44P014M NUV-MT Silicon Photomultiplier (SiPM). The SiPMs have been coupled directly to the samples with dimensions of 2x2x1.5 mm^3 and used for both channels. The measurements were performed in a temperature range between +20o and -40o C, respectively. Figure 1 illustrates the coincidence time resolution spectrum measured at room temperature. The obtained CTR stays below 100 ps (FWHM) in the whole temperature range. A further development of the material and appropriate detector concepts will be discussed.

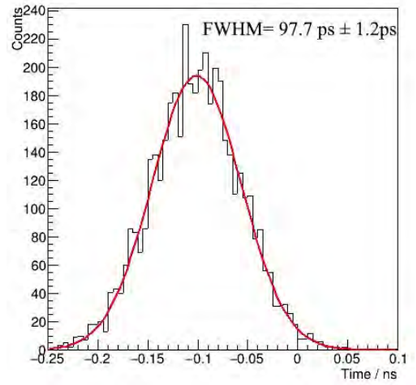


Figure 1. Coincidence time resolution spectrum measured with (Gd,Lu,Y)3Al2Ga3O12:Ce,Mg scintillation ceramics at +20oC temperature.

Oral Sessions | Thursday, July 11th 2024

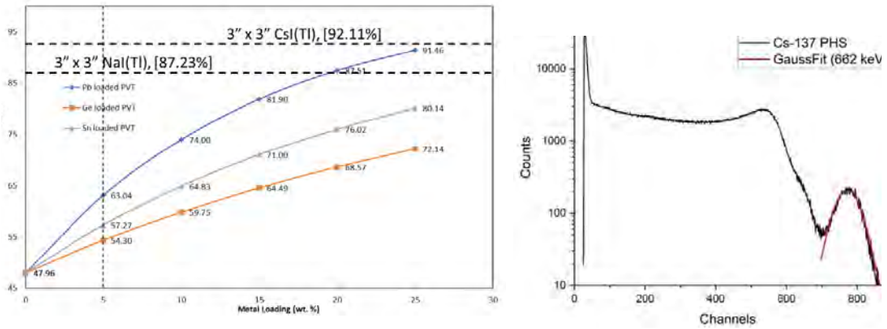
TH-FT13 Metal-Loaded Organic Glass Scintillators for Gamma-Ray Spectroscopy

Ryan J. Witzke[1], Annabelle I. Benin[1], Nicholas R. Myllenbeck[1], Patrick L. Feng[1]

[1]*Sandia National Laboratories: ND Materials and Rad Effects, Livermore, CA, United States*

Corresponding Author Email: rjwitzk@sandia.gov

We have formulated, synthesized, and characterized variations of metal-loaded organic glass scintillators (OGS) aimed at applications in gamma-ray spectroscopy. The introduction of heavy metal additives was done to increase the Z_{eff} of OGS, thereby enabling gamma-ray spectroscopy via the photoelectric effect. Key properties that were examined include energy resolution, detection efficiency, solubility of organometallic compounds, effectiveness of shielding against spin-orbit fluorescence quenching, environmental stability/ durability, and thermomechanical properties relevant for scale-up and production.



$$Intrinsic\ Efficiency(\varepsilon_i) = \frac{Number\ of\ pulses\ recorded}{Number\ of\ radiation\ quanta\ incident\ on\ detector}$$

Pulse height spectrum of a 1 cm OGS cylinder loaded with 10 wt% Sn.

Energy resolution values between 7-12% were obtained along with intrinsic 662 KeVee efficiency of up to 40% NaI(Tl) for equivalent volume. This was achieved for stable compositions up to 15 wt% Sn and 7.5 wt% Pb. These compositions were resistant to environmental aging and plasticization. Light output greater than EJ-200 (13500 photon/MeVee) was observed, while retaining efficient neutron/gamma discrimination. The higher light yield of OGS relative to plastic scintillators enabled these formulations to maintain high performance despite the addition of light quenching metal additives. Examples to date were up to 2.42 in^3 (39.7 cm^3).

Future work will be focused on attenuation length studies to determine the effects of longer pathlengths such as those encountered in radiation portal monitors.

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TH-FT14 A Novel Scintillator Detector For Online High-Resolution Proton Beam Profiling

Michele Caldara[1], Veronica Leccese[1,2], Samuele Bisi[1], Benoit Truc[1], Alessandro Mapelli[3] and Fabrizio Carbone[1].

[1]*Institute of Physics (IPhys), Laboratory for Ultrafast Microscopy and Electron Scattering (LUMES), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne 1015 CH, Switzerland*

[2]*CSEM S.A., 2002 Neuchâtel CH, Switzerland*

[3]*Institute of Mechanical Engineering (IGM), Advanced NEMS Laboratory (NEMS), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne 1015 CH, Switzerland*

Corresponding Author Email: michele.caldara@epfl.ch

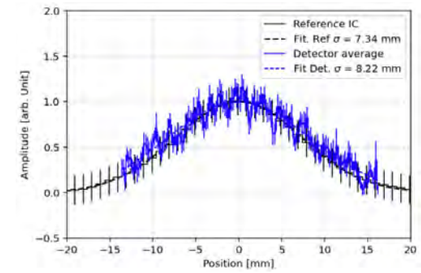
Background and objectives

Organic scintillators, known for their high sensitivity, fast response, and cost-effectiveness, are commonly employed in monitoring high-energy particle beams for diverse applications [1]. However, current measurement methods struggle to efficiently combine high spatial resolution and fast acquisition rates, preventing accurate beam characterization. To address these issues, we propose a novel beam transverse profiler utilizing silicon microchannels filled with a scintillating resin and coupled with a photodetector array. This innovative yet simple approach unlocks the full potential of organic scintillators. The primary objective is to obtain an instrument for beam characterization along the high energy transfer lines of proton therapy accelerators with pencil beam scanning. Our technology promises a compact detector, potentially compatible with FLASH therapy beam requirements, capable of accurate beam profiling at a high rate, making it attractive for proton therapy facilities commissioning and operation.

Methods and Results

The beam profiler is based on an array of microfabricated, 100 µm-width, silicon channels, metal- coated, and filled with a moldable scintillating resin. The device's sensitive area is coupled with a custom-made readout system including a photodetector array and a microcontroller. The design achieves high spatial resolution (~50 µm) and a profile monitoring rate of up to 3.8 kHz, with a settable integration time ranging from 4.5 µs to 1.4 s.

The device underwent testing on a proton beamline at CNAO (Italy) with beam energies ranging from 70 MeV to 230 MeV. The obtained profiles were benchmarked against a reference detector, showing consistency for low energies (<100 MeV).



The beam profilers measured with our detector and with the reference one, a gas ionization chamber (IC). The beam energy was set at 74 MeV.

Conclusions

In summary, our novel beam profiler demonstrates promising results for high-energy particle monitoring, particularly in proton therapy, offering high spatial and temporal resolution essential for accurate beam profiling and for FLASH therapy.

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Oral Sessions | Thursday, July 11th 2024

SESSION 14: NANO- AND METAMATERIALS (PART 2)

TH-NA5 A few recent developments in nanophotonic scintillators

Charles Roques-Carmes[1]

[1]E. L. Ginzton Laboratory, 348 Via Pueblo, Stanford University, CA 94305, USA

Corresponding Author Email: chrc@stanford.edu

Recent developments at the intersection of nanophotonics and scintillator materials development have led to the conceptualization and demonstration of so-called "nanophotonic scintillators [1-4]." Nanophotonic scintillators consist of scintillator materials integrated into nanophotonic structures, patterned at the scale of their optical emission wavelength. Nanophotonic scintillators are a promising platform to control and enhance spontaneous light emission in scintillators.

Mechanisms of light control and generation enhancement with nanophotonic scintillators include (1) angular light emission control and outcoupling enhancements with surface-patterned scintillators [1,2]; and (2) enhancement of the rate of spontaneous emission by volumetric patterning, leveraging the Purcell effect [3,4]. Each of these methods entail the development of dedicated nanofabrication methods to realize wavelength-scale patterns into scintillator materials.

In this talk, I will review some recent theoretical and experimental developments in nanophotonic scintillators. I will first present a general theoretical framework to model scintillation in arbitrary nanophotonic structures, which also lends itself to shape optimization of nanophotonic structures for enhanced scintillation. Then, I will review some recent experimental demonstrations in surface- patterned photonic crystal scintillators and multilayer scintillators. Based on this framework and recent theoretical proposals, I will also present other nanophotonic scintillator designs for enhanced spatial resolution and efficiency, as well as their applications to scintillation-based x-ray imaging.

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T. Lenkiewicz, R. Strassberg, O. Be'er, Y. Bekenstein, and Ido Kaminer, Purcell-enhanced X-ray scintillation, arXiv preprint, arXiv:2302.01300 (2023)

TH-NA6 Tailoring the Purcell enhancement in nanoplasmonic perovskite scintillators

Dominik Kowal[1], Wenzheng Ye[2], Liang Jie Wong[2], Muhammad Danang Birowosuto[1]

[1]Lukasiewicz Research Network – PORT Polish Center for Technology Development, Stablowicka 147, 54-066, Wroclaw, Poland
[2]School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798, Singapore

Corresponding Author Email: dominik.kowal@port.lukasiewicz.gov.pl

Recent progress in the concept of nanoplasmonic Purcell enhanced scintillators, with reported improvement of light yield and scintillation decay time [1], holds great potential for future X-ray imaging solutions, where it could help in achieving greater contrast, higher resolution or scanning speeds. Among various scintillator materials, low dimensional perovskites show a unique combination of bright and ultrafast emission. They are particularly suitable for fabrication of plasmonic heterostructures, due to simplicity of thin film deposition and good coupling efficiency with surface plasmon polariton states. In this work, we carry out experimental- and simulation-based investigation of the Purcell enhancement by varying heterostructure designs and materials. For given choice of materials the achievable enhancement is determined by the resonance between scintillator dipole emitters and surface plasmons. We utilize the design reported in our previous work [1] and we confirm theoretical predictions (Fig. 1a) as we switch from gold to silver plasmonic layer to obtain better enhancement. Particularly, we report photoluminescence (PL) and time resolved PL enhancement with a maximum of 11× (Fig. 1b) for various low dimensional perovskites. Furthermore, we design novel architecture for Purcell enhanced scintillators, combining nanoplasmonic heterostructure scintillator with square photonic lattice that supports bound states in the continuum [2] (Fig. 1c). We demonstrate the proof-of-concept with electromagnetic wave simulation and we show the potential of some novel highly Stokes shifted perovskites for achieving strong enhancement due to less absorption. We also discuss the potential for such hybrid plasmonic- photonic systems for X-ray imaging with improved sensitivity and resolution.

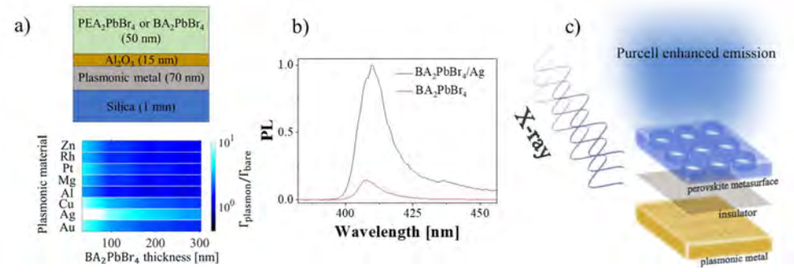

Fig. 1. a) Schematic of nanoplasmonic scintillator heterostructure and predicted enhancement value with different plasmonic metals, reprinted from [1], b) measured PL enhancement with BA2PbBr4/Ag heterostructure, c) design illustration of hybrid plasmonic/BIC emitter stack.

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TH-NA7 Improving the scintillating sensors properties: nanoparticles and nanocomposites

Karmel de Oliveira Lima[1], Cora Moreira da Silva[1], Michele D'Amico[2], Patrick Gredin[3], Alban Ferrier[3], Hana Buresova[4], Dominique Rothan[4], Vincent Schoepff[1], Dominique Tromson[1], Guillaume Bertrand[1]

[1]Université Paris-Saclay, CEA, List, F-91120 Palaiseau, France
[2]Nexdot, 93230 Romainville, France
[3]Chimie ParisTech, PSL University, CNRS, Institut de Recherche de Chimie Paris, 75005 Paris, France
[4]NuviaTech Instruments & Healthcare, 92506 Rueil Malmaison, France

Corresponding Author Email: karmel.deoliveiralima@cea.fr

Plastic scintillators are essential for the detection of nuclear and radioactive materials in the context of Homeland Security and nuclear non-proliferation. Although widely used for their low cost and adaptability, current plastic scintillators have limitations, particularly in the identification of high- energy gamma (γ) emitters due to their low effective atomic number (Z_{eff}). Recent advances in nanophotonics offer promising prospects for the development of nanocomposite scintillators with high Z_{eff} and high light yields, broadening their potential applications [1].

We selected a wide range of high-Z metallic, two- dimensional semiconductors (quantum plates) and Ce- doped fluoride nanoparticles to be incorporated into a polystyrene (PS) matrix to improve the nanocomposite scintillator efficiency towards high-energy gamma (γ) emitters detection [2]. The higher density, robustness and tunability of absorption/emission wavelengths of these nanoparticles can enhance the gamma detection. Whatever the type of nanoobjects incorporated, their optical properties depend directly on their size, shape, crystallographic structure and chemical composition.

Therefore, several nanocomposite scintillators were prepared with different reactional parameters such as particle doping level, nature of surfactants, time and temperature of polymerization process. We characterized the nanoparticles and nanocomposite scintillators by transmission electron microscopy (TEM) before and after the matrix polymerization step, and optimized the experimental conditions to ensure that the nanoparticle properties remain as unchanged as possible into the nanocomposite scintillators. At last we performed radioluminescence and photophysical characterizations on our nanocomposites to evaluate their light yield and total γ absorption peak of different energies.

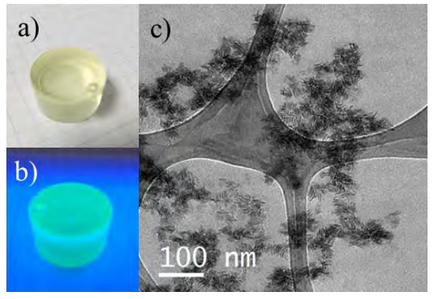

Figure 1. CdSe(dot)/CdS(plate) quantum plates doped polystyrene-based green emitting scintillator irradiated in a daylight (a) and by 365 nm UV lamp (b). TEM image of 70 µm thick-section of polystyrene scintillator with quantum plates dispersed inside, deposited on lacey carbon TEM grid (c).

1. T. J. Hajagos, C. Liu, N. J. Cherepy, Q. Pei, "High-Z Sensitized Plastic Scintillators: A Review", Advanced Materials, 30, 1706956 (2018).
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This work is supported by the French National Research Agency (Agence Nationale de la Recherche) under grant agreement ANR-22-CE39-0011-01. The authors acknowledge the Imagerie-Gif core facility supported by l'Agence Nationale de la Recherche (ANR-10-INBS-04/FranceBioImaging; ANR-11-IDEX-0003-02/ Saclay Plant Sciences).

TH-NA8 Halide- and oxide-based composite, nano and meta materials: comparison and luminescent properties

Václav Čuba[1], Lenka Procházková[1,2], Jan Bárta[1], Xenie Popovic[1], Kateřina Děcká[1], Jan Král[1,2], Etiennette Auffray[3], Eva Mihóková[1,2], Martin Nikl[2]

[1]FNSPE Czech Technical University in Prague, 115 19, Czech Republic
[2]Institute of Physics, Czech Academy of Sciences, Prague, 162 00, Czech Republic
[3]European Organization for Nuclear Research (CERN), Meyrin, 1211, Switzerland

Corresponding Author Email: vaclav.cuba@fjfi.cvut.cz

In recent years, scintillating nanoparticles and nanomaterials have been drawing considerable interest of research communities and the industry. When compared to bulk materials, nano-scaled scintillators offer some unique opportunities, such as finely tunable luminescence spectra, dependent not only on the composition of scintillating compounds, but also on the shape and size of nanoparticles; effects related to quantum confinement; extensive shape customization of the final products. In order to be actually competitive, following critical points in scintillating nanomaterial fabrication should be addressed: they need to feature sufficient stopping power and light yield, high chemical and radiation stability, and low cost of their manufacture. Currently, there is a wide variety of the perceived applications for scintillating nanostructures, including, but not limited to: spectrometry of ionizing radiation, fast timing for medicine and high energy physics, radio and photodynamic therapy, or high resolution electron microscopy. In order to meet the requirements of target applications, and also to circumvent inherent disadvantages of the nanoparticles, scintillating nanocrystals may be incorporated into scintillating heterostructures, nanocomposites consisting of polymer or inorganic matrices with embedded scintillating quantum dots, optical ceramics made of free standing nanopowders, etc.

In this work, we discuss fabrication and characterization of three groups of nanostructured compounds with respect to the aforementioned criteria: (1) cesium lead halide perovskite structures, offering good stopping power and fast scintillation decay. They can be prepared as very small nanoparticles, but their chemical stability is rather low, which relegates these materials as a part of nanocomposites (quantum dots) or heterostructures [1], combining the properties of polymer/inorganic matrices or scintillating wafers with perovskite nanocrystals. (2) Gallium doped zinc oxide structures, featuring the ultrafast scintillation decay, combined with good chemical stability. On the other hand, they have rather low stopping power and low light yield, which needs to be enhanced by incorporating them into nanocomposite or core-shell systems [2]. (3) Y -, Gd -, or Lu - based mixed oxides with garnet or perovskite structures offer excellent chemical stability, good stopping power and light yield. However, limiting the agglomeration of nanoparticles presents significant technological challenge.

1. K. Děcká, F. Pagano, I. Frank, N. Kratochwil, E. Mihóková, E., Auffray, V. Čuba „Timing performance of lead halide perovskite nanoscintillators embedded in a polystyrene matrix," J. Mater. Chem. C, 10, 12836 (2022).
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This work was carried out in the frame of Crystal Clear Collaboration. Financial support was provided by following projects: Horizon 2020 research and innovation programme under grant agreement No. 899293 – SPARTE and CZ.02.01.01/00/22_008/0004596 – SenDiSo.

Oral Sessions | Thursday, July 11th 2024

TH-NA9 Sensitized triplet-triplet annihilation in nanostructured polymeric scintillators allows for pulse shape discrimination

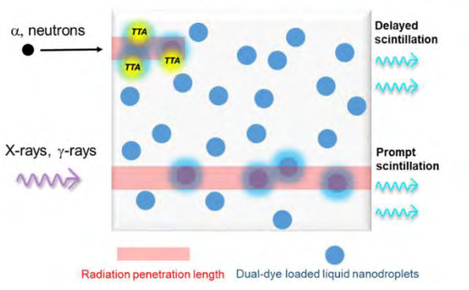
Xueqian Hu[1], Davide Rigamonti[2], Irene Villa[3], Luca Pollice[3], Michele Mauri[3], Marco Tardocchi[2], Francesco Meinardi[3], Christoph Weder[1]*, Angelo Monguzzi[3]*

[1]*Adolphe Merkle Institute, University of Fribourg, CH-1700 Fribourg, Switzerland*
[2]*Institute for Plasma Science and Technology, National Research Council of Italy, Milan, Italy*
[3]*Department of Materials Science, University of Milano-Bicocca, Via R. Cozzi 55, 20125 Milano, Italy*

Corresponding Author Email: christoph.weder@unifr.ch, angelo.monguzzi@unimib.it

Scintillation counters, utilized extensively for detecting and quantifying ionizing radiation through the recording of scintillating materials' photon emission in response to incoming radiation, constitute an important family of radiation detectors. Organic liquid and plastic scintillators find widespread applications in high-energy physics experiments, nuclear threat detection, medical dosimetry, and various other domains. In some of these applications, it is crucial to distinguish high-energy neutrons and charged particles from gamma-radiation background. Pulse shape discrimination (PSD) techniques, which involve a time-gated analysis of the voltage pulses produced by the photodetector of the scintillation counter, provide a means to differentiate different incident radiations. These methods rely on the deconvolution of the scintillation signal into fast and slow components that are associated with prompt and delayed emission processes, which are diagnostic for the nature of the incident radiation. However, achieving efficient PSD with plastic scintillators, which are attractive due to their mechanical robustness, economic effectiveness, and manufacturability compared to liquid or crystalline scintillators, has proved to be challenging.

This study demonstrates the feasibility of rapid and sensitive PSD on the basis of nanostructured polymer scintillators that can be synthesized under ambient conditions in a one-pot procedure. These scintillators comprise a cross-linked solid polymer matrix in which non-polar liquid nanodomains are embedded. These nanodroplets contain a triplet-triplet annihilation-active scintillating dye [1-2] and enable efficient, localized bimolecular energy transfer processes that are typically hard to achieve in solid polymers. We show that the incorporation of a triplet sensitizer further enhances the sensitivity and discrimination ability of the scintillator compared to its non-sensitized counterparts.



In the nanostructured polymeric scintillator presented, the solid matrix hosts liquid nanodroplets containing a TTA- capable dye and a triplet sensitizer dye; α and β particles as well as neutrons trigger delayed emission, X-rays and γ- rays cause prompt emission.

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TH-NA10 Latest Developments on Low-Dimensional Lead-Free Rb-based Metal Halides for Radiation Detection

Roma Mulholland[1], Joey O'Neill[1], Joydip Ghosh[1], Suad Al-Ghamdi[1], Hayden Salway[2], Miguel Anaya[2], Paul Sellin[1], Carol Crean[1]

[1]*Schools of: Chemistry and Chemical Engineering, Maths and Physics, University of Surrey, Guildford, United Kingdom*
[2]*Department of Chemical Engineering and Biotechnology, University of Cambridge, Cambridge, United Kingdom*

Corresponding Author Email: r.mulholland@surrey.ac.uk

The ability to detect ionising radiation is crucial to many areas of modern-day life spanning use in medical imaging, cancer therapies, security, and environmental monitoring as well as potential in military field applications. Conventional scintillators such as $Lu_{1.8}Y_{0.2}SiO_5$:Ce (LYSO:Ce),CsI(Tl) and Bi_4Ge_3O (BGO) are known for their harsh processability and limited structural flexibility[1]. In an effort to develop cost-effective yet equally-emissive, efficient candidate materials - perovskite- inspired metal halides have emerged. Low-dimensional metal halides (LDMHs) have become attractive owing to their structural tunability, unique luminescence mechanisms and chemical stability[2]. Reduced dimensionality facilitates characteristic excitonic emission that results in broadband emission, large Stoke's shifts and ultrafast decay lifetimes. Mitigating the pertinent issue of lead toxicity, all-inorganic Rb-based LDMHs maintain large attenuation coefficients and bright luminescence. Notably, their excellent solution processability allows access to nanocrystal syntheses, affording pathways to nanocomposite fabrication.

Rb_2AgX_3 (X = Cl, Br) has shown promise with broadband emission centred at 514 and 585 nm, respectively, as well as zero self-absorption and nanosecond decay times; ideal for dynamic X-ray imaging. Previous research has not investigated the differences between the two halide systems nor directly compared their X-ray imaging capabilities, until now. Here, we present our latest developments on Rb_2AgX_3, (X = Cl, Br), delving into optimised solution-based syntheses, in-depth characterisations, and the influence of competing excitonic emission mechanisms.

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[2] Shuangyi Zhao, Jinrong Zhao, Saif M. H. Qaid, Dehai Liang, Kang An, Wensi Cai, Qingkai Qian, Zhigang Zang; White emission metal halides for flexible and transparent x-ray scintillators. Appl. Phys. Rev. 1 March 2024; 11 (1): 011408. https://doi.org/10.1063/5.0175849

Oral Sessions | Thursday, July 11th 2024

TH-NA11 Reabsorption-free scintillating MOF crystals activated by ultrafast energy transfer

Jacopo Perego[1], Matteo Orfano[1], Charl X. Bezuidenhout[1], Irene Villa[1], Francesca Cova[1], Anna Vedda[1], Christophe Dujardin[2], Benoit Sabot[3], Piero Sozzani[1], Silvia Bracco[1], Angiolina Comotti[1] & Angelo Monguzzi[1]*

[1] Dipartimento di Scienza dei Materiali, Università degli Studi Milano-Bicocca, via R. Cozzi 55, 20125 Milano, Italy
[2] Institut Lumière Matière, Université Claude Bernard Lyon, Lyon, France.
[3] Université Paris-Saclay, CEA, LIST, Laboratoire National Henri Becquerel (LNE-LNHB), Palaiseau, France.

Corresponding Author Email: jacopo.perego@unimib.it

Limiting the self-absorption of the luminescence emission to maximize the light output is crucial in bulk photonic devices, especially in the case of the luminescent scintillators employed to monitor the ionizing radiations. Unfortunately, large Stokes shift materials, such as phosphorescent chromophores or electronically-doped semiconductor nanocrystals, often show slow emission rates which hinders their use if fast emitters are required to get high quality images in short times, such as in biomedical imaging, or to avoid detrimental pile-up of the recorded emitted photons, such as in high-rate/high-energy events or for the detection and activity quantification of gas radionuclides. [1]

To overcome this limitation, we demonstrated that fast scintillation with large Stokes shift can be obtained in metal-organic frameworks (MOF) crystals engineered with inorganic linking nodes containing heavy elements prone to interact with the ionizing radiations and highly fluorescent conjugated ligands. [2][3] We realized hetero-ligand MOFs with a Stoke shift as large as 1 eV, thus completely eliminating the self-absorption issue, by co-assembly of scintillating ligands with complementary emission and absorption properties. Importantly, the specific electronic properties of the conjugated ligands allow the sensitization of emissive ligands by means of an ultrafast diffusion-mediated non-radiative energy transfers with a rate up to the THz range. This extremely efficient mechanism enables to instantaneously active the ns-lifetime scintillation emission of MOF crystals. The efficient antenna mechanism, and the consequent elimination of reabsorption, enables to preserve the structural and gas adsorption properties of the parent homo-ligands MOF surpassing by 500% its scintillation yield. In the optimal composition, the hetero-ligand MOF has been tested to capture and detect the radioactive krypton isotope ^{85}Kr in the gas phase, demonstrating a high affinity for this radionuclide and an improved detection sensitivity with respect to the reference homo-molecular system. [4]

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We acknowledge support from the European Community through the grant no. 899293, HORIZON 2020—SPARTE FET OPEN and from the the Italian Ministry of University (MUR) through grant PRIN 2020 - SHERPA no. H45F2100343000 and grant MINERVA LuMIminesceNt scintillating hEterostructures foR adVanced medical imaging no. H25E22000490006.

TH-NA12 Recent advancements in development of composite scintillators based on epitaxial structures of oxide compounds

Yuriy Zorenko[1,2], Vitalii Gorbenko[1], Sandra Witkiewich-Łukaszek[1], Yurii Syrotych[1], Tetiana Zorenko[1], R. Kucerkova[3], Jiri A. Mares[3], Martin Nikl[3], Oleg Sidletskiy[4,5], Janusz Winiecki[2], Kei Kamada[6], Akira Yoshikawa[6]

[1]Physical Faculty of Kazimierz Wielki University in Bydgoszcz, 85-090 Bydgoszcz, Poland;
[2]Oncology Centers in Bydgoszcz, 85-796 Bydgoszcz, Poland;
[3]Institute of Physics, Czech Academy of Science, 16200 Prague, Czech Republic
[4]Institute for Scintillation Materials, NAS of Ukraine, 61072 Kharkiv, Ukraine
[5]Centre of Excellence ENSEMBLE3 Sp. z o.o., 01-919, Warsaw, Poland
[6]Tohoku University, Sendai 980-8577, Japan

Presenting author's email: zorenko@ukw.edu.pl

This report presents a brief overview of our latest achievements in the development of ***multilayered composite scintillators*** of phoswich-type (phosphor sandwich) based on the single crystalline films (SCFs) and single crystals (SCs) of garnet, perovskite and orthosilicate compounds using the liquid- phase epitaxy (LPE) growth method for application in the environmental radiation monitoring for simultaneous registration of various types of ionizing radiations in mixed high energy particles and photon fluxes [1], microimaging techniques with high special resolution, and medicine. Such composite scintillators comprise *multilayered epitaxial structures* containing SCF scintillators, LPE grown „step-by-step" onto substrates of SC scintillators. Film and substrate parts of composite scintillators were fabricated from efficient scintillation materials with different scintillation emission spectra or/and decay kinetic achieved by doping by different cations and varying host composition [1].

We present results of fabrication of new types composite scintillators, based on the film and crystals of Ce^{3+} doped $R_3B_5O_{12}$ (R=Lu, Y, Gd, Tb; B= Al, Ga) mixed garnets, Ce^{3+} and Pr^{3+} doped (Lu, Y, Gd)AlO_3 perovskites, and Ce^{3+} and Bi^{3+} doped (Lu,Y,Gd)$_2SiO_5$ orthosilicates using LPE method, as well as the results of study their luminescent and scintillation properties. The application-targeted tests of prototypes of multilayered composite scintillators based on the mentioned oxide compounds for simultaneous registration of α- and β-particles and γ–quanta were performed, and obtained results were analyzed to optimize their scintillation performance.

Composite detectors are also proposed as a very important tool for study of the effects of secondary radiation in Boron-Neutron Capture Treatment (BMCT) and even measuring the dose absorbed by tissues from various types of ionizing radiation (α-particles, ^7Li ions and γ–quanta) [2]. First, the thickness of the top composite scintillation materials is selected according to the attenuation length of ^7Li quanta and α-particles. Secondly, the lower part of the detector comprise thick enough and heavy materials intended to absorb high-energy γ–rays. Several types of composite scintillators based on the different oxides for in-situ-dose measuring of BNCT procedure were proposed. The scintillation, TSL and OSL properties of these composites were examined under selective excitation with α- (^{239}Pu) and β- (^{90}Sr) particles and γ–quanta (^{137}Cs). The results were compared in terms of selecting the composition with the best BNCT performance in laboratory conditions.

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Acknowledgments

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Scintillators in the wild - the present and future of gamma-ray sensing in geophysical applications

Han Limburg[1]

[1]Medusa Radiometrics, Groningen, The Netherlands

Corresponding Author Email: han@medusa-online.com

Since the early days of geophysics, gamma-ray spectroscopy has been one of the basic instruments in the geophysicists' toolbox. Gamma radiation emitted by the naturally occurring isotopes ^{40}K, ^{238}U and ^{232}Th carries the signature of the rocks, soils and sediments these nuclides are embedded in. In other words, the minerals that constitute rocks and soils can be classified by a "radiometric fingerprint"[1], i.e. a specific concentration vector (^{40}K, ^{238}U, ^{232}Th). This notion has been a driving force for the development of gamma-ray spectrometers to be used "in the field".

In the last 10 years, both the advent of drone technology and the rapidly increasing use of gamma-ray spectrometers in agricultural applications has boosted further development of the detector technology in terms of robustness, data quality and ease of use.

The recent advent of drones as a carrier platform[2] for geophysical instrumentation yields certain design challenges to gamma-ray detectors. Drones have a (very) limited payload which contradicts the requirement of maximum detector volume to optimize survey results. For instance, in classic airborne surveys NaI "packs" weighing typically 100 to 200kg are common whereas most commercially viable drones can only carry about 7-10 kg. And using drones can be risky – a soft landing is not always achieved, imposing another requirement on the robustness of the crystals used.

Robustness and ease of use also comes to play in agricultural mapping. Gamma-ray spectrometry has been recognized as an excellent tool to map (the variability of) soil composition in cropfields and the data is nowadays used to generate soilmaps for farmers to optimize their works. Most of the agricultural mapping is done using large detectors mounted on vehicles "bumping" at speeds of 20-30km/h over these cropfields. Which evidently requires very robust and easy to handle equipment. Traditionally used scintillators like NaI are of no use because of their shock- and temperature sensitivity.

The potential market for use of scintillator-based sensors in soil mapping, in particular agricultural, is huge. Now, mostly high-end CsI-based systems are used but price and potential availability issues of CsI are barriers that may slow down the market development. Recently, low-end plastic scintillators have attracted interest as they may be used as "add-on" to the CsI systems or even as a full replacement. Plastics could have a significant impact on the market development as they are relatively cheap, robust and easy to get. However, efficiently deriving proper radionuclide concentrations from the photopeak-lacking "plastic" energy spectra is a challenge that is not at all trivial and is currently being investigated.

In summary, the future for scintillators in geophysics is bright! And it could be even brighter if a material is developed that combines the advantages of of CsI (robustness, relatively good photopeak efficiency) with the low price and abundant availability of plastics.

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SESSION 15: APPLICATIONS OF SCINTILLATORS (PART 3)

F-AP8

The CUPID neutrinoless double-beta decay experiment

Stefano Dell'Oro[1,2], on behalf of the CUPID Collaboration

[1]Università di Milano-Bicocca, 20126 Milano, Italy
[2]INFN – Sezione di Milano Bicocca, 20126 Milano, Italy

Corresponding Author Email: stefano.delloro@unimib.it

Neutrinoless double-beta decay (0νββ) plays a crucial role in addressing some of the major outstanding issues in particle physics, including lepton number conservation and the Majorana nature of neutrinos. Over the past few decades, several efforts have sought to increase the sensitivity on the 0νββ process and the forthcoming-generation experiments, which target the Inverted-Ordering region of the neutrino mass spectrum, aims at sensitivities beyond 10^27 years on the 0νββ half-life. Among the employed techniques, low-temperature calorimetry has proven to be highly promising and is poised to maintain its pivotal role in the near future through the CUPID experiment. CUPID, the CUORE Upgrade with Particle IDentification, is a next-generation experiment that will search for 0νββ of 100-Mo and other rare events using Li_2MoO_4 scintillating bolometers. CUPID will take advantage of the experience acquired by running CUORE (Cryogenic Underground Observatory for Rare Events), the first tonne-scale bolometric array, currently operating at Laboratori Nazionali del Gran Sasso in Italy, and will be hosted in the existing CUORE cryogenic infrastructure. With 1596 scintillating Li_2MoO_4 crystals enriched in 100-Mo, coupled to 1710 light detectors, CUPID enables simultaneous readout of heat and light, allowing for particle identification and a robust rejection of the alpha background. Today, ongoing coordinated efforts, including numerous studies and R&D projects, aim to finalize the CUPID detector design and assess its performance and physics capabilities. In this presentation, we will provide an overview of the current status of CUPID and highlight the upcoming milestones in the construction of the experiment.

NOTE: the speaker's name is a placeholder. The actual speaker will be designed by the CUPID Collaboration in case of acceptance. We will inform the conference organizers as soon as a choice will be made

F-AP9 A monocrystal based detection unit for semi-continuous determination of tritium in wastewater samples

Tomáš Brunclík[1], Karel Blažek[2], Michal Fejgl[3]

[1]Georadis spol. s.r.o., Novomoravanská 321/41 619 00 Brno, Czech Republic
[2]Crytur spol. s.r.o., Na Lukách 2283, Turnov, 511 01, Czech Republic
[3]SÚRO, v.v.i., Bartoškova 28, Praha 4, 140 00, Czech Republic

Corresponding Author Email: brunclik@georadis.com

Presented work describes a newly developed detection unit proposed for semi-continuous through- flow determination of tritium in non-purified liquid effluents from the nuclear power plants (NPPs). The instrument is expected to be able to detect an exceedance of 60kBq/L.

In the field of radioactivity detection there is a substantial need of liquid scintillation cocktails use reduction because of their adverse environmental impact. It brings developments of different new procedures enabling determination of beta activity in liquid samples using solid scintillators. In terms of static measurements of liquid samples in mixture with either solid scintillation micro globes or micro sheets placed into scintillation vials measured using Liquid Scintillation Counter, the detection response to beta emitters with E_{max} over ~150 keV brings viable detection efficiencies (1). However, the determination of tritium activity (Emax=18.6 keV) faces very low detection efficiency and results in unpleasant detection sensitivity.

To perform such kind of tritium analyses in either continuous or semi-continuous time regimes is even more challenging. Firstly, the liquid sample must be propelled through the instrument under high pressure to overcome adhesion and capillary forces. Secondly, liquid sample purity has to be secured to prevent premature fading of the scintillation medium (leaching of scintillation admixture) and contamination. There are devices coping with the mentioned setbacks, such as Waterrad (2) proposed specifically for analyses of the NPPs liquid effluents gaining favorable MSA ~0.54 kBq/L (60m measuring time in semi-continuous regime).

A different approach is described in this contribution. A detection unit is built from scintillation monocrystals assembled with dual light output. A coincidence spectrum mode is used to significantly suppress temperature and electrical noise and to supply adjustable pulse rejection capability. Monocrystals from either the silicates or aluminates family are utilized and a total detection surface area is ~250 cm2.

Such structure brings several fundamental advantages lightening construction demands. Relatively large cavities (2mm) between crystals enable throughput of liquid sample without pressurization. The nature of the crystals brings resistance of detection unit against chemical damage, contamination and against loosing of scintillation capabilities. There isn't need for chemical pretreatment of analyzed liquids, therefore, while chemical decontamination of the detection unit is feasible without affecting the detection capabilities. Only the filtration of the insoluble particles is necessary. On the other hand, large cavities lead to decrease of detection efficiency, which on terms of tritium hardly overcomes 6E-03 %. Nevertheless, thanks to 60mL sample volume and coincidence signal output processing, a reasonable minimal significant activity of ~40 kBq/L is achieved within 50m measuring time in semi- continuous regime. Sensitivity of the tool can be further enhanced by increasing the surface area of the monocrystals, reducing background noise through decreasing the thickness of the monocrystals, and incorporating anticoincidence shielding. The proposed solution is primarily portable and facilitates in situ measurements.

The practical suitability of the developed tool for meeting needs of the control of the NPPs liquid effluents will be discussed along with the primary expected challenges.

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Oral Sessions | Friday, July 12th 2024

F-AP10 Multicomponent nanoscintillators in radiotherapy and Alzheimer's disease treatment

Irene Villa[1], Valeria Secchi[1,3], M. Campione[2,3], S. Rahimipour[4], Angelo Monguzzi[1,3]

[1]Dept. Materials Science, University of Milano-Bicocca, 20125 Milano, Italy
[2]Dept. Earth and Environmental Sciences, University of Milano-Bicocca, 20126 Milano, Italy
[3]NANOMIB BioNanoMedicine Center (https://nanomedicine.unimib.it/)
[4]Department of Chemistry Bar-Ilan University Ramat-Gan 5290002, Israel

Corresponding Author Email: irene.villa@unimib.it

In the last decade, multicomponent nanomaterials (MNs) - consisting of dense scintillating nanoparticles grafted by conjugated photosensitizers (PSs) generating cytotoxic singlet oxygen (SO) species - have been proposed as sensitizers agents for radiotherapy (RT) of cancer and mortal diseases upon X-ray irradiation. [1] Notably, the beneficial activity of these agents is prominent at delivered doses lower than those ones employed in standard protocols.

One fascinating MN is represented by hydrated magnesium silicate scintillating nanotubes (NTs) prepared by hydrothermal synthesis, which show biocompatibility and blood-brain barrier- permeability. Moreover, the outer surface of NTs is brucitic and with a positive Z-potential. This property allows to bind to the surface a variety of negatively charged SO PSs. Here, we present the case of NT grafted by porphyrin moieties, whose efficiency as a coadjutant for RT has been tested *in vitro*, showing a striking efficacy in enhancing both the prompt cytotoxicity of the ionizing radiation and the long-term cytotoxicity given by radiation-activated apoptosis. Another recent outstanding result has been obtained by functionalizing the surface of NT by Chlorin e6 to develop specific drugs for the cure of Alzheimer's disease. Indeed, in this configuration and upon X-rays, the MNs interact selectively with Aβ oligomers - the neurotoxic species in Alzheimer's disease – and inhibit their formation. The reduction of the levels of Aβ oligomers enables to restore functional symptoms in transgenic C. elegans models. [2-3]

Despite the encouraging results in clinics, the mechanism of matter-ionizing radiation interaction in MNs during RT protocols is debated, especially concerning the energy partitioning process - involving non-radiative energy transfer between nanoscintillators and PSs and the capability of MN to harvest the ionizing radiation - considered to be responsible for SO production and so pivotal to the therapeutic effect. Thus, we have investigated the SO enhancement and energy partition in MNs from the point of view of physics in a series of Rhodamine Red C2 functionalized scintillating NT, where the non-radiative energy transfer yield has been tuned by the control of the NT-PS intermolecular distance. Our findings indicate that non-radiative energy transfer has a negligible effect on SO sensitization efficiency, thus opening the way to the development of a variety of architectures for innovative RT coadjutants to be tested in clinics. [4]

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2. I. Villa, "Functionalized Scintillating Nanotubes for Simultaneous Radio- and Photodynamic Therapy of Cancer", ACS Applied Materials & Interfaces, 13 (11) (2021)

3. S. Senapati, "Noninvasive Treatment of Alzheimer's Disease with Scintillating Nanotubes"
Adv. Healthcare Mater, 12(32), 2301527 (2023)

4. V. Secchi, "Energy Partitioning in Multicomponent Nanoscintillators for Enhanced Localized Radiotherapy", ACS Appl. Mater. Interfaces, 15 (2023)

Acknowledgments: This work has been supported by MAECI X-PATH 2020-H45H19000070001, by RF-2016-02362263 Nano Track EXO, by WF-MSCA HANSOME 101003405 and by the OP RDE (SOLID21 CZ.02.1.01/0.0/0.0/16_019/0000760).

Oral Sessions | Friday, July 12th 2024

SESSION 16: APPLICATIONS OF SCINTILLATORS (PART 4)

F-AP11 Potential of radioluminescence for phototherapy in the treatment of Parkinson's disease

I. Muñoz Velasco[1], S. Sousa Nobre[3], O. Renard[3], S. Garcia-Argote[2], P. Colonna[2], S. Feuillastre[2], P. Reiss[4], G. Pieters[2], P. Bleuet[1]

[1]Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France
[2]SCBM, DMTS, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[3]Univ.Grenoble Alpes, CEA, Liten, F-38000 Grenoble, France
[4]Univ. Grenoble Alpes, CEA, CNRS, Grenoble INP, IRIG, SyMMES, F-38000 Grenoble, France

Corresponding Author Email: irene.munozvelasco@cea.fr

Photobiomodulation is a promising technique aiming at slowing down neurodegeneration by illuminating a specific brain region depending on the neurodegenerative disease. Clinatec is currently conducting the first clinical trial with 4 patients, suffering from Parkinson's disease, implanted with an intracerebral optical fiber emitting light at 670 nm wavelength [1].

In this context, a RadioLuminescent (RL) device based on luminescent materials excited by the beta- decay of tritium is of high interest by being less invasive, proposing potentially more efficient light delivery to tissue due to its compactness and ability to produce diffuse light, and with greater energy autonomy for patient comfort.

Several strategies for coupling tritium with luminescent materials are documented, including the use of tritium-gas [2], tritiated water [3] or a solid tritiated matrix [4,5].

In this presentation, we will show quantitative results on the development of a millimeter-sized RL device in which tritium beta-decay excites luminescent materials. The adopted strategy is based on an organic matrix serving as both tritium and luminescent material reservoir. Cylindrical samples made of either silica or cellulose aerogels have been fabricated and characterized. For light emission, red-emitting luminophores and quantum dots such as $Y2O_3$:Eu, YVO_4:Eu and $AgInS_2$ have been selected and their optical properties characterized using photoluminescence, cathodoluminescence, quantum yield measurements, x-rays tomography and BET surface area analysis. Samples were placed within an integrating sphere and exposed to tritium-gas atmosphere (from 0.2 to 1.2 bars), allowing us to quantify their optical performance while varying the tritium pressure. Our findings suggest a direct dependence between the optical power and tritium pressure as well as a potential mechanism for trapping tritium atoms in micrometer-sized luminescent materials. On top of that, we could correlate the brightness to the concentration and material composition. This ongoing work holds promise for developing self-powered luminescent devices for optimized phototherapy in clinical applications.

1. Moro, C. et al., "No evidence for toxicity after long-term photobiomodulation in normal non- human primates", Exp Brain Res, 235, 3081–3092 (2017) + Clinical Trial, Identifier: NCT04261569.

2. A. Korin et al., "Parameters affecting the intensity of light sources powered by tritium", Nuclear Instruments and Methods, 130, 1, 231-237 (1975).

3. Hara M. et al, "Tritium Counting Using a Europium Coordination Complex", Fusion Science and Technology, 71, 496-500 (2017).

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5. Marco, L. et al., "Nanocatalyzed Hydrogen Isotope Exchange", Accounts of Chemical Research, 54, 6, 1465-1480 (2021).

F-AP12 An overview of the CMS High Granularity Calorimeter and its current status

Rajdeep Mohan Chatterjee[1] on behalf of the CMS HGCAL Collaboration

[1]Tata Institute of Fundamental Research: Organization, Mumbai, Maharashtra, India

Corresponding Author Email: rchatter@cern.ch

The CMS Collaboration is preparing to replace its current endcap calorimeters for the HL-LHC era with a high-granularity calorimeter (HGCAL), featuring a previously unrealized transverse and longitudinal segmentation, for both the electromagnetic and hadronic compartments, with 5D information (space-time-energy) read out. The proposed design uses silicon sensors for the electromagnetic section and high- irradiation regions of the hadronic section , while in the low-irradiation regions of the hadronic section plastic scintillator tiles equipped with on-tile silicon photomultipliers (SiPMs) are used. The full HGCAL will have approximately 6 million silicon sensor channels and about 240 thousand channels of scintillator tiles.

