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R E V I E W

on the dissertation for the acquisition of the educational and scientific degree "Doctor" in the scientific direction 4.1 "Physical Sciences", scientific specialty – "Electrical, magnetic and optical properties of condensed matter".

Scientific organization: Institute of Optical Materials and Technologies "Acad. Yordan Malinovski" - B A S

Author: M.Sc. in Physics Nikolay Diyanov Minev

Title: "Obtaining nano-sized layers from 2D materials for applications in optoelectronics"

Reviewer: Plamen Kostadinov PETKOV, Professor, Doctor, Eng., Department of Physics – University of Chemical Technology and Metallurgy

1. Biographical data about the candidate.

Nikolay Minev was born in Ruse in 1994. He graduated with honors from the High School of Chemical Technologies and Biotechnology "Prof. D. Balarev" in his hometown in 2013 and the following year enrolled in the bachelor's program at Sofia University - "Quantum and Space Theoretical Physics". After successfully graduating in 2018, he continued his second degree in the master's program "Medical Physics". In 2021, he brilliantly defended his diploma thesis entitled "Controlled synthesis of nanoscale layers of PtSe2 and study of their characteristics for potential applications in optoelectronics and biomedicine". The professional qualification received so far by Nikolay Minev fully meets the profile of the IOMT - BAS, where he also conducted the experiment for his master's thesis. From that moment on, the doctoral candidate has been inextricably linked to the subject matter and scientific activity of the Optical Metrology and Holography department of the Institute of Optical Materials and Technologies - Bulgarian Academy of Sciences. Having found himself in this academic environment, Master of Science in Physics Minev naturally continued his studies in the third level of education - Doctorate in the Laboratory of Composite and Nanostructured Optical Materials, as a continuation of his master's thesis. Working actively in one of the best groups

specializing in this scientific field, the doctoral candidate gained sufficient experience, and during his regular doctoral studies, in parallel with conducting the experiment, he participated in five scientific projects and more than 48 scientific forums. I was particularly impressed by the publication activity of the doctoral candidate; in recent years, he has prepared 14 publications in journals with IF and SJR, one book chapter and 4 manuscrips in refereed conference proceedings. The dissertation itself is based on 4 publications in high-quartile journals.

2. Relevance of the problem and general characteristics of the dissertation work.

The relevance of the scientific issues is definitely beyond any doubt. Two-dimensional inorganic materials, such as graphene, black phosphorus (BP), hexagonal boron nitride (h-BN) and transition metal dichalcogenides (transition metals and X is a chalcogen (S, Se or Te)), are among the most promising class of ultrathin layered 2D nanomaterials, meeting modern technological requirements:

- controllable optical and electrical properties;
- original mechanical properties;
- reproducibility.

In summary, the development of new and improvement of existing technologies for obtaining 2D materials is a fundamental step towards realizing their enormous potential in optoelectronics.

The dissertation is written on 160 pages, contains 55 figures and illustrations and 7 tables. The literature used extends to 271 literary sources, the majority of which are publications from the last 10 years. The dissertation has a classical structure - introduction, literature review, experimental part, conclusion and contributions, organized in 5 chapters, ending with extensive comments.

In the first chapter, the author has made a creative analysis of the literature data on two-dimensional (2D) materials and the various possibilities for applications in optics and optoelectronics. The chapter contains a brief description of two-dimensional materials as a new class of nanomaterials, their basic physical and chemical properties, and their advantages and disadvantages are discussed. Main attention is paid to the transition noble metal dichalcogenides, the subject of the present study, and their applications in optoelectronics, sensors and photonics.

The second chapter is dedicated to some methods for obtaining 2D materials, and exfoliation from bulk crystal (mechanical exfoliation), exfoliation from liquid phase, atomic

layer deposition (ALD), thermally assisted conversion (TAC), molecular beam epitaxy, chemical vapor deposition (CVD) and metal-organic chemical vapor deposition (MOCVD) are thoroughly examined. A critical analysis of the advantages is made and the shortcomings of the methods, as a good basis for choosing a method for obtaining the objects of the study.

Logically, after obtaining the layers, their charasterization is also necessary, therefore the third chapter is dedicated to the various modern methods and techniques for characterization of materials. The following are discussed in detail: Optical microscopy, X-ray photoelectron spectroscopy, Raman spectroscopy, Ellipsometry, Atomic force microscopy, Transmission electron microscopy, Diffraction analysis.

The heart of the dissertation as fundamental knowledge is the fourth chapter. In it, the dissertation candidate has described the preparation and characterization of dichalcogenides of transition noble metals: platinum selenides ($PtSe_2$) and tellurides ($PtTe_2$) by Chemical vapor deposition (CVD), Thermally assisted conversion (TAC); synthesis with liquid precursors. Details and a discussion on the preparation and characterization of bulk crystals of $PdSe_2$ are presented.

