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Review on a PhD thesis on
"Development of Novel Semiconductor Scintillators",
by MSc Abdellah Bachiri

The subject of the research conducted by MSc Abdellah Bachiri and described in the doctoral dissertation, submitted to me for evaluation, were the spectroscopic properties of three kind of materials, i.e. gallium oxide (β-Ga_2O_3), spinels ($MgGa_2O_4$ and $ZnGa_2O_4$) and mixed (Zn, Be)Se crystals with Be compositions from 2% to 20%.

The aim of the work was to compare the scintillation properties of various materials and to select the one that, in the author's opinion, was the most "promising". The study includes pulse height spectra, scintillation time profiles, and radio- and thermoluminescence measurements. For β-Ga_2O_3, the pure crystals achieved the highest scintillation yield (~9000 ph/MeV) and the best energy resolution (10.6%) with free electron concentrations of 10^{16} cm^{-3}. The samples were compared with each other. Higher concentrations of free carriers led to a decrease in the light efficiency due to Auger quenching. $MgGa_2O_4$ and $ZnGa_2O_4$ crystals were found to scintillate under gamma irradiation, with yields up to 2500 ph/MeV. Mixed (Zn, Be)Se crystals initially showed low scintillation efficiency. For this purpose, optimization was applied, and it was shown that zinc vapor annealing increased the efficiency up to 7700 ph/MeV for Be concentration of 2%.

Part of the research tasks were carried out as part of a research grants financed from the funds of the Polish National Science Centre (NCN) and the German Research Foundation (DFG) in frames of a joint grant (NCN: 2016/23/G/ST5/04048, DFG: GA 2057/2-1). The Author did not hide the fact that he used the input of other research centers. This is worth emphasizing and reflects well on the young scientist's career. Although most of the research was conducted at the Institute of Physics at Nicolaus Copernicus University in Toruń, encompassing scintillation, thermoluminescence, radioluminescence, and thermal property studies, as well as the crystal growth of pure ZnSe and (Zn, Be)Se. However, the growth of β-Ga_2O_3 and the Ga-based spinels was performed at the Leibniz Institute for Crystal Growth in Berlin. This collaborative Toruń-Berlin scientific effort was supported by funding from the National Science Centre (NCN) and the German Research Foundation (DFG) under the joint grant titled

"β-Ga_2O_3:Ce Semiconductor as a New Scintillator-Investigation of Spectroscopic and Scintillation Properties (GO SCINT)" already mentioned in the acknowledgment.

The dissertation was prepared in English, with summaries only in Polish and English. It consists of 6 chapters, each ending with a rich bibliography. The text is written in a clear and transparent manner. Chapter 1 is an "Introduction", while the following chapters are: " Physical bases of the scintillation phenomenon", " Present-day scintillator market", " Materials and experiment", " Results of conducted research with discussion", " Summary and conclusions". However, I would slightly change the structure of chapter 3, where the "Historical overview" appears only towards the end, as subchapter 3.4. This causes a certain discontinuity in the argument when, after the description of organic and inorganic scintillators, a historical outline suddenly appears. "Fluor compounds" is also not clear (chapter 3.1.1.5).

The research work begins in chapter 4. The author describes crystal growth methods here. These include, for example, Bidgman or Czochralski growth. The author also presents the crystal structure of the obtained materials and illustration of the band structure. All of this will allow the Author to develop the physical properties presented later in chapter 5.

The amount of data presented by the Author is impressive and is based on various measurement techniques. As already mentioned, he worked in many scientific centers, with the main measurements being conducted at the University of Toruń. This is confirmed by the hard literature, as for the Author's age. From the presented data, he is the co-author of 7 scientific papers in good journals, 2 oral conference presentations, 5 poster sessions. It is a pity, however, that he did not include copies of his conference papers and posters in his dissertation.

In terms of editorial style, the dissertation was presented correctly. The figures and tables deserve special attention. There are 142 figures and 16 tables. Moreover, if the Author did not make the drawings, appropriate references are provided. When collecting literature, the Author did not only reach for the published results. He reached for unpublished materials, which confirms that he effectively cooperates with the world scientific community, which makes the dissertation more complete.

To sum up my review, I state that the assumptions set by the Author of the dissertation have been realized by him. In particular, these are:

- presentation and analysis of the results of semiconductor scintillator measurements from two separate categories of crystals; the first category includes β-Ga_2O_3 crystals, both pure and doped with silicon, as well as two Ga-based spinels, $MgGa_2O_4$ and $ZnGa_2O_4$;
- analysis of pure ZnSe and (Zn, Be)Se crystals grown at the Nicolaus Copernicus University in Toruń with the active participation of the author of the dissertation.

    - The results of these studies are divided into three groups. The first category includes measurements of scintillation and luminescence properties, focusing on gallium oxide crystals, spinels based on Ga, ZnSe and (Zn, Be)Se; the second group includes measurements of relative light efficiency dependent on temperature for all crystals, carried out during the author's internship at NCBJ in Świerk. The third category examines thermal properties of (Zn, Be)Se crystals.

For this purpose, the following measurements and their interpretation were made:

- research involved measuring pulse height spectra to assess the scintillation efficiency of each crystal;
- the data in Tabs 5.3 and 5.4 reveals that pure β-Ga_2O_3 crystals with free carrier concentrations ranging from 10^{16} to 10^{17} cm^{-3} exhibited the highest scintillation efficiency about 9000 ph/MeV;
- the decrease in light yield (LY) with increasing free carrier concentration was attributed to the Auger effect;
- no positive effect of silicon doping on scintillation efficiency was found;
- pulse height spectra for single crystals of $MgGa_2O_4$ and $ZnGa_2O_4$ confirmed that Ga spinel crystals scintillate under gamma excitation, reaching only 2500 ph/MeV.
- the best scintillators were ZnSe and (Zn, Be)Se crystals, which reached 26,000 ph/MeV for ZnSe and 15,000 ph/MeV for (Zn, Be)Se;
- deconvolution analysis was proposed to isolate the decay profile of scintillation decay profiles;
- an unfavorable relationship was found between efficiency and scintillation rate, which requires a compromise in the choice of active material;
- the harmful effect of temperature on luminescence efficiency has been demonstrated.

The presented dissertation fully meets the formal requirements for a PhD thesis as outlined in the *Act of 20 July 2018 - Law on Higher Education and Science (section 187, p. 1-4)*. Therefore, I strongly recommend the admission of MSc Abdellah Bachiri to the subsequent stages of the doctoral procedure. Serious scientific achievements (publication and conference activity) allow me to propose awarding the doctoral student with a distinction.

Podpisuję z CenCert

Podpisany elektronicznie przez
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