In this talk we present the ideas behind the HGCAL, the current status of the project, the lessons that have been learnt, in particular from beam tests as well as the design and operation of vertical test systems and the challenges that lie ahead.

F-AP13 Multi-energy imaging of SiPM-based photon-counting CT using Ce:YGAG scintillators compared with clinical dual-energy CT

Daichi Sato[1], M. Arimoto[1, 2], K. Yoshiura[1], F. Lucyana[1], T. Tomoda[1], H. Kawashima[1], S. Kobayashi[1], J. Kataoka[2], S. Terazawa[3], S. Shiota[3], and S. Kurosawa[4].

[1]*Kanazawa University: Kakuma, Kanazawa, Ishikawa, Japan*
[2]*Waseda University: Ohkubo, Shinjuku, Tokyo, Japan*
[3]*Proterial, Ltd.: Shimamotocho, Mishima, Osaka, Japan*
[4]*Tohoku University: Katahira, Sendai, Miyagi, Japan*

Corresponding Author Email: dsato1083552@stu.kanazawa-u.ac.jp

Cisplatin and other platinum-based drugs are widely used as anticancer agents, but their side effects are serious, e.g., damage to the various organs, and therefore these administrations must be well controlled. This is because anticancer agents accumulate not only in tumors but also in normal tissues, thereby disrupting physiological functions. However, it is not clear how much anticancer agents actually accumulate and affect normal tissues or tumors. In addition, it is difficult to nondestructively determine the spatial distribution of anticancer agents administered in vivo throughout the body. Therefore, we propose to solve this problem by a new imaging technique using photon-counting computed tomography (PC-CT), which has attracted much attention in recent years [1].

PC-CT is an X-ray CT equipped with a PC detector. It can acquire energy information of individual incident X- rays. Therefore, it is possible to estimate and visualize the spatial distribution of the concentration of contrast agents. We have previously established a silicon photomultiplier (SiPM) based PC-CT system equipped with Ce:YGAG scintillators (Proterial, Ltd.), which is a low-cost alternative, and demonstrated its imaging performance when iodine contrast agent is administered in vivo [2]. Therefore, the development of a new platinum-based anticancer agent marked with iodine and the visualization of the spatial distribution of platinum and iodine is expected to provide a new diagnostic standard for evaluating the efficacy and toxicity of anticancer agents.

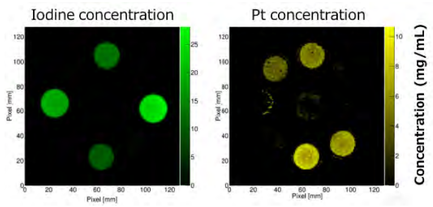

Figure 1. Results of CT imaging using our PC-CT. Iodine and platinum concentrations were successfully estimated and mapped. Left: Iodine concentration map. Right: Pt concentration map.

In this presentation, we report on the visualization of contrast agents mixed with iodine and platinum using our established PC-CT, which was conducted as a basic study for the above concept. Solutions of iodine and platinum mixed in various proportions were prepared as subjects, and CT imaging was performed. As a result of image analysis, we succeeded in discriminating and visualizing iodine and platinum, respectively (Fig. 1). In addition, similar measurements were performed with a conventional clinical CT system. This study is presented in comparison with these results.

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2. D. Sato et al., "Initial results of in vivo CT imaging of contrast agents using MPPC-based photon-counting CT," Nucl. Instr. and Meth. A, 1048, 167960 (2023).

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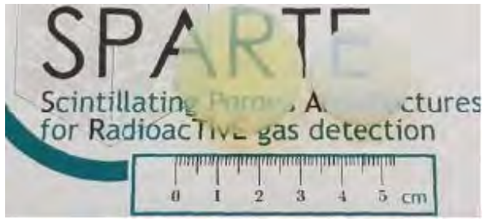
F-AP14 Nanoparticle-based Scintillating Aerogels for Real-time Radioactive Gas Detection

Yannis Cheref[1,2,*] Raphaël Marie-Luce[1], Pavlo Mai[2], Frédéric Lerouge[1], Sylvie Pierre[3], Benoit Sabot[3], Frédéric Chaput[1], Christophe Dujardin[2,4]

[1] *Laboratoire de Chimie, Ecole Normale Supérieure de Lyon, Université Claude Bernard Lyon 1, CNRS, UMR 5182, Lyon, France*
[2] *ILM, Université Claude Bernard Lyon 1, CNRS, UMR 5306, Villeurbanne, France*
[3] *LIST, Laboratoire National Henri Becquerel, Université Paris-Saclay, CEA, Palaiseau, France*
[4] *Institut Universitaire de France (IUF)*

Corresponding Author Email: yannis.cheref@ens-lyon.fr

The measurement of pure β emitting radioactive gases such as 3H and 85Kr is already of major importance for the nuclear safety authorities, and will meet an increasing demand with the expansion of nuclear-based energy production. Due to the short penetration length of β electrons in air, gaseous β emitters must be mixed with radiosensitive elements to enable detection. These are either gas-gas mixtures in an ionization chamber, or gas-liquid mixtures in liquid scintillation. However, none of these existing methods combine real-time analysis, sensitivity to multiple gases, and ease of deployment for on-site measurements.



Aerogels before (left, Ce3+:YAG, yellow sample) and after (right, Ce4+:YAG, white sample) thermal treatment

We demonstrate a new gas-solid mixture approach using inorganic aerogels as nanoporous scintillators. This method combines the above criteria, allowing efficient real-time measurement of 3H and 85Kr activity. This presentation will focus on the preparation of scintillating aerogels, from the 10g-scale synthesis of scintillating nanoparticles to supercritical drying of nanoparticle gels into aerogels. This preparation method has been successfully applied to different scintillating nanomaterials.

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Poster Sessions

Poster Sessions | Summary

APPLICATIONS OF SCINTILLATORS: FUNDAMENTAL RESEARCH, HEALTH, ENVIRONMENT, ENERGY, METROLOGY, INDUSTRIAL CONTROLS

AP15 Application of Airborne Gamma-Ray Spectrometry Using a $LaBr_3$(Ce) Scintillation Detector to the Assessment of Radioactive Cesium Deposition

Young-Yong JI[1], Eunjoong LEE[1], Kotaro OCHI[2], Miyuki SASAKI[2], Sungyeop JOUNG[1], Wanook JI[1], and Yukihisa SANADA[2]

[1]*Korea Atomic Energy Research Institute, Daejeon, Republic of Korea*
[2]*Japan Atomic Energy Agency, Fukushima, Japan*

Corresponding Author Email: yyji@kaeri.re.kr

Airborne gamma-ray spectrometry using a UAV (Unmanned Aerial Vehicle) was conducted to detect and assess radioactive materials and their deposition in the wide area. Especially, the mapping of radioactive contamination from airborne survey has been periodically made around the FDNPP (Fukushima Daiichi Nuclear Power Plants) by JAEA (Japan Atomic Energy Agency) for the purpose of emergency response in the recovery phase. The application of UAV platforms to the radioactive detection and assessment is now available in diverse fields, such as nuclear decommissioning, environmental remediation, and homeland security.

MARK-M1 (Monitoring of Ambient Radiation of KAERI – Multipurpose system #1) has two 2φ"x2" $LaBr_3$(Ce) scintillators for airborne gamma-ray spectrometry[1]. The global positioning system (GPS) and laser altimeter were mounted to signal processing unit of $LaBr_3$(Ce) detectors for recording measured energy spectra depending on the 3D location coordination. Counting periods were then selected according to the flight speed at intervals of every single second. The data interface was directly made by Bluetooth between airborne survey system and control PC on the ground. This airborne survey system has a total weight of below 6 kg including two $LaBr_3$(Ce) scintillators and battery pack.

Fig.1. Airborne survey system based on two $LaBr_3$(Ce) scintillators of KAERI (UAV: JAEA)

The airborne survey was performed in the widely contaminated area around the FDNPP for the performance test of MARK-M1 to assess radioactive cesium deposition in the ground. Ambient dose rates were calculated from measured energy spectra every 2 sec counting period. All survey results were then converted into ambient dose rates at 1 m above the ground by the attenuation correction factor. Three different flight speeds during the airborne survey were applied for the performance in assessing the radioactive cesium deposition according to the variation of FOV (Field-of-view) of two $LaBr_3$(Ce) detectors. Finally, the performance of airborne survey using $LaBr_3$(Ce) detectors was verified by comparing results with ground-based gamma-ray spectrometry around the survey area.

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Acknowledgments

This work was performed under the auspices of the Ministry of Science and ICT (MICT) of Korea, NRF contract number RS-2022-00144210. The Korean participants gratefully acknowledge the valuable help from the staff of the Fukushima Remote Monitoring Group at JAEA during the joint experiment around the FDNPP between JAEA and KAERI.

AP16 Heat Management in Scintillators under High X-ray Flux

K. Pauwels[1], A. Rack[1], T. Martin[1], S. Jarjayes[1], B. Lukic[1], C. Munoz-Pequeno[1], D. Dallé[1] and D. Baboulin[1]

[1]*ESRF – The European Synchrotron, Grenoble, France*

Corresponding Author Email: pauwels@esrf.fr

Single-crystal scintillators are widely used for high-resolution X-ray imaging at synchrotrons. The scintillation light is collected by a set of optical lenses forming a versatile indirect detector requirements ideally suited for X-ray micro-imaging at synchrotron beamlines. As compared to direct detectors or flat panels, this method is based on visible-light microscopy optics and CMOS scientific cameras. It provides a wide range of field-of-view and excellent spatial resolving power, down to sub-micrometer resolution. Scintillator-based X-ray detectors also benefit from a very high resistance to radiation damage. More and more challenging synchrotron applications now require the study of dynamic phenomena at fast and ultra-fast time scales. Examples of such applications are fuel injection and sprays, shock-wave propagation, additive manufacturing and metallic foam formation [1]. For these applications, short exposure times (down to 100ns) are essential if data is to be recorded without detectable motion blur. This in turn requires a very bright scintillation signal, short decay time and very intense X-ray beams. However, the extreme level of energy absorbed by the scintillator under such conditions generates a significant source of heat. This very quickly translates into drastic increases of the temperature since single crystals with small dimensions and rather poor thermal conductance are often selected as scintillators. This excess of heat endangers the lifetime and stability of the scintillator (e.g. cracking, dust incorporation). It also affects its performances and thereby it may be needed to reconsider the material selection criteria. As a complement to earlier work [2,3], we review here the effect of the temperature on the performances of a set of scintillators. Experimental data is presented including light output and timing characteristics acquired over a range of heatload conditions. Additionally, we present a new detector assembly able to distribute the excess of heat while preserving the performances. This proof-of-concept was tested experimentally and compared to typical state-of-the-art detector assemblies. With the scheduled upgrades of the synchrotron light sources, and the ever increasing X-ray flux, solutions like the one proposed here become crucial to fully exploit the potential of extremely bright photon sources.

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Poster Sessions

AP17 Discrimination of Spontaneous Fission Neutrons using Single Crystal Based Scintillator

Mohit Tyagi[1,2] ,Sonu[1,2], R.G Thomas[3], A. Kelkar[4], D.G. Parulekar[5] , A. Kumar[6] and R.Tripathi[2,6]

[1]Technical Physics Division, BARC Mumbai, India
[2]Homi Bhabha National Institute, HBNI, Mumbai, India
[3]Nuclear Physics Division, BARC, Mumbai,India
[4]Nuclear Recycle Board, BARC, Tarapur, India
[5]Technology Development Division,BARC,Mumbai,India
[6]Radiochemistry Division, BARC, Mumbai, India

Corresponding Author Email: tyagi@barc.gov.in

In case of spontaneous fission of neutron, the number of events or time interval between events follows an exponential dependence which is used to discriminate these with random neutrons from background or from (α, n) nuclear reactions. Neutron well counter based on multiple He^3 detectors is widely used for accurate assaying of Pu isotopes having spontaneous fission. This work presents the discrimination of spontaneous fission neutrons from random generated neutrons using a versatile $Gd_3Ga_3Al_2O_{12}$+CsI phoswich detector. Thermal neutrons were detected and discriminated in GGAG single crystal using PSD method [1]. The discrimination of fission neutrons is done based on the time histogram by plotting distribution of the time intervals between detected fission neutron events, which is basically called Rossi-alpha distribution and follows a mono-exponential function. After fitting the amplitude of the exponential, a linear calibration plot was established to assess the unknown amount. The experimental setup along with GEANT4 simulations will be presented in details.

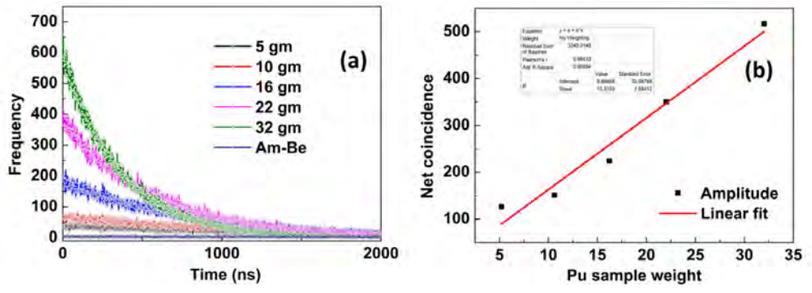

Fig.1 (a) Rossi-alpha distribution plot of different amount of PuO2 sources (b) Linearity of correlated neutrons with PuO2 amount.

Fig.1 (a) Shows the Rossi-alpha distribution of the timestamp events from different amount of PuO_2 sources. The distribution shows the increase of intensity of correlated as well as uncorrelated neutrons measured with GGAG using different amount of PuO_2 after applying PSD cut from PSD value 0.1 to 0.4 and energy cut from 400 to 1500 channels to use filtered timestamps events only for plot rossi- alpha distribution.

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AP18 Resolution study of Compton imaging using different size scintillation detectors

Sen Yang[1], Haonan Li[1], Ning Ren[1], Yongfeng Yang[1] and Zheng Liu[1]

[1] *Paul C. Lauterbur Research Center for Biomedical Imaging, Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China*

Corresponding Author Email: zheng.liu@siat.ac.cn

Compton camera generates image by using the positions and energies measured by the scatter and absorb detectors according to the Compton scattering kinetics [1]. Compared to the traditional single photon emission computed tomography, Compton camera has a potential of achieving higher sensitivity for radionuclides that emit γ rays. Two major factors that affect the imaging quality of a Compton camera are the detector performance and image reconstruction method [2]. In this work, we developed a prototype Compton camera by using a gadolinium aluminum gallium garnet (GAGG) scintillator array read out by a SiPM array as the scatter detector and an lutetium yttrium orthosilicate (LYSO) scintillator array dual-ended read out by SiPM arrays as the absorb detector. GAGG detector can achieve ultra-high spatial resolution and good energy resolution that are required for scatter detector of a Compton camera due to its high light output.

The absorb detector consists of a 23×23 LYSO crystal array with a crystal size of 1×1×20 mm^3 dual-ended read out by an 8×8 SiPM array with a pixel size of 3×3 mm^2. Three size GAGG crystals were used for building three different scatters for comparison the performance of the Compton image quality. The first scatter detector consists of a 42×42 GAGG crystal array with a crystal size of 0.35×0.35×2 mm^3 single-ended read out by an 8×8 SiPM array with a pixel size of 2×2 mm^2. 0.3 mm crystals are used to provide an ultra-high spatial resolution It provides a high 3D spatial resolution. The second scatter detector consists of a 21×21 GAGG crystal array with a crystal size of 0.6×0.6×2 mm^3 with the same readout as first scatter detector. The third scatter detector consists of a 8×8 GAGG crystal array with a crystal size of 1.95×1.95×2 mm^3, which the energy resolution is better but lower position resolution. NIM electronics and a data acquisition developed in our lab are used in this work. Fig 1 shows the flood histograms of the three scatter detectors with different GAGG crystal sizes.

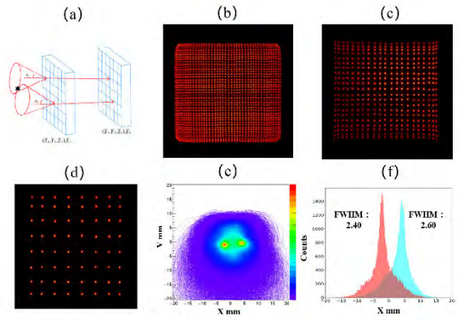

Figure 1, (a) The principle of Compton camera, (b-d) Flood histograms of the three size scatters: 0.3×0.3×2 mm3, 0.6×0.6×2 mm3, 1.95×1.95×2 mm3 (e-d) Images and the X profile of the point source placed the two positions.

A prototype Compton camera consisting of an ultra-high spatial resolution scatter detector and a high 3D spatial resolution absorb detector was built. An image reconstruction algorithm combing the back- projection and MLEM algorithms was developed and tested by using Monte Carlo simulation data and experiment data. The spatial resolution and image performance of the prototype Compton camera using different size of GAGG crystals for scatter were evaluated and studied in this work.

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2. Frandes M, Magnin IE, Prost R. Wavelet Thresholding-Based Denoising Method of List-Mode MLEM Algorithm for Compton Imaging. IEEE Trans Nucl Sci. 2011;58(3):714-23.

Acknowledgments

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Poster Sessions

AP19 The Response of 3D Imaging BGO Calorimeter of DAMPE to TeV e^+/e^- in space

Cong Zhao[1,2]

[1]State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, Anhui, China
[2] Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui, China

Corresponding Author Email: zhaoc@mail.ustc.edu.cn

The DArk Matter Particle Explorer (DAMPE) is a space-borne experiment that indirectly searches for dark matter by measuring the high-energy cosmic ray electrons/positrons (CREs) and gamma rays. The key sub-detector of DAMPE is the Electromagnetic CALorimeter (ECAL), which is designed for precise energy measurement with a large dynamic range from 5 GeV to 10 TeV. The ECAL consists of 308 Bismuth Germanium Oxide (BGO) crystals with dimensions of 2.5 cm ×25 cm ×60 cm. Since its launch at the end of 2015, DAMPE has been operating smoothly for over 8 years, getting a significant dataset of CREs exceeding TeV energies. In this work, we study the behavior of CREs beyond TeV energies in the BGO calorimeter, focusing on their high-energy electromagnetic shower development, including the lateral shower shape and the longitudinal shower shape. We also demonstrate the study of the e/p separation capability beyond TeV energy range using shower development, which plays a major role in the DAMPE experiment to measure the cosmic ray electron flux accurately.

AP20 Measurement of Cross Sections of Cosmic Ray Carbon and Oxygen on BGO from GeV to TeV at the DAMPE Experiment

Enheng Xu[1,2]

[1]State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, Anhui, China
[2] Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui, China

Corresponding Author Email: jingbosun@mail.ustc.edu.cn

The Bismuth Germanium Oxide (BGO) calorimeter of Dark Matter Particle Explorer (DAMPE) is responsible for measuring the energy of heavy cosmic rays in orbit. To investigate and gain crucial insights into the acceleration processes of carbon and oxygen in the Milky-Way galaxy, as well as to determine accurate measurements of cosmic-ray nuclei fluxes, study has been carried out on the inelastic hadronic cross section of their interaction with BGO crystals. In this study, we investigate the inelastic hadronic interaction cross sections of carbon and oxygen nuclei on the BGO calorimeter target, employing the DAMPE experimental data and the survival probability method over a wide energy range spanning from several GeV to TeV. Furthermore, we compare the experimental results with simulations generated with the Geant4 and FLUKA toolkits. This study offers a comprehensive account of the measured inelastic hadronic interaction cross sections, accompanied by in-depth discussions, thereby advancing our understanding of the nature of BGO crystals and the characteristics of hadronic interactions.

Poster Sessions

AP21 Upgrade of the high voltage system for the Avalanche Photodiodes of the CMS ECAL for the High Luminosity phase of the LHC

Federica De Riggi[1,2] on behalf of the CMS Collaboration

[1]Sapienza Università di Roma: Roma, Italy
[2]INFN, Sezione di Roma, Roma, Italy

Corresponding Author Email: federica.de.riggi@cern.ch

The electromagnetic calorimeter (ECAL) of the CMS experiment at the Large Hadron Collider is a homogeneous calorimeter made of about 75000 lead tungstate crystals. The scintillation light is detected by avalanche photodiodes (APD) in the Barrel and vacuum phototriodes in the Endcaps. Thanks to the excellent resolution for high energy electrons and photons, the ECAL has allowed to observe the Higgs boson in its two-photon decay and it has allowed CMS to publish many physics measurements. For the high luminosity phase of the LHC, due to the more intense radiation levels, the Endcap calorimeter will be replaced, while the Barrel crystals and photo-detectors will be preserved. The Barrel front-end and off-detector electronics will be replaced and the temperature of the detector will be lowered by about 10 degrees C. Although nowadays other types of photo- detectors exist which have larger gain, the avalanche photodiodes are still considered a good choice for reading the light of scintillating crystals at collider experiments, providing high compactness, insensitivity to magnetic field, an internal amplification, excellent linearity and good radiation hardness. One of the drawbacks of the APDs is the challenging requirement on the stability of the high voltage source. Indeed, for the CMS ECAL APDs, which are operated at a gain of 50, the variation of the gain as a function of the voltage is 3%/V. The excellent ECAL energy resolution is ensured thanks to the achieved stability of high voltage, temperature and crystal transparency monitoring, whose individual contribution are required to not exceed 0.2%. Therefore the high voltage system stability must be within 60 mV during a period of one month, the typical period over which calibration of the crystals with physics channels can be performed. The legacy high voltage system was developed by CAEN s.p.a. and it is based on the board A1520PE. Each board hosts 9 HV channels, which provide a voltage up to 500 V and a maximum current of 15 mA. Fifty ECAL crystals are connected to one HV channel. The APDs were sorted during the construction to have similar HV working point within a HV channel. The system has provided excellent stability and reliability. The APDs are silicon devices and therefore are subject to radiation damage and particularly their leakage current will increase as much as 10 times the present value. Therefore, a new HV system has been developed, based on the new CAEN board A7420, with maximum voltage of 600 V and maximum current of 20 mA. Stability tests were performed on these new HV boards, as well as noise measurement, using prototypes of the front-end electronics mounted on a spare ECAL supermodule. The poster will show the performance of the new HV system.

AP22 High Radiation Tolerance of Ce-Doped Garnets and Their Applications

O. Zapadlik[1,2,3], A. Beitlerová[1], M. Nikl[1]

[1] Institute of Physics of the Czech Academy of Sciences, Cukrovarnická 10/112, 162 00 Prague 6, Czech Republic.
[2] Faculty of Nuclear Sciences and Physical Engineering, The Czech Technical University, Břehová 78/7, Prague, 115 19, Czech Republic
[3] Crytur Ltd., Na Lukách 2283, 511 01 Turnov, Czech Republic.

Corresponding Author Email: Zapadlik@crytur.cz

Cerium-doped garnet scintillators are widely used in various radiation detection applications, and understanding their resistance to ionizing radiation is crucial for many of them, e.g. in high energy calorimetry [1], [2]. In this study we evaluate the radiation tolerance of several commercially available garnet scintillators produced by the Crytur company [3] after 1.2 MGy gamma irradiation. The radiation-induced absorption characteristics are reported and discussed.

The experimental findings show the remarkable radiation resilience of Ce-doped garnet scintillators, with nearly no degradation in transmittance and absorption spectra after irradiation. Moreover, we highlight the versatility of these scintillators for diverse applications such as medical imaging and nuclear physics, owing to their robustness and consistent performance under gamma irradiation.

The study provides valuable insights into both the radiation tolerance and the application prospects of Ce-doped garnet scintillators, contributing to their wider adoption in radiation detection and imaging technologies.

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Poster Sessions

AP23 The CMS ECAL upgrade for the High-Luminosity LHC

Chiara Basile[1,2] On behalf of the CMS Collaboration

[1]*Sapienza Università di Roma, Rome, Italy*
[2]*INFN - Sezione di Roma, Rome, Italy*

Corresponding Author Email: chiara.basile@cern.ch

The High Luminosity upgrade of the CERN LHC (HL-LHC) will deliver unprecedented instantaneous and integrated luminosities to the detectors, and an average of up to 200 simultaneous interactions per bunch crossing is expected. The CMS detector is undergoing an extensive Phase-2 upgrade program to prepare for these severe conditions and a major upgrade of the electromagnetic calorimeter (ECAL) is foreseen. While a new detector will be installed in the endcap regions, the ECAL barrel lead tungstate crystals and photo detectors are expected to sustain the new conditions. However, the entire readout and trigger electronics system will need to be replaced to cope with the challenging HL-LHC environment and increased trigger latency requirements. Each of the 61,200 ECAL barrel crystals will be read out by two custom ASICs providing signal amplification with two gains, ADC with 160 MHz sampling rate, and lossless data compression for the transmission of all channel data to the off-detector electronics. Trigger primitive generation by updated reconstruction algorithms as well as data acquisition will be implemented on powerful FPGA processors boards. The upgrade of the ECAL electronics will allow to maintain the excellent energy resolution of the detector and, in addition, to greatly improve the time resolution of electrons and photons above 10 GeV, down to a few tens of picoseconds. This talk will present the design and status of the individual components of the upgraded ECAL barrel detector, and the results of energy and time resolution measurements with a full readout chain prototype system in recent test beam campaigns at the CERN SPS. The estimated impact on some of the CMS benchmark physics analyses will be also presented.

AP24 Characterization of high-performance LYSO-based scintillator arrays for PET using Low-Noise High-Frequency electronics

Elena Tribbia[1,2], Giulia Terragni[1,3], Joshua W. Cates[4], Marco Paganoni[2], Marco Pizzichemi[1,2], Etiennette Auffray[1]

[1]*CERN, Geneva, Switzerland,*
[2]*University of Milano-Bicocca, Italy*
[3]*Technical University of Vienna, Austria,*
[4]*Lawrence Berkeley National Laboratory, CA, USA*

Corresponding Author Email: elena.tribbia@cern.ch

Achieving excellent coincidence time resolution is essential in time-of-flight positron emission tomography (TOF-PET) for increasing signal-to-noise ratio and image quality. High-frequency (HF) front-end electronics have demonstrated improved time resolution as they enable the use of the fastest photons, such as Cherenkov emission and fast scintillation, by lowering the leading-edge detection threshold. Allowing to optimally exploit fast light production mechanisms in crystals, HF electronics offer an interesting solution to enhance the performance of TOF-PET systems.

We present the steps towards the integration of a 16-channel low-power low-noise high-frequency readout electronics with fast discriminators in a multi-channel setup. We tested the performance of the multi-channel HF readout using a detector module made of a matrix of 4x4 LYSO:Ce polished crystals 3.1x3.1x15 mm^3 in size, optically coupled to an array of MT SiPMs. A coincidence time resolution (CTR) value of 124 ps full width at half maximum (FWHM) was achieved, which represents a significant improvement with respect to the 158 ps FWHM obtained with the same pixelated crystal module, an Hamamatsu SiPM array and a custom-made multi-channel front-end electronic board (FEB) based on the NINO chip.

In addition, the extraction of the gammas depth-of-interaction (DOI) information is crucial to correct for the DOI-induced bias in timing in long crystals, as well as for reducing parallax error. In this regard, we applied the multi-channel HF readout to a module with DOI capability based on a light-sharing and recirculation mechanism in single-side readout, demonstrating improved timing capabilities using the DOI information.

This work is carried out in the framework of the Crystal Clear Collaboration and supported by CERN Austrian Doctoral Programme and Knowledge Transfer budget. The development of the readout boards was supported by the National Institute of Biomedical Imaging and Bioengineering under award 5TR01EB028286.

AP25 Innovative dual-NaI(Tl) device for determination of ambient dose equivalent with spatial distribution recognition of airborne radioactivity

Michal Fejgl[1], Miroslav Hýža[1], Karin Fantínová[1]

[1] SÚRO, v.v.i., Bartoškova 28, Praha 4, 140 00, Czech Republic,

Corresponding Author Email: michal.fejgl@suro.cz

The presented contribution describes a newly developed Gamma dose rate monitor with enhanced capabilities concerning distinguishing of gamma emitting radionuclides and their spatial distribution. Such capability would be beneficial in case of Emergency situation as it would be able to bring information of contamination plum migration.

There is an early warning network (EWN) in operation in Europe comprising over 4500 stations (1) performing real-time measurements of gamma dose rate. The measurements are performed in normalized conditions at height of 1 meter over the ground level. Measuring output is converted to ambient dose equivalent rate (1).

Most of the stations are equipped by two Geiger-Mueller tubes (GM) of different sensitivity to cover a large range of ambient dose rate between 20 nSv h^{-1} and 5 Sv h^{-1} (1, 2).

Conversion of GM output to ambient dose equivalent rate is well mastered (1), nevertheless relevance of conversion can be biased by fluctuations in the representation of individual radiation components. Therefore, some of the countries with well developed EWN as Germany or the Netherlands enhance the monitoring network by deploying monitoring stations equipped with scintillation detectors. Combining the outputs of both detector types, thanks to their different sensitivities to particular types of radiation, can result in a balanced response to each component of the radiation field (3).

The primary mission of the presented device comprising both scintillation and GM detectors is different. As there haven't been any accidental atmospheric releases of radioactivity, which would trigger alarms in the EWN, the functionality of EWN monitoring stations in conditions of area contamination has not yet been proven.

Accidental scenario under which they would be paralyzed is quite likely, e.g. ground deposition of atmospheric contamination, monitoring results would bring only vague data and their interpretation would be misleading than.

An innovative concept of gamma dose rate monitoring unit was developed with ambition to cope with this issue. The information which is going to be gained is not only gamma dose rate, but also activity of the particular gamma emitting radionuclides and distinguishing their origin – whether the corresponding signal comes from the ground deposition or from the radioactive cloud.

The measurement setup uses two NaI(Tl) detectors, collimated and separated by lead shielding, to distinguish between soil and airborne contamination. However, despite this distinction, there are challenges associated with the deposition of contamination on the surface of the probe. To address this, an additional set of shielded GM detectors has been introduced to assess the contribution of surface contamination, thereby enhancing the analysis and aiding interpretation.

In the contribution the expected detection response of the simulated scenario will be presented in comparison with the detection response recorded by the experimental measurements with gamma emitting radioactive sources. The expected benefits of the developed device for needs of the emergency preparedness system will be summarized.

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Poster Sessions

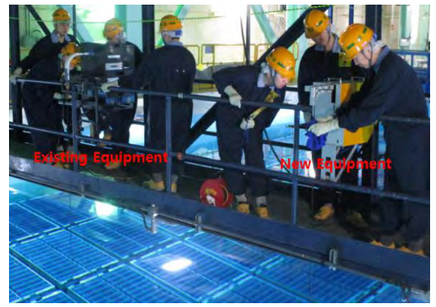
AP26 Investigating the need for a secondary optical fiber radiation sensor in eliminating background radiation signals in high radiation environments

Sung-Woo Kwak[1], Hojik Kim[1], Woojin Kim[1], Yongkwon Kim[2]

[1]Korea Institute of Nuclear Nonproliferation and Control, Daejeon, Republic of Korea
[2]Nucare, Inc., Cheongju, Chungcheongbuck-do, Republic of Korea

Corresponding Author Email: swkwak@kinac.re.kr

Since 2007, the International Atomic Energy Agency (IAEA) has used the Optical Fiber Radiation Probe System (OFPS) for verifying nuclear spent fuel stored in the CANDU-type Wolsung nuclear power plant's storage pond in South Korea. This system incorporates a cerium-activated lithium glass scintillator to detect radiation from spent fuel bundles, transmitting the signal through an optical fiber to a processing unit. To improve upon the OFPS's low detection efficiency, a new instrument has been created, utilizing a p-terphenyl organic scintillator for more efficient radiation detection from the spent fuel. High radiation areas, such as spent fuel storage ponds, pose challenges for optical fiber-based radiation detectors. Techniques to mitigate background radiation noise include using a secondary optical fiber for noise subtraction and optical filters for signal discrimination. The current OFPS model applies a noise subtraction approach, which, despite reducing background radiation, results in thicker optical cables, thereby complicating the verification process of Wolsung nuclear power plant's spent fuel bundles for nuclear safeguards. This study aims to evaluate the necessity of employing a secondary optical fiber for background radiation noise subtraction. It compares the performance of the existing and newly developed instruments in measuring Wolsung's spent fuel bundles. Detailed experimental findings will be presented at a conference, potentially guiding decisions on the use of secondary optical fibers for background radiation elimination in high-radiation fields.



Field experiments were conducted at the Wolsung Nuclear Power Plant to assess the need for an additional optical fiber cable using both existing and newly developed instruments.

This research is funded by the Nuclear Safety Research Program via the Korea Foundation Of Nuclear Safety (KoFONS), with financial support from the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (Grant No. 2106016).

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Poster Sessions

AP27 Optimization of the fabrication of luminescent nanocrystalline $Ce_xLa_{1-x}F_3:Tb^{3+}$ for XPDT applications

Xenie Popovič[1], Marie Urbanová[1], Jan Bárta[1], Lenka Prouzová Procházková[1,2], Václav Čuba[1]

[1]*Department of Nuclear Chemistry, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Břehová 7, 115 19 Prague, Czech Republic*
[2]*Department of Optical Materials, Institute of Physics of the Czech Academy of Sciences, Cukrovarnická 10, Prague 162 53, Czech Republic*

Corresponding Author Email: popovkse@cvut.cz

Rare-earth (RE) doped $Ce_xLa_{1-x}F_3$ nanoparticles hold potential for applications in physics, such as scintillation detectors and dosimetry due to their specific scintillation properties [1,2]. Moreover, $Ce_xLa_{1-x}F_3$:RE nanoparticles also exhibit significant promise as sensitizers in X-ray induced photodynamic therapy (XPDT), owing to their efficient photon emission upon X-ray excitation, enabling targeted and localized therapeutic effects in medicine [3,4]. Unfortunately, the application of nanoparticles in medicine can indeed be limited by their size due to several factors. Aggregated nanoparticles pose several challenges, such as increased immunogenicity, reduced bioavailability and altered pharmacokinetics that limit their suitability for medical applications [5].

This study presents a concept for the synthesis of $Ce_xLa_{1-x}F_3:Tb^{3+}$ nanoparticles and a method to mitigate particle aggregation tailored for XPDT applications. Sol-gel synthesis was employed utilizing various solvents, producing fine nanoparticle dispersions. This synthesis was coupled with differential thermal analysis (DTA) of dried material at different temperatures and under various auxiliary gases. The prepared materials were studied using X-ray powder diffraction (XRPD) analysis, dynamic light scattering (DLS), transmission electron microscopy (TEM) imaging, and radioluminescence (RL) measurements. Our findings reveal that $Ce_xLa_{1-x}F_3:Tb^{3+}$ nanoparticles can be successfully prepared, with higher calcination temperatures yielding enhanced crystallinity. They demonstrated promising luminescent properties and maintained stability in the suspension. Moreover, distinct outcomes were observed based on the choice of reaction solvents. Furthermore, we propose a method to mitigate particle aggregation, thus enhancing their potential for XPDT applications. The results of this research contribute to the optimization of luminescent nanocrystalline $Ce_xLa_{1-x}F_3:Tb^{3+}$ fabrication for effective X-ray induced photodynamic therapy, offering a promising avenue for cancer treatment, and advancing interdisciplinary applications in medicine and physics.

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AP28 Ultra-high light yield scintillation crystal detector based on low-temperature CsI and SiPMs for CEvNS detection

Xilei Sun[1]

1Institute of High Energy Physics, CAS, Beijing, China

Corresponding Author Email: sunxl@ihep.ac.cn

The first experimental measurement of coherent elastic neutrino-nucleus scattering (CEvNS) was successfully conducted using a CsI(Na) scintillation crystal detector. Recognizing that a higher light yield in scintillation crystal detectors correlates with greater physical sensitivity for CEvNS detection, we introduced a novel low-temperature CsI detector design employing SiPMs readout. This design capitalizes on the exceptional brightness of low-temperature CsI crystals combined with the ultra- high photon detection efficiency of SiPMs, thereby significantly improving the light yield and elevating CEvNS detection sensitivity to unprecedented levels. Positioned as a formidable contender for forthcoming CEvNS experiments, this innovative approach has been substantiated by our experimental group's development of a kilogram-scale low-temperature CsI detector [1]. This detector, notable for its leading international standards in light yield and energy resolution, serves as a preliminary proof of concept for the technical feasibility of our proposed scheme. This report delineates the detector scheme's characteristics, elucidating the principal prototype's performance metrics, including light yield, energy resolution, and the influence of SiPMs noise and optical crosstalk on detector performance.

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Acknowledgments

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Poster Sessions

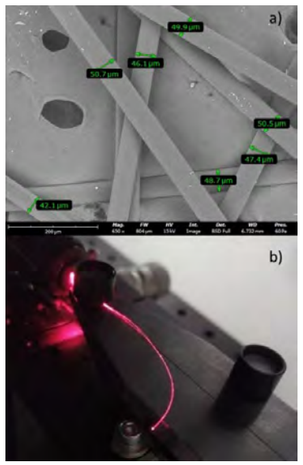
AP29 Development of Micrometric Scintillating Plastic Optical Fibers for Cutting-Edge Dosimetry

Rodrigues, C.[1,2,3], Guerreiro, D. R.[1,2], Saraiva, J. G.[1], Gonçalves, A. P.[3], Peralta, L.[1,2], Sampaio, J. M.[1,2]

[1]*Laboratório de Instrumentação e Física Experimental de Partículas (LIP), Lisbon, Portugal*
[2]*Faculdade de Ciências, Universidade de Lisboa (FCUL), Lisbon, Portugal*
[3]*Centro de Ciências e Tecnologias Nucleares (C2TN), Departamento de Engenharia e Ciências Nucleares (DECN), Instituto Superior Técnico, Universidade de Lisboa, Bobadela, Portugal*

Corresponding Author Email: cristiana@lip.pt

Since their discovery in 1965, scintillating plastic optical fibers have been used as radiation detectors in nuclear and high energy physics research [1]. This study focuses on the development micrometric scintillating plastic optical fibers (mSPOF) to be used in cutting-edge active dosimeters, offering unprecedented microscale sensitivity. Understanding the intricate effects of radiation at the micro-scale is pivotal for advancing cancer treatment strategies. To describe in detail the particle interactions and secondary particle production, there is a need for new detectors that surpass the performance of existing dosimeters, such as ionization chambers [2], microdiamond [3] and silicon [4] based dosimeters. Multiple methods for the production of mSPOFs were investigated, namely electrospinning, melt-electrospinning and fiber drawing. Polystyrene-based mSPOFs with a diameter of 10ths micrometers have been successfully produced via fiber drawing, using a custom setup. Scintillating organic compounds (TPB, POPOP, BBOT) are used to dope the mSPOFs. The mSPOF characterization regarding mechanical, optical and scintillation properties will demonstrate the usability of the freshly produced detectors.



a) Scanning electron microscope image of as- drawn polystyrene microfibers. b) Light transmission through 50 µm microfiber upon irradiation with a red laser diode (650 nm).

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AP30 Scintillating properties of YAG-based fiber optic dosimeters exposed to ultra-high dose rate electron beams

Ivan Veronese[1,2], Maria Giuseppina Bisogni[3,4], Andrea Cavalieri[5], Esther Ciarrocchi[3,4], Francesca Cova[6], Fabio Di Martino[7,8,4], Mauro Fasoli[6], Salvatore Gallo[1,2], Zhitai Jia[9], Matteo Morrocchi[3,4], Jake Harold Pensavalle[3,8], Mauro Tonelli[3], Anna Vedda[6]

[1]*Dipartimento di Fisica, Università degli Studi di Milano, Milano, Italy 2Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Milano, Italy*
[3]*Dipartimento di Fisica, Università di Pisa, Pisa, Italy*
[4]*Istituto Nazionale di Fisica Nucleare, Sezione di Pisa, Italy*
[5]*Center for Instrument Sharing of the University of Pisa (CISUP), Pisa, Italy*
[6]*Dipartimento di Scienza dei Materiali, Università di Milano-Bicocca, Milano, Italy*
[7]*Azienda Ospedaliero Universitaria Pisa (AOUP), Fisica Sanitaria, Pisa, Italy*
[8]*Centro Pisano Multidisciplinare Sulla Ricerca e Implementazione Clinica Della Flash Radiotherapy (CPFR), Pisa, Italy*
[9]*State Key Laboratory of Crystal Materials, Inst. of Crystal Materials, Shandong University, China*

Corresponding Author Email: ivan.veronese@unimi.it

FLASH radiotherapy (RT) is a potentially cutting-edge approach for the treatment of oncological diseases which relies on delivery of therapeutic doses in less than one second using ultra-high dose rates (UHDR), i.e. typically higher than 40 Gy/s. This promising RT modality requires innovative solutions for dosimetry and beam monitoring. Indeed, the well-established dosimeters currently used in conventional RT show saturation effects under UHDR regimes. In this scenario, real-time scintillation-based detectors may have a key role to play in the development of FLASH RT and in the safe and effective clinical transition.

Here we present a study of the luminescence and dosimetric properties of YAG garnets (MEGA Materials S.r.l., Italy) doped with Yb in different concentrations (50%, 60% and 80%), used to produce fiber optic dosimeters (FODs) by coupling the YAG crystals with silica optical fibers.

Spectroscopic characterization of the YAG:Yb crystals by means of photoluminescence emission and excitation measurements, as well as of radioluminescence (RL) measurements under steady state X- ray excitation, revealed the presence of the Yb^{3+} main emission in the near infrared (NIR) region due to $^2F_{5/2}$-$^2F_{7/2}$ transition, whose intensity decreases with increasing the Yb concentration. Furthermore, a progressive decrease of the emission decay time, from approximately 314 µs to 120 µs, with increasing the Yb concentration was observed, because of the concentration-quenching effect.

After assembling, the FODs prototypes were irradiated with 9 MeV electron beams produced by the accelerator ElectronFLASH EF (S.I.T. Sordina IORT Technologies S.p.A., Italy) at the CPFR at Pisa University where the RL signals were acquired in-situ by means of a compact thermoelectric cooled back-thinned CCD array spectrometer (PrimeTM X, B&WTec Inc, USA). A linear dose response of the Yb^{3+} RL signal with increasing the dose per pulse up to a value of approximately 9 Gy/pulse was observed. Such signal proved to be independent of the pulse repetition frequency in the interval 10 Hz-245 Hz. The results of RL spectral measurements performed by changing the angle between the optical fiber axis and the electron beam axis highlighted the important contribution of the stem effect due to the Cerenkov radiation originating in the portion of silica optical fiber exposed to the radiation beam. However, such contribution in the UV-VIS spectral region proved not to influence the NIR Yb^{3+} RL signal of the FODs, making thus possible its removal by optical filtering.

The overall results make YAG:Yb based FODs interesting tools for dosimetry of UHDR electron beams and call for further studies aimed to tune the concentration of the activators to tailor the dynamic range of the RL response. In parallel, considering the density and chemical composition of the YAG crystals significantly different from that of water and soft-tissue, a thorough study of the energy dependence of these dosimeters is required and currently under investigation.

AP31 Comparison of GAGG:Ce afterglow induced by proton irradiation, for detection of terrestrial gamma ray flashes (TGF) in space

Pallu M.[1,2], Pailot D.[2], Bréelle E.[2], Laurent P.[3], Carron J.[1], C. Chapron[2]

[1]French Space Agency (CNES), Toulouse, France
[2]Astroparticule et Cosmologie, CNRS, Université Paris Cité, Paris, France
[3]CEA, DSM/IRFU, Saclay, France

Corresponding Author Email: pallu@apc.in2p3.fr

Fast Gamma ray Spectrometer (FGS) [1] is a gamma ray spectrometer developed for the detection of gamma ray events in space, especially Terrestrial Gamma ray Flashes (TGFs) and Gamma Ray Bursts (GRBs). FGS will be for instance flying onboard a nanosatellite constellation (see Figure) to detect TGFs and GRBs. TGF being fast (< 100 µs) and intense events (~1 ph/cm2 at ~500 km altitude) [2,3], FGS has to reach high performances, including a detection energy range of 20 keV – 20 MeV and a count rate up to 1 ph/5 µs. To reach those performances, we have chosen to use GaGG:Ce scintillators, that are fast, dense, and non-hygroscopic, associated with Silicon Photo-Multipliers (SiPMs) and electronics using a fast ASIC. A phenomenon of luminescence, called "afterglow" [4], has been observed with those scintillators, implying a pollution in low energy channels and a higher background energy spectrum for some time after the exposition to visible photons or high energy particles. This phenomenon could question its use in space, especially because of the South Atlantic Anomaly (SAA) passages, where high energy protons will hit the detector and trigger this afterglow.

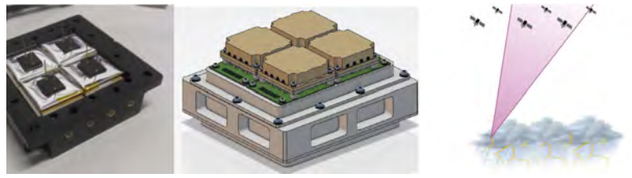

Figure: (left) One FGS 2x2 module composed of 4 GaGG/SiPM pixels. (middle) FGS composed of 4 modules 2x2 (= 16 pixels). (right) Illustration of the future nanosatellite constellation using FGS.