Chapter Five is dedicated to the application of nanolayers of transition noble metal dichalcogenides as: antibacterial coatings against Escherichia coli, transparent, conductive layers in polymer-dispersed liquid crystal devices for applications as light switches in the near infrared region of the spectrum and as an active element in field-effect transistors.

The presentation clearly demonstrates the author's good preparation, which allows him to complete the dissertation work with a relevant assessment of scientific contributions.

As for the educational side, I have no doubt that it has been achieved - the candidate has delved deeply into the subject, is fully familiar with the current state of this issue and can independently interpret scientific results from the field of condensed matter physics and in particular the synthesis and characterization of 2D materials for opto- and nanoelectronics. The national requirements for obtaining the ONS "Doctor" have been exceeded almost twice

The author's abstract of the dissertation work has been prepared according to the established standards and requirements of the Regulations for the Acquisition of Scientific Titles and Holding Academic Positions of IOMT - B A S and correctly reflects the achieved results and scientific contributions reflected in the dissertation.

3. Scientific contributions of the dissertation.

In my opinion, the main scientific contributions of the dissertation correlate with the author's claims. Achieving the goals of the assignment is possible only when solving

tasks of a fundamental nature, such as the characterization of new materials and tasks related to the optimization of synthesis techniques. The scientific contributions of the dissertation can be attributed to purely scientific and to those of a certain applied nature, summarized briefly as follows:

- The influence of two different synthesis methods was studied:
  - o a two-step process of thermally activated conversion (TAC) with a magnetron sputtered metal layer and a liquid precursor at atmospheric pressure;
  - o chemical vapor deposition (CVD) at low pressure using solid precursors, on the structure and properties of 2D nanolayers of noble transition metal chalcogenides;

- Recipes for controllable, reproducible synthesis of $PtSe_2$ and $PtTe_2$ on soda-calcium glass, Si/SiO_2 and quartz by selenization of previously deposited Pt layers at atmospheric pressure and low temperatures have been developed;

- Single crystals of $PdSe_2$ have been successfully synthesized by the high-temperature solution method (flux method);

- The application of $PdSe_2$ as an active element in a field-effect transistor (FET), with pronounced photosensitivity, has been demonstrated;

- For the first time, a thin (7nm) $PtSe_2$- as a transparent, conductive layer in polymer-dispersed liquid crystal structures operating as light switches in the near infrared region has been demonstrated;

- Antibacterial activity of $PtSe_2$ coatings against *Escherichia coli* has been demonstrated for the first time.

4. Assess the degree of personal participation of the doctoral student.

The personal participation of the doctoral student in conducting and analyzing the experiment is undeniable. The basis for this statement is given to me by the long-standing scientific contacts with the laboratory "Composite and Nanostructured Optical Materials", as well as by the results published in scientific journals. Over time, I was a reviewer of the student's master's thesis of Mr.Minev, which was a good basis for developing a doctoral dissertation on

the one hand, and on the other, it allowed me to become acquainted in detail with both the work and the creative pursuits of the doctoral student.

From the materials provided to me and from personal impressions of the work of the team, I come to the conclusion that the presented dissertation work is mainly the personal work of the doctoral student, and naturally, the research was planned and carried out under the expert guidance of the scientific supervisor.

5. Publications on the dissertation.

The main results of the research on the dissertation are the subject of four scientific publications in specialized journals, distributed as follows: one article in the Journal of Crystal Growth; one article in Applied Surface Science; one article in ACS Omega; one article in IEEE Xplore (XXXI International Scientific Conference ELECTRONICS). All the articles used have been published in journals with impact or rank – obviously a very good achievement for a dissertation.

Parts of the dissertation have been reported in more than 10 national and international scientific forums, and the dissertation candidate has also participated with oral reports.

The high publication activity of the doctoral student (mainly in the last years of the doctoral studies), as well as the already noted 11 citations (only on the articles from the dissertation), are an unambiguous assessment of the relevance of the scientific problem on the one hand and the quality of the research conducted, on the other. Nevertheless, I would like to emphasize the undoubted contribution of the dissertation to expanding fundamental knowledge in the field of specialized materials science – development of new 2D media for opto- and nanoelectronics.

CONCLUSION

In terms of its volume and quality, the dissertation fully meets the recommended requirements reflected in the Regulations for the Application of the national rull and the Regulations of the IOMT - BAS for the Acquisition of Scientific Degrees and Holding of Academic Positions. Based on the above, reflecting the undeniable scientific contributions of the dissertation, the importance of the results obtained in the field of condensed matter physics, the good reflection and acceptance of the experimental results by specialists in this scientific field, as well as the good preparation of the doctoral student in the field of condensed matter physics, I recommend with conviction to the members of the Scientific Jury to vote positively for the award of the educational and scientific degree "Doctor" in the scientific field 4.1

"Physical Sciences" - scientific specialty "Electrical, Magnetic and Optical Properties of Condensed Matter" to M.Sc. - Phys. Nikolay Diyanov Minev.

Kassel, 27.05.2026

Reviewer:

/Prof. Dr. Hl.Petkov/