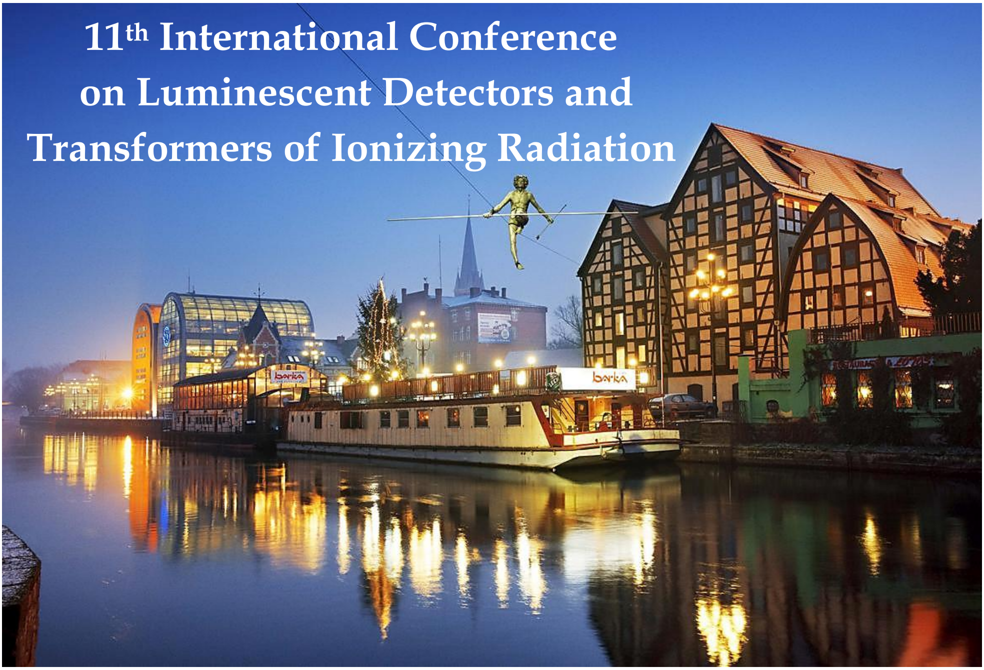
11th International Conference on Luminescent Detectors and Transformers of Ionizing Radiation



Summer School on scintillation, dosimetric and phosphor materials

10-11 September 2021

BYDGOSZCZ

POLAND

Program and Annotations of Lectures

http:// www.lumdetr2021.pl

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PREFACE

Dear Ladies and Gentlemen, Dear Young Colleagues!

We welcome you to the Summer School organized at the 11th International Conference "Luminescent Detectors and Transformers of Ionizing Radiation", LUMDETR 2021, https://www.lumdetr2021.pl.

The organization of such schools at leading international conferences is an effective and very well-rehearsed way to increase the scientific capacity of young scientists working in research topics related to that conference. Meanwhile, the effectiveness of the training of young scientists at such a Summer School very much depends on the qualifications of the lecturers involved in its performance. For this reason, the Organizing Committee of the LUMDETR 2021 conference has invited to give lectures at the School the recognized and didactically experienced lectors from leading scientific institutions working in fields related to the conference topics.

The planned lectures of the LUMDETR 2021 Summer Conference School will address the synthesis methods of luminescent materials in various crystalline forms (crystals, films, micro- and nanopowders) and application of the novel and advanced methods for characterization of luminescent materials properties (time-resolved spectroscopy, radiospectroscopy; synchrotron radiation, etc.). The lectures will also address the state-of-the-art issues related to the application of luminescent materials for detection of ionizing radiation in various fields of science and industry, such as environmental radiation monitoring, medicine, biology, archaeology, non-destructive control of materials and devices, control systems of baggage, etc. In a series of proposed lectures, the PhD students will also learn about the current trends in the design of scintillation and dosimetry materials and the requirements for the use of luminescent materials in the above mentioned applications.