In order to validate the use of GaGG:Ce scintillators in space, we performed proton irradiation to simulate the SAA in-flight passages at the Arronax cyclotron in Nantes (France). In this presentation, we present the results in which we quantified the afterglow and its decay time, for 3 different GAGG:Ce types, from 2 different suppliers. The afterglow induced by proton irradiation on GAGG:Ce is low, and should not pollute data acquired in space. We also present a comparison of the characteristics of the 6 GAGG:Ce scintillators used in this project.

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3. M. S. Briggs, et al., "First results on terrestrial gamma ray flashes from the Fermi Gamma-ray Burst Monitor," Journal of Geophysical Research, (2010). https://doi.org/10.1029/2009JA015242

4. M. Yoneyama, et al., "Evaluation of GAGG:Ce scintillators for future space applications," Journal of Instrumentation (2018). https://doi.org/10.1088/1748-0221/13/02/P02023

The FGS R&D program is supported by CNRS (Centre National de la Recherche Scientifique), France and CNES (Centre National d'Etudes Spatiales), France. We acknowledge Charbel Koumeir for his help at the Arronax cyclotron.

AP32 Implementing plastic scintillator detectors for electron beam quality assurance in Flash-RT

E. Ravera[1,2], R. Anzalone[1,2], A.Cavalieri[1,2], E. Ciarrocchi[1,2], D. Del Sarto[4,2,3], F. Di Martino[3,2,4], M. Massa[2], L. Masturzo[1,3,4], A. Moggi[2], M. Morrocchi[1,2], and M. G. Bisogni[1,2,4]

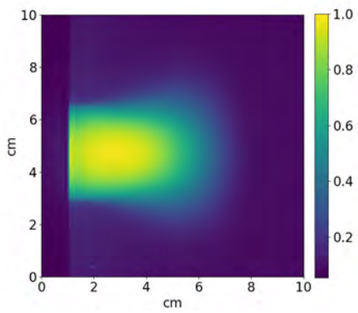
[1]University of Pisa: Department of Physics, Pisa, Italy
[2]National Institute of Nuclear Physics, INFN Sezione di Pisa, Pisa, Italy
[3]Azienda ospedaliero-universitaria pisana, U.O. Fisica Sanitaria, Pisa, Italy
[4]Centro Pisano ricerca e implementazione clinical Flash Radiotherapy (CPFR-CISUP) Pisa, Italy

Corresponding Author Email: eleonora.ravera@phd.unipi.it

Plastic scintillator-based systems emerged as essential tools in radiation therapy quality assurance (QA) protocols [1]. Their remarkable spatial resolution, near water-equivalence, and affordability are what make them stand out. Most importantly, their prompt response, differently from gafchromic films and gels, make them particularly attractive for real time dosimetry. Additionally, thanks to their linear response at high dose per pulse [2], they appear promising for addressing dosimetric challenges introduced by Flash-radiotherapy, which causes saturation problems in standard dosimeters [3].

This study presents results obtained by irradiating three different dosimetric systems based on plastic scintillators with a 9-MeV electron Flash beam at the Pisa Center for Flash Radiotherapy (CPFR). These systems comprise: (i) arrays of dosimeters made of plastic scintillating fibers (SCSF-3HF(1500) by Kuraray, 0.5 mm in diameter) coupled to optical fibers for beam profile measurement; (ii) scintillating sheets (EJ212 by Eljen Technology, 3 and 0.5 mm thick) enabling single-acquisition 2-D dose distribution maps; (iii) scintillating blocks (EJ200 by Eljen Technology, 10 cm side) for volumetric dose distribution assessment. A CCD camera was used to collect light from all the scintillators, either directly or via optical fibers.

A linear response up to 10 Gy was measured for all the systems tested. The imaging capability of the scintillating sheet was assessed acquiring dose distributions both along the longitudinal and transverse planes relative to the beam axis. The spatial resolution measured by means of tungsten bar pattern was estimated at about 400 µm with scintillating sheets. Furthermore, in the case of fibers, we estimated the ratio of spurious Cerenkov light relative to the scintillation to be in range 5-10%, by employing the double fiber method and applying a fitting procedure to the beam profile. To mitigate the contribution of Cerenkov light, we implemented optical filtering.



Percentage depth dose distribution along the beam axis acquired with the scintillating block irradiated with 9 MeV electrons at CPFR

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2. M. Morrocchi, "Experimental characterization and Monte Carlo simulation of scintillator detectors in online electron FLASH radiotherapy dosimetry", JINST, 17 (2022)

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Acknowledgments

Project <<Piano Nazionale di Ripresa e Resilienza (PNRR), Missione 4, Componente 2, Ecosistemi dell'Innovazione – Tuscany Health Ecosystem (THE), Spoke 1 "Advanced Radiotherapies and Diagnostics in Oncology" - CUP I53C22000780001 >>; Fondazione Pisa for funding CPFR with the grant "prog. n. 134/2021; Kuraray CO LTD, Japan

AP33 Calibration and performance of the CMS Electromagnetic Calorimeter in LHC Run 3

M. M. Obertino[1] On behalf of the CMS Collaboration
[1]*University of Turin, Turin, Italy*

Corresponding Author Email: margherita.obertino@cern.ch

The electromagnetic calorimeter (ECAL) of the CMS experiment at the CERN LHC is crucial for many physics analyses, ranging from Higgs measurements to new physics searches. A precise calibration of the detector and all its individual channels is essential to achieve the best possible resolution for electron and photon energy measurements. In addition, the calibration is important for the measurement of the electromagnetic component of jets and the contribution to energy sums used to obtain information about particles that leave no signal in the detectors, such as neutrinos. To ensure the stability of the energy response over time, a laser monitoring system is employed to measure radiation induced changes in the detector hardware and compensate for them in the reconstruction. A dedicated calibration of each detector channel is also performed with physics events exploiting electrons from W and Z boson decays, photons from pi0/eta decays, and from the azimuthally symmetric energy distribution of minimum bias events. This talk will summarize the techniques used for the ECAL energy and time calibrations and it will discuss a new system developed to automatically execute the calibration workflows during the data taking for the LHC Run 3. The ECAL performance achieved for a reprocessing of the data collected by CMS in 2022 and 2023 will be also discussed.

Poster Sessions

AP34 NIR luminescence under diode laser and X-ray excitation of Nd-doped $BaTiO_3$ particles for biomedical applications within 1st and 2nd biological windows

Lorena Feitoza Aragão Domingos[1], Camila Higina Santos Lima[2], Lauro Oliveira Espíndola[1], Ruan Pedro Rodrigues Moura[1], Tatiane Strelow Lilge[1], Maria Andrade Gomes[1], Adriano Borges Andrade[1], José Joatan Rodrigues Júnior[1], Márcio André Rodrigues Cavalcanti de Alencar[1], Mário Ernesto Giroldo Valerio[1,2], Zélia Soares Macedo[1,2]

[1]*Physics Department, Federal University of Sergipe, Marechal Rondon Avenue, Jardim Rosa Elze, São Cristóvão, Brazil*
[2]*Materials Science and Engineering Department, Federal University of Sergipe, Marechal Rondon Avenue, Jardim Rosa Elze, São Cristóvão, Brazil*

lorenafeitoza@academico.ufs.br

In this work, a combination of X-ray imaging and contactless thermometry is proposed, using Nd- doped barium titanate synthesized via a sol-gel route using natural organic matter. A synergistic association between the use of X-ray radiation and an activator in near-infrared (NIR) emission can be employed in bioapplications due to their limitless penetration depth into biological tissues. The high resolution, sensitivity, and deep tissue penetration are some factors making the lanthanide-doped inorganic luminescence materials, with emissions within the 1st (700-950 nm) and 2nd (1000-1350 nm) biological window, promising candidates as contrast agents for bioimaging detection and biosensing, from disease diagnosis to therapy. X-ray can be used directly in several techniques, such as computed tomography, which uses X-ray-sensitive scintillators to absorb and convert high-energy into low energy. Recently, strategies using X-ray excitation have been investigated to activate persistent luminescence materials for high-contrast NIR imaging [1]. Furthermore, in the optics field, luminescent materials also present properties for applications in contactless biosensing within the biological window. Research into biosensing requires the availability of new materials with increasingly better thermometric properties, as well as efficient and economically advantageous methods of synthesizing them. In this sense, combining these features, in the present work a synthesis of Nd-doped barium titanate ($BaTiO_3$) particles was performed through a modified sol-gel route. The chelating capacity of natural humic substances present in river water was used to polymerize the metallic solution, resulting in crystalline nanoparticles. For this study, samples were produced with a concentration of 0.5 g/ml and heat treated at 1473K/5h. The molar concentration of Nd^{3+} in the $BaTiO_3$ matrix was 0.5, 1 and 3 mol%. Scanning electron microscopy (SEM) revealed elongated rod- shaped particles in the micrometer scale. The NIR emission properties under X-ray and continuous wave (CW) diode laser irradiation were analyzed. The radioluminescence spectrum showed emission in the UV, visible light, and NIR regions. The high relative sensitivity (Sr) values of the produced Nd-$BaTiO_3$ particles and the repeatability test results indicate the potentialities of these materials for nanoscale temperature sensing in the physiological temperature range of 303 to 373 K.

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Poster Sessions

AP35 Scintillation Properties of 3D printed using Commecial Acryl Resin for High Dose Rate Proton beams

Sunghwan Kim[1], Gwangsoo Kim[2], Hongjoo Kim[2]

[1]*Cheongju University, Cheongu, Korea*
[2]*Kyungpook National University, Daegu, Korea*

Corresponding Author Email: kimsh@cju.ac.kr

3D printing is creating a three-dimensional object by layering cross-sections of an object. It has become the central technology of the fourth industrial revolution, as it has applications in various fields, such as bio, medical [1], industrial, educational, and space. In this study, we aimed to produce a scintillator resin that can detect radiation using a commercial resin for a DLP 3D printer. The commercial resin was a transparent acrylic resin (Acryl resin pro, Anycubic Co.) with a density of

1.1 g/cm3, a viscosity of 70 mPa-s, and a hardness of 79 (shore D). We fabricated scintillation resin for 3D printing by mixing 1.0 wt% of PPO organic scintillator, 5.0 wt% of MMA, and commercial acrylic resin. We printed cylindrical 3D-shaped plastic scintillator radiation sensors using this resin with a commercial 3D DLP printer (Anycubic Photon M3 Max, Anycubic Co.) [2]. The output parameters for 3D printing were set as follows: slice thickness of 50 μm, irradiation time of 3 seconds, and off-time of 2 seconds. We activated the anti-aliasing function to eliminate the step difference between the printed slices and washed the final printed plastic scintillator with 99% pure alcohol to produce a scintillator sensor. The 3D-printed plastic scintillator's emission wavelength spectrum is located in the range of 350 to 700 nm, peaking at 411 and 497 nm, which matches well with the quantum efficiency of the photomultiplier tube. Moreover, the absorption band for wavelengths below 400 nm was confirmed. The scintillator shows good linearity (R-square 0.998) of absorbed dose and measured data and no dose-rate effects in the 1 nA to 6 uA range for the 45 MeV proton beam of MC-50 in KIRMS. Because of the low light output of the sensors limits their use in low- dose-rate gamma-ray or X-ray dosimetry. However, they can help measure high-energy or high-dose- rate radiation, such as proton and ultra-high dose rate beams, as tissue equivalent materials. The 3D- printed plastic scintillator has the advantage of radiation dosimetry because it has a similar atomic number and density to the human body [3]. Therefore, when used in the human body, it will help evaluate volumetric doses to organs or targets [4], and it is thought that it will be usefully used for measuring various types of non-standardized and complex types of radiation.

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3. A.S. Beddar, "Plastic scintillation dosimetry and its application to radiotherapy", Radiation Measurements, 41(1), S124 (2006).

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Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (MSIT) (NRF-2021R1F1A1059687). Thanks to the staff of the MC-50 Cyclotron Laboratory (KIRAMS) and KOMAC, for the excellent operation and their support during the experiment.

AP36 Study on Novel Red and Infrared Emitting Scintillation Materials for Real-Time Dose-Rate Monitoring System

Shunsuke Kurosawa[1,2,3], Daisuke Matsukura[2,4], Yusuke Urano[2,4], Akihiro Yamaji[1,2], Akira Yoshikawa[1,2], Takushi Takata[5], Hiroki Tanaka[5]

[1]*New Industry Creation Hatchery Center (NICHe), Tohoku University, Sendai, Miyagi, Japan*
[2]*Institute for Materials Research (IMR), Tohoku University, Sendai, Miyagi, Japan*
[3]*Institute of Laser Engineering, Osaka University, Suita, Osaka, Japan*
[4]*Graduate School of Engineering, Tohoku University, Sendai, Miyagi, Japan*
[5] *Institute for Integrated Radiation and Nuclear Science, Kyoto University, Kumatori, Osaka, Japan*

Corresponding Author Email: kurosawa@imr.tohoku.ac.jp

Real dose monitors under the high dose-rate condition are required to remove the debris in the Fukushima Daiichi Nuclear Power Plant as the decommissioning step. We have proposed a dose-rate monitor consisting of a scintillator, optical fiber and photodetector, and scintillation materials are required to have the long-emission-wavelength (550 - 1000 nm) and high light output. Several groups report the scintillation properties with red and near-infrared (NIR) emission bands such as Eu,Sm:SrI_2, Eu,Sm:$CsBa_2I_5$ and our materials:Cs_2HfI_6 [1][2][3]. Such materials have relatively high light output, while they have hygroscopic matures. Although such material can be operated with some sealing to protect moisture, red and/or infrared scintillators with non-hygroscopic nature are also required to have stability for the operation, especially underwater operation. In this study, we search the non- hygroscopic materials with red and/or infrared emissions, and demonstrated the monitor with these materials.

Cr-doped garnet crystals such as Cr:$Gd_3(Ga, Al)_5O_{12}$ were grown by the micro-pulling down method, and emission bands excited by UV and X-rays were investigated. Moreover, we have developed the dose-rate monitoring system with these garnet crystals, and demonstrated this system using a 60Co source with an activity of around 70 TBq at Kyoto University as shown in Fig.1 .

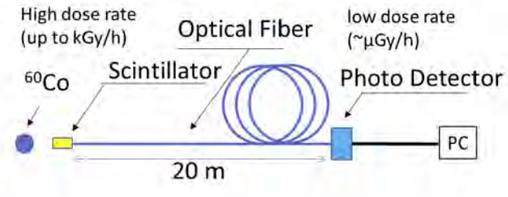

Fig. 1. Schematic view of the demonstration of the dose-rate monitor for the gamma-ray detection.

Cr:$Gd_3(Ga, Al)_5O_{12}$ had emission band around 700 -800 nm. We succeeded in operating the monitor test with a measurement time of the one spot of less than 3 sec using an optical fiber with a diameter of 600 μm for the fiber core. Here, some emission band from optical fiber itself was also observed due to Cherenkov and scintillation photons originating from some defect in the fiber glass under such high dose rate (over 1 Gy/h). From this reason, we evaluated such "fiber noise". The results showed the dose-rate dynamic range was estimated to 50 mGy to over 1 kGy for our system, and our system was found to evaluate the wide dose-rate range in real-time. In this paper, we show the detail of material search and this monitor.

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Poster Sessions

AP37 The SiPM-on-tile system of the CMS HGCAL

Rajdeep M Chatterjee[1] On behalf of the CMS HGCAL Collaboration

[1]*Tata Institute of Fundamental Research, Mumbai, Maharashtra, India*

Corresponding Author Email: rchatter@cern.ch

The high-luminosity phase of the LHC starting in 2029 will provide 10 times as much luminosity as the runs 1, 2 and 3 combined, though with higher pileup and radiation damage to the detectors. The High Granularity Calorimeter (HGCAl) is the upgrade of both the CMS ECAL and HCAL endcaps calorimeters, providing energy, location and timing measurements while ensuring radiation hardness such that it is able to cope with the higher radiation dose. It features a mix of silicon sensors in the most radiation-impacted areas, and cheaper plastic scintillators with SiPM readout elsewhere.

For HGCAL scintillator tiles, readout with individual on-tile silicon photomultipliers (SiPMs), will be used where the radiation levels are expected to be less than 5 x 10^13 n/cm^2. The scintillator tiles will be mounted on highly-integrated “tileboards” (typical area 30 x 30 cm^2) that host up to 108 tiles and their SiPMs, as well as front-end electronics, control and powering components. A dedicated LED system will be implemented to monitor stability effects.

We present recent developments for the HGCAL scintillator material and SiPMs, including quantification of the scintillator and SiPM radiation-damage impact, modeling of SiPM noise and its evolution with time, SiPM production testing and quality control plans. Additionally this contribution presents the first quality test results using the pre-series module production started at the end of 2023. These tests are conducted using a radioactive source setup to measure the light yield of the scintillators tiles, and cosmics or test beam particles to measure the response of fully assembled modules and provide initial calibration constants.

CHARACTERIZATIONS OF SCINTILLATORS

CA14 Response of a high-pressure ^{4}He scintillation detector to nuclear recoils up to 9 MeV

Oskar Searfus[1,2], Peter Marleau[2], and Igor Jovanovic[1]

[1]*University of Michigan, Ann Arbor, MI, USA 2Sandia National Laboratories, Livermore, CA, USA*

Corresponding Author Email: ofsearf@sandia.gov

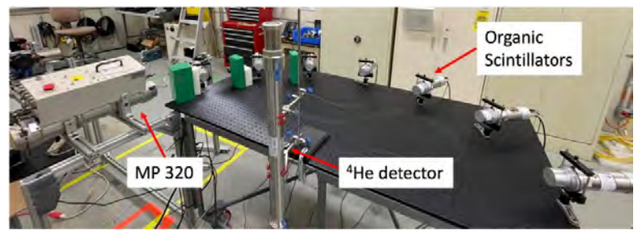


Figure 1: Laboratory configuration for measurement of the 4He detector response.

Helium-4-based scintillation detector technology is emerging as a strong alternative to pulse-shape discrimination-capable organic scintillators for fast neutron detection and spectroscopy, particularly in extreme gamma-ray environments. ^{4}He is intrinsically insensitive to gamma radiation, as it has a low cross-section for gamma-ray interactions, and the stopping power of electrons in the ^{4}He medium is low compared to that of ^{4}He recoil nuclei. Consequently, gamma rays can be discriminated by simple energy deposition thresholding instead of the more complex pulse shape analysis. The energy resolution of ^{4}He scintillation detectors has not yet been well-characterized over a broad range of energy depositions, which limits the ability to deconvolve the source spectra. In this work, an experiment was performed to characterize the response of an Arktis S670 ^{4}He detector to nuclear recoils up to 9 MeV. The ^{4}He detector was positioned in the center of a semicircular array of organic scintillation detectors operated in coincidence with the ^{4}He scintillation detector. Deuterium- deuterium and deuterium-tritium neutron generators provided monoenergetic neutrons, yielding geometrically constrained nuclear recoils ranging from 0.0925 to 8.87 MeV. The detector response provides evidence for scintillation linearity and the existence of wall effect, especially for high-energy recoils. The measured response was used to develop an energy resolution function applicable to this energy range and enables high-fidelity detector simulation for future applications in nuclear nonproliferation, security, and safeguards.

This work was supported by the Department of Energy National Nuclear Security Administration, Consortium for Monitoring, Verification and Technology (DE-NE000863). The work of O. Searfus was performed under appointment to the Nuclear Nonproliferation International Safeguards Fellowship Program sponsored by the National Nuclear Security Administration’s Office of International Nuclear Safeguards (NA-241). Sandia National Laboratories is a multimission laboratory managed and operated by National Technology Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE NA0003525.

CA15 Luminosity, Proton Response, and Spatial Resolution of High-Density Glass Scintillators

Daniel Robertson[1*], Ethan Stolen[1], Ryan Fullarton[2], Rain Hein[3], Robin L. Conner[4], Luiz G. Jacobsohn[4], Charles-Antoine Collins Fekete[2], Sam Beddar[5], and Ugur Akgun[3]

1 Mayo Clinic, Phoenix, AZ, USA;
2 University College London, London, UK
3 Coe College, Cedar Rapids, IA, USA;
4 Clemson University, Clemson, SC, USA
5 University of Texas MD Anderson Cancer Center, Houston, TX, USA

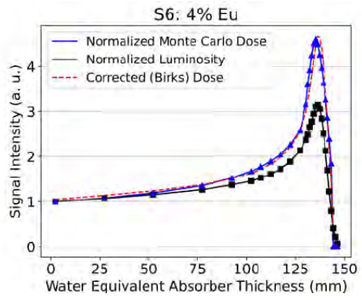
**Corresponding Author Email: Robertson.Daniel@mayo.edu*

Glass scintillators are seen as a potential detector material for proton radiography. Their increased density relative to plastic scintillators provides for stopping the proton beam in a shorter distance, leading to more compact detectors and potentially improved spatial resolution. We synthesized six high-density scintillating glasses and measured relevant properties, including relative luminosity, ionization quenching, and potential spatial resolution for integrating-mode proton radiography.

Four glass samples were prepared using a base with varying percentages of $2H_3BO_3$, Gd_2O_3 and WO_3. These base glasses were activated with Tb_2O_3 or Eu_2O_3 ranging from 2%-4% by weight. The resulting glass scintillators exhibited densities of 5.6 g cm^{-3} – 5.9 g cm^{-3}. Two additional samples were prepared using a base of $2H_3BO_3$ and PbO, one with 3% Tb_2O_3 and one with 4% Eu_2O_3. These exhibited densities of 4.3 g cm^{-3} and 4.5 g cm^{-3}, respectively.

The luminosity was measured relative to bismuth germanate (BGO), and also as a function of depth in a 200 MeV proton beam. The materials were also modeled in the Monte Carlo radiation transport code Geant4 [1], and the absorbed dose and linear energy transfer were calculated as a function of depth. The spatial resolution of proton radiography detectors employing these glass scintillators was studied by constructing a Geant4 model of a proton beam passing through an Al block in a water tank, and depositing the protons' residual energy in a block of each glass scintillator, and also in a block of organic plastic scintillator for comparison. The edge spread function of the scintillator response at the edge of the Al block provides an indication of the spatial resolution of a detector using each scintillator material.

The relative luminosity of the Eu_2O_3-doped scintillators exceeded the Tb_2O_3-doped, and the PbO-based scintillators were brighter than those incorporating Gd_2O_3 and WO_3. The glass scintillator luminosity ranged from 2%-8% relative to BGO. All glass scintillators exhibited similar ionization quenching, with peak to plateau ratios of 33%-37% lower than that of the absorbed dose vs. depth curve. The Birks ionization quenching model [2] described the scintillator response well, enabling the correction of the depth-light curves to match the depth-dose curves. The simulated proton radiograph spatial resolution increased by a factor of 1.7 for the glass scintillators, compared to the organic plastic scintillator.



Depth-light curve for glass scintillator sample 6. The normalized depth-light curve (black) and corrected depth-dose curve (red) is compared to the Monte Carlo calculated depth-dose curve (blue)

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CA16 Effect of Li^+ on the scintillation properties of codoped $Lu_3Al_5O_{12}$: Ce^{3+} nanopowders prepared by sol gel

Z. Akhrib[1], F. Cova[2], M. Fasoli[2], L. Guerbous[3]

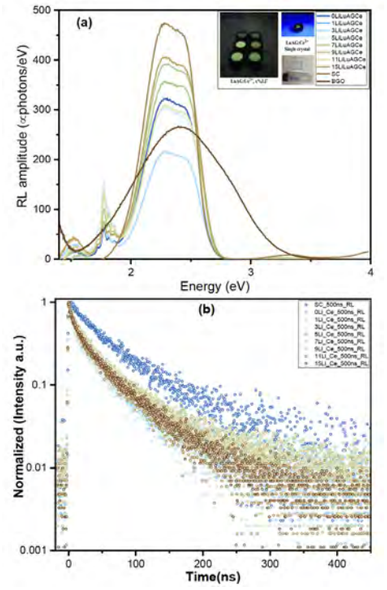
[1]Laboratory for Developing New Materials and their Characterizations, Department of Physics, Faculty of Science, University of Ferhat Abbas Setif 1, Setif, Algeria
[2]Department of Materials Science, University of Milano–Bicocca, Via Cozzi 55, 20125 Milan, Italy
[3]Physics Division/Nuclear Research Centre of Algiers (CRNA), 02, Boulevard Frantz Fanon, B.P. 399, Algiers (16000), Algeria

Corresponding Author Email: akhrib.zohra@univ-setif.dz

Lithium co-doping has emerged as a valuable approach for enhancing the scintillation efficiency by mitigating defects in complex oxide single crystals, such as garnets [1]. While $Lu_3Al_5O_{12}$: Ce^{3+} is a well-known single crystal scintillator, its potential at the nano scale remains largely unexplored. The research investigates nanopowders as a promising alternative to bulk single crystals in scintillator materials, highlighting their advantages in enhancing surface area, precise dopant incorporation, and enabling the development of composite materials with superior mechanical properties.

In this study, $Lu_3Al_5O_{12}$: Ce^{3+} powders codoped with various concentrations of Li+ ions (LuAG: 0.5 at. % Ce^{3+}, x at. % Li+ with x = 0, 1, 3, 5, 7, 9, 11 and 15) were successfully synthesized using the sol gel method and characterized using X-ray diffraction (XRD). Photoluminescence (PL) spectroscopy, Radio-Luminescence (RL) measurements, Thermally Stimulated Luminescence (TSL) and time- resolved spectroscopy have been employed to investigate the luminescence properties and scintillation performance of these materials. XRD analysis revealed that all the diffraction peaks of the samples can be well indexed to the cubic garnet structure phase (JCPDS no. 73–1368), with Ia3d as space symmetry group. The luminescence under X-ray excitation has been evaluated and compared to that of BGO powder scintillator and LuAG: Ce^{3+} single crystal measured in the same experimental conditions. The decay time measurements of the powders were compared to that of LuAG:Ce^{3+} single crystal.

Among the tested compositions, samples with 7% and 15% Li^+ codoping showed the brightest luminescence, indicating notably improved scintillation properties. Importantly, these samples displayed no thermal quenching of Ce emission across a wide temperature range from 10 K to 320 K. Additionally, the absence of Ce^{3+} TSL signal within this temperature range further underscores the promising attributes of these samples for ionizing radiation detection. Detailed discussions on these findings will be presented in this contribution.



RL spectra (a) of LuAG:Ce^{3+} x. at. % Li^+ powders compared to LuAG:Ce^{3+} single crystal and to BGO powder, and RL decay time (b) of LuAG:Ce^{3+} x. at. % Li^+ powders and LuAG:Ce^{3+} single crystal

1. Y. Wu, G. Yang, D. Han, M. Liu, A. Hawari, M-H Du, J. Peng, C. Foster, S. Chen, M. Koschan, and C. L. Melcher, "Role of Lithium Co-doping in Enhancing the Scintillation Yield of Aluminate Garnets", PHYSICAL REVIEW APPLIED 13, 064060 (2020).

Poster Sessions

CA17 Characterising the afterglow intensity of $CeBr_3$ and GAGG:Ce:Mg to correct measurements of short-lived isomers produced using photoactivation

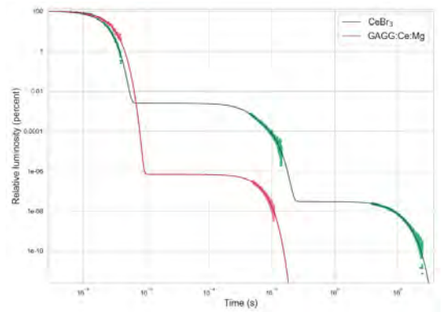
Shaun Delpiano[1], Yves Van Haarlem[1], Jonathan Masters[1], Anatoly B Rosenfeld[2]

[1]*Commonwealth Scientific and Industrial Research Organisation (CSIRO), Sydney, NSW, Australia*
[2]*Centre for Medical Radiation Physics (CMRP), Wollongong, NSW, Australia*

Shaun.Delpiano@csiro.au

An intense pulsed X-ray source can be used to induce short-lived isomers via photoactivation, such as ^{75m}As, with a 17.6 millisecond half-life. In cases where the cross sections for these reactions are small, the flux per pulse across a sample limits detection. Scintillators such as $CeBr_3$ and GAGG:Ce:Mg are a clear choice for these measurements, requiring high resolution, high throughput and substantial resistance to the effects of radiation damage[1][2]. When combined with a switching voltage divider, such a system can measure short-lived photoactivation down to as little as half a millisecond after an X-ray pulse.

With a rapid measurement following irradiation, scintillator afterglow can cause significant issues for measuring short-lived activation, as any fluorescent pulses will be superimposed with a gradually decaying signal from afterglow. While the CAEN DT5740D digitiser used for analysis does facilitate the calculation of a baseline to subtract from signal prior to integration[3], this is only calculated as a single rolling average prior to a pulse trigger. As a result, any events occurring soon after irradiation will have an error in the integral value due to a static baseline estimate when the true value is a decaying signal due to scintillator afterglow, resulting in the degradation of detector resolution.



Combined fluorescence and afterglow measurements for each scintillator. Measured data (scatter plot) and fitted components (line plot) are normalised to the intensity of luminescence of each scintillator immediately following a short X-ray pulse.

This error can be corrected after a measurement by characterising each scintillator's afterglow using the value of the baseline determined by the digitiser for each pulse processed, which is stored when the digitiser is operated in waveform mode. With the waveform timestamps synchronised to the X- ray pulses, the afterglow signal can be reconstructed. This requires hundreds of X-ray pulses to generate enough data to fit an exponential decay function using a nonlinear least squares method, with thousands of individual pulses used to reduce systematic errors potentially introduced by beam instability. As operating a digitiser in waveform mode substantially increases dead time, any analysis of short-lived isomers requires a separate measurement, which can be corrected using the fit afterglow function, allowing for the restoration of some of the detector's resolution for events detected immediately after an X-ray pulse.

1. N. J. Cherepy et al., "Transparent ceramic scintillators for gamma spectroscopy and MeV imaging," Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XVII (2015)

2. W. Drozdowski, P. Dorenbos, A. J. J. Bos, G. Bizarri, A. Owens and F. G. A. Quarati, "CeBr3 Scintillator Development for Possible Use in Space Missions," IEEE Transactions on Nuclear Science, 55, pp. 1391-1396 (2008).

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CA18 Influence of composition on luminescence properties of $Cd_{1-x}Zn_xWO_4$ solid solutions

Nataliya Krutyak[1,2], Vitali Nagirnyi[1], Boris Zadneprovski[3], Maksym Buryi[4], Dmitry Spassky[1,5]

[1]*Institute of Physics, University of Tartu, 50411 Tartu, Estonia*
[2]*Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia*
[3]*All-Russian Research Institute for Synthesis of Materials, 601650 Alexandrov, Russia*
[4]*Institute of Plasma Physics of the Czech Academy of Sciences, 18200 Prague 8, Czech Republic*
[5]*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119991 Moscow, Russia*

Corresponding Author Email: nataliya.krutyak@ut.ee

Solid solutions of tungstates allow tailoring of their optical and luminescent properties and for that reason have been extensively studied in various combination of cations. In particular, an increase in light output by a factor of 1.5 and 3 has been registered for $Zn_xMg_{1-x}WO_4$ bulk crystals [1] and nanoparticles [2], respectively. The enhancement of light yield in solid solutions is ascribed to the modifications in energy transfer processes induced by structural disorder. Here we present the results of the luminescence study of $Cd_{1-x}Zn_xWO_4$ solid solutions, including their emission and excitation spectra, emission decay kinetics and thermostimulated luminescence (TSL). Electron paramagnetic resonance (EPR) spectroscopy was used for the determination of the origin of charge carrier traps.

A set of single-phase $Cd_{1-x}Zn_xWO_4$ (x = 0–1) solid solutions was synthesized by spontaneous crystallization technique. It was shown by powder XRD method that all compounds were crystallized in wolframite structure. The Zn and Cd content in solutions was verified using X-ray fluorescence. Luminescence spectra of all studied solutions are characterised by a single emission band peaking at 485-500 nm, which related to the intrinsic emission of self-trapped excitons. The dependence of luminescence spectra and TSL curves on solution composition was investigated, and the origin of TSL peaks was analysed on the basis of the EPR data. It is shown that the values of optical bandgap and activation energy of luminescence thermal quenching gradually change with solution composition. Several phenomena are observed in solid solutions predominantly at intermediate concentrations of Cd and Zn cations that can be connected with the structural disorder of the solid solutions. In particular, the deviation of lattice parameters from the Vegard's law, the redshift and broadening of the emission band, the suppression of low-temperature (T<80 K) TSL peaks related to self-trapped holes and the broadening of high-temperature (100–200 K) TSL peaks related to structural defects. The structural disorder arises due to the non-homogeneous distribution of substitutional atoms in cation lattice sites and deformation of crystal lattice. The latter effect is supposed to be due to the pronounced mismatch in ionic radii of substitutional cations, which reaches 28.3% for Cd^{2+} and Zn^{2+}.

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Poster Sessions

CA19 An overview of GAGG-type single crystals in scintillation spectrometry

Joanna Iwanowska-Hanke[1], Kamil Brylew[1], Tomasz Szczęśniak[1], Agnieszka Syntfeld-Każuch[1], Lukasz Swiderski[1], Kei Kamada[2,4], Akira Yoshikawa[2,3,4]

[1]National Centre for Nuclear Research, Soltana 7, 05-400 Otwock
[2]Institute for Materials Research (IMR), Tohoku University, Sendai, 980-8577, Japan
[3]New Industry Creation Hatchery Center (NICHe), Tohoku University, Sendai, 980-8579, Japan
[4]C&A Corporation, 6-6-40 Aramaki Aza Aoba, Aoba-ku, Sendai, 980-8579, Japan

Corresponding Author Email: joanna.iwanowska@ncbj.gov.pl

Scintillation crystals, used with photodetectors for X-ray and gamma-ray spectrometry in fields like industrial radiography, medical imaging, and nuclear physics, should ideally possess traits like high light yield, strong gamma-ray absorption, good energy resolution, proportional response, fast scintillation, chemical stability, durability, and appropriate crystal dimensions. Garnet-structured oxide materials, with their transparency, low emission, and ease of rare-earth element doping, show promise due to established technology used in laser hosts. GAGG(Ce) crystals are a unique type of scintillation crystals composed of gadolinium aluminum gallium garnet - $Gd_3(Ga,Al)_5O_{12}(Ce)$. Initially developed in 2011 using the micropulling down method by Kamada et al. [1], these garnet single crystals represented a significant advancement. Efforts to improve their light emission led to high-resolution GAGG (HR-GAGG), known for its high light yield and excellent energy resolution. However, this optimization prolonged the light pulse's decay time. Subsequent research focused on co-doping with magnesium (Mg^{2+}), resulting in faster decay times in GFAG crystals, offering a promising alternative in applications where fast timing is crucial.

The GAGG samples under test are 10×10×5 mm cubes. Using a calibrated Hamamatsu R6231-100

PMT, we measured the photoelectron yield, nonproportionality, and energy resolution. Table 1 shows the photoelectron yield and energy resolution for 662 keV for all samples, while Fig. 1 illustrates the non-proportionality of the light yield for all the samples. The further measurements covers the test of time resolution, emission spectra and the measurements of the light pulses for various gamma-ray energies, using the modified Boilinger-Thomas method [2].

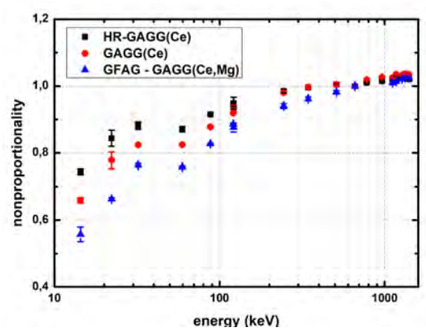

Fig. 1 Nonproportionality of the light yield for a wide energy range measured for three samples of GAGG-type scintillators.

Table 1
Photoelectron yield for the testes GAGG-type scintillators

	HR-GAGG	GAGG	GFAG
Photoelectron yield (phe/MeV)	~7000	~6700	~3000
Energy resolution (%) @ 662 keV	~5,4	~6,3	~9,2

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CA20 Development of BGO/ZnO(ZnO:Ga) Heterostructures for Ultrafast γ-ray Detection

Nataliya Babayevska[1], Mariusz Jancelewicz[1], Igor Iatsunskyi[1], Marcin Jarek[1], Aravinthkumar Padmanaban[2], Ivan Yakymenko[2], Oleg Sidletskiy[2,3]

[1] NanoBioMedical Centre, Adam Mickiewicz University, Poznań, Poland
[2]Centre of Excellence ENSEMBLE3 Sp. z o.o., Warsaw, Poland
[3]Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine

Corresponding Author Email: natbab@amu.edu.pl

Positron emission tomography (PET) scanners are among the most efficient tools for the identification of tumors in the human body. However, the temporal resolution of Time-of-Flight (TOF-PET) is limited by both the metabolism of the tracer molecule in the patient's body, and delayed response of scintillation detectors to generated γ-quanta. Scintillation detectors with improved timing performance should enable both to increase TOF-PET sensitivity, and reduce radioactive doses injected into patients [1]. Heterostructures combining a heavy scintillator, which efficiently absorbs γ-quanta, with a light and fast scintillator, which converts recoil electrons from the heavy scintillator to fast light photons are considered among the approaches to enhance the TOF-PET timing [2].

In this work, BGO and ZnO(ZnO:Ga) were chosen as heavy and light components of the heterostructure, respectively. ZnO is a wide band gap semiconductor (*Eg* = 3.4 eV) with a large exciton binding energy (60 meV), strong exciton and defect luminescence at room temperature with a sub-nanosecond lifetime, and a low afterglow [3]. These important advantages make this material very promising for application in ultrafast scintillating detectors. Moreover, ZnO properties can be easily tuned by doping with n-type and p-type impurities, such Ga3+donor ions enhancing scintillation efficiency [4].

ZnO(ZnO:Ga) films were successfully obtained by the sol-gel technique on BGO substrates. ZnO/ZnO:Ga thickness was tuned to adjust luminescence and scintillation parameters. The proposed synthesis method enables obtaining highly crystalline ZnO/ZnO:Ga films with a thickness ranging from 10 to 100 μm on BGO substrates. The surfaces are homogeneous and consist of ZnO seeds with sizes approximately 100 nm. Pristine ZnO films under 325 nm exhibit exciton and defect luminescence bands peaked in UV (353 nm) and visible green (657 nm) ranges, respectively. The variation of ZnO thickness as well as the presence of the impurities allows for tuning of luminescence spectra of ZnO.

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3. J.C. Sin et al, "Preparation of rare earth-doped ZnO hierarchical micro/nanospheres and their enhanced photocatalytic activity under visible light irradiation," Ceram. Int., 40 5431 (2014).

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This work was supported by the National Science Centre of Poland from the OPUS project DEC- 2022/47/B/ST5/02288.

Poster Sessions

CA21 Influence of Yttrium Segregation on Scintillation Performance of Heavily Y-Doped Barium Fluoride Crystals

Xiang Li[1], Jiaqian Zheng[1], Jiawei Xu[1, 2], Chen Peng[3], Shiyun Sun[1],Yong Du[1], Fan Yang[3], Dong Wang[1], Junfeng Chen[1, 2]

[1]R&D Center for Novel Materials, Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China
[2]Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing, China
[3]School of Physical, Nankai University, Tianjin, China

Corresponding Author Email: jfchen@mail.sic.ac.cn

Barium Fluoride (BaF_2) crystal is a unique scintillator with a sub-ns fast scintillation component[1]. Previous studies have demonstrated that slow scintillation component in BaF_2 crystal can be effectively suppressed through yttrium (Y) doping [2-3]. In this study, large Y doped BaF_2 (BaF_2:Y) crystal boules with length up to 250 mm were grown in a vacuum using the vertical Bridgman method. Several series of small samples cut from a large 10at% BaF_2:Y crystal boule along the growth direction, and a 200-mm-long large BaF_2:Y crystal sample were prepared. The actual doping concentration, distribution characteristic along crystal growth direction, and effective segregation coefficient (K_{eff}) of yttrium in large BaF_2 crystal with a 10 at% nominal yttrium doping were analyzed by inductively coupled plasma emission spectroscopy. Yttrium segregation influence on scintillation properties, including transmittance, radioluminescence (*RL*), fast/slow (*F/S*) ratio of light output (*LO*), light response uniformity, etc., were investigated. Results reveal that the actual yttrium concentration increases along the growth direction with a K_{eff} of 0.84. Compared with undoped BaF_2 crystal, 10 at% yttrium doping in BaF_2 crystal suppresses the RL intensity of slow component by a factor of about 10, while the RL intensity of fast component decreases to about 60% of that of undoped crystal. The F/S ratio of LO and emission weight longitudinal transmittance (*EWLT*) exhibit a strong correlation with Y actual doping concentration, the slow component of sample decreases to 10.4%-6.1% from the seed end to the tail end, and the fast component LO is reduced to 86.8%-73.9% compared to undoped BaF2 crystal. The 200-mm-long BaF_2:Y crystal shows better uniformity of light response with tail end coupling (4.46±1.66%) to PMT than seed end coupling (-26.2±1.9%) to PMT.

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Acknowledgment

This research was financially supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA25030600), the National Key Research and Development Program of China (2022YFB3503902), the Natural Science Foundation of China (U1867211). The authors would like to thank Yugui Lu, Xuejun Qi, Lei Chen at the Shanghai Institute of Ceramics, Chinese Academy of Sciences, for the assistance in preparing crystal samples.

CA22 Green-emitting polystyrene scintillators for plastic scintillation dosimetry

Łukasz Kapłon[1,2,3], Gabriel Moskal[2,4]

[1] Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University, Krakow, Poland
[2] Total-Body Jagiellonian-PET Laboratory, Jagiellonian University, Krakow, Poland
[3] Center for Theranostics, Jagiellonian University, Krakow, Poland
[4] Faculty of Chemistry of the Jagiellonian University, Krakow, Poland

Corresponding Author Email: lukasz.kaplon@uj.edu.pl

Plastic scintillators are used in many applications connected with medical devices, for example in time-of-flight positron emission tomography [1, 2], long-axial field of view positron emission tomography scanners [3] and in plastic scintillation dosimetry [4]. Green-emitting plastic scintillators have several advantages over blue-emitting scintillators for dosimetry applications. Firstly, green light is less attenuated by polystyrene matrix and yellow compounds resulting from radiation damage. Secondly, the longer the wavelength of scintillators light, the smaller portion of Cerenkov light is emitted in this green bandwidth in plastic dosimeter and subtraction of this stem signal is easier. Thirdly, green light around 500 nm is the least attenuated in plastic optical fibers usually glued to plastic scintillators forming scintillation dosimeter.

Purpose of this research is to find optimal fluorescent dyes combination dissolved in polystyrene matrix for dosimetry applications. Polymer scintillators were synthesized from styrene monomer in bulk radical polymerization [5]. Polystyrene was selected as a base of scintillators due to its water equivalent needed in dosimetry [6]. In this research one the best fluorescent compound emitting ultraviolet light, BPBD, is combined with a few blue [7] and green fluorescent dyes (anthracene, coumarin and perylene derivatives) shifting scintillators emission to green light. The concentration of the ultraviolet BPBD dye and the best green fluorescent dye Solvent Green 5, affects the light output, rise and fall times, and emission spectra of the scintillator samples. Emission maxima of manufactured polystyrene scintillators are in green region of visible light (484 – 525 nm) and are close to maximum quantum efficiency of light detectors used in plastic scintillation dosimetry. The best green polystyrene scintillator emits 4000 photons/MeV and have duration of signals around 15 nanoseconds.

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7. Ł. Kapłon, G. Moskal, "Blue-emitting polystyrene scintillators for plastic scintillation dosimetry," Bio-Algorithms and Med-Systems, 17, 191 (2021)

Poster Sessions

CA23 Scintillation and luminescence mechanism in undoped and Ce-doped $LaLuO_3$ single crystals

Jan Pejchal[1], Christo Guguschev[2], Katerina Rubesova[3], Vit Jakes[3], Vladimir Babin[1], Alena Beitlerova[1], Romana Kucerkova[1]

[1]*Institute of Physics, Czech Academy of Sciences, Cukrovarnicka 10, 16200 Prague, Czech Republic*
[2]*Leibniz-Institut für Kristallzüchtung, Max-Born-Str. 2, 12489, Berlin, Germany*
[3]*Department of Inorganic Chemistry, University of Chemistry and Technology, Technicka 5, 166 28, Prague 6, Czech Republic*

Corresponding Author Email: pejchal@fzu.cz

Perovskites represent an important group of promising scintillation materials [1]. The reported decay time of the Ce-doped $YAlO_3$ (YAP) luminescence is as short as 18 ns, which makes it one of the fastest materials among the Ce-doped oxide scintillators [2]. Furthermore, YAP:Ce shows very small nonproportionality of the scintillation response, which results in its excellent energy resolution.

