Prof. dr hab. Andrzej Suchocki
Instytut Fizyki PAN
Warszawa

Warsaw, February 5, 2025

**Review of the doctoral dissertation entitled "Development of Novel Semiconductor Scintillators" of M.Sc. Abdellah Bachiri**

This doctoral dissertation concerns the research of new materials that are nominally semiconductors. These materials have postulated applications as scintillators, which are part of the radiation detector family, converting the energy of high-energy particles and quanta into photons with energies in the visible light range.

Doctoral thesis of M.Sc. Abdellah Bachiri prepared at the Faculty of Physics, Astronomy, and Informatics of the Nicolaus Copernicus University in Toruń under the supervision of Prof. Dr. Hab. Winicjusz Drozdowski and Dr. Marcin E. Witkowski (co-supervisor), pertain to the research of new materials, potentially applied as scintillators, i.e. β-$Ga_2O_3$, which has recently become more and more important in many fields of optoelectronics, as a kind of replacement for gallium nitride, also for applications as a scintillator, two spinels $MgGa_2O_4$ and $ZnGa_2O_4$, and also two more classical semiconductors such as ZnSe and (Zn,Be)Se. The use of semiconductors as scintillators is indeed a new approach to studying these materials, which looks encouraging, especially after the previous first reports of the relatively high scintillation efficiency of β-$Ga_2O_3$.

The tested materials (β-$Ga_2O_3$ and Ga-based spinels) were produced at the Leibniz Institut für Kristallzüchtung in Berlin (β-$Ga_2O_3$), with which the Nicolaus Copernicus Iniversity in Toruń has been cooperating for many years, as part of relevant research projects financed by the National Center Nauki (NCN) and Deutsche Forschungsgemeinschaft (DFG) and at the Nicolaus Copernicus University in Toruń (ZnSe, (Zn,Be)Se). The excellent effects of fruitful international cooperation between these centers should be emphasized here again. I think it is worth emphasizing the role of Dr. Z. Gałązka, who works in Berlin, which is most likely the basis for the growth of the crystals used in this work. Also the contribution of Prof. Karol Strzałkowski of Nicolaus Copernicus University to preparation of selenide crystals should be acknowledged here.

The dissertation is divided into six chapters. Each substantive chapter ends with an appropriate reference list, containing large number of links in some cases. The first three

chapters form the introduction to the description of the experimental results obtained during thesis implementation. Chapter 2 describes the physical basis of the scintillation effect. Chapter 3 presents an overview of the today's scintillation market, including the parameters and features of scintillators and the scintillator's application fields. Chapter 4 deals with the description of studied materials, i.e., with their growth techniques, and basic properties important for the process of scintillation, as well as detailed description of the measurement techniques used for studying the scintillation properties of the materials.

The content of these chapters shows that the author of the dissertation has a good understanding of both the subject of the research being conducted and the techniques used to characterize studied materials and processes leading to the scintillation effects occurring in them. I do not have many comments on this part of the thesis; however, perhaps it would be interesting, if during the discussion of the scintillation market the author of the dissertation had given some examples of various scintillators together with their typical parameters in the form of a table.

In my opinion, the description of the properties of examined scintillation materials is well done and this part of the thesis deserves an honorable mention. On the other hand, the description of the absorbance and transmittance spectroscopic equipment contains some faulty statements. On page 84 of the thesis the author write that "the visible spectrophotometers typically employ prisms to isolate specific ranges of wavelength" which is not generally true.

Chapter 5 of the thesis contains the results of the studies performed by Mr. Bachiri. For all examined compounds, the results of investigations of pulse height spectra, scintillation time profiles, radioluminescence, thermoluminescence, and temperature dependences of pulse height and scintillation yield are presented. Interesting, however, not very strong, negative thermal quenching phenomena were observed for radioluminescence, which was described by the Shibata model for some of the examined crystals. Chapter 5 ends with the presentation of the results of studies of band-gap as a function of Be concentration and thermal properties of ZnSe and (Zn,Be)Se crystals. The results of band-gap measurements are shown cursorily,

without providing a graph presenting the obtained results, which can be done better having the results of the absorption. For example, the author mentions that the bandgaps were estimated using Tauc plots, which are not shown here. In contrast, to that the results of thermal measurements using the photopyroelectric technique look very interesting.

The thesis's general conclusion is that the scintillation efficiency and light yield depend on carrier concentration in the measured materials. This is somehow obvious since the Auger effect (energy transfer from localized luminescence centers to carriers (mainly electrons in this case)) leads to effective luminescence quenching. So, semiconducting properties are not very helpful for obtaining highly efficient scintillators; however, they may help in shortening the decay times of scintillation. Generally the materials studied in this thesis do not have very high scintillation efficiencies but they can be useful for particular specific type of applications.

Chapter 6 of the dissertation provides a short, although concise, summary of achieved results.

Despite my previous criticisms of certain parts of the thesis, the scientific results presented in this dissertation are original and important. Mr. A. Bachiri demonstrated experimental skills, including handling various experiments, leading to interesting results. I consider the level of his knowledge presented in the introductory theoretical chapters of the dissertation to be high.

The dissertation ends with a list of publications with the author's participation. There are seven of them given here, published in good scientific journals. Mr. Abdellah Bachiri is the first author of one of these papers, published in Optical Materials Express. In addition, he participated in a few scientific conferences and meetings, presenting posters and oral communications. It should be considered as good dissemination result of his research.

In my opinion, the doctoral dissertation of M.Sc. Abdellach Bachiri meets the requirements of the Article 187 of the Act on Higher Education and Science of July 20, 2018 (as amended) necessary to obtain the academic degree of Doctor of physics and I hereby apply to the Council of the Discipline of Physical Sciences of the Nicolaus Copernicus University in Toruń to allow him to continue the procedure leading to obtaining the degree of Doctor of Physical Sciences.