The lecturers will be world-recognized scientists from leading institutes and universities of the European Union, e.g. from the Institute of Physics, Academy of Sciences, Prague, Czech Republic (Prof. M. Nikl; Prof. V. Laguta); the Laboratory of Luminescent Materials of Lyon1 University, France (Prof. C. Dujardin); the Department of Materials Science of University of Milano-Biccoca, Italy (Dr. Mauro Fassoli), the Institute of Physics of University of Tartu, Estonia (Prof. M. Kirm and Prof. M. Brik), Institute of Physics of the Polish Academy of Sciences in Warsaw, Poland (Prof. A. Suchocki), Institute of Nuclear Physics in Krakow, Poland (Prof. Paweł Olko), Institute of Physics of Jan Długosz University in Częstochowa, Poland (Prof. A. Mandowski); Institute of Physics of UKW in Bydgoszcz, Poland (Prof. Yu. Zorenko and K. Fabisiak), as well as the Institute for Scintillation Materials in Kharkov, Ukraine (Prof. O. Sidletskiy).

The participation of such well-known scientists in the Summer School will undoubtedly result in establishing new and expanding already existing international contacts between young and experienced scientists working in the field of detectors and transformers of ionizing radiation.

Each of the invited teachers will give lecture on the latest topics, which will last 40 or 80 minutes. The specialization of the lecturers and the content of their lectures are briefly described in the Programme and Abstracts of Lectures of the LUMDETR 2021 Summer School.

In addition, the programme of the LUMDETR 2021 Summer School includes an educational excursion to the city of Toruń in order to show places related with Nicolaus Copernicus and to better understand his role in the groundbreaking scientific discovery.

I wish you fruitful deliberations and acquisition of new knowledge at the Summer School.

Prof. Dr. Yuriy Zorenko,
hairman of the LUMDETR 2021 Conference

PROGRAM

Thursday, 09.09.2021
Arrival of Participants and Lecturers

Friday, 10.09.2021, PARIS Center, meeting room B

07:45–08:15	**Registration at LUMDETR Summer School with coffee/tee and sweets refreshment.**
08:15–08:30	**OPENING ceremony**
08:30–11:00	**S1 Scintillators and Detectors 1** **Chairman: Christophe Dujardin**
08:30–09:50	**Martin Nikl,** *Institute of Physics of the Czech Academy of Sciences,* ***Prague, Czech Republic.*** **R&D of scintillation materials: principles, strategies, examples.**
09:50–10:30	**Oleg Sidletskiy,** *Institute for Scintillation Materials NAS of Ukraine.* **Basic methods of scintillation crystal growth from melt.**
10:30–11:00	**Coffeee-break**
11:00–13:00	**S2 Scintillators and Detectors 2** **Chairman: Martin Nikl**
11:00–12:20	**Christophe Dujardin,** *Université Claude Bernard Lyon****, Lyon, France*****. Scintillators: Uses and Mechanisms of light production.**
12:20–13:00	**Yuriy Zorenko,** *Kazimierz Wielki University in Bydgoszcz, Poland.* **Liquid Phase Epitaxy – an excellent technique for producing of single crystalline film scintillators and thermoluminescent detectors.**
13:00–14:00	**Lunch**
14:00–16:00	**S3 Advanced Radio- and Opto-spectroscopic Methods and Technique** **Chairman: Mikhail Brik**
14:00–15:20	**Valentyn Laguta,** *Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic.* **Introduction to magnetic resonance spectroscopy (EPR, NMR) and its application in material science.**
15:20–16:00	**Kazimierz Fabisiak,** *Kazimierz Wielki University in Bydgoszcz, Poland.* **Development of CVD polycrystalline diamond TL dosimeters.**
16:00–16:30	**Coffee-break**
16:30–20:00	**Excursion to Torun city with visits in Planetarium and M. Copernicus memory sites**