Another interesting group of perovskite materials are the interlanthanide perovskites, such as $LaLuO_3$ [3], which has a very high density of 8.2 g/cm^3 and high effective atomic number and it melts congruently at a quite high temperature of 2120°C. The photoluminescence of the Ce-doped crystal is placed in the blue spectral region with fast decay time of 24 ns. Not much attention to the studies of its scintillation properties has been given so far, also due to discouraging results which suggested luminescence quenching and troubled energy transfer from the matrix towards the Ce^{3+} doping ion [3]. On the other hand, some paper confirmed the Ce^{3+} luminescence stability [4] and to our best knowledge, the scintillation properties using ionizing radiation have not been studied at room temperature for this material until now. Therefore, we prepared undoped and Ce- doped $LaLuO_3$ single crystals (Fig. 1.) and studied their luminescence and scintillation properties to confirm or exclude the potential of this material in scintillation applications. The luminescence mechanism and energy transfer will be explained using photoluminescence studies including temperature dependences of spectra and decay kinetics and will be discussed together with results of radioluminescence (Fig. 1.) and thermoluminescence experiments. Complementary results on $LaLuO_3$-based sintered ceramics will be discussed as well.

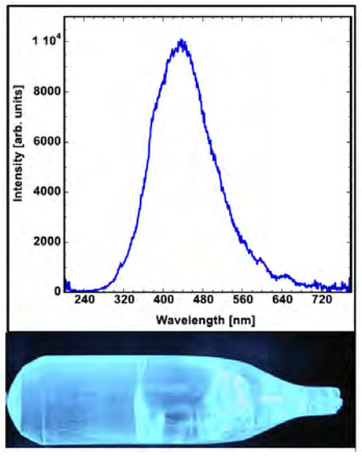

Fig. 1. The as-grown Ce:$LaLuO_3$ single crystal under UV illumination and its radioluminescence spectrum

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CA24 Bridgman Growth and Scintillation Properties of $Zn_xBe_{1-x}Se$ Crystals

A. Bachiri, K. Strzałkowski, M. Boumhamdi, K.J. Drozdowski, A. Guerchi, M.E. Witkowski, W. Drozdowski

Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń, ul. Grudziądzka 5, 87-100 Toruń, Poland

Corresponding Author Email: abdellah@doktorant.umk.pl

Several new series of ternary $Zn_xBe_{1-x}Se$ crystals have been grown by the high-pressure, high-temperature vertical Bridgman method [1]. Four different beryllium contents were chosen, resulting in the following samples: $Zn_{0.98}Be_{0.02}Se$, $Zn_{0.95}Be_{0.05}Se$, $Zn_{0.9}Be_{0.1}Se$, and $Zn_{0.8}Be_{0.2}Se$. X-ray diffraction analysis, employing the Vegard's law, has been conducted to ascertain the composition of the $Zn_xBe_{1-x}Se$ compound across the various concentrations of Be. The presence of the zinc blende phase has also been confirmed through this analysis. Next, some thermal properties, including diffusivity, effusivity, and thermal conductivity, have been studied. The determination of the energy gap for each composition of $Zn_xBe_{1-x}Se$ has also been carried out. Then, the basic scintillation properties of the $Zn_xBe_{1-x}Se$ crystals have been investigated, with the main attention focused on the influence of various content of Be. Room temperature pulse height spectra have been measured in order to estimate the scintillation light yields. Scintillation time profiles have been recorded to determine the decay components and related decay times. X-ray excited emission (radioluminescence) spectra have been taken at various temperatures between 10 and 350 K to recognize emission bands and observe their thermal variations. Finally, low temperature thermoluminescence glow curves have been recorded to identify possible charge trapping processes.

The setup used for the Bridgman growth of $Zn_xBe_{1-x}Se$ crystals.

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Poster Sessions

CA25 Enhancing Light Yield in NaI:Tl Crystal Scintillator Detector Assembly for the COSINE-100 Upgrade

Jaeyoung Cho[1,2] On behalf of the COSINE collaboration.

[1]*Department of Physics, Kyungpook National University, Daegu 41566, Korea*
[2]*Center for Underground Physics, Institute of Basic Science, Daejeon, 34126, Korea*

Corresponding Author Email: hongjoo@knu.ac.kr

The COSINE-100 experiment is a direct dark matter search experiment employing a total of 106 kg NaI(Tl) crystals to test the DAMA/LIBRA collaboration's claim, operated from September 2016 to March 2023 at Yangyang underground laboratory in Korea. Currently, a detector upgrade for the next phase, COSINE-100U, is underway at the newly constructed underground laboratory, Yemilab, primarily aimed at enhancing light collection efficiency through detector design upgrades. Moreover, it is crucial to comprehend the characteristics of photomultiplier tubes to quantify improvements in the new detector assembly, particularly in light yield estimation.

In this presentation, we report on the optimized estimation of the light yield of COSINE-100U detectors and comparison of COSINE-100 experiment.

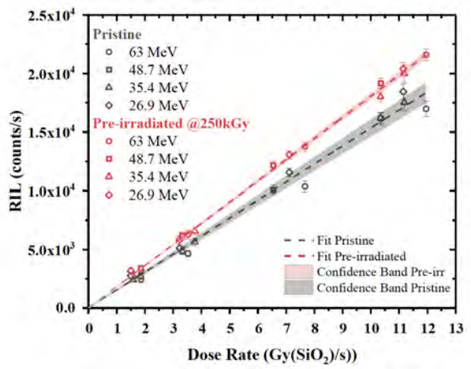
CA26 Pre-irradiation Influence on Proton Radioluminescence Responses of Sol-gel Optical Fibers

F. Fricano[1], A. Morana[1], C. Hoehr[2], C. Campanella[1], C. Belanger-Champagne[2], M. Trinczek[2], D. Lambert[3], P. Paillet[3], H. El Hamzaoui[4], B. Capoen[4], M. Bouazaoui[4], A. Boukenter[1], E. Marin[1], Y. Ouerdane[1] and S. Girard[1]

[1]*Université Jean Monnet, Laboratoire Hubert Curien, Saint-Etienne, 42000, France*
[2]*TRIUMF, Vancouver, Canada*
[3]*CEA, DAM, DIF, Arpajon, France*
[4]*Université de Lille, PhLam, Lille, France*

Corresponding Author Email: fiammetta.fricano@univ-st-etienne.fr

Among the various uses of silica-based optical fibers, their implementation as radiation dosimeters is currently under progress. Under irradiation optically-active centers are generated causing radiation induced attenuation and Radiation Induced Emission (RIE). RIE can be exploited to build a simple radiation detector, since it corresponds to the light emission (Cerenkov or Radioluminescence (RIL)) when the sample is exposed to radiation. For the best materials, the RIL intensity linearly depends on the dose (fluence) or dose rate (flux) so that, with a proper calibration, the fiber can act as a real-time dosimeter. Fibers made by sol-gel techniques are promising candidates for this application thanks to their RIL properties associated with the incorporated emitting ions in their cores such as Cerium (Ce), Copper (Cu) or Terbium (Tb). Their rod glass versions have already been tested under protons [1], [2] but the study on the fibers drawn from these rods is attracting interest for the possibility to provide a better spatial resolution and for the extension of the dynamic range to higher dose rates [3].



Proton Dose rate dependence of the Radioluminescence (RIL) from Cerium-doped samples, either not-irradiated or pre-irradiated at 250 kGy. The probes were tested under different proton energies and at different fluxes (dose rates). The dispersion related to the linear fit is also shown in the fulfilled areas.

The RIL measurements that will be presented, have been carried out at the TRIUMF (Canada) facility, using the 74 MeV beam extracted from the main cyclotron. We observed a good linearity response in the 1.5-12 Gy(Si)/s dose rate range for different proton energies (26.9 to 63 MeV). In particular, no energy dependence is noticed. This is especially important for proton therapy, where the linear energy transfer changes along the Bragg peak during the tumor treatment. To give an idea, the figure reports the outcome from the tests on Ce-doped samples (1 cm long). We tested simultaneously a pristine (i.e. never irradiated) sample and one pre-irradiated under X-rays at 250 kGy. The positive effects of the pre-treatment will be detailed during the conference but as first result the linearity of the RIL vs dose rate is improved. This leads to a lower dispersion of the dosimeter calibration with different proton energies. The dosimeter sensitivity is slightly increased, also in the case of CeTb-codoped fibers. For Cu-doped samples we measured almost no dependence on the cumulated dose, so benefiting the measurement repeatability over the time. Monte Carlo simulations will be also carried out in order to verify the effective dose deposition and to provide a more accurate dosimetry.

1. S. Girard et al., IEEE Trans. Nucl. Sci. 64 (2017) 567–573.
2. C. Hoehr et al., in: 2017 IEEE Nucl. Sci. Symp. Med. Imaging Conf. NSSMIC, IEEE, Atlanta, GA, 2017.
3. F. Fricano et al., Very High Dose Rate Proton Dosimetry with Radioluminescent Silica-based Optical Fibers, IEEE Trans. Nucl. Sci., (under revision).

Poster Sessions

CA27 Luminescence and scintillation properties of NaI:In crystal

Sujita Karki[1,2], Indra Raj Pandey[2,3], Arshad Khan[4,5], Phan Quoc Vuong[1], H. J. Kim[1], Y. D. Kim[6,7], Moo Hyun Lee[6,7]*

[1]*Department of Physics, Kyungpook National University, Daegu 41566, Korea*
[2]*Department of Chemistry, Northwestern University, Evanston, Illinois 60208, United States*
[3]*Material Science Division, Argonne National Laboratory, Lemont, Illinois 60439, United States*
[4]*Department of Physics, Faculty of Arts and Sciences, Najran University, Najran, Saudi Arabia.*
[5]*Advanced Materials and Nano-Research Centre (AMNRC), Najran University, Najran, 11001, Saudi Arabia*
[6]*Center for Underground Physics, Institute for Basic Science (IBS), Daejeon 34126, Korea*
[7]*IBS School, University of Science and Technology (UST), Daejeon 34113, Korea*

**Corresponding Author Email: mhlee@ibs.re.kr*

Single crystals of NaI activated with 0.02, 0.05, 0.1, and 0.5mole% indium (In) have been grown with a two-zone vertical Bridgeman furnace. The luminescence measurement of the crystals was carried out under the excitation of X-rays and photoluminescence (PL). Under X-ray excitation, the emission has broad bands peaking at 450 and 535 nm. The maximum radioluminescence of the crystal is obtained for NaI:0.1mol%In. The pulse height spectra of the crystals are measured under 662 keV γ-rays excitation from a Cs-137 source. The absolute light yields of the crystals are calculated by comparing the 662 keV γ-rays photopeak with that measured for reference CsI:Tl and the indium-doped NaI crystals. The maximum light yields of ~ 42,000 photons/MeV is found for NaI:0.5%In.

Keywords: Single Crystal, Bridgeman furnace, luminescence spectrum, absolute light yield, pulse height spectra.

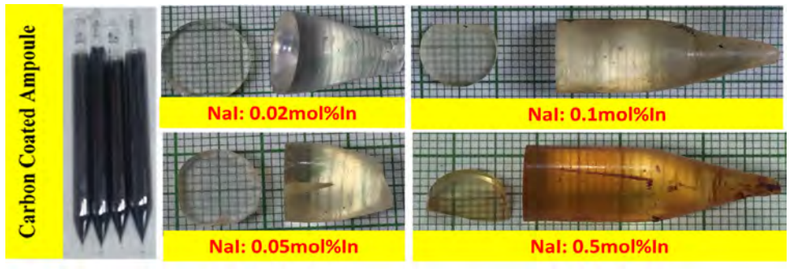


Fig. 1. Photographs of carbon-coated ampoules, grown NaI crystals, and crack-free samples with ~2 mm thickness.

CA28 Characterization of novel composite scintillators based on the epitaxial structures of TbAG:Ce/GAGG:Ce and TbAG:Ce,Mg/GAGG:Ce in mixed radiation field

A. Syntfeld-Każuch[1], T. Szczęśniak[1], J. Iwanowska-Hanke[1], V. Gorbenko[2], Y. Syrotych[2] ,O. Sidletskyi[3], Yu. Zorenko[2,4]

[1]*National Centre for Nuclear Research, Otwock-Świerk, Poland*
[2] *Department of Physics, Kazimierz Wielki University in Bydgoszcz, Bydgoszcz, Poland*
[3]*Institute for Scintillation Materials, NAS of Ukraine, Kharkiv, Ukraine*
[4]*Oncology Center in Bydgoszcz, Bydgoszcz, Poland*

Corresponding Author Email: Agnieszka.Syntfeld@ncbj.gov.pl

This work is the next step in the development of multilayer composite scintillators based on the epitaxial structures of garnet compounds for the simultaneous registration of the different components of the mixed radiation fluxes [1]. The composite scintillators under study were the LPE grown doubly-layered structures based on the TbAG:Ce and TbAG:Ce,Mg single crystalline films (SCF), grown using liquid phase epitaxy (LPE) method onto substrates, prepared from the Czochralski grown GAGG:Ce bulk single crystals (SC). We present the preliminary studies of the scintillation light yield (pulse high spectra (PHS)) and decay kinetic under excitation γ-rays of ^{137} Cs (661 keV), α-particles (5.5 MeV) and 59-keV γ-rays of ^{241}Am, and β-particles of 90Sr in order to evaluate the α, β, and γ discrimination performance of the composite scintillators in mixed radiation fields. Fig.1 shows the α-spectra measured for all scintillator samples. For the TbAG:Ce SCF/GAGG:Ce SC scintillators, the two peaks are registered suggesting probably different response of the and γ-rays, respectively. In the case of TbAG:Ce,Mg SCF/GAGG:Ce SC scintillators, the strong decrease of light output and acceleration of the scintillation decay kinetic was observed for all types of radiation due to Mg^{2+} co-doping of SCF scintillator (Table 1). Fig.2 presents the light pulse shapes of composite samples measured using an experimental setup from [2]. Both types of and TbAG:Ce,Mg SCF/GAGG:Ce SC composites shows good ability for the simultaneous registration of the mentioned components in mixed radiation fields with very suitable (>0.2) FOM values.

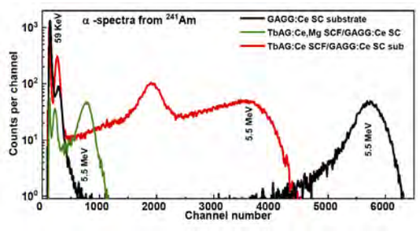


Fig.1. The PHS of TbAG:Ce SCF/GAGG:Ce SC and TbAG:Ce,Mg/GAGG:Ce composite scintillators in comparison with GAGG:Ce SC substrate under excitation by 5.5-MeV α-particles from 241Am.

1. S. Witkiewicz-Lukaszek et al. Materials, 15(3), 1249, (2022)
2. L. Swiderski et al. Nucl. Instrum. Methods A, 749, 68 (2014)

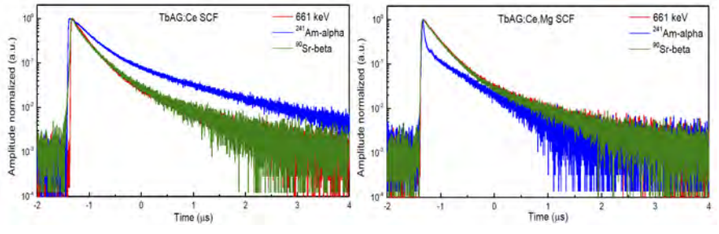


Fig.2. The light pulse shapes of TbAG:Ce/GAGG:Ce and TbAG:Ce,Mg/GAGG:Ce under excitation by 661-keV γ-rays, α-particles (241Am), and β−particles (90Sr).

SCF	Substrate	Radiation	τ_1,μs	Inten.1,%	τ_2,μs	Inten.2,%	FOM (α/γ), τ_1/τ_2,	FOM (α/β), τ_1/τ_2,	FOM (β/γ), τ_1/τ_2,
-	GAGG:Ce SC	γ ^{137}Cs	0.24	71.3	0.97	28.7	0.09/0.08	0.12/0.24	0.03/0.16
		β ^{90}Sr	0.23	67.0	0.70	33.0			
		α ^{241}Am	0.29	76.6	1.14	23.4			
TbAG:Ce	GAGG:Ce SC	γ ^{137}Cs	0.25	71.9	1.00	28.1	0.18/0.22	0.25/0.39	0.08/0.19
		β ^{90}Sr	0.21	55.9	0.68	44.1			
		α ^{241}Am	0.35	59.8	1.57	40.2			
TbAG:Ce,Mg	GAGG:Ce SC	γ ^{137}Cs	0.26	72.4	0.99	27.6	0.79/0.27	0.79/0.27	0.006/0.005
		β ^{90}Sr	0.25	72.4	0.98	27.6			
		α ^{241}Am	0.03	18.2	0.57	81.8			

Table 1. The decay times, τ, and intensities of scintillation light components for the samples under study.

FOM $(\alpha/\gamma) = (\tau_\alpha - \tau_\gamma)/(\tau_\alpha + \tau_\gamma)$; FOM$(\alpha/\beta) = (\tau_\alpha - \tau_\beta) / (\tau_\alpha + \tau_\beta)$; FOM $(\beta/\gamma) = (\tau_\beta - \tau_\gamma)/ (\tau_\beta + \tau_\gamma)$

1. S. Witkiewicz-Lukaszek et al. *Materials*, **15(3)**, 1249, (2022)
2. L. Swiderski et al. *Nucl. Instrum. Methods A*, **749**, 68 (2014)

Poster Sessions

CA29 GSAG:Ce based single crystals: scintillation performance optimization and bottlenecks

Martin Nikl[1], Jan Pejchal[1], Pavel Bohacek[1], V. Babin[1], Ondřej Zapadlík[1,2], Alena Beitlerova[1], Romana Kucerkova[1]

[1]*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[2]*Crytur spol. s r. o., Turnov, Czech Republic*

Corresponding Author Email: nikl@fzu.cz

The discovery of multicomponent garnet single crystal scintillators in 2011 (1) started a new period in R&D of oxidescintillators. Due to band-gap engineering the $Gd_3Al_{5-x}GaxO_{12}$:Ce, 2<x≤3, (GAGG:Ce) single crystals became the most efficient bulk single crystal scintillator within oxide materials with further practical advantages of mechanical and chemical stability and stable crystal growth in industrial conditions. Because of Ga presence in chemical formula, there is an unavoidable need of usage of iridium crucible (2) which makes their production very expensive. Thus, the question arose, if electronic band structure of such a multicomponent garnet can be shaped and electronic traps suppressed in a similar way as in GAGG:Ce, but with chemical formula of material which would enable to use a cheaper technology, based e.g. on molybdenum crucibles used for industrial production of classical YAG:Ce or LuAG:Ce single crystals (3).

Such a choice includes the Sc-admixed garnets of the general formula $(Gd,Sc)_3(Al,Sc)_2Al_3O_{12}$, doped by Ce^{3+} (GSAG:Ce), which were revisited in recent literature (4,5). We have employed the micropulling-down and Czochralski crystal growth methods to prepare such crystals starting from reported congruent composition (6). Using molybdenum crucible we achieved LY up to about 10000 ph/MeV (7), more than four times lower compared to GAGG:Ce grown with the same technique (1).

In this contribution we will report the results of composition tuning and postgrowth thermal annealing to increase scintillation efficiency and LY of GSAG:Ce. We will also show spectral and decay characteristics of these crystals and discuss the origin of lower performance of GSAG:Ce compared to GAGG:Ce.

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(2) K. Kamada, et al, Multiple shaped-crystal growth of oxide scintillators using Mo crucible and die by the edge defined film fed growth method. J. Cryst. Growth 535, 125510 (2020).

(3) Ji. Kvapil, et al,. Czochralski Growth of YAG:Ce in a Reducing Protective Atmosphere. J. Cryst. Growth 52, 542 (1981).

(4) D. Spassky et al, Influence of the Sc cation substituent on the structural properties and energy transfer processes in GAGG:Ce crystals. CrystEngComm 22, 2621 (2020).

(5) K. L. Hovhannesyan, et, al, Radiation Damage of GSAG:Ce Crystals with Codopants under
Gamma-Ray Irradiation. Phys. Stat. Sol (a) 220, 2300386 (2023).

(6) I. A. Kaurova, et al, Evaluation of Stability Region for Scandium-Containing Rare-Earth Garnet Single Crystals and Their Congruent-Melting Compositions. J. Cryst. Growth 468, 452 (2017).

(7) O. Zapadlík,et al, Composition-Engineered GSAG Garnet: Single-Crystal Host for Fast Scintillators. Crystal Growth & Design 21, 7139 (2021).

CA30 Pushing timing performances of heterostructured scintillators with Double-Sided Readout

Carsten Lowis[1,2], Fiammetta Pagano[3], Giulia Terragni[1,4], Marco Pizzichemi[5], Joshua W. Cates[6], Karl Ziemons[7], Karl-Josef Langen[2], Etiennette Auffray[1]

[1]*CERN, Meyrin, Geneva, Switzerland*
[2]*RWTH Aachen University, Aachen, North Rhine-Westphalia, Germany 3Instituto de Instrumentación para Imagen Molecular (i3M), Valencia, Spain*
[4]*Technical University of Vienna, Vienna, Austria*
[5]*University of Milano-Bicocca, Milan, Country*
[6]*Lawrence Berkeley National Laboratory, Berkeley, California, United States of America*
[7]*FH-Aachen University of applied Sciences, Aachen, North Rhine-Westphalia, Germany*

Corresponding Author Email: carsten.lowis@cern.ch

Heterostructures made of alternating layers of two scintillators with complementary properties offer a novel approach to address the trade-off between high detection efficiency and fast timing properties, which is critical for advances in fields such as Time of flight Positron Emission Tomography (TOF-PET). Nevertheless the coincidence time resolution of heterostructures is also limited by its intrinsic geometry made of layers of two scintillators worsening the light transport which could be improved by knowledge of Depth of Interaction as recently demonstrated.

The method used for DoI measurement is a double-sided readout configuration, where a scintillator is sandwiched between two silicon photomultipliers, which are read out by high-frequency electronics. This setup allows for the acquisition of energy and time signals from both sides of the scintillator, providing valuable information on the Depth of Interaction and light transport. Our study involves the measurement of bulk and layered BGO, bulk and layered EJ232 as well as layered heterostructures made out of these two materials. These materials have been extensively studied due to their complementary properties: BGO offers high gamma-ray stopping power, while EJ232 offers fast timing properties with a similar light yield. The experimental work is also supported by Monte Carlo based simulations.

The aim of this study is to gain a better understanding of the light transport, depth of interaction and related timing optimisation in the heterostructured scintillators. We focus on the individual materials in bulk and layered structure that make up the heterostructured scintillator.

This work is carried out in the framework of the Crystal Clear Collaboration and supported by CERN Austrian and Gentner (grant no. 13E18CHA) Doctoral Student Programs and CERN Budget for Knowledge Transfer to Medical Applications.

Poster Sessions

CA31 Structural and Luminescent Study of Mn^{2+}-Doped $NaBiF_4$ Synthesized via a One-Step Method

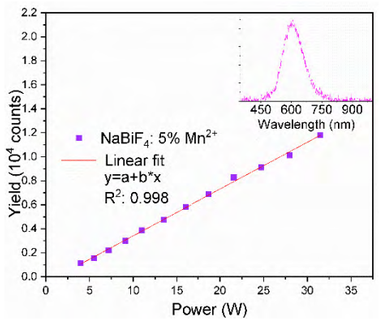
Thaíse de J. Monteiro[1], Willamis A. Silva[1], Adriano. B. Andrade[1,2], Mário E.G. Valerio[1,2], and Zélia S. Macedo[1,2]

[1]Laboratory of Preparation and Characterization of Materials, Physics Department, Federal University of Sergipe, 49100-000 São Cristóvão - SE, Brazil

[2]Materials Science and Engineering Department, Federal University of Sergipe, 49100-000, São Cristóvão – Sergipe, Brazil

Corresponding Author Email: mmonteiro@academico.ufs.br

This work reports the structural, spectroscopic, and scintillating properties on a series of novel Mn- activated $NaBiF_4$. The material was synthesized using a one-step method through the reverse precipitation approach at room temperature [1]. The combination of fast methodology and doping with transition metal, sparing the use of rare earth metals as activating ions, is unprecedented for this host. An investigation with X-ray diffraction measurements and Rietveld refinement showed the formation of the pure hexagonal phase of $NaBiF_4$. A linear decrease in the lattice parameters was observed as the doping concentration increases, which was associated to the successful doping process. Photoluminescence excitation under 235 nm showed a broadband emission for all doped samples. The emission was attributed to the Mn^{2+} ion transition from the lowest excited level $^4T_{1g}(^4G)$ to the $^6A_{1g}(^6S)$ fundamental state [2]. The excitation spectrum is composed of at least four bands, consistent with Mn^{2+} ions in octahedral coordination environment. The performance of Mn-doped NaBiF4 when exposed to X-rays was also investigated, showing that the material already presents a noticeable scintillation signal at a minimum dose rate exposure of 0.3 mGy/s. The scintillating yield versus Mn-doping content shows no quenching effect in the concentration range studied. The luminescence stability and material reusability were investigated, and no degradation was observed, indicating good stability under successive irradiation, as well as resistance for high absorbed X- ray irradiation dose. Chromaticity coordinates for all doped samples showed that the emission wavelength does not shift as the doping concentration increases, indicating the absence of Mn clusters in the sample.



Radioluminescence measurements of the 5%Mn -doped $NaBiF_4$ when exposed to X-ray in function of X-ray tube power.

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2. Y. Li, S. Qi, P. Li, Z. Wang, "Research progress of Mn doped phosphors," RSC Adv, 7, 38318–38334 (2017).

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CA32 Collection Efficiency of Scintillation Light Depending on Surface Treatment of BGO

Dongwoo Jeong[1], Jaeyoung Cho[1,2], Eunjin Choi[1], Luan Thanh Nguyen[1], H.J. Kim[1]

[1] Department of Physics, Kyungpook National University, Daegu, 41566, Korea

[2]Center for Underground Physics, Institute of Basic Science, Daejeon, 34126, Korea

Corresponding Author Email: hongjoo@knu.ac.kr

A Bismuth Germanate ($Bi_4Ge_3O_{12}$, BGO) scintillation crystal is suited for detecting gamma rays due to its high density and effective atomic number. These properties make BGO popular in various fields, especially in medical imaging [1] or high energy physics experiments [2]. Since BGO has a high refractive index of 2.15, a significant portion of the scintillation light produced within BGO is trapped by internal reflection due to a high index of refraction and cannot reach the photodetector. Consequently, the efficiency of scintillation light collection is influenced by the surface treatment of BGO. Notably, a diffused surface can improve this efficiency due to the random reflection on the surface. In this presentation, we investigate the difference in light collection efficiency between polished and diffused surfaces of a 3 × 15 cm^2 side using a 3 × 3 × 15 cm^3 BGO crystal employed in the KNU Advanced Positronium Annihilation Experiment (KAPAE-II) [3]. By coupling 8 polished BGO crystals to the photomultiplier tube (PMT) window on one side of the 3 × 3 cm^2 BGO surface using optical grease, we measured them, then reprocessed them with 3 × 15 cm2 four side surface diffusion and measured eight diffused BGO crystals again. We observed a significant improvement in the scintillation performance of diffused BGO crystals. Specifically, diffused BGO exhibited an average light collection efficiency approximately 56% higher than polished BGO. This led to an approximately 21% enhancement in energy resolution. Furthermore, we also investigate this effect using the Monte Carlo simulation of optical photons in the GEANT4 toolkit. The detailed results will be presented in this presentation.

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Poster Sessions

CA33 New Approach to Obtaining Organic Polycrystalline Scintillators

Anton Krech, Yaroslava Polupan, Igor Lazarev, Eugenia Martynenko, Sergii Makhota, Sergii Minenko, Oleg Tarasenko, Ilarion Khromiuk

Institute for Scintillation Materials of NAS of Ukraine, Kharkiv, Ukraine

Corresponding Author Email: Antonkrech@gmail.com

In the last two decades, organic polycrystalline scintillators have been developed, which are effective for the detection of short-range radiation. They, unlike fragile single crystals, have more opportunities for mechanical processing, which allows to creation of detectors of complex shapes. One of the disadvantages of polycrystalline scintillators is a significant deterioration in the optical and, as a consequence, scintillation characteristics of scintillators as their thickness increases [1]. The starting material for the production of existing polycrystalline scintillators is grains obtained by cryogenic crushing of a single crystal ingot or plates obtained by recrystallization from an organic solvent. All currently known methods of obtaining organic polycrystalline scintillators are limited to the use of these materials for pressing, and to improve the characteristics of polycrystalline scintillators, the parameters of temperature, pressure, pressing time, grains size, etc., are varied.

Photographs of p-terphenyl polycrystals with a diameter of d = 20 mm and a thickness of h = 5 mm obtained by hot pressing: (a) a sample obtained by a known method of pressing crystalline granules, (b) a sample obtained by a new method.

This work proposes a new approach to obtaining the starting material for polycrystalline scintillators based on *p*-terphenyl. The material for pressing in the form of an ingot by zone melting is obtained. The proposed method of producing polycrystals provides a significant improvement in their scintillation and optical characteristics in relation to existing analogs. An increase of the light output when detecting alpha and beta radiations up to 185% is observed. An increase in optical transmittance by 170% at a wavelength corresponding to the maximum of the photoluminescence (360 nm) is observed, too. As you can see in the Figure polycrystal scintillators obtained by new methods are visually more transparent in relation to those obtained by known methods.

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CA34 Ba-Si Glass Scintillation Material Heavy Loaded with Large Amount of Gd for High Energy Physics Applications

Valerii Dormenev, Kai-Thomas Brinkmann, Dzmitry Kazlou, Rainer W. Novotny and Hans-Georg Zaunick

2nd Physics Institute Justus-Liebig-University Giessen, Germany

Corresponding Author Email: valery.dormenev@exp2.physik.uni-giessen.de

Future progress in the development of scintillating materials for ionizing radiation detectors is one of the key challenges in the planning and construction of future high-luminosity accelerator complexes. Proper choice of the working material for the detectors is a mandatory step to ensure functionality and durability of the detection equipment in a harsh radiation environment. Nowadays inorganic scintillators exhibit an attractive combination of features: high density, high scintillation yield, fast scintillation response, and high radiation tolerance to electromagnetic as well hadronic components of radiation background. Glass based on barium di-silicate $BaO\text{-}_2SiO_2$ (DSB) promises to become a new scintillation material suitable for operation even in harsh radiation environments such as those in collider experiments [1-3]. This glass is produced from an inexpensive initial charge and allows manufacturing in large quantities by standard technology exploited in the glass industry. Its light yield is lower than that of the most efficient scintillators but exceeds the light yield of $PbWO_4$, which is nowadays the most extensively used scintillating material in HEP experiments [4]. After an appropriate tempering process, the transparent glass ceramics contains nano-sized particles of Ba_2SiO_5 enhancing the scintillation properties of the material. Significant progress in the technology optimization was achieved in the frame of the ATTRACT project [5]. These glasses, heavily loaded with Gd, were investigated too. Here, we report recent test results of the glass samples produced in close cooperation with the glass manufacturer Schott (Mainz, Germany). Figure 1 contains photos of the investigated samples of three different geometries.

Figure 1. Photos of glass samples delivered by Schott: set of 2x2x0.5 cm3, 2x2x5 cm3 samples (left) and 2x2x15 cm3 sample (right)

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5. E. Auffray et al. "Development of radiation-hard and cost-effective inorganic scintillators for calorimetric detectors based on binary glass compositions doped with cerium – SCINTIGLASS," available at https://attract-eu.com/wp- content/uploads/2019/05/SCINTIGLASS.pdf.

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Poster Sessions

CA35 High Resolution Temporal Response of Organic Plastic Scintillators in γ-fields

Jacob Sebastian[1], Bethany Goldblum[1,2], Josh Brown[1], Thibault Laplace[1]

[1]*University of California, Berkeley, Berkeley, CA., USA*
[2]*Lawrence Berkeley National Laboratory, Berkeley, CA., USA*

Corresponding Author Email: jacob.sebastian@berkeley.edu

A Time Correlated Single Photon Counting (TCSPC) system was developed at Lawrence Berkeley National Laboratory to measure the temporal response of plastic scintillators under γ-ray irradiation. A suite of organic scintillators from Eljen Technology—EJ-200, 204, 208, 230, 232, 232Q, and 276D—were investigated under excitation from Cs-137 and Eu-152. Initial analyses suggest a discrepancy between commonly reported intrinsic rise times of these scintillators [1] and the results of this study. The TCSPC setup constructed in this work borrows from the canonical approach by Bollinger and Thomas [2] and improves upon it using modern fast photomultiplier tubes (PMTs) as well as ultrafast digital acquisition.

The temporal responses of these plastic scintillators are of interest in fundamental scintillator physics [3] as well as in facilitating their deployment in novel detector systems [4][5]. The available data on plastic scintillator rise time is lacking in the literature [6], and where provided, often cited without reference to uncertainty nor collection method. Additionally, a detailed study of the inherent rise time of organic plastic scintillators in response to different types of ionizing radiation is lacking in the literature. This study lays the groundwork for investigation of particle dependent pulse shape measurements and could provide insight into the mechanisms for excitation in plastic scintillating media [3].

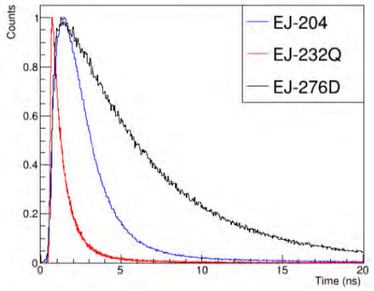

Fig. 1: Normalized Reconstruction of the Temporal Response of EJ-204, EJ-232Q, and EJ-276D, measured using the described TCSPC setup, which have been temporally shifted such that their 10% pickoff time occurs simultaneously.

The TCSPC system uses two Hamamatsu H-6533 PMTs closely coupled to the scintillator under investigation. A Photonis MCP-PMT PP-2365-AD with a manufactured transit time spread of 11 ps is used as the single photon counter and is positioned at a standoff distance to ensure that no more than 1 in 100 events in the primary PMTs results in an event in the MCP-PMT. The system is read out using a LeCroy WaveSurfer oscilloscope with a sampling rate of 10 GHz, triggering on coincidences between the primary PMTs and the single photon counter. The system resolution is dependent on the scintillator being measured and so varies but resolution on the order 45 ps have been achieved.

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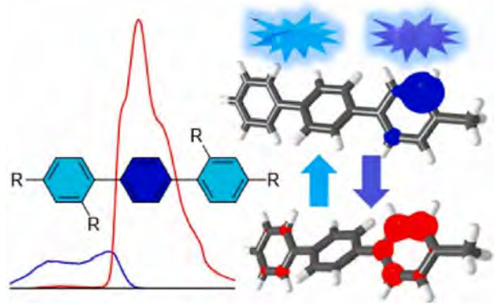
CA36 Structural tailoring of p-terphenyl scaffold: Towards advanced plastic scintillator

Michaela Fecková[1], Martina Vachtlová[1], Jan Podlesný [1], Zuzana Burešová [2], Oldřich Pytela [2], Milan Klikar [2], Jiří Janda [3], Hana Burešová [4], Radek Pjatkan [4], Filip Bureš [1,2]

[1]*Institute of Technology and Business in České Budějovice, České Budějovice, Czech Republic*
[2]*Institute of Organic Chemistry and Technology, Faculty of Chemical Technology University of Pardubice, Pardubice, Czech Republic*
[3] *NBC Defence Institute, University of Defence, Vyškov, Czech Republic*
[4]*NUVIA a.s., Kralupy nad Vltavou, Czech Republic*

Corresponding Author Email: hana.buresova@nuvia.com

A comprehensive series of fifteen p-terphenyl derivatives has been designed and prepared using facile synthetic approaches (Suzuki-Miyaura and Friedel-Crafts reactions). Various alkyl, alkoxy or trifluoromethyl groups have been attached to p-terphenyl to gain both symmetrical and unsymmetrical derivatives. Symmetry breaking accounts for improved solubility of mono-substituted derivatives. Thermal analysis revealed a reversible formation of several crystalline phases and very high thermal robustness. Reduction and oxidation of the parent p-terphenyl π-system affected by the electronic and steric effects of the substituents were recorded by cyclic voltammetry. When compared to parent p-terphenyl, a narrowed HOMO–LUMO gap has been measured/calculated for most of the prepared derivatives. The absorption and emission maxima ranged from 286 to 293 and 341–360 nm, respectively. The latter is affected by the substitution more significantly, the fluorescence quantum yields are within the range of 0.52–0.75. Stokes shifts up to 6400 cm-1 were measured pointing to a large structural rearrangement (planarization) upon excitation.



PTP derivatives were further used as primary and secondary lumino-phores for scintillation. 4-Methyl-p-terphenyl proved to be a superior luminophore with a straightforward synthesis, easy isolation, large solubility and excellent luminescence characteristic. Based on this derivative, a plastic scintillator has been manufactured that showed superior performance as compared to standard and widely used unsubstituted p-terphenyl. Thus, a relatively minor structural change (appending single methyl group) altered scintillation properties significantly.

The work was supported by the Enterprise and Innovations for Competitiveness Operational Programme (OP EIC) "New scintillation systems for ionizing radiation detection" No. CZ.01.1.02/0.0/0.0/ 20_321/0024977, mediated by the Ministry of Industry and Trade of the Czech Republic.

Poster Sessions

CA37 Assessing Age Effects on Pulse Shape Discrimination Capabilities of Organic Glass Scintillators

E. A. Schneider[1], T. E. Maurer[1], K. L. Meagher[1], S. D. Clarke[1], P. L. Feng[2], S. A. Pozzi[1]

[1]*Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI, USA*
[2]*Sandia National Laboratories, Livermore, CA, USA*

Corresponding Author Email: eschne@umich.edu

Organic glass scintillators (OGS) are useful tools in nuclear engineering for their ability to detect both fast neutrons and gamma-rays. However, this material can undergo recrystallization and other forms of aging, which can impact detection efficiency and pulse shape discrimination (PSD) capabilities. An understanding of such changes is necessary for long-term applications of these materials. The University of Michigan Scintillator Laboratory is equipped with capabilities to melt- cast Sandia National Laboratories' small-molecule organic glass scintillators. This process allows for the fabrication of scintillators with custom geometries, and we have produced two OGS scintillators with heights and diameters of 2.54 cm over the last five years. The first cylinder was produced in 2019 with unoptimized melt-cast processes, which exclude current procedures, such as thorough degassing and protective coatings to prevent recrystallization of the scintillator surface. As a result, the cylinder cast in 2019 is not translucent. In the summer of 2022, we cast a 2.54 cm diameter OGS cylinder and compared this cylinder to the aged cylinder in 2019. Using the same readout and electronic system of a DT5730S CAEN digitizer and a 7.62 cm diameter photomultiplier tube, we measured a Cf-252 source with each cylinder individually to evaluate their pulse shape discrimination (PSD) capabilities. Although we found that the newer cast scintillator outperformed the older scintillator's PSD capabilities by roughly 10 percent in terms of the figure or merit at 662 keV, the scintillator cast in 2019 was still PSD-capable and had comparable neutron detection efficiency to the scintillator cast in 2022. We plan to cast another 2.54 cm OGS scintillator in 2024 and repeat this series of Cf-252 measurements with all three scintillators. In this way, we will compare age effects of OGS on PSD-capabilities and detection efficiency.

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CA38 Fast scintillators for APS-U experiments

Chris Campbell[1], Ao Zhang[2], Qingwen Tan[2], Zachary J. Corey[3,*], Liyuan Zhang[4], Aiping Chen[1], Dana M. Dattelbaum[1], Renyuan Zhu[4], Quanxi Jia[3], Guangda Niu[2], C. L. Morris[1], and Zhehui Wang[1,†]

[1] *Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[2] *Huazhong University of Science and Technology, Wuhan 430074, PR China*
[3] *University at Buffalo, Buffalo, NY 14260, USA*
[4] *California Institute of Technology, Pasedena, CA 91125, USA*
[*] *Currently with EWI, Buffalo, NY 14211, USA*

[†] *Correspondence: zwang@lanl.gov*

[For 17th International Conference on Scintillating Materials and their Applications (SCINT 2024), Milan, Italy, July 8-12, 2024]

Advanced Photon Source (APS) at the Argonne National Laboratory is currently undergoing an upgrade towards brighter more coherent hard X-ray sources with a 48- bunch mode. With a pulse-to-pulse bunch spacing about 77 ns, the APS-U may need faster and brighter scintillators than existing ones that are widely used in APS such as LuAG, LSO/LYSO. We have characterized the light yield and decay time of a set of scintillators including perovskite crystals [1], perovskite thin films, and high entropy perovskite thin films [2], powdered scintillators (YAP, LYSO), and existing fast scintillators such as BaF_2, $LaBr_3$ [3]. Possible applications of these scintillators to ultrafast X-ray imaging in APS-U will be discussed [4-5].

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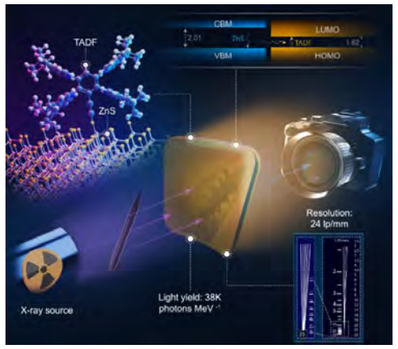
Poster Sessions

CA39 Enhancing the Sensitivity and Spatial Imaging Resolution of a Hybrid X-ray Imaging Screen via Energy Transfer at the ZnS (Ag)–TADF Interface

Shorooq A. Alomar[1], Jian-Xin Wang,[1] and Omar F. Mohammed*, [1]

[1]*Advanced Membranes and Porous Materials Center and KAUST Catalysis Center, Division of Physical Science and Engineering, King Abdullah University of Science and Technology, Thuwal 23955-6900, Kingdom of Saudi Arabia*

Novel scintillation materials have played an indispensable role in the recent remarkable progress witnessed for X-ray imaging technology. Herein, a high-performance X-ray scintillation screen was developed based on a highly efficient hybrid system combining inorganic ZnS (Ag) with thermally activated delayed fluorescence (TADF) scintillator materials via an interfacial energy transfer (EnT) mechanism. ZnS (Ag) has a high X-ray absorption capacity and functions as the initial layer for efficiently converting high-energy X-ray photons into low-energy visible light (acting as a sensitizer) while also serving as an energy donor. The TADF component, on the contrary, is an energy acceptor and forms an active scintillating layer. By harnessing TADF chromophores that can efficiently capture both singlet and triplet excitons, our composite material offers a remarkable spatial imaging resolution of 24 line pairs per millimeter, surpassing those of the majority of existing organic and inorganic scintillators. Further, our interfacial energy transfer strategy effectively amplifies the radioluminescence intensity of the TADF scintillator by a factor of 75, offering an outstanding light yield of 38,000 photons/MeV. This advancement represents a remarkable breakthrough in organic X-ray scintillation technology and is a notable achievement within the X-ray imaging field, paving the way for novel applications in medical imaging and security inspection.



CRYSTALS: GROWTH AND STRUCTURAL CONTROL

CR6 Photoconductivity and Radiation Response of Vapor Grown $Pb_2P_2Se_6$ Single Crystals

Venika Ekanayake[1], Peng Wang[1]

[1]*Department of Chemistry, Queen's University, Kingston, Ontario, Canada*

Corresponding Author Email: 21mvea@queensu.ca

In various fields such as medical imaging, nuclear safety, and security, there is a pressing need for radiation detectors operating at room temperature [1]. An ideal detection material should have high sensitivity to radiation, high density, and an appropriate band gap [2]. The chalcogenide compound $Pb_2P_2Se_6$ has emerged as a promising candidate for cost-effective room temperature X/γ-ray detection [3]. $Pb_2P_2Se_6$ is a semiconductor with an indirect band gap of 1.88 eV and exhibits an electrical resistance of 10^{12} Ω cm. However, challenges persist in the growth of single crystalline $Pb_2P_2Se_6$ using modified vertical Bridgman methods, including the presence of secondary phase particles, grown-in point defects, and engineering hurdles in material purification and crystal growth processes. Initial polycrystalline sample synthesis involved melting lead, phosphorus, and selenium in stoichiometric ratios at 850°C within a hermetically sealed ampoule.

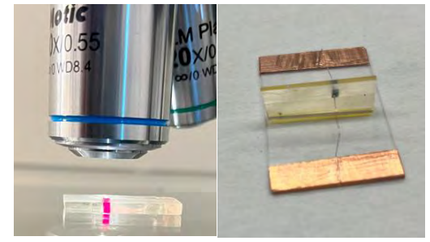


Figure 1 (a) Grown single crystal embedded in epoxy irradiated under visible light, (b) Fabricated detector sample.

Subsequently, single crystals of up to ~7mm in length were grown via the vapor transport (VT) method, employing a gradient temperature profile to enhance size and yield. Confirmation of phase structure and purity was attained through powder X-ray diffraction (PXRD) analysis. These single crystals were then embedded in epoxy and polished to fabricate detector devices. Testing of these devices included evaluating current-voltage characteristics and pulse height measurements to assess the radiation detection performance. The $Pb_2P_2Se_6$ single crystal detectors exhibited exceptional photoresponse and high sensitivity across a voltage range of 1–1000V, with photocurrents 13 orders of magnitude higher than the dark current, indicating outstanding photoresponse to visible light.