PROGRAM

Saturday, 11.09.2021, Paris Center, small meeting room

08:30–10:30	**S4 Defects and Dopants in Luminescent Materials** **Chairman: Pawel Olko**
08:30–09:50	**Mauro Fassoli,** *University Milano-Biccoca, Italy*. **Thermoluminescence: a tool for the investigation of luminescent materials**
09:50–10:30	**Andrzej Suchocki,** *Institute of Physics Polish Academy of Science, Warsaw, Poland*. **High pressure as a tool for studying phosphor materials**
10:30–11:00	**Coffeee-break**
11:00–13:00	**S5 Advanced Methods: Synchrotron and Particle Radiation** **Chairman: Yuriy Zorenko**
11:00–12:20	**Marko Kirm,** *Institute of Physics University in Tartu, Estonia*. **Synchrotron Radiation and free electron lasers in luminescence materials research.**
12:20–13:00	**Pawel Olko,** *Institute for Nuclear Physics PAN in Krakow, Poland*. **Microdosimetry of luminescence detectors**
13:00–14:00	**Lunch**
14:00–16:00	**S6 Theory and calculation** **Chairman: Andrzej Suchocki**
14:00–15:20	**Mikhail Brik,** *Institute of Physics University in Tartu, Estonia*. **Energy levels of multielectron atoms.**
15:20–16:00	**Arkadiusz Mandowski,** *Jan Dlugoszcz University in Częstochowa, Poland.* **Strategies for mathematical modeling of thermoluminescence, optically stimulated luminescence and related phenomena.**
16:00–16:30	**Concluding remarks and School closing**
17:00–19:00	**Farewell dinner**

ANNOTATIONS OF LECTURES

R&D of scintillation materials: principles, strategies, examples

Martin Nikl

Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic

Scintillation materials, as an indispensable part of detectors of ionizing radiation and accelerated charged particles, appeared as a research topic at the moment of discovery of X-rays in 1895 and their research flourished a lot in last three decades both in terms of materials chemical composition and application demands. This lecture will review the working principles and an essence of underlying physical mechanisms, will show the modern strategies how to prepare and optimize them for particular application(s) and will provide few examples of successful material optimization and also some persistent bottlenecks in their performance yet waiting for a breakthrough.

Basic methods of scintillation crystal growth from melt

Oleg Sidletskiy

Institute for Scintillation Materials National Academy of Science of Ukraine, Kharkiv, Ukraine

The lecture addresses common principles and technologies of bulk and shaped scintillation crystal growth from melt. Historical overview and perspectives, physical background, technological equipment of the Czochralski, Bridgman-Stockbarger, Kyropoulos, Micro-pulling-down, Top-seeded solution growth, Edge-defined film-fed growth, Laser-heated pedestal growth, Gradient freezing, Verneuil, Skull methods, as well as combined Czochralski-Kyropoulos methods with melt feeding are presented. The methods are illustrated by practical examples on the growth of different types of scintillators, including oxide garnet, ortho- and pyrosilicate crystals, “traditional” CsI and NaI-based, as well as emerging Eu-doped halogenide crystals.

Scintillators: Uses and Mechanisms of light production

Christophe Dujardin

Université Claude Bernard Lyon1, Lyon, France

Seeing what cannot be seen is the main goal of a scintillating material, which converts the energy deposited by an X or γ-ray, but also from other ionizing particles such as electrons or neutrons, into visible light (or Ultra- Violet and Infrared).

Each induced flash of light can be then be detected using a traditional photodetector. The scintillator is thus a key element of ionizing radiation detectors. They are widely used in various societal sectors such as medical imaging, homeland security or oil drilling. A wide range of scintillator types exist, due to the wide range of performance and parameters required for the various applications.

The first part of the lecture will briefly describe the scintillation and the various ways of using it. Then the scope of the different applications and the related societal fields using these converting materials as well as the role and impact of the various quality criteria will be described.

In a second part, the physics of scintillation, with a particular focus on the energy relaxation will be detailed. Being rather complex, this description is not essential for understanding the first part. Nevertheless, it becomes of interest for material scientists. Indeed, a tiny change in the material may lead to huge consequences for performance. The optimization of performance and the synthesis processes thus require a good overview of these mechanisms, which include energy transfers as well as luminescence.