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Poster Sessions

CR7 Exploring Cesium Lead Bromide for Emerging Scintillation Applications

Mert Turfanda[1], David Kunar[1], Peng L. Wang[1]

[1]*Department of Chemistry, Queen's University, 90 Bader Ln, Kingston, ON K7L 2S8, Canada.*

Corresponding Author Email: wang.peng@queensu.ca

Cesium lead bromide ($CsPbBr_3$) has emerged as a captivating material in the realm of scintillation applications. Previously, the scintillation properties of $CsPbBr_3$ were reported under cryogenic conditions. [1]. Pure $CsPbBr_3$ crystals exhibited a fast decay response of 1 ns at 7K, a 50k±10k photons/MeV light yield at X-ray excitation (12 keV at ^{137}Cs) and 109k±22k photons/MeV light yield at α-particle excitation (^{241}Am) [1].

Currently, $CsPbBr_3$ has been produced as high purity, large single crystals for semiconducting applications. Hence, the existing growth mechanism and sample preparation method could be easily adapted to produce cesium lead bromide for scintillation applications. In this work, we present the synthesis of binary precursor solutions, purifications and a modified-zone refining methods of produce high purity $CsPbBr_3$ crystals with lower than 1 ppm trace element impurity [2]. As-grown crystals were fabricated into squares of various thickness for potential scintillation property measurements.

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CR8 Growth of Ce:GGAG Scintillation Crystals with Character of High Light Yield and Fast Decay by the Optical Floating Zone Method

Yun Shi[1, 2*], Tong Wu[1, 3], Ling Wang[1, 3], Hui Wang[1], Yifei Xiong[1, 4], Xitang Huang[3], Haibo Wang[4]

[1] State Key Laboratory of High Performance Ceramics and Superfine Microstructure, Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China
[2] R&D center for novel materials, Shanghai Institute of Ceramics ,Chinese Academy of Sciences, Shanghai, China
[3] College of Physical Science and Technology, Central China Normal University, Wuhan, China
[4] School of Material Science and Engineering, Nanjing Tech University, Nanjing, China

Corresponding Author Email: shiyun@mail.sic.ac.cn

Driven by the development of new-generation X-ray computed tomography (X-CT) technology and its demand for high performance scintillator detectors, there has been continuous interests on R&D of novel scintillation materials through composition design or technology optimization. Among those, $(Ce, Gd)_3(Ga, Al)_5O_{12}$ (Ce:GGAG) scintillator was proposed to have the highest light yield in the oxide compounds found so far[1-2]. Ce:GGAG was thus considered as the most potential candidate scintillators in next generation of X-CT detectors with respect to the presently used commercial scintillators, that is, HiLight, Gemstone, and Gd_2O_2S (GOS) ceramics.

Till now, Ce:GGAG crystals were mainly grown by the CZ method and μ-PD method, However, Ga2O3 is easy to decompose and volatilize ($Ga_2O_3 \rightarrow Ga_2O + O_2$) at a high temperature, it needs to be inhibited by O_2-rich atmosphere which is difficule considering the problem of iridium crucible oxidation. In this work, we grown a series of $(Ce_xGd_{1-x})_3Ga_2Al_3O_{12}$ (x = 0−0.8%) (Ce:GGAG) crystals by the optical floating zone (OFZ) method. Fast decay and high ratio of the fast component (71 ns / 66%) were successfully obtained in Ce:GGAG crystals with a Ga/Al = 2/3 ratio, which might be attributed to the suppression of composition deviation by introducing O2 (100%) atmosphere during crystal growth. Stable growth of Ce:GGAG crystal scintillators was accomplished by the traveling solvent floating zone method. Fast decay component was optimized to 64 ns / 85% furtherly. It demonstrates the OFZ and TSFZ method are efficient to grow Ce:GGAG crystals that have an incongruent-melting trend with lower Ga/Al ratio in the compositions. The work gives a potnetial way to extend the exploration range of novel scintillation compounds .

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Acknowledgments

This work was financial support by the National Natural Science Foundation of China (No. 62175249).

Poster Sessions

CR9 Growth of GSAG:Ce scintillator by floating zone method under pressurized oxygen atmosphere

František Zajíc[1], Jiří Pospíšil[1], Romana Kučerková[2], Pavel Boháček[2], Martin Nikl[2],

[1]*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
[2]*Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic*

Corresponding Author Email: frantisek.zajic@matfyz.cuni.cz

Gadolinium-scandium-aluminium garnet (GSAG) was originally studied mainly for its potential as a solid-state laser host, the first article reporting the scintillation properties of the GSAG:Ce was published in 1994 [1]. The effect of Sc admixture on GAGG:Ce has been recently investigated, the balanced composition among Al-Ga-Sc in $Gd_3Sc_2(Al_{3-x}Ga_x)O_{12}$ substantially increased light yield (LY) up to 24 000 ph/MeV showing competitive fast scintillation response with decay times 12 ns (11%) + 56 ns (89%), for the stoichiometry with x = 2 [2].

We present the possibility of preparation of GSAG:Ce scintillator single crystals by laser-diode floating zone method (LDFZM) [3], which decreases considerably the production cost and the unprecedented use age of oxygen overpressure suppresses the creation of oxygen vacancies that contribute to a longer scintillation response, as they act as effective electron traps [4]. These are detrimental in both the Czochralski and μ-PD methods used traditionally for the melt growth of these materials from the crucibles, which either inhibit the presence of any oxygen at all using even a reductive reducing atmosphere (Mo, W crucible) or allow only very low oxygen content in the otherwise neutral atmosphere of nitrogen or argon (Ir crucible). Our sample set shows in general lower scintillation performance compared to μ-PD samples prepared from Ir or Mo crucibles [5], especially in terms of LY. Usage of an oxygen atmosphere results in the stabilization of Ce^{4+} evidenced by related charge transfer absorption transition in absorption spectra. Its presence visibly accelerates scintillation decay in comparison with samples prepared by μ-PD technique. Photoluminescence decays show partial ionization of the $5d^1$ excited state of Ce^{3+}, which might be one of the reasons for lower LY (2600 – 2800 ph/MeV) and slower tail (τ_2 = 75 – 95 ns, $LS_2 \cong$ 70%), due to the delayed luminescence.

Reported results show the potential of utilization of the (laser-diode) floating zone method for the preparation of oxide-based scintillators with high melting point temperatures without costly crucibles. All details of our work are published in the Journal of Crystal Growth [6].

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The work was supported by the Czech Science Foundation under Grant No. 21-17731S., and further supported by the Charles University Grant Agency (Project No. 294123). The preparation of single crystals was performed in MGML (http://mgml.eu/), which was supported within the program of Czech Research Infrastructures (Project No. LM2023065).

CR10 Advancing Figure of Merit in Ce-Doped CLYC and CLLB Crystals: Manipulating Phase Transitions and Cerium Concentrations

Xianggang Zhang, Zhuochen Cai, Jinbo Liu, Kejing Liu, Zhe Kang, Ziang Yin, Qinghua Zhao, Tao Wang*

State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an, Shaanxi, China

Corresponding Author Email: taowang@nwpu.edu.cn

Neutron and gamma detections play a crucial role in homeland security and nuclear energy development. Cs_2LiYCl_6: Ce (CLYC) and $Cs_2LiLaBr_6$: Ce (CLLB) crystals exhibit dual-mode detection capability and excellent scintillation properties. However, the lack of reports on the detailed growth processes hampered the development of high-quality crystals, mainly due to the lack of fine phase diagrams. In this study, the Cs_2LaBr_5-LiBr phase diagram was constructed for the first time. High-quality CLYC and CLLB crystals were prepared using the vertical Bridgman method (VB).

The problem of inaccurate measurement of highly hygroscopic crystals was resolved. Phase transitions were identified through powder XRD and DSC tests. The CLYC and CLLB single crystal ingots were grown with different initial LiX (X=Cl, Br) and Ce doping concentrations. Precise elemental concentrations were measured by ICP-MS. A phase diagram that can guide the growth of CLLB crystals was constructed. Two peritectic reactions of L + Cs_3LaBr_6 ↔ Cs_2LaBr_5 and L + Cs_2LaBr_5 ↔ CLLB, a eutectic reaction of L ↔ CLLB + LiBr appeared in this phase diagram. The initial melt with hyper-peritectic ratios (55<LiX/mol.%<61) was found beneficial to maintain the interface stability during VB crystal growth. Clear CLYC and CLLB crystals (1.5 inch) were grown successfully with low LiX concentration.

The Ce concentrations along the CLYC and CLLB ingots were measured. The effective segregation coefficient of Ce in CLYC and CLLB crystals was 0.22 and 1.59, respectively. The effects of actual Ce concentration on scintillation properties and neutron/gamma discrimination ability were discussed. The optimal energy resolution and neutron/gamma discrimination ability were achieved by adjusting the Ce doping concentration. Figure of Merit (FoM) of 4.2 for CLYC and energy resolution (@662 keV) of 3.0% for CLLB were obtained. Neutron detection devices were prepared and tested at high and low temperatures.

In summary, high-performance CLYC and CLLB crystals were prepared by VB method due to the detailed insights into phase transitions and Ce segregation. The study on growth mechanisms and segregation behavior contribute to advancing elpasolite crystal growth and neutron/gamma detection applications.

Poster Sessions

CR11 Structural, optical, and photoluminescence properties of Ag^+ ion implantation on (100) orientated europium doped β-Ga_2O_3 single crystals

K.V.Akshita, Hariharan. R, S. Moorthy Babu *

Crystal Growth Centre, Anna University, Chennai – 600025, INDIA

**Email: smoorthybabu@yahoo.com; smoorthybabu@gmail.com*

Gallium oxide (Ga_2O_3) is a semiconductor material that has a wider bandgap (4.9 eV) than GaN (3.4 eV) and ZnO (3.37 eV) and is commonly utilized for power devices. β-Ga_2O_3 semiconductor crystals with good transparency in the visible region as well as in the near UV region, good thermal stability, high density, and good radiation hardness are of great interest to extend our knowledge and discovering new options for semiconductor scintillators [1]. Doping of rare earth metals as emission centers is a typical way to enhance scintillation properties. Rare earth-doped Ga_2O_3 semiconductors are considered a good host, additionally the significance of ion implantation to modify the material properties and enhance the potential application in optoelectronic devices [2]. The melt growth methods are most suitable for the production of large-sized Gallium oxide single crystals with high crystalline quality. Among various melt growth techniques, the major advantage of Optical Floating Zone (OFZ) growth eliminates the need for crucibles and thus erases impurity incorporation from crucible walls. In this present work, (100) orientation undoped (β-Ga_2O_3) and Eu:β-Ga_2O_3 single crystals were grown using the OFZ technique under a compressed air atmosphere. Wafer processing optimization was performed, and mechanical polishing (CMP) method. The processed wafers were subjected to Ag^+ ions implantation as a co-dopant on the 100 oriented Eu:β-Ga_2O_3 wafers with a fluence of 1×10^{15} cm^{-2} at 50 keV. The structural, optical properties and photoluminescence properties of before and after Ag^+ ion implanted Eu:β-Ga_2O_3 wafers were investigated.

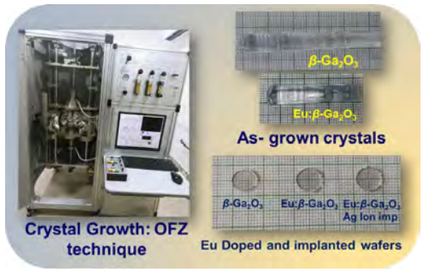

Fig. 1: Experimental design, as-grown single crystals and wafers of β-Ga2O3, Eu:β-Ga2O3 and Ag^+ ion implanted Eu:β-Ga2O3

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CR12 Growth of GSAG:Ce scintillation crystals by the Bridgman method and their characterization

K.L. Hovhannesyan[1], M.V. Derdzyan[1], G. Badalyan[1], G. Kharatyan[1], J. Pejchal[2], M. Nikl[2], C. Dujardin[3,4], A.G. Petrosyan[1]

[1]Institute for Physical Research, National Academy of Sciences of RA, Ashtarak 0203, Armenia,
[2] Institute of Physics of the Czech Academy of Sciences, 16200 Prague, Czech Republic
[3]Universite Claude Bernard Lyon 1, Institut Lumière Matière UMR 5306 CNRS, F-69622, Villeurbanne, France
[4]Institut Universitaire de France (IUF)

khovhannisyan9@gmail.com

GSAG:Ce scintillator is gaining a renewed interest [1,2] since, unlike gallium multicomponent garnets, it can be grown using Mo crucibles, instead of highly expensive Ir-ones. It contains no volatile components and, consequently, no evaporation compensation in starting charge is needed. In this study we present our data on crystal growth by the Bridgman method, actual composition analysis and optical properties of GSAG:Ce crystals with Ca, Mg, Li and Mg(Ca):Li co-doping.

Single crystals were grown in Mo tubes under Ar/H2 atmosphere at rates ≤2 mm/h in a <100> orientation. Distribution of components along the length of the boules measured by SEM for the cases of congruent and stoichiometric melts is in agreement with the data for Czochralski-grown crystals [3]. Regardless of melt composition, crystals tend to grow in congruent composition. Introduction of Ca^{2+} or Mg^{2+}, as in other Ce-doped garnets (LuAG, YAG, GGAG), leads to an increase of absorption below 350 nm, which may indicate the formation of Ce^{4+} states, while no effect is seen with Li^+ co-doping. Despite of almost equal sizes of Sc^{3+} and Li+ ions in octahedral coordination, there is no evidence of such substitution. According to results of gamma-ray irradiation [2], GSAG:Ce,Li exhibits the least induced absorption supporting interstitial location of Li^+ and decrease of the concentration of oxygen vacancies.

Despite a good crystal quality and several co-doping strategies, the scintillation yield does not surpass 10000 ph/Mev. In this contribution, the scintillation properties will be described and analyzed.

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Poster Sessions

CR13 Development and Growth of Low-Cost High-Quality $CsPbBr_3$ Single Crystals for Scintillation Applications

David A. Kunar[1], Matthew F. Webster[1], Serge Nagorny[1], Peng Li Wang[1]*

1Queen's University, Kingston, Ontario, Canada

Corresponding Author Email: david.kunar@queensu.ca

Radiation detecting materials represent a class of materials that can convert ionizing radiation into a detectable, resolved signal. Of them, scintillators are a class of radiation detecting material that can convert ionizing radiation into photons, which can then be captured by an appropriate device. Good candidate materials for scintillation radiation detection require good conversion efficiency, high light yield, large stopping power, and fast decay times [1,2]. Considering these properties, various metal- halide perovskites have been investigated; the all-inorganic perovskite $CsPbBr_3$ has shown promise as both a scintillating and semiconducting radiation detecting material. It exhibits a fast decay time of 1 ns at 7K, and has a high light yield of 50000 ± 10000 ph/MeV under excitation from 12 keV X- rays and 109000 ± 22000 ph/MeV under excitation with α-particles from ^{241}Am [3,4]. While this material shows good promise, production of large volume detector-grade single crystals requires high-quality starting materials that require further processing to reach the desired chemical purity.

In this work polycrystalline $CsPbBr_3$ was synthesized from low-purity reagents ($CsCO_3$, 99% and $PbCO_3$, ACS) and used to produce high-purity, detector grade single crystals through a high efficiency procedure, which consists of purification through melting under flow of H_2 to remove oxide impurities, and zone refining to segregate impurities based on their segregation coefficient [5]. Utilizing this method, large semi-cylindrical single crystal ingots of up to 120 mm in length and 22 mm in diameter with a mass of 200 g were grown from this material. Ingots showed good phase purity and high trace metal purity (2.34 ppm across 73 elements, with the majority impurity being Cl) [5]. The electrical and optical properties of the material were further explored. To better understand the variation of light yield between X-rays and α-particles, comparisons of the luminescence properties of $CsPbBr_3$ grown from our method and the Bridgman method will be studied.

Figure 1: Large single crystal ingot of $CsPbBr_3$.

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CR14 Improvement of the radiation resistance of YAG:Pr and GSAG:Pr garnets by Li^+ co-doping

M.V. Derdzyan[1], K.L. Hovhannesyan[1], I.A. Ghambaryan[1], G. Kharatyan[1], C. Dujardin[2,3], A.G. Petrosyan[1]

[1]Institute for Physical Research, National Academy of Sciences of RA, Ashtarak 0203, Armenia,
[2]Universite Claude Bernard Lyon 1, Institut Lumière Matière UMR 5306 CNRS, F-69622, Villeurbanne, France
[3]Institut Universitaire de France (IUF)

mderdzyan@gmail.com

The γ-ray induced absorption coefficients (μ(ind)) in Pr-doped garnets are usually very high even after low irradiation doses due to formation of F^+- and F-type centers absorbing at around 300 and 370 nm [1,2]. In this study, we present our data on the radiation resistance of Pr^{3+}-doped YAG:Pr and GSAG:Pr garnets with Li^+-codoping, which is seen effective to control oxygen vacancies in YAG [3]. Single crystals with 0.1-0.4 at% of Pr^{3+} and 40-200 ppm of Li^+ were grown by the Bridgman method and irradiated with a ^{60}Co γ-ray source. The values of μ(ind) are calculated at 323 nm, close to the emission maximum of YAG:Pr.

In YAG:Pr, μ(ind) values after the dose 1 kGy are in the range 20-80 m^{-1} increasing with Pr^{3+} concentration. An inverse relationship after the dose 250 Gy was reported for Czochralski-grown crystals [2], although Mo technology was used in both methods. In YAG:Pr,Li(40 ppm) crystals, μ(ind) values show an improvement by a factor of 2. In YAG:Pr,Li(150 ppm), μ(ind) is above 100 m^{-1}, approaching the value observed in YAG:Pr,Ca. The parameter μ(ind) is found to correlate with intensities of color centers present in as-grown crystals below 300 nm (other types of F centers and else defects) which, during irradiation, are transformed into F-type centers absorbing at >300 nm. Li^+ co-doping imparts a much more remarkable effect in GSAG:Pr. In the set of GSAG:Pr, μ(ind) after the dose 1 kGy is around 20 m^{-1} for all concentrations of Pr^{3+} (around 200 m^{-1} after the dose 10 kGy). In the set of GSAG:Pr,Li(50 ppm), this parameter is almost zero after both doses. Introduction of high amounts of Li^+ leads to the same effect as in YAG:Pr.

In both YAG:Pr and GSAG:Pr, evidence is obtained of a decrease of oxygen vacancies after co- doping with small amounts of Li^+, as a result of the charge compensation mechanism [3]. At high concentrations, Li^+ ions are forced into lattice sites increasing the concentration of oxygen vacancies. We can assume that the incorporation behavior of Li^+ is the same in both crystals despite the differences in unit cell volumes and size mismatch between host cations and Li^+.

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CR15 Growth and scintillation properties of CaO and SrO crystals by Core Heating method

Kyoung Jin Kim[1,3], Kei Kamada[2,3], Shiori Ishikawa[3], Rikito Murakami[1,3], Masao Yoshino[2], Takahiko Horiai[1,3], Akira Yoshikawa[1,2,3]

[1]*IMR, Tohoku Univ., Sendai, Miyagi, Japan*

[2]*NICHe, Tohoku Univ., Sendai, Miyagi, Japan*

[3]*C&A Corp., Sendai, Miyagi, Japan*

Corresponding Author Email: kim.kyoung.jin.b7@tohoku.ac.jp

In recent years, the development of new materials for scintillators used in radiation detection has become active, and scintillator properties have been reported both domestically and internationally when a host material is combined with a dopant element that acts as a luminescence center to function as a scintillator. Ca^{48} is known as an isotope that causes double beta decay without neutrino emission, and is used in the CANDLE (CAlcium fluoride for the study of Neutrinos and Dark matters by Low Energy Spectrometer) experiment to observe and explore double beta decay using CaF_2 as a scintillator [1]. While CaO holds promise for applications such as scintillators for double beta decay experiments, CaO and SrO have high melting points of 2572°C and 2531°C, respectively, making it impossible to grow crystals using an Ir crucible. For example, with the skull melt method, which is a single crystal growth method that does not use a crucible, it is difficult to produce crystals in small amounts and in a short time. With the floating zone method, it takes a lot of time and effort to prepare raw material rods and grow crystals, and melting becomes difficult for materials with high transparency to heating light. Therefore, we proposed the Core Heating (CH) method as a new crystal preparation method using molten metal as a heat source. In the CH method, a metal such as Ir is embedded in an oxide raw material as a heat source, and the oxide raw material is melted using the molten metal as a heat source. In this study, CaO and SrO crystals doped with various rare earth elements as emission centers were produced using the CH method, and the crystallinity and scintillator properties of the produced crystals were evaluated.

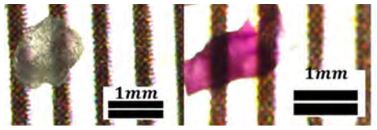

Figure 1 Undoped and Eu-doped CaO crystal grown by CH method.

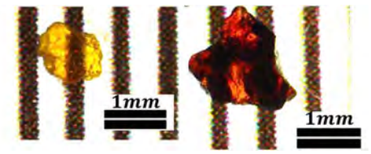

Figure 2 Ce- and Eu-doped SrO crystal grown by CH method.

As an example of the CH method, an Ir metal pellet was embedded in an oxide raw material. By heating and melting the pellet with arc plasma, the surrounding oxide raw material was heated, melted, and solidified to obtain a crystalline material. Figures 1 and 2 show undoped and Eu-doped CaO crystals, and Ce- and Eu-doped SrO crystals as examples of crystals produced. A colorless and transparent crystal was obtained, and when Eu was doped, light emission due to Eu^{3+} 4f-4f was confirmed at 500-700 nm by X-ray excitation. Details of the crystal fabrication method, evaluation of scintillator properties, and fabrication examples of other high-temperature oxides will be reported at the conference.

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CR17 Synthesis and Metal Doping of MAPbBr3 Single Crystals for Cryogenic Scintillator

Somnath Mahato[1,*], Michal Makowski[1] , Dominik Kowal[1], Romakanta Bhattarai[2], Trevor David Rhone[2] and Muhammad Danang Birowosuto[1]

[1] *Lukasiewicz Research Network- PORT Polish Centerfor Technology Development, Wroclaw 54- 066, Poland*

[2]*Department of Physics, Applied Physics, and Astronomy, Rensselaer Polytechnic Institute, Troy, NY, 12180, USA*

Corresponding Author Email: Somnath.Mahato@port.lukasiewicz.gov.pl

The remarkable brightness and rapid scintillation observed in perovskite single crystals (SCs) become even more striking when they are operated at cryogenic temperatures. [1] In this study, we present advancements in enhancing the scintillation properties of methylammonium lead bromide ($MAPbBr_3$) SCs by optimizing the synthesis process and metal doping. We optimized the concentration of antisolvent tetrahydrofuran (THF) to grow bigger-sized (≥5mm) and high- quality $MAPbBr_3$ perovskite SCs displaying bright emission from the entire top and side surface under UV light.[2] Therefore, with these $MAPbBr_3$ SCs with high crystalline quality, efficient bright emission, and low-cost solution processability, $MAPbBr_3$ SCs can be used as fast cryogenic scintillators. [3] According to the low-temperature photoluminescence (PL) measurement, we have observed a structural phase transition from cubic to orthorhombic. To calculate the phonon band structure, we used density functional theory (DFT) using the Vienna ab initio simulation package (VASP) package that uses the projector augmented wave pseudopotential to describe the interaction between valence electrons and ion cores. The Pedrew-Burke-Ernzerhof (PBE) type of generalized gradient approximation (GGA) was used to describe the exchange and correlation functional. [4] We observed that in orthorhombic phase has a higher number of phonon frequencies as compared to the cubic phase. In addition, the frequency range is also higher for the former phase. i.e. the orthorhombic phase has vibrational frequencies between 140 and 180 cm^{-1} as well, whereas no such frequency exists for the cubic phase in that range. While the appearance of such frequency might be the result of numerical errors in the calculations. To verify this, we perform the phonon calculations of cubic phase in a larger supercell of size 3 × 3 × 3. We find that the soft mode still exists in its phonon spectrum, indicating cubic phase as a possible metastable phase of $MAPbBr_3$. This also agrees with our experimental results.

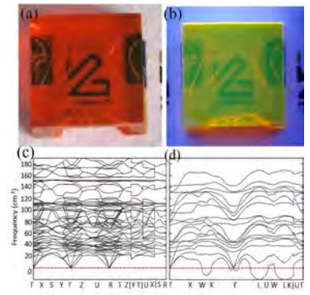

Figure 1: Photographs of THF-0.4M $MAPbBr_3$ single crystals under (a) normal light and (b) UV light. Phonon spectra of $MAPbBr_3$ in low frequency regime (c) orthorhombic (d) cubic phase.

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MECHANISMS AND THEORY OF SCINTILLATION

TH8 Acceleration of Emission Decay in Ce-doped Multicomponent Garnet Scintillators by Heavy Magnesium Codoping

S. Nargelas[1], A. Solovjovas[1], Y. Talochka[1], Ž. Podlipskas[1], G. Tamulaitis[1], M. Kucera[2], Z. Lucenicova[2]

[1]*Institute of Photonics and Nanotechnology, Vilnius University, Vilnius, Lithuania*
[2]*Faculty Mathematics & Physics, Charles University, Prague, Czech Republic*

Corresponding Author Email: saulius.nargelas@ff.vu.lt

Future applications of scintillation detectors demand substantial improvements in the timing properties of scintillating materials for both medical imaging and high-energy physics experiments. Garnet-type single crystals, including multicomponent garnets enabling electronic band structure engineering, are attractive matrices in the search for faster Ce-activated scintillators. Codoping by divalent ions, typically calcium (Ca^{2+}) or magnesium (Mg^{2+}), has been demonstrated as an effective way to improve the scintillation response time of Ce-activated scintillators. The improvement in scintillation timing properties is generally attributed to the stabilization of Ce^{3+} ions in their tetravalent state, which is more favorable for capturing irradiation-induced electrons to the emitting Ce centers, and suppressing the influence of trapped electrons on the rise time of the scintillation response.

We present a study aimed at unveiling the characteristics of recombination centers in heavily aliovalently codoped Ce-activated garnet-type scintillators, and revealing the interplay between radiative and nonradiative recombination processes. The investigation was conducted on a series of LuGAGG:Ce,Mg films with a nominal composition of $Lu_{0.8}Gd_{2.2}Ga_{2.5}Al_{2.5}O_{12}$:Ce,Mg, grown via isothermal dipping liquid phase epitaxy on (100)-oriented Czochralski-grown $Gd_3Ga_{2.7}Al_{2.3}O_{12}$ substrates using $BaO-B_2O_3-BaF_2$ flux. The films had a constant Ce content of 1%, whereas the Mg content varied from 0 to 6000 ppm. The epitaxial growth method facilitated a higher Ce segregation coefficient in the flux enabling the congruent incorporation of up to 1 at% of Ce. Additionally, the method allowed for a high concentration of codopant ions without substantial deterioration of the crystalline lattice.

To investigate the excitation relaxation dynamics, we utilized photoluminescence, time-resolved photoluminescence, and transient absorption spectroscopy within a wide range of sample temperature, from 80K to 600K. Time-resolved cathodoluminescence spectroscopy at 10 keV electron beam for excitation was employed to complement the results obtained using optical methods.

The observed acceleration of Ce emission with increasing aliovalent codoping level was attributed to the coexistence of two types of emission centers: regular Ce^{3+} ions and Ce^{3+}+Mg^{2+} centers consisting of Ce ions located close to Mg ions. We revealed that the latter centers exhibit a smaller energy barrier for thermal quenching and introduce a barrier-free channel of nonradiative recombination resulting in a faster overall emission decay. Increasing the magnesium content results in a growing fraction of Ce^3 ions affected by magnesium, transforming them into Ce^3+Mg^2 centers. A comparison of light emission intensity dependence on the codoping level at the electron beam and selective photoexcitation of Ce^{3+} emitting level shows that the excitation losses due to nonradiative recombination of electron-hole pairs already populating the emitting centers, especially the Ce^{3+}+Mg^{2+} center, dominate over the excitation losses during the excitation transfer to the centers.

TH9 High-throughput Experimental Screening for Performance Modulation of Bismuth Germanate Crystals for Next-generation High-energy Physics

Mingxue Deng[1], Yangmin Tang[1, 2], Lei Chen[1], Dong Wang[1,2], Junfeng Chen[1,2]

[1]*Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China*
[2]*University of Chinese Academy of Sciences, Beijing, China*

Corresponding Author Email: jfchen@mail.sic.ac.cn

The international high-energy physics (HEP) community has proposed several next-generation intensity frontier facilities, such as the Circular Electron Positron Collider (CEPC) and the Future Circular Collider (FCC) [1]. To meet the challenges of unprecedentedly high event yields and extreme radiation environments in the electromagnetic calorimeters of these colliders, development of high- density inorganic scintillators with higher radiation hardness and fast decay is needed. As a classic high-density scintillator with excellent comprehensive performance, bismuth germanate ($Bi_4Ge_3O_{12}$, BGO) crystal has been one of the main candidate detection materials for the calorimetry of CEPC and FCC [1]. To meet harsh requirements of these HEP facilities, it is urgent to regulate and further improve the performance of BGO crystals.

In this study, a combined-material high-throughput experimental method was used to rapidly screen out the components that modulate the scintillation performance of BGO, providing a research basis for subsequent long cycle (1-2 months), high-cost crystal growth [2-3]. Polycrystalline samples with rich Bi vacancy and Ce-doping were prepared. BGO polycrystalline with rich Bi vacancy shows significantly enhanced luminous intensity and radiation hardness. The optimized $Bi_{3.6}Ge_3O_{12}$ polycrystalline shows 178% of luminescence intensity compared to that of normal $Bi_4Ge_3O_{12}$ polycrystalline. After 50 h of ultraviolet irradiation, $Bi_{3.6}Ge_3O_{12}$ with rich Bi vacancies possesses ~80% of original luminescence intensity, much superior to the 60% for BGO. The existence of the Bi vacancy is identified by experimental and theoretical studies. The mechanism studies show the Bi vacancies could cause the symmetry destruction of the local field around the Bi^{3+} ion. It enhances scintillation luminescence by increasing the probability of radiative transition while resisting nonradiative relaxation caused by irradiation damage. A Ce-doping strategy is adopted for efficiently improving the overall performance (e.g., irradiation resistance, decay time). The optimized Ce-doped BGO (BGO:Ce) displays higher radiation resistance ability under UV irradiation (97% of original) and a faster fluorescence lifetime (269 ns), superior to pure BGO. Furthermore, BGO:Ce shows ~30% luminescence intensity of pure BGO, well eliminating the oversaturation of SiPM coupled with scintillation detectors. Theoretical calculations imply that an intense competition between electron or hole traps and Ce ions (Ce^{3+}, Ce^{4+}) can effectively reduce the concentration of color centers, thus enhancing irradiation resistance ability. What's more, the results of BGO:Ce single crystal also further validates their significantly faster scintillation decay time and enhanced irradiation hardness with light output reduction.

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TH10 Triplet Reflection at Boundaries of Grains of Organic Composite Detectors and Its Influence on Their Scintillation and Optical Characteristics

Ilarion Khromiuk, Anton Krech, Oleg Tarasenko, Eugenia Martynenko, Nataliya Karavaeva

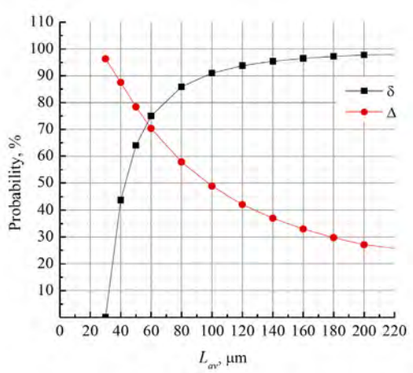
Institute for Scintillation Materials of NAS of Ukraine, Kharkiv, Ukraine

Corresponding Author Email: ikhromiuk@gmail.com

The task of separate detection of ionizing radiations with different values of the specific energy losses has great practical and scientific importance. This can be either the case of detection, for example, neutron fluxes in the presence of a gamma background, or spectroscopy of fast neutrons themselves.

For these tasks, several types of organic scintillators are widely used. The technology for obtaining organic single crystals imposes strict restrictions on their maximum size and shape and is quite expensive. To solve this problem, new scintillation materials were created. These are heterostructured organic scintillators containing scintillation grains. These grains are connected either by sintering during hot pressing (polycrystals), or are introduced into a transparent gel composition (composite scintillators). [1].

This work is devoted to the influence of grain size on the scintillation characteristics of composite scintillators of stilbene and *p*-terphenyl. The effect of reflection of a triplet exciton from the boundary of an organic scintillator crystal [2] was not previously taken into account, since its influence was insignificant for previously studied samples. However, in the case of composite scintillators, in which the diffusion displacement of the triplet exciton is close in magnitude to the size of its individual micrograins, this effect is significantly enhanced. The results of modelling the diffusion of triplet excitons in a single spherical grain confirmed the results of previous studies, in which it was experimentally shown that the optimal grain size under experimental conditions is 60 μm (see Fig).



Theoretically calculated optimal size of a stilbene-based composite scintillator in case of irradiation with alpha- particles of ^{239}Pu source.

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NANO- AND METAMATERIALS, HYBRIDS, AND OTHER NOVEL MATERIALS

NA13 Raman Spectroscopy and Optoelectronic Properties of Green Dye Doped Nanoparticles Embedded Polymer for Sensing Applications

Haitham Al-Tameemi* and Maha Al-Hamadani

Laser Applications Research Group (LARG), Department of Physics, College of Science, University of Basrah, Basrah, Iraq

**Corresponding Author: Email: haithamsaadon@yahoo.com (Haitham)*

Recently, significant scientific and technological interest has focused on dye-sensitized optical sensor based on polymer-inorganic nanoparticles. Dye-doped polymer nanoparticles are a new category of materials which exhibit good optoelectronic properties. These materials are interesting because of their flexible and transparent nature, and they are easy to fabricate. Therefore, the search alternative materials are needed for building construction applications [1- 3]. In this work, nanocomposite thin films developed using green dye extracted from Ficus Carica (FC) doped ZnO nanoparticles embedded into Polyvinyl alcohol (PVA) with varying weight percentage (wt%) of ZnO were prepared and can provide high-performance new materials that find applications in optical sensing. The optoelectronic parameters of the prepared nanocomposite films are presented. The Raman spectroscopy and characterizations of the nanocomposite films were performed and found to be stable in structure. Finally, we show new results regarding the incorporation of nanopartcles into green dye, as well as the performance can be optimized by adjusting the parameters for the nanocomposite films according to different working conditions to meet the requirements. The obtained results showed that the nanocomposite makes it attractive for sensing applications and could open the way for further and future prospective studies among green dyes with nanomaterial or other dyes in developing optical devices and using as sensitizers for solar cell devices.

1. M. A. Rahma and H. L. Saadon, "Natural Dyes Extracted from Plants and their Application to All-Photonic Devices", AIP Conference Proceedings 2190, (2019) p1-9

2. U. Ahmed, A. Anwar," Application of natural dyes in dye-sensitized solar cells. In: Dye-Sensitized Solar Cells. Academic Press, (2022) pp. 45–73.

3. N. M. M. Pires, T. Dong, U. Hanke, and N. Hoivik, "Recent Developments in Optical Detection Technologies in Lab-on-a-Chip Devices for Biosensing Applications," Sensors 14, (2014) p15458-15479

Poster Sessions

NA14 Preparation and Characterization of Natural Dye-Doped TiO2 Nanoparticles: Applications for Green Photonics Devices

Maha Al-Hamadani* and Haitham Al-Tameemi

Laser Applications Research Group (LARG), Department of Physics, College of Science, University of Basrah, Basrah, Iraq

**Corresponding Author: Email: mahabct@yahoo.com (Maha)*

Dye-doped nanoparticles (NPs) have taken a highly of interest due to their exceptional physico-chemical characteristics, and that results in new optical properties can be useful for the use of new photonic devices. Dye-doped NPs produce a highly amplified optical signal compared with a single dye molecule. Consequently, the green photonics technologies are expected to provide high efficient and low cost devices in optical communication, optical limiting, security etc. This research dedicated to preparing natural dye-doped nanoparticles (NPs). Titanium oxide (TiO_2)-based NPs synthesized by pulsed laser ablation. Natural dye extracted from clitoria ternatea (CT) is dissolved in deionized water and purified. The mixture was filtered using filter paper. CT dye-doped TiO_2 NPs nanocomposite was prepared by varying the concentration of the dye. The nanocomposite material was characterized with X-ray diffraction, SEM, and UV-visible. Results of the CT dye-doped TiO_2 nanocomposite showed interesting optical absorption and emission characteristic, and its figures of merit can be optimized by adjusting the doping concentration. Thus, green and cost effective nanocomposite could be fabricated by doping with CT natural dye which augment their optical properties and make good candidate for green photonic applications in designing optical limiting and other green photonic devices.

1. M. A. Rahma and H. L. Saadon, Natural Dyes Extracted from Plants and their Application to All-Photonic Devices, AIP Conference Proceedings 2190, (2019) p1-9

2. S. Sujecki, Photonics Modelling and Design (CRC Press, Taylor & Francis Group, 2015).

3. Awatif A. Hendi etc, "Dye-sensitized solar cells constructed using titanium oxide nanoparticles and green dyes as photosensitizers", J. of King Saud Uni – Sci. 35, (2023), p 102555

NA15 Assessment of Electron-Vibrational Interaction (EVI) in $4f^{n-1}5d^1$ Excited States of Ce^{3+} and Pr^{3+} ions doped Scintillator Nanomaterials

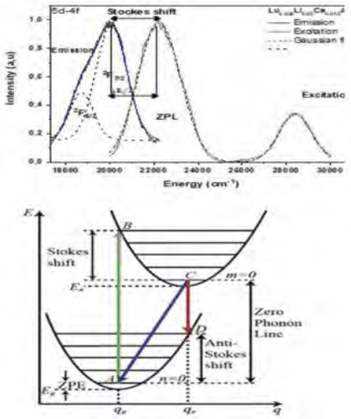
L. Guerbous

Physics Division/Nuclear Research Center of Algiers, 02 Bd. Frantz Fanon, BP 399 Alger,

Corresponding Author Email l.guerbous@crna.dz, guerbous@yahoo.fr

The luminescence of Ce^{3+} and Pr^{3+} plays a key role in the detection of high-energy ionizing radiation, thanks to their parity allowed for the 5d → 4f transitions. Indeed, the 5d → 4f transition energies of the Ce^{3+} and Pr^{3+} ions spanning a wide spectral range depend on the host compounds, which requires the in-depth study of the understanding of this dependence. In fact, ions in a host lattice interact with the vibrations of the lattice, inducing nonradiative transitions. Whatever the strength of the coupling, there is always a competition between radiative and nonradiative transitions. The 4f ($^2F_{5/2}$) → 5d excitation and 5d → 4f ($^2F_{5/2}$) emission depends upon the host and therefore, it is important to analyze EVI parameter for 5d electron state of Ce^{3+} and Pr^{3+} in such materials hosts. Dense material oxides based on yttrium, lutetium and gadolinium nanoscintillators, such as $(Lu, Y)_3Al_5O_{12}$, (Lu, Y)PO_4, (Lu, Y, Gd)BO_3, (Y, Lu, Gd)SiO_5 possessing exceptional luminescence properties, particularly when they are doped with Ce^{3+} or Pr^{3+}, thus giving the possibility to be candidates for scintillation applications.

In this work, we perform comparative and assessment studies of the EVI of Ce^{3+} and Pr^{3+} doped nanoscintillateurs 5d excited states by the estimation of the four parameters namely the Stokes shift, Zero Phonon-Line (*ZPL*), the Huang–Rhys factor (*S*) and the effective phonon energy (ħω) (Figure). Verification of the results obtained was carried out by modeling the shapes of the 5d → 4f emission bands of Ce^{3+} and 5d4d → 4f of Pr^{3+} [1] and look for good agreement with the experimental spectra, thus confirming the validity of the analysis carried out.



Excitation and emission experimental spectra, with Gaussian fitting curves. Franck–Condon diagram of the ground and excited states. of the optical center in solids.

1. L. Guerbous, M. Seraiche and O.Krachni, Photoluminescence and electron- vibrational interaction in $4f^{n-1}5d$ states of Ce^{3+} or Pr^{3+} ions doped LnBO3 (Ln= Lu, Y, La) orthoborates materials Journal of Luminescence 134, 165 (2013).

Poster Sessions

NA16 Are (Gd,Y)VO_4:Eu^{3+} Nanoparticles RT Protectors or Enhancers?

S.L. Yefimova[1], P.O. Maksimchuk[1], V.K. Klochkov[1], K.O. Hubenko[1,2], O.V. Tomchuk[3,4]

[1]*Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine*
[2]*Leibniz Institute for Solid State and Materials Research Dresden, 01069 Dresden, Germany*
[3] *ISIS Neutron and Muon Source, Rutherford Appleton Laboratory, Harwell Oxford, Didcot, OX11 0QX, United Kingdom*
[4] *The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Radzikowskiego 152, Kraków 31-342, Poland*

Corresponding Author Email: ephimovasveta@gmail.com

Radiation therapy (RT) has become one of the first lines treatment modalities in oncology. Unfortunately, cancerous cells could be resistant to RT that requires enhanced doses of irradiation. However, high doses of radiation, in their turn, inevitably damage healthy cells and tissues located near the treatment area that limits exposed radiation doses. Recently, a new strategy in RT for cancer treatment based on the application of nanoparticles (NPs) containing high-Z elements and possessing high X-ray absorption has been proposed [1].

Here we report the effects of X-ray irradiation on hydroxyl radical (*.OH*) generation in aqueous solutions containing (Gd,Y)VO_4:Eu^{3+} nanoparticles pre-treated at different conditions. (Gd,Y)VO_4:Eu^{3+} NPs were synthesized by the colloidal route and characterized using TEM, XRD, XPS, SAXS methods.

Obtained experimental data have revealed that a preliminary treatment of (Gd,Y)VO_4:Eu^{3+} NPs with UV light is the effective tool to change drastically their redox properties. (Gd,Y)VO_4:Eu^{3+} NPs, which were UV-light pre-treated (L-GdYVO), exhibit strong *.OH* generation during X-ray exposure, whereas the same NPs, which were kept in the darkness before the experiment (D-GdYVO), show radioprotective action. The mechanism of D-GdYVO radioptotective action (*.OH* scavenging) is ascribed to the presence in the (Gd,Y)VO_4:Eu^{3+} NPs crystal lattice of a large amount of V^{4+} and V^{3+} ions. Electrons stored in vanadium ions participate in neutralization of *.OH* formed at both water radiolysis and water splitting via reaction with the h^+ -mediated reaction. The mechanism of X-ray induced *.OH* generation in L-GdYVO is more complicated and three processes could be separated: (i) direct *.OH* generation with the participation of thermalized holes (h^+) formed in NPs at X-ray irradiation, (ii) X-ray facilitated jumps of h^+ formed in the valence band at UV light pre-treatment and trapped in local levels formed by RSP, and (iii) formation of hydrogen peroxide (H_2O_2) via photo- induced electrons interaction with oxygen molecules and it further radiolysis under X-ray exposure. Thus, depending on pre-treatment condition, we can change oppositely the redox properties of (Gd,Y)VO_4:Eu^{3+} NPs that makes this nanomaterials unique theranostic agents for RT enhancement allowing the problem of RT resistant hypoxic tumour to be overcame.

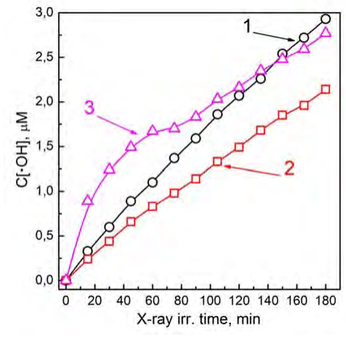


Figure 1. Changes of .OH concentration in water solutions containing 0.5 g/L (Gd,Y)VO_4:Eu^{3+} NPs during X-ray irradiation: 1 – control (without NPs); 2 – NPs stored in the dark conditions; 3 – UV-light pre-treated NPs.

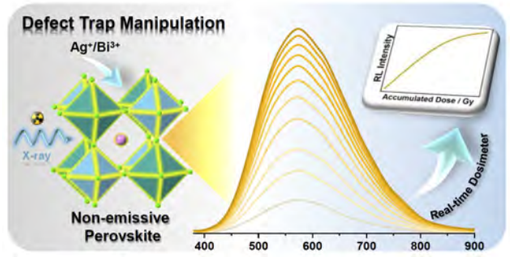
1. S. Goel, D.Ni, W. Cai, "Harnessing the Power of Nanotechnology for Enhanced Radiation Therapy", ACS Nano 11 5233 (2017).