Liquid Phase Epitaxy – an excellent technique for producing single crystalline film scintillators and thermoluminescent detectors

Yuriy Zorenko

Institute of Physics of Kazimierz Wielki University in Bydgoszcz, Poland

The liquid phase epitaxy method play a very important role in the development of scintillators and TL detectors in the single crystalline (SCF) form. First of all, the LPE method enables receiving SCFs of several oxide compounds which are difficult to grow by the Czochralski or other melt-growth methods (TbAG, LuAP, Lu_2O_3, etc.). Secondly, the SCFs of garnet and other oxides still possess the large potential for creation of the scintillation and thermoluminescent (TL) materials in the film form as well as for the development of the composite film/crystal scintillators and TL detectors for different applications. Thirdly, the SCFs of garnet, perovskite, silicates etc. are very useful model objects for investigations of the fundamental optical properties of complex oxide compounds due to the absence of antisite defects and very low concentration of oxygen vacancies in them as well as related with them optical centers.

Taking into account mentioned above, the lecture consists of the three parts. Part 1 is devoted to the basic aspects of the LPE technology at producing SCF scintillators/TL detectors. The second part of the lecture is concentrated on the application of scintillators based on the SCFs of oxide compounds, first of all as scintillation screens for the microtomography, including imaging with typical X-ray sources and synchrotron radiation. The novel concepts of creation of the multi-layered SCF scintillating screens and TL detectors are considered as well. In Part 3 of the lecture, it is considered the use of SCFs of different oxides as model objects for the basic research of the luminescent and scintillation properties complex oxide compounds.

Introduction to magnetic resonance spectroscopy (EPR, NMR) and its application in material science

Valentyn Laguta

Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic

The aim of the lecture is to give the basic principles of modern methods of Electron Paramagnetic Resonance (EPR) spectroscopy and shortly Nuclear Magnetic Resonance (NMR) spectroscopy and their application in different fields of material science (physics, chemistry, biology) with particular attention to scintillation and optical materials.

A brief introduction to EPR and NMR methods will be given. This includes (i) physical principles of continuous wave (CW) and pulse (Fourier-Transform) methods of EPR/NMR detection; (ii) quantitative description and analysis of EPR spectra on the base of effective spin Hamiltonian. Then application of EPR to investigation both defects and local properties of materials will be considered. In particular, this includes identification of different defect states in scintillation materials, determination their local structure and concentration and correlation with optical properties; (ii) study of dynamic processes such as charge-transfer kinetics in insulating and semiconducting materials. The second part of the lecture will be devoted to short review of Modern methods in EPR/NMR spectroscopy. This will include (i) EPR/NMR imaging (MRT, micro-tomography), (ii) electrical and optical detection of EPR; (iii) Electron-nuclear double resonance; (vi) high-frequency EPR and NMR.

Development of CVD polycrystalline diamond TL dosimeters

Kazimierz Fabisiak

Institute of Physics, Kazimierz Wielki University in Bydgoszcz, Poland

Diamond is characterized by low atomic number (Z = 6) and is therefore can be considered as essentially soft tissue (Z = 7.4) equivalent. In such case, diamond can be attractive material for applications in clinical dosimetry where the radiation absorption in the dosimetric sensor material should be as close as possible to that of human tissue.

Synthetic diamond prepared by chemical vapour deposition (CVD) offers an attractive option for this application.

In present work a set of diamond layers was synthesized by Hot Filament Chemical Vapor deposition (HF CVD) from methanol-hydrogen ($CH_3OH–H_2$) gas mixture. By changing feed gas composition the obtained diamond films show different morphologies.

The obtained diamond films were analysed by Scanning Electron Microscopy (SEM), X-ray diffraction (XRD), cathodoluminescence (CL) and thermoluminescence (TL) spectroscopy

The aim of the present work is to report results on the thermoluminescence (TL) properties of CVD diamond samples. The annealing procedure, the linearity of the TL response as a function of dose, a short-term fading experiment and some kinetic properties have been investigated and are reported here.