NA17 Manipulation of Shallow-Trap States in Halide Double Perovskite Enables Real-Time Radiation Dosimetry

Yumin Wang[1], Yaxing Wang[1], Shuao Wang[1]

1 State Key Laboratory of Radiation Medicine and Protection, School for Radiological and Interdisciplinary Sciences (RAD-X) and Collaborative Innovation Center of Radiation Medicine of Jiangsu Higher Education Institutions, Soochow University, Suzhou 215123, China

Corresponding Author Email: shuaowang @ suda.edu.cn



Storage phosphors displaying defect emissions are indispensable in technologically advanced radiation dosimeters.1 The current dosimeter is limited to the passive detection mode, where ionizing radiation-induced deep-trap defects must be activated by external stimulation such as light or heat. Herein, we designed a new type of shallow-trap storage phosphor by controlling the dopant amounts of Ag^+ and Bi^{3+} in the host lattice of $Cs_2NaInCl_6$. A distinct phenomenon of X-ray-induced emission (XIE) is observed for the first time in an intrinsically nonemissive perovskite. The intensity of XIE exhibits a quantitative relationship with the accumulated dose, enabling a real-time radiation dosimeter. Thermoluminescence and in situ X-ray photoelectron spectroscopy verify that the emission originates from the radiative recombination of electrons and holes associated with X-ray induced traps. Analysis of temperature-dependent radioluminescence spectra provides evidence that the intrinsic electron−phonon interaction in 0.005 Ag^+@$Cs_2NaInCl_6$ is significantly reduced under X-ray irradiation. Moreover, 0.025 Bi^{3+}@ $Cs_2NaInCl_6$ shows an elevated sensitivity to the accumulated dose with a broad response range from 0.08 to 45.05 Gy.2 This work discloses defect manipulation in halide double perovskites, giving rise to distinct shallow-trap storage phosphors that bridge traditional deep-trap storage phosphors and scintillators and enabling a brand-new type of material for real-time radiation dosimetry.

1. Yanagida, T.; Okada, G.; Kawaguchi, N. Ionizing-radiation induced storage-luminescence for dosimetric applications. J. Lumin. 207, 14 (2019).

2. Wang, Y M.; Chen G Y.; et al. Manipulation of Shallow-Trap States in Halide Double Perovskite Enables Real-Time Radiation Dosimetry. ACS Cent. Sci. 9, 1827 (2023).

Poster Sessions

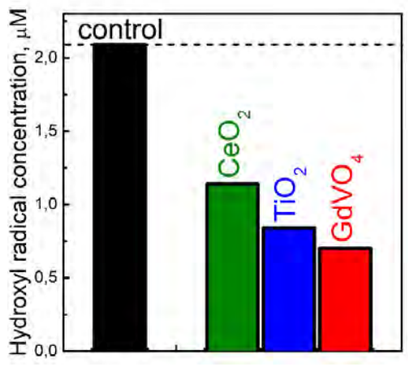
NA18 Radioprotective Properties of Oxide Nanocrystals

Kateryna Hubenko[1,2], Pavel Maksimchuk[1], Vladimir Klochkov[1], Iryna Bespalova[1], Andrey Onishchenko[3], Lesya Demchenko[4,5], Svetlana Yefimova[1]

[1]*Institute for Scintillation Materials, National Academy of Sciences of Ukraine, Kharkiv, Ukraine*
[2]*Leibniz Institute for Solid State and Materials Research, Dresden, Germany*
[3]*Kharkiv National University of Radio Electronics, Kharkiv, Ukraine*
[4]*National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine*
[5]*Stockholm University, Stockholm, Sweden*

Corresponding Author Email: k.hubenko@gmail.com

Cellular respiration in living cells generates biologically active molecules known as reactive oxygen species (ROS). Among these ROS, superoxide anions, hydrogen peroxide, and hydroxyl radicals are produced within mitochondria and play pivotal roles in cellular metabolism. However, an elevation in hydroxyl radical (•OH) levels, the most potent oxidants among ROS, can instigate various pathological processes within cells, ranging from heightened lipid peroxidation of cell membranes to DNA damage. Hydroxyl radicals are generated through water radiolysis during X-ray or gamma irradiation of cells. Their extremely high reactivity, coupled with an average lifespan of only a few nanoseconds in a biological environment, poses a considerable challenge for the cell's internal defense mechanisms in effectively neutralizing them. In response, we propose the utilization of three distinct types of oxide nanocrystals - containing variable valence ions (CeO_2, TiO_2, and $GdVO_4$) - as promising materials for the efficient neutralization of hydroxyl radicals.



Neutralizing of •OH radicals formed during radiolysis of water solutions containing synthesized nanocrystals.

These nanocrystals, CeO_2, TiO_2, and $GdVO_4$, exhibit remarkable capabilities in scavenging hydroxyl radicals generated in water solutions during X-ray irradiation. Their hydroxyl radical-neutralizing properties are intricately linked to the high concentration of reduced variable valence ions (such as Ce^{3+} in CeO_2, Ti^{3+} in TiO_2, and V^{4+}/V^{3+} in $GdVO^4$), which possess the ability to donate electrons during hydroxyl radical neutralization reactions. Small oxide nanocrystals, characterized by the presence of structural imperfections like oxygen vacancies, enable the reduction of neighboring variable valence ions, as validated by XPS experiments for all three types (CeO^2, TiO^2, and $GdVO^4$).

The proficiency of these small oxide nanocrystals containing variable valence ions (CeO^2, TiO^2, and $GdVO^4$) in efficiently neutralizing hydroxyl radicals in aqueous solutions highlights their potential as effective antioxidants and radioprotectors within living cells. This promising avenue opens new possibilities for cellular defense and therapeutic applications.

This research was supported by the Philipp Schwartz-Initiative of the Alexander von Humboldt Foundation.

NA19 On the origin of the light yield enhancement in polymeric composites scintillators loaded with dense nanoparticles

Irene Villa[1], Angelo Monguzzi[1], Roberto Lorenzi[1], Matteo Orfano[1], Vladimir Babin[2], František Hájek[2], Karla Kuldová[2], Romana Kučerková[2], Alena Beitlerová[2], Ilaria Mattei[3], Hana Buresova[4], Václav Čuba[5], Lenka Prouzová Procházková[2,5], and Martin Nikl[2]

[1]*Dept. Materials Science, University of Milano-Bicocca, 20125 Milano, Italy*
[2]*Institute of Physics of the Czech Academy of Sciences (FZU), Czech Republic*
[3]*INFN Sezione di Milano, via G. Celoria 16, 20133, Milan, Italy*
[4]*NUVIA a.s, Trojanova 117, 278 01 Kralupy nad Vltavou, Czech Republic*
[5]*Faculty of Nuclear Sciences and Physical Engineering CTU in Prague, Czech Republic*

Corresponding Author Email: irene.villa@unimib.it

Fast emitting plastic scintillators are currently highly requested for advanced applications where high signal-to-noise detections is required in a short time window as like for rare event in high energy physics experiments, or to acquire high quality image for diagnostics at low doses of radiotracers.[1] Polymeric composite nanoscintillators are proposed in tandem with traditional dense inorganic crystals to realize heterostructures exploiting the benefits from both the building block materials, i.e. fast time response and high light yield (LY).[2] However, the density of plastic scintillators is low, thus they show a limited stopping power of high energy radiation and low light output intensity. Additional dyes as wavelength shifter can be used to harvest more efficiently the energy deposited in the matrix and then populate the final emitters through energy transfer mechanisms. However, this strategy results in a delayed system's time response. The loading of the polymeric host with high-Z nanoparticles is another strategy proposed to enhance the stopping power of plastics and sensitize their scintillation but preserving the fast time response. To point out the mechanism behind the LY enhancement in composites, we investigate the scintillation properties of polymeric composites based on polystyrene doped with POPOP as scintillating dye. This is then modified i) by adding the p- terphenly (TP) as wavelength shifter and ii) by loading with hafnium dioxide (HfO_2) nanoparticles (ρ= 9.68 g cm-3). The scintillation mechanism is modelled considering the energy transfer processes involved as a function of the material composition and studied by photoluminescence and scintillation spectroscopy. Notably, the light yield scintillation enhancement of 200% achieved with the loading of HfO_2 nanoparticles is comparable to the one obtained using the wavelength shifting dye while preserving the scintillator fast time response. We ascribe this effect to a locally enhanced release of energy in proximity of the nanoparticles. The locally increased density of diffusing charges boosts their recombination probability to form the emissive POPOP molecular excitons, thus increasing the material light yield. Our findings indicate that the loading with optically inert dense nanoparticles could be an excellent strategy to surpass the limits of the currently employed fast emitting conjugated materials by finely controlling the punctual release of energy to manipulate the charges recombination kinetics at the nanoscale.

1. J. Perego, "Highly luminescent scintillating hetero-ligand MOF nanocrystals with engineered Stokes shift for photonic applications" Nature communications 13.1, 3504 (2022)

2. M. Orfano, "Fast emitting nanocomposites for high-resolution ToF-PET imaging based on multicomponent scintillators", arXiv preprint arXiv:2309.14968 (2023)

Acknowledgement

PRIN 2020-SHERPA H45F2100343000, MINERVA H25E22000490006 and LUMINANCE H53D23004540001; HORIZON 2020 - SPARTE FET OPEN 899293; MSCA-WF 101003405-HANSOME, and CZ.02.01.01/00/22_008/0004596/MEYS project.

NA20 Perovskite nanocrystals with nanosecond luminescence as a prototype of a fast scintillator

Tamara Skrypnyk, Iryna Bespalova, Oleh Viahin, Svetlana Yefimova, Oleksandr Sorokin

Institute for Scintillation Materials of NAS of Ukraine, Kharkiv, Ukraine

Corresponding Author Email: iiganinabespalova@gmail.com

The development of scintillation materials science and modern applications of scintillation detectors require a cheaper scintillator manufacturing process at the same time with more stringent requirements in terms of their light output and fast output. For example, in time-of-flight positron emission tomography a coincidence time resolution method is used for which a spatial resolution is strongly dependent on a time resolution [1,2]. Thus, researchers aim to achieve a 10 ps time resolution to obtain the spatial resolution on the millimeter scale [3,4]. Such systems have shown the possibility of obtaining a time separation of several tens of picoseconds. As a result, different nanoscale scintillators have been actively studied to respond to this demand. It has recently been shown that layer perovskite nanocrystals (PNCs) can be a material that can meet all the requirements [5,6]. However, the use of nanocrystals does not aliminate the application of traditional bulk crystals. On the contrary, a sandwich-like structure combining the bulk scintillator with high stopping power and semiconductor nanocrystals with ultrafast decay times is considered a promising way for novel detectors [1,4-6].

In this work, we considered new composite scintillation materials based on luminescent PNCs $CsPbX_3$ (X = Br, Cl). Due to the quantum size effect, that PNCs have fast nanosecond luminescence. It is also possible to control their optical properties in a wide spectral range by replacing anions in the Cl/Br series, which leads to a change in the bandgap. Such properties of these PNCs allow us to consider them as scintillation materials.

The colloidal solution of PNCs was prepared with LARP-technology. Optical and scintillation parameters of PNCs in a polymethyl methacrylate (PMMA) film without a substrate were defined. The obtained $CsPbX_3$-PMMA films have intense photoluminescence signal and nanosecond luminescence decay time ($\langle\tau\rangle \geq 2$ ns). Moreover, the advantage of such composite films is that use of PNCs makes it possible to obtain transparent films or bulk materials containing few scattering centers for scintillation photons. The CsPbX3-PMMA films also have a very fast scintillation response of $\langle\tau\rangle \geq 1.4$ ns. Our studies show the prospects of the creation of high-speed scintillation detectors based on lead halide perovskite nanocrystals.

This research received funding through the EURIZON project, which is funded by the European Union under grant agreement No.871072 and in the frame of Horizon Europe ERA Widening Project no. 101078960 “TWISMA”. The authors thank the Ukrainian army for the opportunity to make this work.

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2. P. Lecoq, et al. “Inorganic scintillators for detector systems. Physical principles and crystal engineering”, Cham, Switzerland: Springer International Publishing, 2nd ed. (2017).

3. P. Lecoq, et al. “Roadmap toward the 10 ps time-of-flight PET challenge,” Phys. Med. Biol., 65, 21RM01 (2020).

4. J. Perego, et al. “Composite fast scintillators based on high-Z fluorescent metal-organic framework nanocrystals,” Nat. Phot., 15, 393 (2021).

5. S.K. Gupta, Y. Mao, “Recent advances, challenges, and opportunities of inorganic nanoscintillators,” Front. Optoelectron., 13, 156 (2020).

6. A. Dey et al. “State of the Art and Prospects for Halide Perovskite Nanocrystals”, ACS Nano, 15, 10775 (2021).

NA21 Development of New Composite Scintillators Based on Poly(divinylbenzene) Aerogels with PPO and POPOP Dopants

P. Antico[1], G. D’Amora[1], C Daniel[2,1], A. Monguzzi[3], A. Comotti[3], J. Perego[3], M. Orfano[3], C. Dujardin[4], B. Sabot[5]

[1]Nano Active Film S.r.l., Napoli, Italy
[2]Dipartimento di Chimica e Biologia, Università degli Studi di Salerno, Fisciano (SA), Italy
[3]Dipartimento di Scienza dei Materiali, Università degli Studi Milano-Bicocca, Milano, Italy
[4]Institut Lumière Matière UMR5306, Université Claude Bernard Lyon 1, Villeurbanne, France
[5]Université Paris-Saclay, CEA, LIST, Laboratoire National Henri Becquerel, Palaiseau, France

Corresponding Author Email: cdaniel@unisa.it

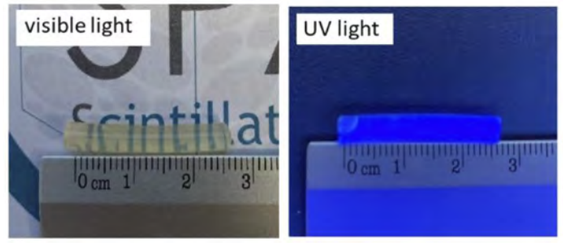
The detection of radioactivity is very important in many fields, such as energy production in nuclear power plants, medicine in diagnosis and treatment, customs inspection, homeland security.

For γ-ray emitting isotopes such as ^{60}Co and ^{137}Cs, it is easy to measure and analyze radioactivity, and chemical separation from other radioisotopes is hardly required. On the other hand, low energy beta-ray emitters such as ^{3}H, ^{14}C, and ^{63}Ni have low depth penetration, β-rays cannot penetrate a thick medium and this makes them difficult to analyze [1].

Generally, low-energy β-rays have been measured in systems such as liquid scintillation counters and gas proportional counters, but this approach requires a long time for pretreatment and waste generated after the analysis is harmful to the environment.

Recent rapid advances in organic matter and nanotechnology have brought attention to solid composite porous scintillators as an alternative approach [2].

In this contribution we will report on the preparation and the characterization of highly transparent polydivinylbenzene (PDVB) aerogels with apparent porosity up to 40 % and surface area (BET) up to 650 m2/g doped with 2,5-diphenyloxazole (PPO) and 1,2-bis (5-phenyl-oxazolyl- 2)-benzene (POPOP) fluorescent dyes (see Figure).



PDVB aerogel doped with PPO and POPOP dyes under visible and UV light.

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2. M. Orfano et al., “Porous composites based on scintillating metal-organic frameworks nanocrystals for radioactive gas detection” SCINT 2022 - 16th SCINT 2022 Scintillating Materials and their Applications, Sept 2022, Santa Fe, USA

Acknowledgement: this research has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 899293–SPARTE.

Poster Sessions

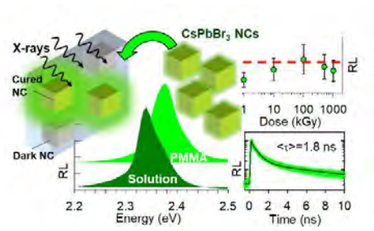
NA22 Scintillation Properties of CsPbBr3 Nanocrystals Prepared by Ligand-Assisted Reprecipitation and Dual Effect of Polyacrylate Encapsulation

F. Cova[1], A. Erroi[1], M. Zaffalon[1], A. Cemmi[2], I. Di Sarcina[2], J. Perego[1], A. Monguzzi[1], A. Comotti[1], F. Rossi[3], F. Carulli[1], and S. Brovelli[1]

[1]*Department of Materials Science, University of Milano - Bicocca, 20125 Milano, Italy*
[2]*ENEA Fusion and Technology for Nuclear Safety and Security Department, ENEA Casaccia Research Center, 00123 Rome, Italy*
[3]*IMEM-CNR Institute, 43124 Parma, Italy*

Corresponding Author Email: francesca.cova@unimib.it

Lead halide perovskite nanocrystals (LHP- NCs) embedded in polymeric hosts are gaining increasing attention as a new generation of highly scalable and cost- affordable nanocomposite scintillation detectors for a variety of technologically relevant applications. Despite important advances in the design of LHP-NC scintillators, important questions are still outstanding. Specifically, very little is currently known about the scintillation properties and stability of LHP-NCs prepared by the Ligand Assisted Re-Precipitation (LARP) method, which allows mass scalability at room temperature unmatched by any other type of nanostructure, and the impact of incorporating LHP-NCs into polyacrylate hosts is still largely debated.



Here we show that LARP-synthesized $CsPbBr_3$ NCs have comparable scintillation and radiation hardness properties to NCs from less scalable hot injection routes [1] and combine spectroscopic and radiometric techniques to unravel the effects of their incorporation into polyacrylate hosts. A dual effect of the polar acrylic groups is found: partial degradation of the NCs luminescence is counterbalanced by the passivation of electron-poor surface defects, suppressing defect-related contributions to scintillation emission. Side-by-side experiments on $CsPbBr_3$ NCs with tailored surface defects highlight that the ultimate balance between such beneficial and detrimental effects of polymer encapsulation on the optical and scintillation properties is determined by the surface defect density and offer useful guidelines for further materials optimization.

1. M. L. Zaffalon, F. Cova, et al. "Extreme γ-ray radiation hardness and high scintillation yield in perovskite nanocrystals", Nat. Photonics, 16 (12), 860−868 (2022)

This work was funded by the Horizon Europe EIC Pathfinder program, Project 101098649- UNICORN, and by the Italian Ministry of Research PRIN program, Project IRONSIDE.

NA23 Radioluminescence and photoluminescence energy transfer in $CeF_3:Tb^{3+},Eu^{3+}$ nanocrystals

M. Crozzolin[1], J. Ueda[2], G. Okada[3], M. Back[1]

[1]*Ca' Foscari University of Venice, via Torino 155, 30172 Venezia−Mestre, Italy*
[2]*Graduate School of Advanced Science and Technology, Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, Ishikawa 923-1292, Japan*
[3]*Department of Applied Chemistry, Kanazawa Institute of Technology, Nonoichi, Ishikawa 921- 8501, Japan*

Corresponding Author Email: michele.crozzolin@unive.it

Since the 1980s, research on bulk scintillators with Ce^{3+} activators has flourished following Takagi and Fukazawa's elucidation of the rapid scintillation mechanism in $Gd_2SiO_5:Ce^{3+}$ [1]. Collaborative efforts led by the Crystal Clear Collaboration and the SCINT conference have significantly advanced scintillator technology, particularly focusing on the CeF_3 system, with applications ranging from positron emission tomography (PET) to high-energy physics (HEP) calorimeters [2].

Despite initial interest in HEP, CeF_3's versatility as a nanomaterial has sustained ongoing research, especially in emerging fields like theranostics, such as X-ray-induced photodynamic therapy (XPDT). CeF_3 nanoparticles, known for their reactive oxygen species generating capability [3], offer potential in emitting infrared (IR) light.

In this study, we investigate the phenomenon of energy transfer (ET) by comparing it's activation both in photoluminescence (PL) and radioluminescence (RL), in order to gain deeper insights into this latter process.

Results obtained from analyzing the CeF_3:(Tb,Eu) system provide evidence of substantial differences between the two processes. RL results suggest the presence of PL-like energy transfer via direct excitation of Tb rather than a double ET Ce → Tb → Eu pathway. This result warrants further investigation into the system's behavior under ionizing radiation.

Moreover, vacuum ultraviolet (VUV) analysis indicates a potential deviation in the nature of a PLE band at 300 nm from current understanding, in line with recent hypotheses [4].

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3. S. Clement et al. "X-ray induced singlet oxygen generation by nanoparticle-photosensitizer conjugates for photodynamic therapy: determination of singlet oxygen quantum yield", Sci. Rep., 6, 19954 (2016).
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Poster Sessions

NA24 Flexible setup for the characterization of innovative scintillating nanocrystals

Emanuele Mazzola[1,2], Etiennette Auffray[3], Chiara Brofferio[1,2], Silvia Capelli[1,2], Stefano Dell'Oro[1,2], Luca Gironi[1,2], Claudio Gotti[1,2], Massimiliano Nastasi[1,2], Matteo Salomoni[1,3], Vojtěch Zabloudil[3,4]

[1]*University of Milano-Bicocca, I-20126 Milano, Italy*
[2]*INFN section of Milano-Bicocca, I-20126 Milano, Italy*
[3]*European Organization for Nuclear Research (CERN), Geneva, Switzerland*
[4]*Czech Technical University in Prague, Prague, Czech Republic*

Corresponding Author Email: e.mazzola@campus.unimib.it

Nanocomposite (NC) scintillators are bulk matrices of different materials that incorporate innovative scintillating crystals with diameters in the nanometer range. NC scintillators aim at combining high energy resolution, efficiency and stability, while ensuring mass scalability of the detectors.

The production process for nanocrystals has been consolidated over the years and today it allows for a full energy separation between absorption and emission spectra. This feature is crucial in preventing auto-absorption in samples with dimensions in the centimeter range. Due to their exceptional properties and cost-effective production, these materials are rapidly gaining traction in both research and commercial domains [1].

The UNICORN project aims to create unprecedented NC-scintillator detectors using engineered nanomaterials for radiation detection across diverse applications. The primary investigation is neutrinoless Double Beta Decay (0νDBD), an extremely rare nuclear process whose observation would prove that the lepton number is not a conserved symmetry and that neutrinos have a Majorana-mass component, thus paving the way towards Beyond Standard Model scenarios.

In the study of 0νDBD, nanocrystals containing candidate 0νDBD-emitting nuclides, such as ^{116}Cd, ^{82}Se, or ^{130}Te, are of particular interest. To develop competitive NC for 0νDBD, nanocrystal concentrations >10% are mandatory. However, such a high concentration poses significant challenges, including nanocrystal agglomeration and light self-absorption by the sample.

In this work, we present an experimental setup designed to characterize NC scintillators as particle detectors within a controlled environment with adjustable pressure and temperature. We use Silicon PhotoMultipliers (optically coupled with the NC through optical grease) for the light readout and alpha, beta and gamma sources to study the response to different types of radiation. In particular, we are able to produce custom alpha sources, that can directly be implanted on the scintillator. In order to extract the largest information from the pulses, we acquire the whole signal waveforms, thus allowing for an optimized offline analysis of amplitude and shape.

We present preliminary results of characterizing scintillators in terms of light yield and quenching factor.

In parallel with the measurements, we are developing Geant4 Monte Carlo simulations of both standard organic and NC scintillators. Dedicated measurements with well-known scintillators can be performed to validate the simulations, which in turn will help us to better understand measurements with new compounds.

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This work has been performed in the framework of Pathfinder Open project UNICORN (GA 101098649).

NA25 Scintillation performance of 2D Perovskite single crystals

S. Alanazi[1], A. Dickinson[1], J. Ghosh[1], C. Crean[1], P.J. Sellin[1], L. Basiricò[2], A. Ciavatti[2], L. Margotti[2], B. Fraboni[2],

[1]*University of Surrey, Guildford, UK*
[2]*University of Bologna, Italy*

Corresponding Author Email: p.sellin@surrey.ac.uk

The development of perovskite scintillators has seen significant advances in recent years, including scintillation from perovskite nanoparticles and single crystals. The synthesis of perovskites using low- cost growth methods has also been widely studied, including solution-growth and slow-cooling crystallization techniques. The ability to engineer the optical properties of perovskite scintillators is a further advantage, for example by changing the chemical composition or the dimensionality of the material structure. The family of hybrid organic-inorganic 2D perovskite materials are of particular interest as scintillators, such as the Ruddlesden-Popper (RP) class of 2D perovskites [1,2]. In RP perovskites inorganic perovskite layers are interspersed with bulky organic cations which act as spacers between the layers. There materials show high light yields, good X-ray absorption due to high-Z atoms, and a large Stokes shift. Furthermore, their nanosecond scintillation decay times are well suited to medical applications where fast scintillation is required, such as TOF-PET.

In this study we report the scintillation performance of single crystal samples of the RP 2D perovskites BA_2PbI_4 and PEA_2PbBr_4. No additional dopants were used in the synthesis of the materials. Crystal synthesis was carried out by a slow cooling (BA sample) and controlled evaporation (PEA sample) method [3]. The scintillation light yield, compared to a standard sample of BGO, was measured using an integrating optical sphere with a 50 kVp X-ray beam. Of the 2 perovskite materials studied, the phenethylamine (PEA) lead iodide crystal showed 3.5x the effective brightness of BGO, which is equivalent to an estimated light yield in excess of 28,000 ph/MeV.

Other RP 2D perovskite materials potentially offer similar, or improved performance [4]. We will show a systematic comparison of the scintillation performance of a range of RP 2D perovskite crystals, and discuss their performance in terms of light yield, decay time and their potential for use as X-ray and gamma spectroscopy detectors.

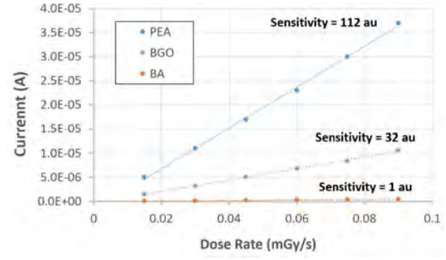

Figure 1: Comparison of 50 kVp X-ray scintillation light output for 2mm thick crystals of BA_2PbI_4 and PEA_2PbBr_4 single crystals, compared to BGO scintillator

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Poster Sessions

NA26 Nanostructure-Mediated Luminescence of Barium Fluoride Scintillators

Fan Zhang, Bo Liu*

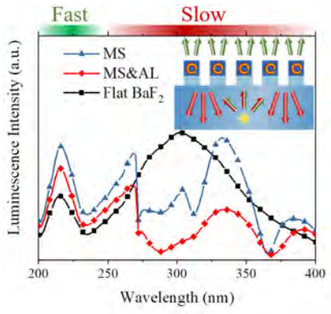
Shanghai Key Laboratory of Special Artificial Microstructure Materials and Technology, School of Physics Science and Engineering, Tongji University, Shanghai 200092, China

**Corresponding Author Email: lbo@tongji.edu.cn*

Barium fluoride (BaF_2) scintillators are known for their applications in high-energy physics experiments due to their ultrafast scintillation component centered at 220 nm with a subnanosecond decay time. However, a critical concern arises from its slow scintillation component centered at 300 nm with a 600-ns-decay time. The light yield of the slow component is much higher than that of the ultrafast component, which leads to pile-up issues in high-rate applications. Previous research efforts have shown that the slow component can be suppressed by rare-earth doping, but it is challenging to enhance the fast component by such a method. At present, there is a pressing demand for a method that can mediate the luminescence of BaF_2 scintillators, i.e., enhance the fast component and suppress the slow component. In this work, we introduce various nanostructures, including photonic crystal (PhC) structures and resonant metasurfaces, to mediate the luminescence of BaF_2 scintillators.

To enhance the fast component of BaF_2 scintillators, we utilize the PhCs consisting of hexagonal close-packed nanosphere arrays or hollow-sphere arrays. Such PhCs couple with evanescent waves by whispering gallery modes (WGMs) and extracts them by Bragg diffraction, overcoming the limitations of total internal reflection and facilitating the emission of the fast component. Simulation and experiment results indicate that the light output of the fast component is significantly enhanced with an enhancement ratio of 1.5.

Moreover, to simultaneously enhance the fast component and suppress the slow component, we utilize resonant metasurfaces consisting of a square-packed double-layer pillar array with high refractive index contrast. For wavelengths from 270 to 310 nm, where the slow component is strong, the interaction between the light and the metasurface induces electric quadruple (EQ) resonance, which exhibits insensitivity to incident angles, resulting in a decrease in transmittance. The EQ resonance can be further engineered by introducing an absorption layer, leading to significant and selective absorption of the slow component. However, the transmittance of the fast component is almost unaffected due to the absence of EQ resonance in the corresponding wavelength range. Additionally, similar to the PhCs, the resonant metasurfaces could enhance the fast component by WGMs and Bragg diffraction. The effectiveness of resonant metasurface in mediating BaF_2 luminescence is demonstrated through simulations, providing insights into potential applications in high-energy physics experiments.



Predicted luminescence spectra for BaF_2 scintillators covered by the metasurfaces (MS) and MS with an absorption layer (AL). The inset shows the schematic diagram of MS on BaF_2, and the physical mechanisms for the light mediation effect.

NA27 Investigating Medium Range Order in Mg-Al binary metallic glasses: molecular dynamics approach

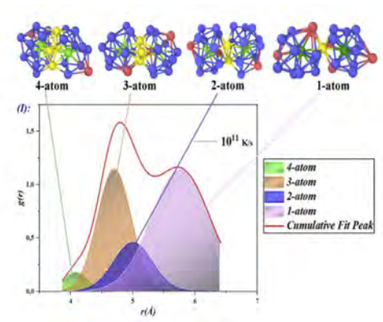
Mohamed El Ayoubi[1], Abderrahim Khmich[1], Abdelali.Samiri[1] And Abdellatif Hasnaoui[1]

[1] LS2ME Laboratory, Polydisciplinary faculty of Khouribga, Sultan Moulay Slimane University of Beni Mellal, B.P. 145, 25000 Khouribga, Morocco

Corresponding Author Email: mohamedelayoubi2014@gmail.com

In this work, we used molecular dynamics (*MD*) simulations in order to investigate the Medium- Range Order (*MRO*) in Mg-Al binary metallic glasses (*MGs*). The embedded atom method (EAM) has been adopted to accurately model the interatomic interactions. Various techniques such as radial distribution function (*RDF*), coordination number (*CN*) analyses and Gaussian fitting have been mobilized to comprehensively study the impact of cooling rate, composition and mechanical solicitations, on the structural properties at the

MRO level. Our results reveal that the 1-atom connection mode is consistently dominant across all cooling rates. Moreover, as the cooling rate increases in the $Mg_{25}Al_{75}$ binary MG, the abundance of the *4-atom* and *2-atom* connection modes increases, while the percentage of the *3-atom* mode experiences a slight decrease. Furthermore, we investigate the influence of composition on the properties of Mg_xAl_{100-x} alloys, demonstrating that the RDF peaks and connection modes are highly sensitive to variations in the Al concentration. Additionally, we explore the relationship between mechanical properties and connection modes during tensile deformation. The *3-atom* connection mode exhibits superior hardness and stability, while the *4-atom* and *2-atom* connection modes offer increased flexibility. These significant findings enhance our understanding of MGs' structural evolution, stability and deformation behavior. Ultimately, this knowledge facilitates the design and optimization of tailored MGs for advanced applications.



Four Gaussian curves fit of the second neighbor shell at 100 K of $Mg_{25}Al_{75}$ binary MG.

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Poster Sessions

NA28 Enhancing Scintillation Efficiency in Nanoparticle Scintillators Embedded in Polymer Host Materials: First Geant4 Simulations and Scattering Studies

Vojtěch Zabloudil[1,3], Matteo Salomoni[1,2], Emanuele Mazzola[2], Luca Gironi[2], Solangel Rojas[1,3], Etiennette Auffray[1]

[1] European Organization for Nuclear Research (CERN), Geneva, Switzerland
[2] Università degli Studi di Milano-Bicocca, Milan, Italy
[3] Czech Technical University in Prague, Prague, Czech Republic

Corresponding Author Email: vojtech.zabloudil@cern.ch

In the quest for advanced scintillating materials capable of high-resolution and rapid-response detection, the European path finder project Unicorn proposes to develop novel composite material consisting of nanoparticle scintillators (such as Dot-in-Plate Cadmium Selenide/Cadmium Sulfide (CdSe/CdS)) embedded in a polymer matrix for radiation detection.

The presented study explores the scintillation properties and the containment efficiency of nanoparticles embedded in a polymer host material based on a simulation developed with Geant4 framework, aiming at applications in gamma and beta decay detection with a focus on double beta decay events. A set of studies investigating the containment efficiency and the light collection efficiency with varying Rayleigh scattering length was performed for a detector block with the following geometry: 5x5x5cm^3 nanocomposite scintillator read out by 5x5 cm^2 square PMT on each face and optimized for a nearly perfect reflection on non-PMT covered surfaces.

We plan to conduct a study tackling the light scattering and absorption inside the composite experimentally with a set-up featuring an integrating sphere in order to compare the experimental results with the ones of the simulation.

This work has been performed in the framework of European Pathfinder Open project UNICORN (GA 101098649).

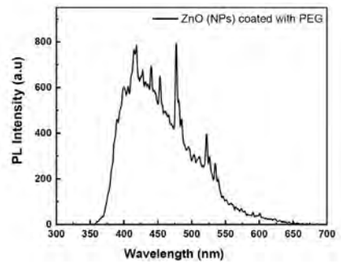
NA29 Synthesis, structural and luminescence properties of polymer coated zinc oxide nanoparticles for scintillation applications.

Widad Bekhti[1], Lakhdar.Guerbous[2]

[1]Laboratoire de Physique Theorique et Interaction Rayonement Matière (LPTHIRM), Département de physique, Faculté des Sciences, Université de Blida 1 Saad-Dahleb, Route de soumaa BP 270 Blida, Algeria
[2]Physics Division/Nuclear Research Centre of Algiers (CRNA), 02, Boulevard Frantz Fanon, B.P. 399, Algiers (16000), Algeria.

Corresponding author Email: bekhti_widad@univ-blida.dz

Inorganic nanoscintillators are luminescent materials which absorb the ionizing radiation and convert them to ultraviolet-visible photons. They have been playing a major role in many fields of radiation detection, including: astrophysics, medical diagnostic and therapy, security, high energy physics and biology [1, 2]. Although, ZnO has been widely studied as a semiconductor for many applications, nevertheless, its application as a both radio- luminescent scintillator and photosensitizer is not well investigated. Indeed, given that ZnO is known as a biocompatible, chemically inert, antibacterial, non- toxic material and able of biodegrade with high and thermal and chemical stabilities, it is the most promising for medical applications [3]. Zinc oxide (ZnO), exhibit scintillation (radioluminescence) being used for detection of ionizing radiation. The radioluminescence properties depend on the optical properties of ZnO (NPs), which themselves depend on the preparation method which has a relationship with the defects created. For practical applications, it is important to improve the luminescence efficiency of ZnO (NPs) and the surface coating by polymers like PEG is one of the methods [4].



PL spectra of ZnO coated with PEG

In this contribution, hydrothermal method has been used to synthetize ZnO-PEG or PVA powders. the growth ZnO coated PVA or PEG particles are ended hydrothermally in autoclave. The samples were characterized by XRD, SEM, Raman, and luminescence spectroscopy (figure). An increase of the lattice-defect luminescence is observed which can enhance the scintillation light yield (LY) of ZnO-polymer coated.

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Poster Sessions

NA30 Porphyrin functionalized ZnO nanosystems in radio-oncological treatment: from synthesis, radioluminescence spectroscopy to energy deposition modeling

S. Mostoni[1,2], I. Villa[1], M. Fasoli[1], A-L. Bulin[3], M. D'Arienzo[1,2], B. Di Credico[1,2], A. Vedda[1], and R. Scotti[1,2]

[1] Dept. of Materials Science, University of Milano - Bicocca, Via Cozzi 55, I-20125, Milano, Italy
[2] INSTM, University of Milano - Bicocca, Via Cozzi 55, I-20125, Milano, Italy
[3] University Grenoble Alpes, Inserm U1209, CNRS UMR5309, Cancer Targets and Experimental Therapeutics Team, Institute for Advanced Biosciences, 38000 Grenoble, France

Corresponding Author Email: silvia.mostoni@unimib.it

Recently, hybrid nanoscintillators (HNS) represent the driving force of the progress in diverse expertise fields, from high energy physics, homeland security, to biomedicine. HNS are made by heavy inorganic nanoparticles (NPs) conjugated with an organic emitter with specific properties according to the targeted application. In this field, the search for straightforward synthesis and functionalization strategies to produce novel HNS with definite properties is active. Recently, HNS have been proposed as coadjuvant in radiation oncology, allowing to achieve better therapeutic results with lower doses compared to traditional radiotherapy (RT). In this case, HNS are made by biocompatible core of dense scintillating NPs with surface grafted cytotoxic photosensitizer (PS), whose therapeutic effect – expressed as production of singlet oxygen (SO) species – must be maximized under ionizing radiation. The creation of cytotoxic species by PS might be triggered by different mechanisms: the radiative and/or non-radiative energy transfer from the scintillating core to the organic molecules, and the energy deposition enhancement due to an increase interaction of the ionizing radiation with the dense NPs.

Here we propose the case study of ZnO NPs anchored on SiO_2 NPs as carrier (ZnO/SiO_2) and surface functionalized with a tetrakis(4-carboxyphenyl)porphyrin (TCPP) as PS. [1-2] We performed steady state and pulsed photoluminescence experiments and radioluminescence measurements at increasing energy of the ionizing radiation beam up to 10 keV and coupled the results with Monte Carlo Geant4 simulation modelling the interaction of the ionizing radiation in keV energy range in such HNS. The conducted study allowed to shed light on the prevalent mechanism that must be turned on in HNS to activate the PS luminescence under X-rays irradiation and thus to induce an efficient generation of SO in RT. Indeed, we unveil that the role of ZnO in stopping ionizing radiations is more and more important as the energy of the latter is rising. Thus, our findings put the real protagonists of sensitizing the therapeutic outcomes of HNS under ionizing radiation-based therapy into the spotlight. Besides the radiative energy transfer activation that can just partially excite the PS on the surface of the dense scintillating NPs and induce its red luminescence, an efficient and improved energy deposition process occurring in the HNS, involving ZnO at X-rays energy of 10 keV, is the main responsible of TCPP luminescence enhancement. This discovery is fundamental to guide the design of future HNS to be used in clinics, where a specific augmentation of energy deposition mechanism is foreseen and boosted.

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2. R. Crapanzano, "Photo-and radio-luminescence of porphyrin functionalized ZnO/SiO2 nanoparticles", Physical Chemistry Chemical Physics, 24.35 (2022)

NA31 Systematic material design of eutectic scintillators with excellent neutron and gamma radiation discrimination

Kei Kamada[1,2], Rei Sasaki[1], Masao Yoshino[1,2], Naoko Kutsuzawa[2], Kyoung Jin Kim[1,2], Takahiko Horiai[1,2], Rikito Murakami[1,2], Akira Yoshikawa[1,2]

[1]Tohoku University. Sendai, Miyagi, 980-8579, Japan
[2]C&A corporation. 1-16-23, Itiban-tyo, Aoba-ku, Sendai, Miyagi, 980-0811, Japan

Corresponding Author Email: kei.kamada.c6@tohoku.ac.jp

In recent years, scintillation detectors using inorganic solid scintillators containing ^6Li have been increasingly employed owing to their ease of handling and radiation resistivity. In the past decade, inorganic solid scintillators containing Li, such as Ce or Eu:$LiCaAlF_6$ (LiCAF) [1] and Ce:Cs_2LiYCl_6 (CLYC) [2], have been developed in addition to the traditional Li-glass scintillator for thermal neutron detection. To achieve neutron detectors with excellent performance, it is necessary to develop scintillators with high Li content, low density, high light yield and fast decay time. In compound crystals, the Li content is limited by the chemical composition. On the other hand, the Li content can be increased in the eutectic according to the phase diagram. Up to now, fluorides such LiF/$LiGdF_4$, LiF/$BaCl_2$, LiF/CaF_2/$LiBaF_3$, chlorides such LiCl/Li_2SrCl_4, LiCl/$BaCl_2$, bromides such LiBr/$CeBr_3$, LiBr/$LaBr_3$ [3], etc. have been reported. Eutectics are composed of neutron-capturing phases containing ^6Li and scintillator phases. The ^6Li-containing phase converts n-rays into α-rays and ^3H, which are absorbed by the scintillator phase and converted into light.

In this study, eutectics with good n/γ-ray discrimination performance were systematically investigated under the material design guideline of combining the γ-ray scintillator phases, which has good α/γ-ray discrimination performance. Tl:CsI/LiBr, Tl:NaI/LiBr, $LaBr_3$/LiBr (pure, Ce and Sr co-doped), and $LaCl_3$/LiCl (pure, Ce doped) were selected as materials meeting the material design guidelines. And for NaI-LiBr, which has not been reported, a state diagram was prepared. In the presentation, details of eutectic growth, structure, and scintillator characterization will be reported. We will also report on the correlation between n/γ-ray discrimination performance and scintillator properties, which is expected from the α α/γ-ray discrimination performance of the γ-ray scintillator phases.

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Poster Sessions

NA32 Luminescent J-Aggregates in Liquid Crystal Matrices: Towards Novel Nanostructured Materials

I. Yu. Ropakova[1], S. S. Hrankina[1, 2], I. I. Grankina[1], S. L. Yefimova[1], O. V. Sorokin[1], O. M. Samoilov[1], N. A. Kasian[1], L. N. Lisetski[1]

1Institute for Scintillation Materials of NAS of Ukraine Kharkiv, Ukraine 2 Kharkiv National Medical University, Kharkiv, Ukraine

adelma@ukr.net

The integration of nanoparticles into liquid crystal (LC) hosts has emerged as a promising avenue for advancing optoelectronic applications. Composite luminescent materials based on liquid crystals have attracted considerable interest due to their unique optical properties. However, such systems often face the problem of fluorescence quenching, which limits the possibilities for their real-world application. To address this issue, innovative strategies are employed to engineer complex LC systems, including the incorporation of luminescent polymer dots covalently linked to rod-shaped LC molecules.

Among luminescent aggregates, J-aggregates stand out as low-dimensional molecular crystals with distinct optical properties. Their formation within LC phases offers opportunities for creating highly anisotropic LC-systems. Here, we report the successful formation of J-aggregates of the anionic cyanine dye TDBC within the nematic LC matrix of 5CB, resulting in intriguing optical and electro-optical properties. Despite the small exciton coherence length in LC compared to water, enhanced fluorescence quantum yield and lifetime were observed, indicative of suppressed non- radiative relaxation and anomalous radiative lifetime.

Furthermore, the photostability of TDBC J-aggregates in the LC matrix showed significant improvement compared to that in water. These findings underscore the potential of J-aggregates in LC matrices for the development of novel luminescent liquid crystal materials. Our results provide insights for further detailed investigations into these promising nanostructured materials, offering avenues for future research and technological advancements.

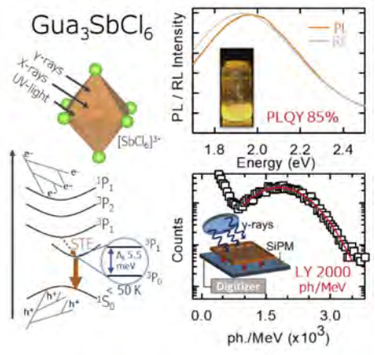
I. I. Grankina, O. M. Samoilov, N. A. Kasian, I. Yu. Ropakova, S. S. Hrankina, S. L. Yefimova, L. N. Lisetski, and O. V. Sorokin «Spectral features of the dispersion of carbocyanine dye J- aggregates in a liquid crystal matrix», Optical Materials Express, Vol. 13, Issue 6, pp. 1741-1751 (2023)

NA33 Zero-Dimensional Gua_3SbCl_6 Crystals as Intrinsically Reabsorption-Free Scintillators for Radiation Detection

Matteo L. Zaffalon[1*], Ye Wu[2,3], Francesca Cova[1], Luca Gironi[4], Xiaoming Li[2], Valerio Pinchetti[1], Yang Liu[2,5], Muhammad Imran[6], Alessia Cemmi[7], Ilaria Di Sarcina[7], Liberato Manna[3], Haibo Zeng[2], Sergio Brovelli[1]

[1] Department of Materials Science, Università degli Studi Milano-Bicocca, Milano, Italy;
[2] School of Materials Science and Engineering, Nanjing University of Science & Technology, Nanjing, China;
[3] Istituto Italiano di Tecnologia, Genova, Italy;
[4] Department of Physics, Università degli Studi Milano-Bicocca, Milano, Italy;
[5] Department of Physical Chemistry, Campus Universitario Lagoas Marcosende, Vigo, Spain;
[6] Department of Electrical and Computer Engineering, University of Toronto, Toronto, Canada;
[7] ENEA Fusion and Technology for Nuclear Safety and Security Department, Casaccia, Italy.

**Corresponding Author Email: matteo.zaffalon@unimib.it*



Metal halides, especially lead halide perovskites, are gaining attention as cost-effective scintillating materials with scalable low-temperature synthesis, high average atomic number (Z), defect tolerance, and tunable, highly efficient excitonic luminescence. Recently, lead-free low- dimensional halides, such as antimony halides, have been explored for their potential as non-toxic scintillators, offering a high Z value (Z_{Sb} = 51) and efficient, Stokes- shifted visible luminescence. Despite their promise, detailed studies on the scintillation process and their suitability for applications like gamma detection remain scarce. In addition, antimony halide systems combined with organic moieties in a hybrid organic–inorganic scintillator are potentially interesting materials for fast neutron detection.

Here we contribute to this field by investigating the scintillation properties of a hybrid organic– inorganic zero-dimensional antimony chloride system, namely Gua_3SbCl_6, which consists of alternating layers of $[SbCl_6]^{3-}$ octahedra separated by N,N'-diphenylguanidinium (Gua^+, $C_{13}H_{14}N_3^+$) cations. Concomitant optical and radiometric experiments show that the optical properties of Gua_3SbCl_6 are determined by the absorption by isolated $[SbCl_6]^{3-}$ units and that both the photoluminescence (PL) and the radioluminescence (RL) are due to the essentially purely radiative decay of self-trapped excitons (STEs) in isolated $[SbCl_6]^{3-}$ octahedra. This leads to PL quantum efficiency ~85% and light yields (LY) of up to 2000 ph·MeV^{-1} using ^{57}Co as a 120 keV γ source, despite the relatively low density of the material (1.468 g·cm^{-3}). Temperature-dependent PL and RL measurements confirm the minor role of non-radiative channels, which are completely suppressed below 100 K. Finally, thermally stimulated luminescence measurements suggest that the traps in Gua_3SbCl_6 crystals have a significantly large energy depth distribution below the absorbing state.

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Poster Sessions

NA34 Impact of the particle size on the scintillation performance of $CsPbBr_3$ perovskite nanocrystals

Andrea Fratelli[1], Matteo Zaffalon[1], Francesco Carulli[1], Dimitri Dirin[2], Ihor Cherniukh[2], Clara Otero Martinez[3], Liberato Manna[3], Maksym Kovalenko[2], Sergio Brovelli[1]

[1] Dipartimento di Scienza dei Materiali, Università degli Studi di Milano-Bicocca, Milano, Italy
[2] Department of Chemistry and Applied Bioscience, ETH Zürich, Zürich, Switzerland.
Laboratory for Thin Films and Photovoltaics and Laboratory for Transport at Nanoscale Interfaces, Empa – Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland.
[3] Nanochemistry, Istituto Italiano di Tecnología, Via Morego 30, Genova, Italy

Corresponding Author Email: sergio.brovelli@unimib.it

Over the last few years, nanocomposite scintillators have emerged in the attempt to address the drawbacks of inorganic scintillator crystals (expensive, generally slow and hardly scalable) and plastic scintillators (low density and efficiency) and at the same time capitalize on their strengths. Nanocomposite scintillators feature optical-grade plastic matrices as the waveguiding component, while high-Z semiconductor nanocrystal (NCs) synthesized using scalable chemical techniques provide scintillation. Importantly, using NCs as nanoscintillators in polymeric waveguides overcome the scalability limitations of conventional materials and also possibly enhance the scintillation performance. This is due to the unique photophysics of quantum-confined materials, providing size- tunable emission spectra matching with the spectral sensitivity of light detectors and ultrafast sub- nanosecond scintillation kinetics resulting from recombination of multi-exciton generated upon interaction with ionizing radiation, as demonstrated recently across various classes of NCs. In this context, lead halide perovskite LHP-NCs gained increasing attention, with $CsPbBr_3$ emerging as the dominant player. Lead halides NCs feature an effective high-Z, remarkable resistance to radiation, extensive scalability facilitated by low-temperature methods, and efficient scintillation owing to the unique tolerance of their luminescence to structural defects. However, despite its potential, the multiexciton regime suffers from detrimental losses via Auger recombination (AR), which in NCs is not constrained by momentum conservation as it is in bulk materials and its rate increases with the inverse of the particle volume, posing a significant challenge in NC-based technologies such as lasers, light emitting diodes or solar cells. Although the effects of AR on such technologies have been extensively studied over the years, its impact on the scintillation of NCs remains an open question. Here we aim to fill this gap by investigating the effect of particle size on the scintillation efficiency and kinetics of $CsPbBr_3$ NCs ranging in size from 3 nm to 15 nm, with tunable emission from 470 nm to 520 nm and AR rates spanning nearly two orders of magnitude. The dependence of scintillation efficiency and timing on particle size is first theoretically analysed and then experimentally validated, yielding a complicated parametrical space where the initial exciton population per NC and the AR rate are the key elements. We have evaluated all the parameters necessary to describe the recombination mechanisms using a combination of optical spectroscopy and scintillation experiments on two sets of $CsPbBr_3$ NCs synthesised independently by two laboratories, in order to generalise the observed trends. AR was found to be efficient under ionising excitation. The scintillation efficiency was largely dominated by the single exciton PL efficiency in all samples, with an essentially negligible effect of AR. This is important as it highlights the importance of optimising the emission process in the single exciton regime to maximise the scintillation yield, while NC engineering to suppress AR plays a minor role. It is also noteworthy that the acceleration of the ultrafast sub-ns biexciton contribution to scintillation decay by AR results in an increasingly faster effective scintillation lifetime, which together with the invariant light output leads to faster estimated coincidence time resolution (CTR) values for small NCs, suggesting a possible strategy for fast timing technologies.

This work was funded by Horizon Europe EIC Pathfinder program through project 101098649 – UNICORN and by the PRIN programme of the Italian Ministry of University and Research (IRONSIDE project).

NA35 Synthesis of luminescent nanoparticles and their assembly into dense assemblies

Madeleine Fellner[1], Yannick Dahler[1], Alessandro Lauria[1]

[1]Laboratory for Multifunctional Materials: Federal Institute of Technology – ETH Zurich, Zurich, Switzerland

Corresponding Author Email: alessandro.lauria@mat.ethz.ch

Advanced synthetic methods to produce luminescent nano- and microparticles hold great promise for tailoring their features and enable improved fabrication processes of functional materials and composites bridging properties from the nanoscale to the macroscale. The control of structure and composition is crucial to state their emission properties, while their surface chemistry plays a key role in the stability of NPs dispersions, which can act as functional inks for their assembly to form particle- based materials. Indeed, luminescent particles can be applied in several fields such as lighting and display technologies, or bio-imaging, among others. However, to be used in scintillator applications, nanoparticles must be processed into more compact assemblies in order to ensure high stopping power toward ionizing radiation and good optical quality. Hence, innovative NPs systems and suitable deposition techniques are highly demanded.

Caesium hafnium halides crystals like Cs_2HfCl_6 (CHC) possess strong intrinsic fluorescence at 375 nm, with high light yield and excellent energy resolution and proportionality. Such materials can also be produced in the form of a micropowder. A water-in-oil microemulsion synthesis was designed to generate CHC particles with sizes in the microscale, yet carrying similar optical properties as those measured in bulk single crystals.[1] However, the development of their dispersibility, morphology or size, tuned for specific applications, is of primary importance to make them possibly suitable for microstructured scintillators based on particle building-blocks.

Among the methods for particle assembly, field driven ones like electro-phoretic deposition (EPD) seem to be a fast and effective way to assemble particles in denser green bodies.

The arrangement of nanoparticles on the substrate is pivoted by the deposition methodology and by the surface chemistry of the particles, determining the final microstructure. Here we present the EPD of HfO_2 nanocrystals synthesized by a solvothermal route and its applicability for the assembly of nanoparticles towards functional films. Titanium and hafnium dioxide nanoparticles with a size of few nm were considered. The doping with europium was used to activate the fluorescence of HfO_2, making it suitable for phosphor and scintillator applications. The influence of several EPD parameters on the film thickness, transparency, relative density and morphology were studied. [2]

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Poster Sessions

NA36 Investigating the yield and non-linear quenching of 4.5 ML CdSe/CdS core-crown nanoplatelets using intense laser excitation

Simon Jessen[1], Brian Julsgaard[1], Rosana Martinez Turtos[1]

[1]*Department of Physics and Astronomy: Aarhus University, Aarhus, Denmark*

Corresponding Author Email: jessen@phys.au.dk

An important application of scintillation detectors is the medical imaging technique known as Positron Emission Tomography (PET) which is currently the best tool for detecting and imaging cancerous tumors. Current efforts to improve the technique include attempts to enhance the timing capabilities of the scintillation detectors with the ultimate goal of developing *real-time* PET. This requires a scintillator with an emission rate of 100 photons/MeV/ps when exposed to 511 keV gammas which represents a 20-fold improvement on the current state-of-the-art LYSO-based scintillators [1]. As this lies beyond the material response of all known bulk scintillators, it prompts the search for new materials.

A possible solution to this problem has emerged with the development of direct band-gap semiconductor nanoplatelets (NPLs). An example is 4.5-ML CdSe/CdS core-crown NPLs which has many remarkable optical properties including a unique sub-ns decay component associated with emission from room temperature stable biexcitons. One study has demonstrated that introducing layers of drop casted films of this material in a bulk scintillator does in fact enhance the timing capabilities [2]. However, the composite nature of the detectors makes it difficult to determine whether the limiting factor is the intrinsic light yield of the platelets, or a deficiency related to the macroscopic detector.

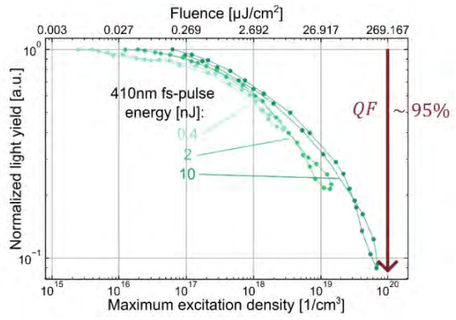

Figure 1: Photoluminescence measurements of CdSe/CdS NPLs at excitation densities up to 1020 e-h pairs per cm³. The excitation density is found by using an absorption length of 66.7 nm which might be an overestimation based on recent findings. The excitation densities shown should therefore be considered an upper limit.

In this study, we present an original approach to understanding the decay kinetics and quenching processes of novel and fast scintillating materials at excitation densities which mimics the energy deposition of ionizing radiation. This is demonstrated using 4.5-ML CdSe/CdS core-crown drop- casted films and a powerful femtosecond laser and a translating lens using the z-scan luminescence method. Such experiments have previously been used to understand the quenching processes of many bulk state-of-the-art scintillators [3]. As a preliminary results, we report that the platelets exhibit a total quenched fraction (QF) of at least 95% at 10^{20} electron hole pairs per cm^3 as shown in Figure 1. This seems to indicate that the platelets suffer from considerable non-linear quenching at high excitation however further studies are needed to translate such a quenching factor into number of photons emitted and reduce the uncertainties associated with the estimation of excitation density.

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2. : Turtos, R. M. et al., "On the use of CdSe scintillating nanoplatelets as time taggers for high- energy gamma detection", npj 2D Materials and Applications, 3, 37. (2019)

3. : Grim, J. Q. et al., "Nonlinear quenching of densely excited states in wide-gap solids", Physical Review B, 87, 5117. (2013).

OPTICAL CERAMICS AND GLASSES

CE6 NIR-emitting scintillation of YAG:Yb optical ceramics as testing platforms for medical bioimaging

Alessandra Ronchi[1], Francesca Cova[1], Jan Hostaša[2], Francesco Picelli[2], Laura Esposito[2], Valentina Biasini[2], Alberto Paleari[1], Anna Vedda[1], and Roberto Lorenzi[1]

[1] *Department of Materials Science, University of Milano – Bicocca, Via Cozzi 55, 20125 Milan, Italy*

[2] *CNR ISSMC, Institute of Science, Technology and Sustainability for Ceramics, Via Granarolo 64, 48018 Faenza, Italy*

Corresponding Author Email: a.ronchi16@campus.unimib.it

Ionizing radiation, especially X-rays and γ photons, are essential in many tools and techniques developed for bioimaging. The most common application regards their use in direct medical imaging such as radiography and tomography. In such applications, the main building blocks of radiation detectors are scintillating materials, that absorb and down-convert the energy deposited by the incoming ionizing radiation to low-energy UV-Vis-IR light, which is then easily read out by common photodetectors. A valuable class of scintillating materials is represented by rare-earth doped garnets. Garnets in the form of single crystals are already used in some medical instruments and are also promising candidates for Time-of-Flight Positron Emission Tomography (TOF-PET) detectors where stringent requirements on fast time response are crucial to optimize the spatial localization of the tumours and detection accuracy. Moreover, they can be easily obtained as micro- and nano-sized powders and, in this form, they can be used as phosphors in optical bioimaging. The latter technique consists in the inoculation of the nanoparticles in the tissues to be treated and the imaging occurs through laser-stimulated luminescence in the biological window where tissue absorbance is minimal (700 – 1350 nm). However, this approach presents some drawbacks: the signal monitoring is difficult since excitation and emission lights are close in frequency, and more importantly, the required laser power is very high and may lead to skin damage and to autofluorescence [1].

Here we explore a new approach in optical bioimaging by exploiting the scintillation properties of specifically designed $Y_3Al_5O_{12}$ (YAG) nanoparticles doped with near infrared emitting rare-earth ions (Yb, Nd, or Er). The needed NIR emission is quite unusual for standard scintillating materials and not yet adequately investigated [2], since they have been optimized to match the sensitivity peak of conventional photodetectors in the visible region. An important advantage afforded by this approach is the use of low dose X-rays as excitation source instead of lasers, thus eliminating autofluorescence, tissue damages, and detector overexposure.

These materials can also be easily produced in the form of ceramics with the desired size and shape, not achievable by their single crystal counterparts, but with comparable optical quality, and more affordable costs. Therefore, for the development of YAG nanoparticles, we study the properties of rare-earth doped YAG optical ceramics as a transparent testing platform to identify the best doping ion and its concentration, towards the optimization of the scintillation properties of rare-earth doped garnets for optical bioimaging.

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Poster Sessions

CE7 Trapping mechanisms in nanostructured glass-ceramics with embedded Ga_2O_3 nanoparticles

R. Lorenzi[1], N.V. Golubev[2], E.S. Ignat'eva[2], V.N. Sigaev[2], M. Fasoli[1], A. Paleari[1], and F. Cova[1]

[1]Department of Materials Science, University of Milano –Bicocca, Via Cozzi 55, 20125 Milan, Italy
[2]P.D. Sarkisov International Laboratory of Glass-based Functional Materials, Mendeleev University of Chemical Technology of Russia, Miusskaya Square 9, 125190 Moscow, Russia

Corresponding Author Email: roberto.lorenzi@unimib.it

Gallium sesquioxide is a wide bandgap semiconductor, which in recent years has become increasingly important in the manufacture of ionizing radiation detectors and scintillators [1]. In these areas, it is used both as the active electrical part of microelectronic devices (such as Schottky barrier diodes, heterojunctions, metal-oxide-semiconductor and metal-semiconductor-metal structures) and directly as a scintillator coupled to suitable photodetectors. In the latter application, pure undoped Ga_2O_3 single crystals have demonstrated light yield of up to 15000 ph/Mev with the emission peak centered in the range 380-420 nm and a decay time of the order of tens of nanoseconds [2]. This emission is related to the donor-acceptor pair (DAP) recombination involving an oxygen vacancy, interstitial Ga, and Ga vacancies. The majority of studies on the scintillation of gallium oxide have focused on the monoclinic beta phase, which is the most stable crystalline form. However, there are 5 known crystalline phases of Ga_2O_3. Among them, the cubic defect spinel gamma phase can be readily obtained in the form of nanocrystals embedded in a germanosilicate glass matrix. Although they share similar DAP recombination processes, γ-Ga_2O_3 generally has superior photoluminescence performance compared to β-Ga_2O_3, and for this reason this type of nanostructured glass-ceramics has recently been proposed as a promising scintillating material. Here we present a preliminary assessment of the role of defects in the scintillation mechanism of these glass-ceramics [3]. We have investigated a sample with nominal composition 7.5Li_2O-2.5Na_2O-20Ga_2O_3-35GeO_2-35SiO_2 mol%. The initial glass was prepared in ~250 cm^3 platinum crucible at 1500 °C. To increase the homogeneity, the glass synthesis additionally included oxygen bubbling through glass melt. After homogenization the melt was casted into an unheated steel mold. The cast glass was annealed and then heat-treated by two-step regime (618 °C for 3.5 h + 640 °C for 15 min) to produce fully transparent optical glass-ceramics containing γ-Ga_2O_3 crystals of the order of few nanometers in diameter. Trapping mechanisms have been assessed by combining temperature-dependent X-ray and UV luminescence and wavelength-resolved thermally stimulated luminescence. Experiments were also carried out on glasses of the same nominal composition, but prepared by melt-quenching method and prior to any thermally induced nanosegregation, and on similar glasses whose composition has been stripped of Ga to mimic the amorphous matrix surrounding the γ-Ga_2O_3 nanoparticles, as well as on commercially available powders of micrometre-sized β-Ga_2O_3. The results support an active role of defects strictly related to the presence of Ga and located either in the nanoparticle or on its surface, while negligible contributions come from defects located in the glass matrix.

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We acknowledge the Italian Ministry of Research under project Luminance of the PRIN2022 program.

CE8 Improvement in the scintillation properties of GGAG:Ce powder synthesized by Solvothermal method

Nisha Oad[1], Divya Pandya[2], Sheetal Rawat[2]*, Prakash Chandra[1], Mohit Tyagi[3], Brijesh Tripathi[2], Pavan Gurrala[4]

[1]Department of Chemistry: School of Energy Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India
[2]Department of Physics: School of Energy Technology: Pandit Deendayal Energy University, Gandhinagar, Gujarat, India
[3]Technical Physics Division: Crystal Technology section, Bhabha Atomic Research Centre, Mumbai, Maharashtra, India
[4]Department of Mechanical Engineering: School of Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India

Corresponding Author Email: Sheetal.rawat@sot.pdpu.ac.in

The present work comprehensively investigates the optimization of miscellaneous synthesis parameters of the scintillation properties of GGAG:Ce. These parameters include dopant selection and concentration, synthesis method and temperature, sintering conditions, post-treatment annealing, co-doping, morphology, size control, and precursor selection [1]. Moreover, a novel solvothermal approach for the synthesis of GGAG:Ce^{3+} powder has recently been reported by our group [2]. This pioneering approach yielded promising results, particularly when employing a 4 mol% Ce doping concentration within the GGAG matrix. Subsequent investigations focused on enhancing the luminescent characteristics of the material by modifying the Ga/Al ratio within the standard stoichiometry of GGAG:Ce ($Gd_3Ga_3Al_2O_{12}$:Ce^{3+}) powder synthesized by the solvothermal method. This effort led to significant advancements in both photoluminescence (PL) and radioluminescence (RL) intensities from the standard stoichiometry of this material, which increases by around 125% ($Gd_3Ga_{3.2}Al1.8O_{12}$:Ce^{3+}). Building upon these findings, our ongoing research endeavours are aimed at optimizing the sintering process of this material under reduced atmospheric conditions with different Ga/Al ratios. The goal is to mitigate the oxidation of Cerium ions during sintering, potentially reducing the prevalence of Ce in +4 oxidation states within the material. This approach holds promise for further enhancing the scintillation properties of GGAG:Ce, thus advancing its potential applications in various fields.

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The 57/14/05/2021-BRNS grant is used for funding this project.

Poster Sessions

CE9 Utilizing digital light processing 3D printing for compacting in the production of transparent GYAGG:Ce ceramics

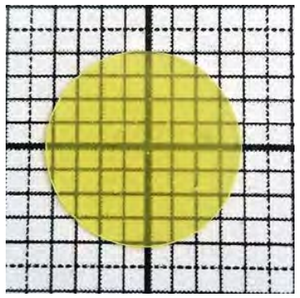
I.Y. Komendo[1], P.S. Sokolov[1], L.V. Ermakova[1], V.G. Smyslova[1], P.V. Karpyuk[1], D.E. Lelekova[1], A.G. Bondarau[2], V.A. Mechinsky[1,2], M.V. Korzhik[1,2]

[1]*National Research Centre «Kurchatov institute», Moscow, Russia*
[2]*Institute for Nuclear Problems, Belarus State University, Minsk, Belarus*

Corresponding Author Email: ilia.komendo@cern.ch

Crystalline materials of the garnet structural type $(Gd,Y)_3Al_2Ga_3O_{12}$:Ce (GYAGG:Ce) are promising to engineer scintillation and luminescent materials with outstanding properties [1, 2]. The ceramics production method, when providing a high level of transparency, has advantages over the single crystal production method due to its ability to reach an affordable price for the product. Therefore, the development of the capabilities to make ceramics production cheaper is highly demanded.

For the first time, polycrystalline transparent ceramics have been obtained using an easy-commercially available digital light processing (DLP) stereolithography-based 3D printer for green body formation, sequence debinding, and pressureless sintering processes at 1650°C in an oxygen atmosphere. The major functional properties of the produced ceramic samples are comparable to those obtained by the traditional method, which includes uniaxial pressing for the green body specimen's production. The photoluminescence and photoexcitation spectra of the ceramics have a typical shape for the Ce^{3+} ion in the garnet oxide matrix. The effective photoluminescence decay time was 62 ns. Light output under 662 keV was measured to be 43–45 photons/keV.



GYAGG:Ce ceramics produced by utilizing the 3D-printed green body, dia. 15 mm, thickness 0.5 mm

The capability to obtain high-transparency ceramics and complex- shape with involvement in the production process of 3D printing is debated. Advantages, which are promoted by using for UV-curable slurries the submicrocrystalline powders GYAGG:Ce, which were obtained by coprecipitation and thermal treatment [3] and limits due to a need to use phosphorus-free dispersing additive for stabilization and reduction of slurries viscosity [4], are considered.

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CE10 Luminescence of Na_2O-ZnO-SiO_2 glass composite under X-ray excitation

V. Babin[1], V. Jarý[1], P. Vařák[2], P. Nekvindová[2], J. Mrázek[3]

[1]*FZU – Institute of Physics of the Czech Academy of Sciences, Cukrovarnicka 10, Prague 6, 16200, Czech Republic*
[2]*Department of Inorganic Chemistry, University of Chemistry and Technology, Prague, Technická 5, Prague 6, 166 28, Czech Republic*
[3]*Institute of Photonics and Electronics of the Czech Academy of Sciences, Chaberská 1014/57, Prague 8, 182 51, Czech Republic*

Corresponding Author Email: babinv@fzu.cz

Rare-earth doped silica optical fibers are finding their application in the construction of distributed radioluminescent sensors [1]. However, the overall performance of the system under X-rays is strongly influenced by the low solubility of RE ions in the glass matrix [2]. However, the creation of the inorganic composite nanoparticles and their distribution inside the glass matrix can improve the nanostructuring of the fiber core [3]. The final luminescence properties of such nanostructured optical fibers are defined by the properties of the incorporated nanoparticles. Therefore, the successful preparation of inorganic nanocomposites consisting of nanoparticles distributed inside the host glass matrix and consequent characterization represents the challenging task for current material research.

In current work, besides Ce^{3+} impurity ions, we investigate the Er^{3+}, Yb^{3+}-doped Na_2O-ZnO-SiO_2 glass compositions prepared using controlled crystallization of precursor glass by annealing in the 700 – 900 °C range, which contain scintillating nanoparticles of various forms, such as Na_2ZnSiO_4, Zn_2SiO_4 or others. Their scintillation and optical properties were studied by the steady-state and time-resolved luminescence spectroscopy methods using photo- and X-ray excitation. The intense fast UV scintillation decay time under the X-ray excitation was found in UV range, thus making these materials worth further investigation in the field of distributed radiation detectors. In a current study, a set of glass systems, doped by Er^{3+}, Yb^{3+} of different content or preparation methods will be investigated. Their luminescent characteristics in near infrared range will be mutually compared towards further optimization of glasses performance.

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Poster Sessions

CE11 Alkaline-Earth Co-Doping Effects on Scintillation and Microstructure of Ce:GAGG Ceramics

Peter Bleier[1], Steven Lass[1], Federico Moretti[2], Weronika Wolszczak[2], Romain Gaume[1,3,4]

[1]*Department of Materials Science and Engineering, University of Central Florida, Orlando, Florida, USA*
[2]*Lawrence Berkeley National Laboratory, Berkeley, California, USA*
[3]*CREOL, The College of Optics and Photonics, University of Central Florida, Orlando, FL, USA*
[4]*NanoScience Technology Center, University of Central Florida, Orlando, FL, USA*

Corresponding Author Email: peter@bleier.com

Cerium-doped gadolinium aluminum gallium garnet Ce:$Gd_3Al_2Ga_3O_{12}$, commonly referred to as Ce:GAGG, boasts commendable scintillation properties and density, rendering it a material of interest for applications necessitating fast and intense scintillators, such as CT scanners and high- energy X-ray detection systems. Previous research has explored the fabrication and assessment of Ce:GAGG ceramics co-doped with magnesium and calcium, revealing an acceleration in scintillation kinetics albeit at the expense of light yield [1]. Additionally, investigations into barium co-doping in Ce:GAGG single crystals have aimed to enhance radiation hardness, albeit with a trade-off in scintillation decay [2]. However, the exploration of strontium and barium co-doping in Ce:GAGG ceramics remains largely unexplored. Motivated by the quest to understand the impact of strontium and barium as co-dopants on the microstructural and scintillation characteristics of Ce:GAGG ceramics, this study was undertaken. Ceramic samples doped with 500 and 1000 ppm magnesium, calcium, strontium and barium, respectively were fabricated under the same conditions and subjected to comprehensive microstructural and radioluminescence analyses, such as shown on the figure.

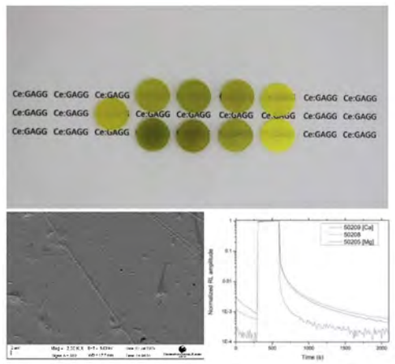

Figure: Top, from left to right: Ceramics of Ce:GAGG, Mg, Ca, Sr and Ba codoped Ce:GAGG, at a 500 ppm (top row) and 1000 ppm (bottom row) level, respectively. Bottom: SEM micrograph of a sample microstructure and afterglow characterization of Mg:Ce:GAGG and Ca:Ce:GAGG samples.

1. X. Huang, J. He, "Ultrafast GGAG:Ce X-ray scintillation ceramics with Ca^{2+} and Mg^{2+} co- dopants," Ceramics International, 48(16) 23571-23577 (2022)
2. M. Tyagi, F. Meng, "Effect of Co-doping on the Radiation Hardness of Gd3Ga3Al2O12:Ce Scintillators" IEEE Transactions on Nuclear Science, 62(1) 336-339 (2015)

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SCINTILLATORS FOR FAST TIMING DETECTION AND IMAGING

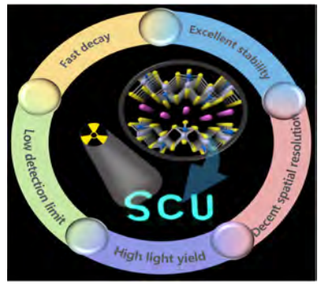
FT15 Emergence of a Lanthanide Chalcogenide as an Ideal Scintillator for a Flexible X-ray Detector

Liangwei Yang[1], Yaxing Wang[1], Shuao Wang[1]

[1]*Soochow University, Suzhou in Jiangsu province, China*

Corresponding Author Email: yxwang@suda.edu.cn

The development of high-performance X-ray detectors requires scintillators with fast decay time, high light yield, stability, and X-ray absorption capacity, which are difficult to achieve in a single material. Here, we present the first example of a lanthanide chalcogenide of $LaCsSiS_4$:1%Ce^{3+} that simultaneously integrates multiple desirable properties for an ideal scintillator. $LaCsSiS_4$:1%Ce^{3+} demonstrates a remarkably low detection limit of 43.13 nGy_{air}/s and a high photoluminescence quantum yield of 98.24%, resulting in a high light yield of 50480 ± 1441 photons/MeV. Notably, $LaCsSiS_4$:1%Ce^{3+} exhibits a fast decay time of only 29.35 ± 0.16 ns, making it one of the fastest scintillators among all lanthanide-based inorganic scintillators. Furthermore, this material shows robust radiation and moisture resistance, endowing it with suitability for chemical processing under solution conditions. To demonstrate the X-ray imaging capacity of $LaCsSiS_4$:1%Ce^{3+}, we fabricated a flexible X-ray detector that achieved a high spatial resolution of 8.2 lp/mm. This work highlights the potential of lanthanide chalcogenide as a promising candidate for high-performance scintillators.



Ideal lanthanide chalcogenide scintillator: The compound simultaneously possesses excellent scintillation properties, including high light yield, fast decay time, low detection limit, and decent radiation/moisture resistance, which has potential applications in X-ray imaging.

Acknowledgements

I am grateful for funding support from the National Natural Science Foundation of China (22222606, 22106117) and the Natural Science Foundation of Jiangsu Province (BK20211546). I am very grateful to the professor Shuao Wang and professor Yaxing Wang from Soochow University.

Poster Sessions

FT16 Scintillation, Luminescence, and Structural Properties Ce-activated Multicomponent Garnets Admixed with Ga and Sc Ions

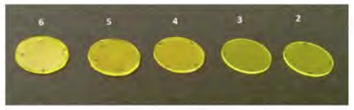
M. Kucera[1], M. Rathaiah[1], D. Strachotova[1], M. Nikl[2], A Beitlerova[2], R. Kucerkova[2]

[1] *Charles University, Faculty of Mathematics & Physics, Prague, Czech Republic*
[2] *Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic*

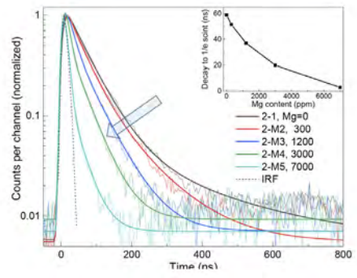
Corresponding Author Email: miroslav.kucera@matfyz.cuni.cz

Low afterglow and short decay time are crucial properties of scintillators in applications where fast response is required, such as electron beam inspection systems, high-speed imaging techniques, or medical applications [1]. Single crystalline garnet films are being used as state-of-the-art scintillating screens for X-ray microimaging with submicrometer spatial resolution.

Here we focus primarily on scintillation, optical, and structural properties of Ce^{3+} - activated gadolinium-scandium garnets, $Gd_3(Sc_xAl_{1-x})_5O_{12}$:Ce (GSAG:Ce), with variable Ce content ranging from 0.04 to 3% and Sc admixture of x = 1 – 2.2. The results are compared to well-established gallium admixed multicomponent GGAG:Ce garnets. Several sample sets of single crystalline films with various compositions were grown for this research by liquid phase epitaxy methods. Due to the large lattice constant of the GSAG host, the crystal lattice adopts a significantly higher content of cerium ions than conventional YAG or LuAG crystals. At Ce concentrations of 1%, the effect of shallow energy traps on the scintillation characteristics is significantly reduced resulting in improved scintillation properties. The scandium segregation coefficient is strongly dependent on the melt composition, and the GSAG garnet shows a high tendency toward congruent composition with two scandium atoms per formula unit. The substitution of Sc for Al results in the narrowing of the optical band gap due to the mixing of 4s scandium states at the bottom of the conduction band. This causes a reduction of the thermal quenching temperature and a partial ionization at room temperature. The combined effect of Sc and Gd substitution leads to an increase of the Stokes shift and a red shift of the emission with a maximum at 555 nm. The co-doping with divalent Mg^{2+} ions caused a considerable acceleration of the decay kinetics from 58 to 3 ns, see Figure, lowering of the afterglow signal, and a decrease in the light yield.



GSAG:Ce,Mg garnet epitaxial films.



Scintillation decays of GSAG:Ce,Mg with various Mg^{2+} co-doping.

1. Z. Wang, C. Dujardin, et al., IEEE Trans. Nucl. Sci, 70 (2023) 1244-1280.

Acknowledgments

The work was supported by Czech Science Foundation, project no. 21-17731S.

FT17 Morphology and Time Resolved Photoluminescence Study of $BaLuF_5:Pr^{3+}$(1%) Nanoparticles Under VUV Excitations

Sanu Bifal Maji[1], Alexander Vanetsev[1], Hugo Mändar[1], Vitali Nagirnyi[1], Kirill Chernenko[2] and Marco Kirm[1]

[1] *Institute of Physics, University of Tartu, Tartu, Estonia*
[2] *MAX IV Laboratory, Lund University, Lund, Sweden*

Corresponding Author Email: sanu.bifal.maji@ut.ee

In recent years, ternary fluoride compounds have gained attention for potential applications as scintillators in medical imaging and high-energy physics [1]. In pursuit of such materials, we synthesized $BaLuF_5:Pr^{3+}$(1%) nanoparticles using a one-step hydrothermal synthesis method. Synthesized nanoparticles were roughly spherical with an average particle size of 21 ± 4 nm, and stable up to 600°C, as was confirmed by high-temperature X-ray diffraction analysis.

Time-resolved luminescence spectroscopy (incl. decay kinetics) of $BaLuF_5:Pr^{3+}$(1%) nanoparticles under vacuum ultraviolet (VUV) photon excitation at the FinEstBeAMS beamline unveiled a two-photon emission process attributed to the $^1S_0$ state positioned below the $4f^15d^1$ band of Pr^{3+} ions. Thus, no emissions assigned to the 5d-4f transitions in Pr^{3+} were detected in the UV region. An intrinsic broad emission of self-trapped excitons (STE) was observed at 3.7 eV under host excitation. The band gap value ~12.4 eV was estimated from the excitation spectra. Time-resolved emission spectra measured under the excitation by 45 eV photons shown in two-time windows (duration of 0-1 ns and 1-300 ns) in Fig. 1 exhibited a series of slow Pr^{3+} 4f-4f emission bands as well as a fast-cross luminescence at 5 eV with a decay time of 160 ps corresponding to time-resolution of the setup. This CL band is due to the recombination of electrons from the F 2p valence band with Ba^{2+} 5p core holes. Time-resolved excitation spectra analysed within the same short time window revealed the onset of the CL excitation band at 18 eV assigned to the Ba^{2+} 5p level. The peculiarities of relaxation processes leading to either intrinsic (CL, STE) or 4f-4f emissions in Pr^{3+} doped $BaLuF_5$ nanoparticles under excitation in the Pr^{3+} 4f-5d bands as well as in excitonic band and fundamental absorption region will be discussed.

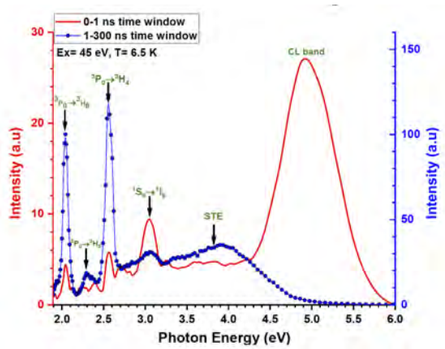


Fig.1. Time-resolved photoluminescence spectra of $BaLuF_5:Pr^{3+}$(1%) nanoparticles excited by 45 eV photons. It is presented in two-time windows with 0-1 ns (red line) and 1-300 ns (blue symbols) duration.

1. J. Saaring, A. Vanetsev, K. Chernenko, et al., J. Alloys Compd. 883, 160916 (2021).

Poster Sessions

FT18 The SHERPA project: Monte Carlo study of a proof-of-principle detector for TOF-PET in a clinical-like scenario

Ilaria Mattei[1], Angelo Monguzzi[2], Charl Xavier Bezuidenhout[2], Silvia Bracco[2], Angiolina Comotti[2], Luigi Montalto[3], Matteo Orfano[2], Jacopo Perego[2], Stefania Praiola[4], Luisa Raimondo[2], Daniele Rinaldi[3], Paola Rizzo[4], Matteo Sala[2], Adele Sassella[2], Irene Villa[2]

[1]National Institute of Nuclear Physics, Section of Milan, Milan, Italy
[2]Università degli Studi di Milano Bicocca, Milan, Italy
[3]Università Politecnica delle Marche, Ancona, Italy
[4]Università degli Studi di Salerno, Fisciano (SA), Italy

Corresponding Author Email: ilaria.mattei@mi.infn.it

In diagnostic TOF-PET, a resolution of the order of 200-300 ps is achieved, which limits the spatial resolution obtained in TOF-PET images. To overcome this time resolution limit, the scientific research community is focusing on several topics such as crystal type, detector geometry, new scintillating materials, electronic read-out, image reconstruction techniques [1]. The SHERPA (Scintillating HEterostructures for high Resolution fast PET imAging) project proposes a novel fast scintillating material, coupled to a high density inorganic crystal to form a heterostructure [2], which has the advantage to reach a high Coincidence Time Resolution (CTR), of the order of few tens of ps, without losing the energy resolution needed to select the 511 keV PET photon signal. In this contribution, the detector unit proposed by SHERPA is embedded in a clinical-like TOF-PET Monte Carlo simulation by means of the FLUKA code [3] to assess the expected CTR of a TOF-PET SHERPA detector in a clinical environment.

1. D. R. Schaart, "Physics and technology of time-of-flight PET detectors," Phys. Med. Biol., 66, 09TR01 (2021).
2. P. Krause et al., "Design rules for time of flight Positron Emission Tomography (ToF-PET) heterostructure radiation detectors," Heliyon, 8 e09754 (2022).
3. A. Ferrari, et al., "FLUKA: a multi-particle transport code (Program version 2005)." p.405. CERN-2005-010, SLAC-R-773, INFN-TC-05-11 (2005).

FT19 3D printing of CsI:Tl composite film for X-ray imaging application

Divya Pandya[1], Sonu[2], Nisha Oad[3], Sheetal Rawat[1], Prakash Chandra[3], Brijesh Tripathi[1], Pavan Gurrala[4], Mohit Tyagi[2]

[1]Department of Physics: School of Energy Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India
[2] Technical Physics Division: Crystal Technology section, Bhabha Atomic Research Centre, Mumbai, Maharashtra, India
[4]Department of Chemistry: School of Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India
[3]Department of Mechanical Engineering: School of Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India

Corresponding Author Email: Sheetal.Rawat@sot.pdpu.ac.in

The increasing demand for X-ray detectors has fueled a need for innovative approaches to indirectly convert X-rays, particularly through the use of scintillators. Given that scintillators play a crucial role in X-ray detection, there is a growing necessity to explore novel classes and alternative fabrication methods beyond the currently saturated established techniques for scintillator growth [1]. An additive manufacturing or 3D printing technique to fabricate scintillators can be an alternative due to its cost effectiveness, flexibility and versatility. It offers the end user to customize and fabricate a composite scintillator by embedding desired application based nano or micro particles into the organic matrix [2]. For a composite scintillator by 3D printing method, Digital Light Processing (DLP) method is identified as best suitable option. In this work, CsI:Tl microcrystal has been prepared and embedded in resin matrix. In the composite matrix, CsI:Tl is chosen as an inorganic scintillator due to its high light yield (55,000 Ph/MeV), less hygroscopicity and easy preparation method in powder form. Two films, measuring 1 inch in diameter with thicknesses of 0.1 mm and 0.2 mm, were fabricated using 3D printing techniques and subsequently tested by structural and radiation characterizations, and suitability for X-ray imaging.

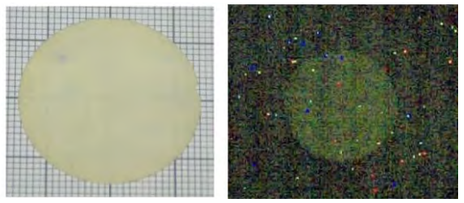


Figure 1: (A) 3D printed 0.2 mm thick film under natural light, (B) X-ray imaging of 0.2mm thick film.

The findings highlight the inherent trade-off between light yield and resolution in 3D printed scintillator films. The optimal thickness selection depends on the specific application requirements, prioritizing either high sensitivity or superior resolution. The X-ray imaging results of the two have been shown in the figure 1. Further optimization strategies, such as incorporating higher loading that could potentially mitigate this trade-off and enable the development of 3D printed scintillators are to be explored further for performance enhancement.

1. Z. Wang et al., "Needs, Trends, and Advances in Scintillators for Radiographic Imaging and Tomography," in IEEE Transactions on Nuclear Science, vol. 70, no. 7, pp. 1244-1280, July 2023.
2. Sibilieva, T er al., 3D printing of inorganic scintillator-based particle detectors. Journal of Instrumentation, 18(03), P03007, 2023.

This work is supported by 57/14/05/2021-BRNS grant.

Poster Sessions

FT20 Tuning scintillation performance of YAG:Ce single crystals by scandium doping

Iaroslav Gerasymov[1]*, Serhii Tkachenko[1], Daniil Kurtsev[1], Denys Kofanov[1], Pavel Maksimchuk[1], Oleh Viahin[1], Roberto Cala'[2,3], Loris Martinazzoli[2], Louis Roux[2,4], Etiennette Auffray[2], Oleg Sidletskiy[1,5]

[1]*Institute for Scintillation Materials NAS of Ukraine, Kharkiv, Ukraine*
[2]*European Organization for Nuclear Research (CERN), Geneva, Switzerland*
[3] *Università degli Studi di Milano-Bicocca, Milan, Italy*
[4] *Université Claude Bernard Lyon1, UMR5306 CNRS, Institut Lumière Matière, Lyon, France*
[5]*Centre of Excellence ENSEMBLE3 Sp. z o.o., Warsaw, Poland*

Corresponding Author Email: yarosgerasimov@gmail.com

Timing stands as a primary criterion for selecting scintillation materials in applications like TOF- PET [1] or future collider experiments [2]. Cerium-activated oxide scintillation single crystals are renowned for their swift performance owing to fast d-f relaxation in Ce^{3+}. Nevertheless, the long scintillation decay time of GAGG:Ce, the brightest oxide scintillator, does not meet the requirement of a phase 2 upgrade of LHCb experiment [3]. Additionally, GAGG:Ce and other Ga-containing scintillators are obtained in large sizes exclusively in Ir crucibles. Substituting Ga with Sc in the gadolinium garnet (GSAG:Ce,Mg) grown from Mo crucible [4] resulted in a strong decrease in the light yield compared to GAGG:Ce without significant enhancement in timing.

In this work, an attempt was made to reduce the luminescence decay time in YAG:Ce crystals by adding Sc that modifies the band gap by analogy with Ga addition into GAGG:Ce, and Ca^{2+}, which induces transfer of cerium Ce^{3+} to Ce^{4+} and eliminates carrier trappping. $(Y_{1-x-y}Ce_xCa_y)_3(Al_{1-z}Sc_z)5O_{12}$ (YAG:Sc,Ce,Ca) crystals with a Sc content of up to 25 at.%, diameter of up to 18 mm and length of up to 60 mm were grown from W crucibles by the Czochralski method in the CO-containing atmosphere (Fig. 1). Polished crystalline elements were annealed in oxidizing atmosphere. Optical absorption spectra clearly indicate the partial transfer of Ce into tetravalent state. The main Ce^{3+} band at 460 nm band remarkably weakened, while the short- wavelength (<300 nm) absorption increase, which corresponds to the Ce^{4+} - O2- charge transfer absorption, as well as may certify the reduction in the band gap. The maximum light yield of 14600 ph./MeV with an averaged luminescence decay time of 21.16 ns corresponds to 1 at. % Sc-doped sample. Further increase of Sc concentration in YAG:Sc,Ce,Ca leads to reduction in the decay time, but even faster decrease in the light yield.

Fig. 1. As grown YAG:Sc,Ce crystals under UV irradiation (Sc content changes from 1 to 25at.% from left to right)

1. P. Lecoq, "Pushing the Limits in Time-of-Flight PET Imaging," IEEE Trans. Nucl. Sci., 1, 6 (2017)

2. B. Schmidt, "The High-Luminosity upgrade of the LHC," Journal of Physics: Conference Series, 706 (2016).

3. L. Martinazzoli et al, "Compositional engineering of multicomponent garnet scintillators: towards an ultra-accelerated scintillation response", Mater. Adv., 3, 6842 (2022)

4. O. Zapadlik et al., "Composition-Engineered GSAG Garnet: Single-Crystal Host for Fast Scintillators", Cryst. Growth Des., 21, 7139−7149 (2021).

This work was made in the frame of Horizon Europe ERA Widening Project no.101078960 "TWISMA".

FT21 Synthesis and characterization of $TlAlF_4$ composite films for X-ray imaging applications

D. Joseph Daniel, N.D. Ton, Jaeyoung Cho, H.J. Kim*

Department of Physics, Kyungpook National University, Daegu 41566, Republic of Korea

Corresponding Author Email: hongjoo@knu.ac.kr

Radiographic films are widely used in high-energy physics, national security and medical imaging fields, etc,. These Radiographic films are containing scintillation materials, which can transform the incident high-energy particles (X-ray or gamma-ray) into detectable visible light. In order to achieve good X-ray image quality, the scintillation film thickness should be thin enough. There are several methods available to fabricate films such as sputtering, ion diffusion, implantation, sol-gel and liquid phase epitaxy, etc,. However, these methods involve complex preparation conditions and are expensive, which limits mass production and hinders the broader applications in X-ray imaging.

Polymer-based composite films are considered to be one of the most promising techniques due to their simple experimental procedure, low cost and large volume production [1]. However, the composite films typically have low X-ray absorption and low light yield due to their low density and thickness. Therefore, choosing a scintillator crystal with high-density high- X-ray absorption is essential.

Recently, scintillation properties of $TlAlF_4$ crystal have been reported by D J Daniel et al [2], which has high density (ρ = 6.1 g/cm-3) and high effective atomic number (Z_{eff} = 70.07). Herein, we report the synthesis and characterization of $TlAlF_4$ loaded composite film prepared by solvent casting technique. To obtain a high-quality X-ray image, various weight percentages of $TlAlF_4$ crystalline powder have been loaded and optimized. The X-ray image was recorded using a homemade radiographic system using the Raspberry Pi HQ camera and shown in Figure 1. The preparation of the composite film and various characterizations will be discussed in more detail.