Thermoluminescence: a tool for the investigation of luminescent materials

Mauro Fassoli

University Milano-Bicocca, Italy

The thermally stimulated luminescence (TSL) technique can provide detailed information not only on point defects in luminescent materials but also on the physical processes involved. The first part of the lecture will cover a brief introduction on the basic principles of TSL and on the related numerical analysis methods. Then, several examples of TSL measurements applied to the investigation of luminescent materials (in particular scintillators and dosimeters) will be presented.

High pressure as a tool for studying phosphor materials

Andrzej Suchocki

Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

Pressure is one of the fundamental thermodynamic variables, which allows for precise changing (decreasing) the interatomic distances of materials. Therefore the strength of the crystal field experienced by emitting ions can be this way effectively increased resulting in changes of electronic structures of host materials and dopant ions. This leads to transformation of luminescence spectra of phosphors. Several examples of such effects will be presented. It will be shown, for example, that pressure: (i) transforms a broad-band luminescence of Cr^{3+} ions in low-strength crystal-field materials (e.g., $LiNbO_3$:Cr) into a sharp line type spectrum, due to a replacement of the Cr^{3+} first excited state from the strongly coupled to the lattice $^4T_2$ state to weakly coupled ^2E state [1]; changes non-luminescent at ambient pressure materials doped with Ce^{3+} (e.g., GGG:Ce) into highly efficient emitting ones, which is associated with removal of degeneracy of the 5d Ce^{3+} level with conduction band of host [2]; (iii) causes quenching of Mn^{2+} luminescence in certain materials (e.g., $NaScSi_2O_6$:Mn and Gd(Zn,Mg)B_5O_{10}:Mn) due to pressure–induced crossing between $^4T_{1g}$ and $^2T_{2g}$ excited states [3,4].

Pressure also shifts positions of certain luminescence bands changing effectively the color of emission. In this way high pressure, which can be applied in precise and controlled way, allows to check and establish the best conditions for obtaining the desired luminescence properties of the material for practical applications.

References:

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[3] J. Barzowska, Zhiguo Xia, D. Jankowski, D. Włodarczyk, K. Szczodrowski, Chong-Geng Ma, M.G. Brik, Ya. Zhydachevskii, and A. Suchocki, *High pressure studies of Eu^{2+} and Mn^{2+} doped $NaScSi_2O_6$ clinopyroxenes*, RSC Advances **7**, 275 (2017).

[4] L.-I. Bulyk, L. Vasylechko, V. Mykhaylyk, C. Tang, Ya. Zhydachevskyy, Y.A. Hizhnyi, S.G. Nedilko, N. I. Klyui, A. Suchocki, *Mn^{2+} luminescence of Gd(Zn,Mg)B_5O_{10} pentaborate under high pressure*, Dalton Transactions 2020, **49**, 14268 – 14279

Synchrotron Radiation and free electron lasers in luminescence materials research

Marko Kirm

Institute of Physics University in Tartu, Estonia

Synchrotron radiation (SR) is the electromagnetic radiation emitted by relativistic charged particles moving with acceleration in magnetic field. This radiation is now widely used as brilliant research tool in physics, chemistry, materials and life sciences. SR has many superior properties which use will be discussed in the presentation. It is polarized and tunable in wide energy range, it has pulsed nature (~100 ps) and appreciable photon flux. It can be focused down to study nano-size objects. In my talk it will be explained how storage rings and free electron lasers generate photons, why advanced beamlines and experimental stations are needed for efficient use of SR.

MAX IV Laboratory and Photon Science, DESY are among most modern and brightest synchrotron radiation facilities in the World, located in Lund (Sweden) and Hamburg (Germany). Both facilities have increasing number of operational beamlines, which enables scientists to perform spectroscopy, microscopy and scattering experiments in highest level using hard and soft X-ray radiation. Developments of luminescence research carried out in both facilities will be reviewed. The first international FinEstBeAMS beamline, constructed by Estonian and Finnish universities, has a luminescence end-station located 1.5 GeV storage ring at MAX IV. FemtoMAX provides 10 keV X-ray pulses with 100 fs duration. At PETRA III storage ring the P66 beamline, follower of famous SUPERLUMI, dedicated to luminescence research is in commissioning process. In my talk, various luminescence and related spectroscopy methods (incl. time-resolved) will be discussed with ongoing activities at various beamlines with advanced research examples. Also other spectroscopic research methods allowing investigation different properties of materials will be discussed.

Microdosimetry of luminescence detectors

Paweł Olko

Institute of Nuclear Physics Polish Academy of Sciences, Poland

Luminescence detectors are broadly used in individual, environmental and space dosimetry because of their sensitivity, small size and stability in environmental conditions. Physical processes which lead to generation of the detector signal take places at distances typically much smaller than 1 micrometer. At this level the pattern of energy deposition of ionising radiation cannot be uniform because the energy of ionising radiation is transferred to the medium in the form of discrete, spatially correlated events, mainly due to ionisations or excitations. Therefore, the relationship between the measured signal and the average absorbed energy per unit mass of detector is not unique. Several microdosimetric models were proposed to explain observed dose and energy response of luminescence detectors and to predict their response for radiation modalities and dose ranges not available for the calibration.

The lecture will demonstrate how the concepts of microdosimetry can be applied to understand the properties of thermoluminescence detectors (TLD) exposed to ionising radiation and what effects in solid state detectors can be explained by considering the structure of charged particle tracks. The knowledge of the TLD response after high doses of γ-rays may be useful in predicting the low-dose response of TLDs after Heavy Charged Particle (HCP) irradiation, and of the photon energy response after doses X-rays. Explanation of the manner in which the dose, energy- and LET- responses of luminescence detectors are intercorrelated, is perhaps the most important contribution of microdosimetry to solid state dosimetry.

Energy levels of multielectron atoms

Mikhail Brik

Institute of Physics University in Tartu, Estonia

The lecture will be focused on physical origin of multielectron atoms' energy levels. Basic concepts of systematics of atomic states and notation of the spectral terms will be reviewed. Difference between the d- and f-ions energy level schemes (including crystal field effects) will be highlighted.

Strategies for mathematical modeling of thermoluminescence, optically stimulated luminescence and related phenomena

Arkadiusz Mandowski

Department of Experimental and Applied Physics, Jan Długosz University in Częstochowa, Poland

Defect-related luminescence in crystalline phosphors is characterized by very long recombination lifetimes. The phenomenon is typically used for passive dosimetry of ionizing radiation as well as for dating of archeological and geological sample. For this purpose usually thermoluminescence (TL) and optically stimulated luminescence (OSL) phenomena are employed.

Theoretical background of these phenomena is based on the concept of traps capturing charge carriers during the excitation stage. This metastable state may exist for quite a long time (even millions of years). Thermal or optical stimulation releases charge carriers which subsequently undergo radiative or non-radiative recombination. The rate of recombination depends on various parameters of traps and RCs but the most important factor is the kinetic mechanism of the process of detrapping and recombination.

Determination of the recombination mechanism is of crucial importance for the analysis of TL and OSL data. Theoretical analysis is usually limited to delocalized recombination mechanisms when charge carriers released form traps go through the conduction or valence bands. However other mechanisms – including localized, semi-localized and cluster-type recombination – are also possible. Moreover, most experimental TL, OSL and spectrally resolved data indicate that real detectors show a very complex structure. Analysis of TL glow curves, OSL decay and other experimental results may help to identify appropriate mechanism of recombination.

The Summer School on scintillation, dosimetric and phosphor materials will be held before LUMDETR 2021 conference, on September 10-11, 2021 as part of and with the support of LUMDETR 2021 Conference. Leading experts in respective fields will provide lectures related to material preparation technology, advanced characterization methods and applications. The school is organized for university and PhD students and young scientists under 35 year age.

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