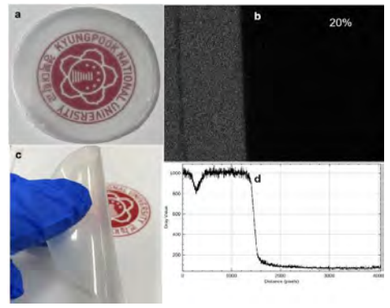


Figure 1 a &, c shows the prepared $TlAlF_4$ composite film and c &d shows the recorded X-ray image of thin metal wire and the gray value.

1. Pengcheng Du et al., "LuAG:Ce-PDMS composite scintillator films for X-ray imaging," Journal of Luminescence, 247 (2022) 118910.

2. D Joseph Daniel, Arshad Khan, Mohit Tyagi, HJ Kim "Scintillation properties of tetrafluoroaluminate crystal," IEEE Transactions on Nuclear Science, 6, 67 (2020).

Acknowledgments

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Poster Sessions

FT22 Fast emitting nanocomposites for high-resolution ToF-PET imaging based on multicomponent scintillators.

Matteo Orfano[1], Fiammetta Pagano[2], Ilaria Mattei[3], Francesca Cova[1], Valeria Secchi[1], Silvia Bracco[1], Edith Rogers[4], Luca Barbieri[1], Matteo Sala[1], Roberto Lorenzi[1], Gregory Bizarri[4], Etiennette Auffray[5], Angelo Monguzzi[1]

[1]*Dipartimento di Scienza dei Materiali, Università degli Studi Milano-Bicocca, Milano, Italy*
[2]*Instituto de Instrumentación para Imagen Molecular, Valencia, Spain*
[3] *INFN, Milano, Italy*
[4] *CERN, Geneva, Switzerland*
[5] *Cranfield University, School of Aerospace, Transport & Manufacturing, Cranfield, UK*

Corresponding Author Email: angelo.monguzzi@unimib.it

Time-of-Flight Positron Emission Tomography is a medical imaging technique, based on the detection of two back-to-back γ-photons generated from radiotracers injected in the body. Its limit is the ability of employed scintillation detectors to discriminate in time the arrival of γ-pairs, i.e. the coincidence time resolution (CTR). A CTR < 50 ps would enable fast imaging with ultralow radiotracer dose. Monolithic materials do not have simultaneously the required high light output and fast emission characteristics, thus the concept of scintillating heterostructure is proposed, where the device is made of a dense scintillator coupled to a fast-emitting plastic scintillator. Here is presented a composite polymeric scintillator loaded with hafnium oxide nanoparticles. This enhanced by +300% its scintillation yield, surpassing commercial plastic scintillators. The nanocomposite is coupled to bismuth germanate oxide (BGO) realizing a multilayer meta-scintillator [1]. We observed the energy sharing between its components, which activate the nanocomposite fast emission enabling a net CTR improvement of 25% with respect to monolithic BGO. These results demonstrate that a controlled loading with dense nanomaterials is an excellent strategy to enhance the performance of polymeric scintillators for their use in advanced radiation detection and imaging technologies.

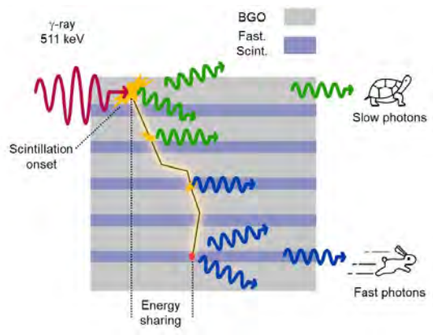

Figure 1: sketch of a multilayer meta-scintillator.

1. G. Konstantinou, P. Lecoq, J. M. Benlloch and A. J. Gonzalez, "Metascintillators for Ultrafast Gamma Detectors: A Review of Current State and Future Perspectives," in IEEE Transactions on Radiation and Plasma Medical Sciences, vol. 6, no. 1, pp. 5-15, Jan. 2022, doi: 10.1109/TRPMS.2021.3069624.

FT23 Scintillation Properties of Tl^+ and Sr^{2+} co-doped $Cs_3Cu_2I_5$ for the gamma-ray monitor in BNCT

Yusuke Urano[1,2], Shunsuke Kurosawa[2,3,4], Akihiro Yamaji[2,3], Akira Yoshikawa[2,3], Yuntao Wu[5]

[1]*Graduate School of Engineering, Tohoku University, Sendai, Miyagi, Japan*
[2]*Institute for Materials Research (IMR), Tohoku University, Sendai, Miyagi, Japan*
[3]*New Industry Creation Hatchery Center (NICHe), Tohoku University, Sendai, Miyagi, Japan*
[4]*Institute of Laser Engineering, Osaka University, Suita, Osaka, Japan*
[5]*Artificial Crystal Research Center Shanghai Institute of Ceramics, Chinese Academy of Sciences (SICCAS), Shanghai, P.R. China*

Corresponding Author Email: urano.yusuke.s1@dc.tohoku.ac.jp

Boron neutron capture therapy (BNCT) is the next-generation radiation-therapy based on the nuclear reaction of boron (^{10}B) and thermal neutrons. The ranges of alpha particles and Li atomic nuclei produced by the $^{10}B(n, \alpha)^7Li$ reaction are shorter than the diameter of a cell; this treatment modality can selectively treat cancer cells with little or no damage to normal cells. To estimate the treatment effect in real time, the use of prompt gamma rays (478 keV) emitted by the $^{10}B(n,\alpha)^7Li$ reaction has been proposed [1]. In the treatment field, the background (BG) events include 511-keV gamma rays from positron and electron annihilation, and thermal neutrons. To discriminate the 478-keV gamma- ray signal from such BG events, a scintillator with an energy resolution better than 6.5 % (FWHM) at 511 keV is required. $Cs_3Cu_2I_5$ (CCI) scintillators [2,3] have a high light output of 41,500 photons/MeV and high energy resolution of 4.4% at 662 keV (FWHM) [2]. In addition, CCI has lower hygroscopicity compared to CsI crystal, an important advantage for practical use in gamma- ray monitors. However, the scintillation decay time of the CCI is 1040 ns, in order to measure under high radiation count rates, the scintillation decay time is required to be faster.

In iodide scintillators, it has been reported that co-doping Tl^+ and Sr^{2+} improves energy resolution, faster scintillation decay time, and significantly improves non-proportionality [4]. Therefore, we grew Tl^+ and Sr^{2+} co-doped CCI (Tl,Sr:CCI) crystals and evaluated their luminescence and scintillation properties.

The raw material samples CsI, CuI, TlI and SrI2 were mixed inside the glove box filled with Ar gas, and sealed in quartz ampoule. Tl,Sr:CCI crystals were grown by the vertical Bridgman-Stockburger method. The phase for the each obtained crystal was verified by powder X-ray diffraction (XRD) with D8 DISCOVER (Bruker). Photoluminescence (PL) excitation and emission wavelength were measured with a spectrofluorometer (FP-8300, JASCO). To evaluate the light output, the pulse height spectra excited by gamma rays from a ^{137}Cs source were measured with a photomultiplier tube (R7600U-200, Hamamatsu K.K.), shaping amplifier (572A, ORTEC) and multichannel analyzer (Pocket Fig. Scintillation decay curve of Tl,Sr:CCI MCA8000D, AMPTEK). In addition, the scintillation decay times fitted with a single component exponential were measured with an oscilloscope (TDS3052B, Tektronix).

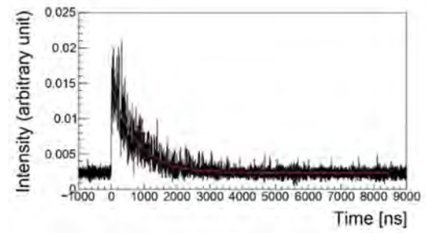

Fig. Scintillation decay curve of Tl,Sr:CCI fitted with a single component exponential function

We succeeded in growing Tl^+ and Sr^{2+} co-doped $Cs_3Cu_2I_5$ crystals. Each crystal phase was confirmed by the powder XRD measurements. The photoluminescence results showed Tl,Sr:CCI have an emission wavelength of approximately 500 nm, which was longer than CCI's emission wavelength of 440 nm. The scintillation decay was fitted by a single exponential function, with the decay constant of 750 ± 21 ns, which was shorter than that of Tl-doped CCI. In this presentation, we also show the other scintillation characteristics.

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2. L. Stand et al., Instrum. Methods Phys. Res. A, 991, 164963 (2021)
3. T. Jun et al., Adv. Mater., 30, 1804547 (2018)
4. K. Yang et al., J. Appl. Phys., 118, 213106 (2015)

Poster Sessions

FT24 A novel scintillator-based Time of Flight Proton Radiography: overview and preliminary experimental results of the TOFpRad project

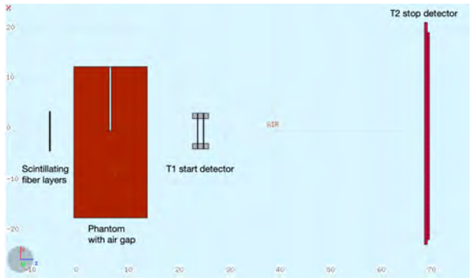
Y. Dong[1], R. Anzalone[2, 7], G. Battistoni[1], E. Ciarrocchi[2, 7], M. Francesconi[6], L. Galli[7], A. M. Goanta[2, 7], N. Krah[3], A. Mereghetti[4], S. Muraro[1], M. Pullia[4], G. Traini[5], M. Morrocchi[2, 7]

[1]*Istituto Nazionale di Fisica Nucleare sezione di Milano, Milano, Italy*
[2]*Università di Pisa, Pisa, Italy*
[3]*Centre de Research en Imagerie Medicale, Lion, France*
[4]*CNAO Centro Nazionale di Adroterapia Oncologica, Pavia, Italy*
[5]*Istituto Nazionale di Fisica Nucleare sezione di Roma1, Roma, Italy*
[6]*Istituto Nazionale di Fisica Nucleare sezione di Napoli, Napoli, Italy*
[7]*Istituto Nazionale di Fisica Nucleare sezione di Pisa, Pisa, Italy*

Email: yunsheng.dong@mi.infn.it

Proton radiography is an imaging technique based on the detection of the proton position or trajectory and of its energy loss in an object. It can provide a density resolution of 1%-2% with a radiation dose comparable to or even lower than that of X-ray techniques. In addition, it can also be exploited for range monitoring during treatment sessions of particle therapy [1].

The existing proton imaging devices are typically based on the measurement of the residual kinetic energy of particles exiting the target using a calorimeter. Recently, different studies have been conducted to evaluate the possibility of retrieving the proton kinetic energy by measuring their Time Of Flight (TOF), showing that this approach can increase the energy resolution [2].



The TOFpRad project preliminary experimental setup tested at CNAO. T2 stop detector distance is not to scale

The TOFpRad project aims to assess the viability of a proton radiography system based on the TOF approach by realising a prototype consisting of two fast plastic scintillator detectors for the TOF measurement and a set of layers of plastic scintillator fibres for tracking purposes, both read with SiPMs. A preliminary TOF measurement system has been developed and tested at CNAO (Pavia) with 62-227 MeV protons, showing the capability of the system to detect an air gap of the order of a few millimetres located at different depths in a water equivalent phantom.

Details about the TOFpRad project, the FLUKA Monte Carlo simulation studies and the results of the data taking will be shown.

1. R.W.Schulte et al., "Density resolution of proton computed tomography," Medical physics, 32 (4), 1035-1046 (2005).
2. N. Krah et al., "Relative stopping power precision in time-of-flight proton CT", Physics in medicine & biology, 67, 2022

FT25 Inorganic Perovskite Scintillating Thin Film and its application

Yatharth Thakar[1], Divya Pandya[1], Sheetal Rawat[1]

[1]*Department of Physics: School of Energy Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India*

Corresponding Author Email: sheetal.rawat@sot.pdpu.ac.in

Perovskites scintillators, with their tunable bandgaps, high light yield, and solution processability, are emerging as game-changers in X-ray imaging. This research addresses these challenges by exploring the potential of lead free perovskite scintillating thin films for medical imaging application. Our work focuses on exploration of facile synthesis routes like spin-coating, anti-solvent approach and drop casting method. Enabling cost-effective and scalable production of high-quality thin films of their high emission stability, unique self-trap exciton emission, and high quantum light yield as well as their relatively low toxicity and earth- abundant constituents [1]. Conventional crystal and bulk form of scintillator are fragile and restrict the detection on flexible sides . Cs3Cu2I5: Tl is highly stable, high light yield scintillator (98,200 ph/MeV) [2].

(a) *(b)*

Figure: Cs3Cu2I5: Tl thin film fabricated on flexible substrate (a) under visible light (b) under the UV light

In this work, The $Cs_3Cu_2I_5$:Tl powder is synthesized through an anti-solvent approach, followed by the characterization of films on ITO-coated PET substrate using spin coating and drop casting methods. The fabricated films undergo UV-Vis and photoluminescence characterization. The calculated estimated band gap is 3.72 eV, and a remarkably intense photoluminescence peak at approximately 450 nm aligns with previously reported data. Detailed radiation characterization and imaging results are underway. The thin film prepared holds promising potential for X-ray detection in medical applications.

1. Li, Chang-Xu, et al. "Monodisperse lead-free perovskite Cs3Cu2I5 nanocrystals: role of the metal halide additive." Chemistry of Materials 34.15 (2022): 6921-6932.
2. Stand, L., Rutstrom, D., Koschan, M., Du, M. H., Melcher, C., Shirwadkar, U., ... & Zhuravleva, M. (2021). Crystal growth and scintillation properties of pure and Tl-doped Cs3Cu2I5. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 991, 164963.

Poster Sessions

FT26 Development and GEANT4 Simulation of an Economical Position-Sensitive CsI:Tl 4 × 4 Single Crystal Pixelated Array

Sheetal Rawat[1,*], Apoorva Bhatt[1], Nisha Oad[2], Divya Pandya[1]

[1]Department of Physics, School of Energy Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India
[2]Department of Chemistry, School of Energy Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat, India

Corresponding Author Email: Sheetal.Rawat@sot.pdpu.ac.in

In the realm of medical imaging, recent advancements are underway in the development of pixelated gamma and X-ray cameras featuring discrete detector elements with a compact Field of View (FOV). The detectors of choice are primarily single crystal scintillators, including LYSO, CdW04, CsI:Tl, and BGO. Subsequently, these scintillator crystals with high-spatial resolution are intricately assembled into an array and connected to a Position Sensitive Photomultiplier Tube (PS-PMT) and a readout system. Array performance is further fine-tuned through thoughtful design choices and the use of specific reflector materials. To date, the properties of single crystal scintillators surpass those of their polycrystalline and composite counterparts in crucial aspects such as light yield, timing, energy resolution, and radiation hardness. This

superiority motivates ongoing exploration by researchers into cost-effective fabrication techniques. One notable method gaining attention is the Modified Inverse Temperature Crystallization (ITC) Method. This technique involves maintaining a constant temperature in a supersaturated solution, facilitating the growth of high-quality, large-size single crystals. In our research, we aim to develop a cost effective and efficient 4 × 4 position-sensitive CsI:Tl crystal array, schematic illustrated in Figure 1. The growth of individual single crystals utilizing the modified Inverse Temperature Crystallization (ITC) method significantly contributes to cost-effectiveness in developing this position-sensitive pixelated array. The scintillation structure comprises 4 × 4 scintillator elements with 2.0 × 5.0 × 7.0 mm³ pixels, and the thin 0.1 mm dead zone of light-reflective material between pixels is precisely measured using optical microscopy. To optimize performance, a 100 µm thick white TiO2 reflector paint is applied to the five blind surfaces of the CsI:Tl array within a 4 × 4 epoxy mask coupled with a readout system. Spatial resolution calculations, both experimental and theoretical, are conducted at various source distances, and the sensitivity of the detector is estimated through GEANT4 simulation of energy deposition in the array, ensuring a comprehensive evaluation of array performance.

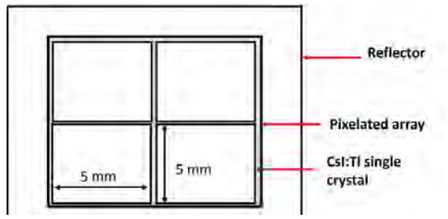


Figure 1: Schematic of the Pixelated CsI:Tl single crystal array

1. G.-Z. Shi, R.-F. Chen, K. Chen, A.-H. Shen, X.-L. Zhang, J.-D. Chen, C.-M. Du, Z.-G. Hu, G.- W. Fan, Development of a position sensitive CsI(Tl) crystal array, Nuclear Engineering and Technology, 52, 835-840 (2019).

2. Miguel A. Cortés-Giraldo, et al., Geant4 Simulation to Study the Sensitivity of a MICRON Silicon Strip Detector Irradiated by a SIEMENS PRIMUS Linac, Nuclear Science And Technology, 2,191-196 (2011).

Acknowledgments should appear near the bottom of the page.

FT27 3D-Printed Plastic Scintillator: A Potential Avenue for Heterostructured Radiation Detectors

V. Anand[1], Bhavika[1], G. Bizarri[2], G. Anil Kumar[1], V. Ranga[1],Varun Sharma[3]

[1]Department of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, India
[2]Cranfield University, Bedfordshire, MK43 0AL, England, United Kingdom
[3]Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, Roorkee-247667, India

Corresponding Author Email: vivek_a@ph.iitr.ac.in

Positron Emission Tomography (PET) has gained widespread clinical acceptance due to its ability to offer functional insights at the molecular level, facilitating early diagnosis of multiple diseases. A significant advancement in PET technology came with the integration of Time-of-Flight (ToF), which led to enhanced performance [1]. ToF-PET is highly dependent on the stopping power and decay time of the used scintillator. Finding a detector material with a sub-nanosecond time response with equivalent light output and stopping power than LSO would drastically improve PET performance and open the door to the possibility of achieving Coincidence

Time Resolution (CTR) (10-50 ps), enabling a new type of modality for PET. However, existing monolithic scintillators exhibit a trade-off between these two properties. The current standard material, LSO, meets the criteria for small attenuation length but falls short in achieving sub- nanosecond decay times. To address this challenge, the concept of heterostructure, employing two distinct scintillator materials—one with high stopping power (the matrix) and the other with ultra-fast time response (the filler)—working synergistically, has been introduced [2-3]. Heterostructure configurations often involve intricate geometries and necessitate precise micro-level dimensional tolerances. 3D printing offers a potentially novel solution for rapid prototyping complex geometries with good precision. This technique is cost-effective, requires minimal or no post-processing, and significantly reduces fabrication time compared to conventional thermal polymerization methods. Utilizing a Digital Light Processing (DLP)-based 3D printer, which employs UV light to solidify polymeric materials, Plastic Scintillators (PS) can be fabricated effectively. PS is characterized by fast decay kinetics, making it a potential filler material.

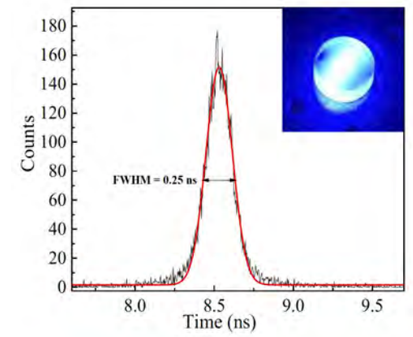


Fig.: 3D printed PS under UV illumination (inset) and the measured CTR spectrum.

In this study, we present the development of a high aromatic-content PS using DLP for use in heterostructure ToF-PET systems. Additionally, we present the CTR of a 3D-printed PS. The presentation will include the synthesis and characterization of a cylindrical PS (Ø25mm × 10mm) fabricated using vinyl toluene and a hexacrylate monomer in a 2:1 ratio. PPO and POPOP are used as primary and secondary dopants, respectively. The 3D printed scintillator demonstrates an emission peak at 427 nm with a maximum transmission of 55%. The density of the PS is 1.2 g/cm³, and its light output is approximately 5800 photons/MeV. Notably, it exhibits fast fluorescent decay times of 0.12 ns (55.63%) and 1.48 ns (44.37%). To evaluate CTR, two scintillators of similar shape and size were mounted on identical PMTs. Initial optimization of the parameters yields an FWHM of 250 ps. A preliminary simulation of the performance of the scintillator within heterostructures will also be presented. Leveraging 3D printing technology may offer innovative avenues for producing scintillators, especially ones that require complex geometry, such as the currently developed heterostructured detectors for ToF-PET.

1. Dennis R Schaart, "Physics and technology of time-of-flight PET detectors," Phys. Med. Biol., 66, 09TR01 (2021).

2. P. Krause, G. Bizarri, et al., "Design rules for time of flight Positron Emission Tomography (ToF-PET) heterostructure radiation detectors," Heliyon, 8, 6 (2022)

3. P. Krause, G. Bizarri, et al., "Advances in Design of High-Performance Heterostructured Scintillators for Time-of- Flight Positron Emission Tomography," Advanced Theory and Simulations, 7, 1 (2023)

Poster Sessions

SCINTILLATORS FOR NEUTRON DETECTION AND IMAGING

NE5 Synthesis and photophysical propeties of polyaromatics cyclophanes: towards a new generation of plastic scintillators

O.Diallo[1,2], G.H.V.Bertrand[1], D.Kreher[2]

[1] Laboratoire Capteurs et Instrumentation pour la Mesure DRT/LIST/DM2I/SCI/LCIM ; CEA Saclay F-91191 Gif-sur-Yvette CEDEX ; France
[2] Institut Lavoisier de Versailles ; UMR ; CNRS 8180 ; 45 Avenue des Etats-Unis ; 78000 Versailles ; France

Corresponding Author Email: Oumou.diallo@cea.fr

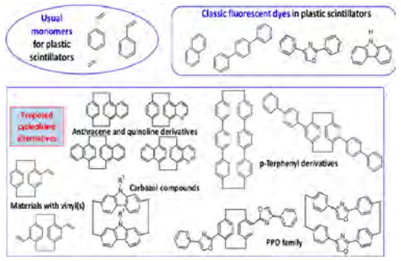
The SORG team and LCIM lab (CEA) have recently collaborated on the integration of molecules from the cyclophane family in radiation detection devices, plastic scintillators [1]. A major issue in the field is in fact the differentiation of signals originating from an interaction with a neutron or a gamma ray: n / γ discrimination [2]. However, it has been identified that the addition of cyclophane improves the discriminating properties of certain scintillators. We would therefore like to explore other poly-aromatic cyclophane molecules and test them with new methods of manufacturing scintillators [3]. This multidisciplinary project, in an application framework, will therefore allow skills to be gained in various fields: cyclophane chemistry, photophysics, radiation / matter interaction, etc.

More precisely, this PhD co-funded by the LaBex an CEA can therefore be conceived in three stages:

1) Designing, synthesizing and characterizing new promising cyclophane-based derivatives, with exploring the possibility of a scale-up on the most promising molecules.

2) Investigating the ability of these new cyclophanes towards triplet stabilization and TTA promotion, with focusing on developing a theoretical model on TTA in radioactive ionization.

3) Fabricating scintillators and evaluating cyclophane effects on n/γ discrimination power.



This project is then highly inter-disciplinary, as it requires a capacity and expertise in three different fields: cyclophane chemistry, high density photo-physics and plastic scintillation manufacturing. These three areas and their synergy are essential to have a multi-scale understanding of the project. Plastic scintillation will provide macroscopic responses and guide the improvements for an optimal result, while photophysical experiments will provide an analysis of the molecules and theory associated with TTA. This Macroscopic, theoretical and molecular approach is obviously not possible without the synthesis of the targeted poly-aryl cyclophanes, their synthesis being itself not devoid of challenges to provide considerable advances in this field.

1. G. H. V. Bertrand, M. Hamel, D. Kreher, E. Montbarbon, FR1860318, 2018
2. Bertrand, G. H. V.; Sguerra, F.; Hamel, M. Chem. Eur. J. 2014, 20, 15660–15685
3. Beilstein J. Org. Chem. 2015, 11, 1274–1331. doi:10.3762/bjoc.11.142

NE6 Development of Organic Glass Scintillators for Nuclear Physics Experiments

Edgar van Loef,[1] Urmila Shirwadkar,[1] Tawan Jamdee,[1] Jared Schott,[1] Chuncheng Ji,[1] Lakshmi Soundara Pandian,[1] Jarek Glodo,[1] Patrick L. Feng,[2] Lucas Nguyen,[2] Anabelle Benin,[2] Remco G. T. Zegers [3]

[1] Radiation Monitoring Devices Inc., 44 Hunt Street, Watertown, MA, USA
[2]Sandia National Laboratories, Livermore, CA, USA
[3]Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI, USA

Corresponding Author Email: EvanLoef@RMDInc.com

In order to explore exotic nuclei and their interaction with non-relativistic hadron particles such as protons and neutrons, the nuclear physics community relies on state-of-the-art detector systems, in particular low-to-intermediate energy (150 keV – 100 MeV) neutron detectors. For example, the Low Energy Neutron Detector Array (LENDA) at the Facility for Rare Isotope Beams (FRIB) in Michigan, USA, studies the weak-interaction strength associated with beta- decay in astrophysical scenarios, such as supernovae.

Typically, liquid scintillation detectors are used in nuclear physics experiments due to their high light yields and excellent neutron/gamma pulse shape discrimination (PSD). However, a drawback is that they can be bulky and hazardous to work with. Alternatively, PSD-capable plastic scintillators offer efficient neutron detection and PSD, but typically have lower light yields than liquid scintillators.

Recent research at Sandia National Laboratory (SNL) and Radiation Monitoring Devices, Inc. (RMD) into Organic Glass Scintillators (OGS) has shown that these novel materials can provide efficient neutron detection, have a fast response, and have higher light yields with better neutron/gamma PSD than plastic scintillators [1,2]. Compared to stilbene crystals, OGS have comparable or in some energy ranges better performance [3]. Additionally, boron and metal-loaded versions of OGS provide excellent thermal neutron and gamma-ray detection, respectively, with the latter showing an energy resolution of about 10% at 662 keV. Finally, due to the high light yield of OGS, the threshold to detect low energy neutrons can be as low as 20 keV.

LENDA bar fabricated at SNL.

In this paper we report on the development of OGS for Nuclear Physics Experiments, in particular the scale-up of OGS to LENDA bar sizes. For a 15 cm long bar, the attenuation length was measured to be 1.2 m with an energy resolution of 20 keV at 60 keV (^{241}Am).

1. Joseph S. Carlson et al., "Melt-cast organic glasses as high-efficiency fast neutron scintillators", Nucl. Instr. Meth. Phys. Res. A 832, 152 (2016).
2. U. Shirwadkar et al., "Development of Multi-mode Organic Glass Scintillators for Nuclear Physics Applications," 2021 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), Piscataway, NJ, USA, 2021, pp. 1-4, doi: 10.1109/NSS/MIC44867.2021.9875655.
3. Tony H. Shin et al., "Measured neutron light-output response for trans-stilbene and small-molecule organic glass scintillators", Nucl. Instr. Meth. Phys. Res. A 939, 36 (2019).

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NE7 Performance Characteristics of Li Co-Doped NaI:Tl Single Crystal Detector

Sonu[1], M.Tyagi*[2], R.G Thomas[3], D.G. Parulekar[4] , A. Kumar[5] , and R.Tripathi[2,5]

[1]Technical Physics Division, BARC Mumbai, India
[2]Homi Bhabha National Institute, HBNI, Mumbai, India
[3]Nuclear Physics Division, BARC, Mumbai, India
[4]Technology Development Division, BARC, Mumbai, India
[5]Radiochemistry Division, BARC, Mumbai, India

Corresponding Author Email: tyagi@barc.gov.in

With the increasing demand for enhanced security applications and in light of the ongoing ^{3}He supply crisis, the development of a novel, neutron-sensitive scintillator has become an urgent priority. The discrimination capability of lithium co-doped NaI:Tl (NaIL) single crystal towards neutron and gamma interactions has been found to be good with Figure of merit ranging from 2 to 4 [1]. A single crystal of NaI doped with 0.1% Tl and co-doped with 2% lithium, having a diameter and length of 2 inches, was grown using a 4-zone vertical Bridgman furnace. After cutting, polishing and encapsulation of 2 inch dia. and 1cm thick sample, different characterization were done like radio-luminescence (RL), decay time, pulse height spectra etc. RL studies shows that Li co-doping does not introduces new luminescence centre in the host matrix. Experimental exploration were conducted using spontaneous fission (SF) neutrons from standard PuO_2 sources after thermalization with HDPE. FOM value for discrimination of neutrons and gamma was calculated to be 2 at energy value of 2.2 MeVee to 3.8MeVee. The resolution of the detector at 662keV was 8%. The efficiency of the thermal neutron detector, as measured with the standard neutron flux was 20%.

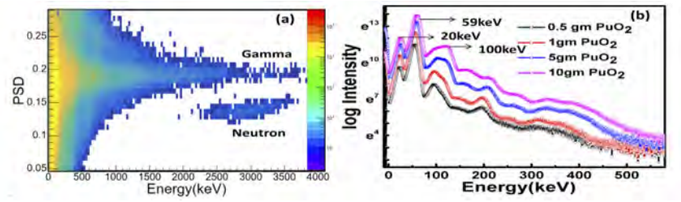


Fig.1(a) Pulse shape discrimination (PSD) spectrum of PuO2 gamma and neutrons from standard PuO2 source (b) Pulse height spectra of NaIL with gamma from different amount of PuO2 sources.

Fig. 1(a) shows the neutron gamma PSD = (1-QS/QL) in NaIL. The upper band corresponds to gamma from PuO_2 source and the lower band is due to thermal neutrons. After applying the PSD cut from PSD value 0.10 to 0.16 and energy cut from 1500 to 4000, and taking the projection of the lower band on the x-axis, we obtained the pulse height spectrum due to thermal neutron interaction. Fig.1 (b) shows the pulse height spectrum of gamma measured with NaIL with the same setup using different amounts of PuO_2. By increasing the amount of PuO_2,the counts in the region of interest (ROI) shows linearity with the amount of PuO_2. Moreover, the neutron peak intensity also shows linearity with the amount of PuO_2. Thus, by calibrating the detector with PuO_2 concentration, it can be used to measure the unknown amount of PuO_2. More results like Rossi-Alpha distribution, theoretical simulation, etc., will also be presented in details.

1. Kan Yang, Peter R. Menge and Vladimir Ouspenski, Li Co-Doped NaI:Tl (NaIL) "A Large Volume Neutron-Gamma Scintillator With Exceptional Pulse Shape Discrimination", IEEE Trans Nucl Sci, 64, 8, (2017).

NE8 Organic Glass Scintillators for High-Resolution Fast Neutron/X-ray Radiography

Nicholas Anastasi, Tawan Jamdee, Edgar van Loef, Charles Sosa, Urmila Shirwadkar, Bipin Singh, Lakshmi Soundara Pandian, Vivek V. Nagarkar

Radiation Monitoring Devices, Inc., Watertown, MA 02472, U.S.

Corresponding Author Email: NAnastasi@RMDinc.com

The capability to produce high-resolution fast neutron and X-ray radiographs in short time frames is vital for advancements in various fields such as homeland security, cargo inspection, nondestructive evaluation, material science, and medical imaging. While commercial X-ray detector systems offer exceptional radiographic performance, there's a demand for fast neutron radiography systems providing comparable spatial resolution and detection efficiency. In scintillator-based detectors, our aim is to find converter materials that maintain a strong response to fast neutrons while retaining precise spatial information. To this end, RMD is developing scintillators for fast neutron/X- ray radiography based on organic glass scintillator (OGS). This material demonstrates impressive properties with a light yield of ~ 20,000 photons/MeV, fast decay times of ~ 2 ns, and a figure of merit > 3 for n-γ pulse shape discrimination [1].

Importantly, OGS doped with tin (Sn) has shown promising results in imaging with both X- rays & fast neutrons. A 3mm-thick sample (Figure 1 left) showed a spatial resolution of over 7 lp/mm (< 70 µm) when imaged with X-rays. This same sample was used to acquire clear images of a tungsten cylinder under both 70 kVp X-rays and 2 MeV fast neutrons (Figure 1 right). We have successfully produced up to 25mm- thick sample of Sn-OGS, the thickest of which exhibits a spatial resolution of 2.8 lp/mm at 10% MTF with X- rays. This achievement is noteworthy considering the scintillator's thickness, demonstrating its potential for high-resolution imaging applications.

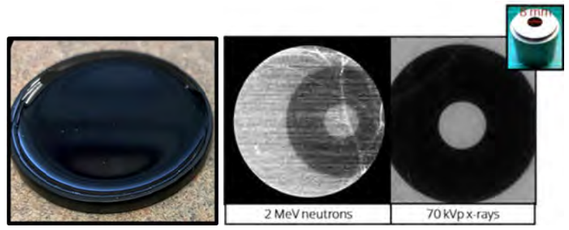


Figure 1 (left) picture of the 3 mm thick Sn loaded OGS sample (right) 10- minute exposure fast neutron image (2 MeV, 5×10^5 n/cm2/s flux) and 70 kVp X- ray image of a tungsten cylinder using 3 mm-thick OGS lens-coupled to an EMCCD.

Currently, efforts are in progress to enhance the detection efficiency and resilience of OGS by incorporating other materials like metals and polymers. RMD aims to manufacture OGS in large- area formats to enable coupling with various readout platforms, facilitating the creation of a fast neutron/X-ray radiography detector. Such a versatile detector, harnessing both types of radiation for imaging, will prove invaluable across diverse domains. In this presentation, we will discuss the outcomes of our fast neutron and X-ray imaging data, obtained using our novel OGS scintillators.

1. Carlson, Joseph S., and Patrick L. Feng. "Melt-Cast Organic Glasses as High-Efficiency Fast Neutron Scintillators." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 832 (2016): 152–57. https://doi.org/10.1016/j.nima.2016.06.116.

Poster Sessions

NE9 Tailoring Thermomechanical Properties and Stability of Organic Glass Scintillators

Annabelle I. Benin, Huu M. Tran, Tyler P. Eckles, Nicholas R. Myllenbeck, Melinda Sweany, Patrick L. Feng

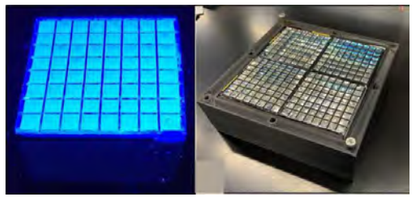
Sandia National Laboratories, Livermore, California, United States of America

Corresponding Author Email: abenin@sandia.gov

High-performance neutron and gamma-ray detection materials are an integral part of national security and nuclear physics applications. The development of high-throughput production methods for these materials is important to meet the emerging needs of specific detector configurations such as the pixelated detector concepts for neutron source localization and imaging applications.

Recently, we have reported a new class of Organic Glass Scintillator (OGS) materials that can be melt-cast to produce highly transparent parts that display high light yields of up to 16,000 photons/MeVee, as evaluated against EJ-200 plastic scintillators and solution-grown trans-stilbene crystals. The prepared organic glasses exhibit neutron/gamma pulse-shape discrimination (PSD) and are compatible with wavelength shifters to reduce optical self-absorption effects that are intrinsic to pure materials such as crystalline organics.[1]

In its pure form, the OGS material is brittle and susceptible to cracking when force is applied or upon cooling from the melt in a non-pliable mold due to negative thermal expansion. Initial formulation development work was reported to improve the thermomechanical properties which involved blending polymers or small-molecule plasticizers into the OGS matrix.[2] This enabled the successful fabrication of 64- channel segmented OGS detector arrays with individual 5mm x 5mm x 30mm pixels.



The appearance of cracking in array pixels over time as they are stored at room temperature has been problematic with previous OGS formulations such as those containing small molecule additive 2-(p-tolyl)-1,3,2-Dioxaborinane. Pixel cracking is undesirable due to the unpredictable nature of their appearance and the negative impact on array performance due to reduced light collection efficiency.

Here we present a more extensive study of different small molecule and polymeric additives into OGS formulations and their effects on thermomechanical properties and stability. We observed that the inclusion of various small molecules had the common result of recrystallization or pixel cracking in arrays over time but found more success with the incorporation of different polymeric additives into the OGS matrix. Preliminary mechanical testing on a series of OGS-polymer compositions (modulus of rupture and Vickers Microhardness) illustrated improved strength with increased polymer content. Formulation changes also necessitated modifications in processing methodology which will also be discussed.

1. J.S. Carlson, P. Marleau, R.A. Zarkesh, and P.L. Feng, "Taking Advantage of Disorder: Small- Molecule Organic Glasses for Radiation Detection and Particle Discrimination," J. Am. Chem. Soc., 139, 9621 (2017).

2. L.Q. Nguyen, H.M. Tran, A.I. Benin, J.S. Carlson, P. Marleau, M. Sweany, and P.L. Feng, "Organic glass scintillator formulations and mold development towards scalable and cast-in-place pixelated fabrications," Nucl. Inst. Meth. Phys. Res. A., 1036, 16835 (2022).

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NE10 Composition optimization of nanostructured polymeric scintillators for PSD applications

Luca Pollice[1], Xueqian Hu[2], Davide Rigamonti[3], Irene Villa[1], Michele Mauri[1], Marco Tardocchi[3], Francesco Meinardi[1], Christoph Weder[2], Angelo Monguzzi[1]*

[1]Department of Materials Science, University of Milano-Bicocca, 20125 Milano, Italy
[2]Adolphe Merkle Institute, University of Fribourg, CH-1700 Fribourg, Switzerland
[3]Institute for Plasma Science and Technology, National Research Council of Italy, Milan, Italy

Corresponding Author Email: Angelo.monguzzi@unimib.it

Scintillating materials can enable the discrimination of neutrons and charged particles from γ-rays by exploiting the pulse shape discrimination (PSD) technique. The ability to discriminate between high energy photons and ionizing particles is indeed useful in several fields, for example to estimate the power generated in nuclear reactors or to identify threat radioactive materials (Uranium-235 and Plutonium-230) from the reaction of other non-threat sources.

PSD techniques involve a time-gated analysis of the transient voltage pulse generated in the photodetector of the scintillation counter. This analysis allows to distinguish between fast and slow components of the scintillation signal, i.e., prompt and delayed emission, whose relative intensity and lifetime depend on the type of the incident radiation [1].

We demonstrated that sensitive and fast PSD detection can be achieved in nanostructured polymer scintillators. The material is made of a solid polymer matrix, which provides structural stability but is optically passive, liquid nanodomains containing an extremely high concentration of a triplet- triplet-annihilation (TTA) dye and optionally a triplet sensitizer, so that the delayed fluorescence occurs even at ultra-low energy densities [2].

In this work we investigated the PSD response of a series of nanostructured scintillators as a function of the composition, in order to point out the mechanism behind the sensitization of the delayed fluorescence intensity in the presence of a triplet sensitizer. The obtained results provide the guidelines for the design and fabrication of high performance nanostructured multiphase scintillators that can surpass the state-of the art, commercially available, PSD plastic scintillators.

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Poster Sessions

NE11 Light neutron-sensitive inorganic scintillation materials

Ilia Komendo[1], Daria Lelekova[1], Peter Karpyuk[1], Valentina Smyslova[1], Valery Dubov[1], Alexei Bondarev[2], Vitaly Mechinsky[2], Anton Rastimeshin[1], Eugeniy Litvinovich[1], Mikhail Skorokhvatov[1,3], Mikhail Korzhik[1,2]

[1]National Research Centre "Kurchatov Institute", Moscow, Russia
[2]Institute for Nuclear Problems Belarus State University, Minsk, Belarus
[3]MePhI, Moscow, Russia

Corresponding Author Email: ilia.komendo@cern.ch

Recently, our group investigated polycrystalline $Li_2CaSiO_4:Eu^{2+}$ as a neutron-sensitive scintillator, which is devoid the disadvantages of zinc sulfide (high effective charge of the compound, opacity to its own scintillations light, and long scintillation kinetics). Coatings of $Li_2CaSiO_4:Eu^{2+}$ are transparent, and the gamma-sensitivity of the 180 μm thick coating is 14 % lower than that of the commercial Scintacor ND screen. The efficiency of detecting neutrons with such a coating equals 14.7 % [1]. Further studies showed that by optimizing the activator concentration it is possible to increase the light output to ~104,000 photons/neutron [2]. It was also confirmed that partial replacement of silicon with aluminum makes it possible to increase the photoluminescence intensity by almost 2 times [3]. Such scintillation properties, with scintillation kinetics of less than 500 ns, as well as the possibility of improving properties, make the $Li_2CaSiO_4:Eu^{2+}$ scintillator a promising candidate to replace the century-old ZnS.

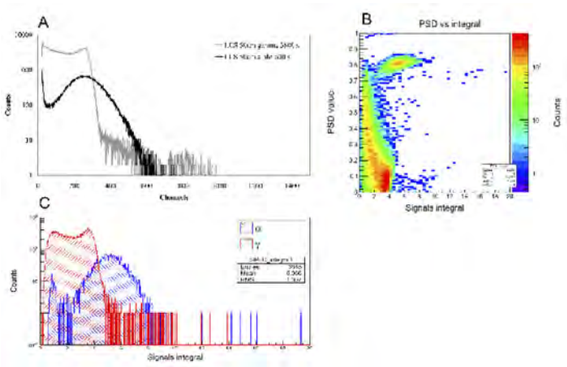

Fig 1. Pulse height spectra of 5.5 MeV α-particle and 661 keV γ-quanta for 50 μm $Li_2CaSiO_4:Eu^{2+}$ layer on EJ200A 10 mm plastic (a). PSD spectrogram of 50 μm $Li_2CaSiO_4:Eu^{2+}$ layer on EJ200A 10 mm plastic under 5.5 MeV α-particle and 661 keV γ-quanta excitation (b). Signal area spectrum for 50 μm $Li_2CaSiO_4:Eu^{2+}$ layer on EJ200A 10 mm plastic under 5.5 MeV α-particle and 661 keV γ-quanta excitation. Separation based on PSD value filtering (c) technique (fig 1b and c), which makes it possible to register antineutrino using the coincidence scheme.

Recent studies of the $Li_2CaSiO_4:Eu^{2+}$ scintillator have shown its applicability for detecting antineutrino radiation. Polycrystalline $Li_2CaSiO_4:Eu^{2+}$ was deposited in a 50-μm layer onto EJ200A scintillation plastic and irradiated with alpha and gamma radiation sources (^{238}Pu and ^{137}Cs, respectively). In this experimental setup, the scintillation plastic played the role of a target with which an antineutrino interacts to form a neutron and a positron. The product of the reaction of a neutron with the nucleus of a lithium atom of the $Li_2CaSiO_4:Eu^{2+}$ scintillator is an alpha particle and a triton:

$$^{6}Li + n + \rightarrow {}^{4}He + {}^{3}H + 4.8\ MeV$$

The alpha particle and triton interact with the $Li_2CaSiO_4:Eu^{2+}$ scintillator, and the annihilation gamma quanta from the reaction of positrons with electrons interact with plastic scintillator. As a result of the experiment, it turned out that the signals from the registration of alpha particles and gamma quanta (fig 1a.) are separated by PSD

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3. Retivov V. et. al. Compositionally Disordered Crystalline Compounds for Next Generation of Radiation Detectors // Nanomaterials. 2022. № 23 (12). P. 4295

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NE12 Ternary cesium lithium iodide crystals grown by vertical Bridgman method for scintillation applications

K. Křehlíková[1,2], R. Král[1], V. Vaněček[1], R. Kučerková[1], P. Zemenová[1], J. Rohlíček[1], P. Průša[1,3], A. Falvey[1,4], M. Nikl[1]

[1]Institute of Physics, Czech Academy of Sciences, Cukrovarnicka 10, Prague, Czech Republic
[2]Faculty of Chemistry and Technology, University of Chemistry and Technology in Prague, Technicka 5, Czech Republic
[3]Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehova 7, 11519, Prague, Czech Republic
[4]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, Prague, Czech Republic

Corresponding Author Email: zlouzeova@fzu.cz

Neutron detectors find wide applications in fields such as nuclear power generation, nuclear decommissioning and decontamination, border and homeland security, nuclear proliferation and nuclear medicine [1,2]. Since 2008, the world has been facing the shortage of ^{3}He, which has become extremely expensive, as the supply became limited. As ^{3}He proportional counters represent the industry standard for neutron detection [2], a new scintillation material meeting present and future challenges is sought-after. Such material should fulfill low-cost, solid-state and potential to be mass- produced from readily available materials and technology [3]. Moreover, there is still an ongoing need to develop and improve methods of detecting radioactive materials [1].

For both neutron and X- and γ-ray detection, ternary alkali halides, such as $Cs_2Li_3I_5$ (CLI) could represent an alternative material. CLI exhibits a light yield of ca. 40 000 to 55 000 photons/neutron, a primary decay time of just 250 ns for thermal neutron interactions and 500 ns for γ-rays [3]. The formation of a ternary CLI phase was already confirmed by Meyer and Gaebell in 1983 [4], nevertheless, the preparation of large CLI single crystals has not been published as of now. The goal of this work is to prepare single crystals of ternary CLI, confirm its phase purity and perform basic structural, physical, thermal, optical, luminescence, and scintillation characterizations. Further aim is to analyze the influence of doping of monovalent ions (e.g., Tl, In) in the matrix on its luminescence properties.

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