OPINION

Regarding the dissertation submitted for the award of the educational and scientific degree of Doctor (PhD) in Professional Field 4.1 – Physical Sciences, Scientific Specialty "Electrical, Magnetic and Optical Properties of Condensed Matter"

Title of the dissertation: *Synthesis of Nanoscale Layers of 2D Materials for Applications in Optoelectronics*

Candidate: Nikolay Diyanov Minev, Institute of Optical Materials and Technologies "Acad. Yordan Malinovsky", Bulgarian Academy of Sciences

Prepared by: Prof. Dr. Teodor Milenov, "Acad. E. Djakov" Institute of Electronics, Bulgarian Academy of Sciences, according to Order No. RD-15-311/15.04.2026

The dissertation of Nikolay Minev is structured into five main chapters, together with several supplementary sections (Introduction, Conclusion, Main Contributions, References, etc.). The results presented in the dissertation have been published chronologically in IEEE Xplore, *Applied Surface Science*, *Journal of Crystal Growth*, and *ACS Omega*, i.e., in three journals with an impact factor (two in the first quartile, Q1, and one in the second quartile, Q2) and one publication indexed in a conference proceeding. The dissertation contains 55 figures, 7 tables, and cites 271 references.

In the first chapter, the doctoral student summarizes the main literature data on the structure and physical properties of the most widely studied 2D materials, namely graphene and transition metal dichalcogenides. In the second chapter, he reviews the known methods for synthesizing transition metal dichalcogenides, thereby providing a rationale for the selection of the methods employed in his research. The third chapter describes the characterization techniques and equipment used to analyze the synthesized samples, including X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM), transmission electron microscopy (TEM), optical ellipsometry, and Raman spectroscopy.

In the fourth chapter, the candidate presents the results of the synthesis and characterization of the obtained materials, including:

- synthesis of $PtSe_2$ and $PtTe_2$ thin films by the Thermally Assisted Conversion (TAC) method;
- synthesis of $PdSe_2$ thin films by Chemical Vapor Deposition (CVD);
- synthesis of $PdSe_2$ thin films from a liquid precursor;
- synthesis of $PdSe_2$ single crystals by the solution–melt crystallization method, followed by the preparation of microscale flakes from these crystals for the fabrication of field-effect transistors (FETs).

The synthesized materials were characterized using XRD, XPS, AFM, TEM, optical ellipsometry, and Raman spectroscopy.

The fifth chapter presents examples of successful applications of some of the synthesized materials:

- the use of $PtSe_2$ nanosheets as light switches in polymer-dispersed liquid crystal (PDLC) devices;
- the application of mechanically exfoliated $PdSe_2$ microscale flakes in field-effect transistors (FETs);
- the evaluation of the antibacterial properties of $PtSe_2$ nanosheets.

The relevance of the research presented in this dissertation is unquestionable. During the past two decades, the synthesis and application of 2D materials, including graphene, black phosphorus, WS_2, MoS_2, and many others, have been the subject of extensive scientific investigation. The objectives of the dissertation are clearly formulated, while the tasks designed to achieve them are appropriate, realistic, and successfully accomplished.

The doctoral student has carried out an impressive amount of experimental work involving the synthesis, characterization, and application of various thin-film materials. Judging by the most important criterion- the achieved results- the choice of synthesis methods has been highly successful. I would particularly like to emphasize the wide range of synthesis approaches employed, including methods utilizing precursors in different phase states. The selection of characterization techniques demonstrates a solid understanding of one of the most important aspects of materials science. In my opinion, the obtained materials have been characterized to a fully sufficient extent, with the exception of the thin-film and single crystal XRD analyses discussed in the comments below.

I was particularly impressed by Chapter V, which describes several practical applications of the synthesized materials. Such application-oriented studies are relatively rare in doctoral (PhD) dissertations over the past 20- 30 years.

The abstract accurately reflects the content of the dissertation.

Based on the authorship of the publications included in the dissertation (the candidate is first author on two publications and second author on the remaining two), I conclude that he has made a substantial contribution to the research presented and has played a leading role in most stages of the work. In many aspects, particularly the synthesis experiments, he appears to have been the principal contributor.

Comments and Recommendations

I have no significant comments regarding the scientific content of the dissertation. However, concerning the XRD characterization, I would like to make the following observations:

1. Regarding the analysis of the $PdSe_2$ single crystals, I believe that the measurement procedure corresponding to the diffractogram shown in Figure 41b is not described in sufficient detail. Assuming that a crystal sample was mounted directly on the sample holder, I cannot conclude with certainty that the diffractogram corresponds to a true

single-crystal measurement. In principle, such an analysis would be more appropriately performed using a single-crystal X-ray diffractometer. Moreover, such equipment, as well as highly qualified specialists, are available at the Institute of Crystallography of the Bulgarian Academy of Sciences. Nevertheless, this remark does not cast doubt on the successful synthesis of single-crystal $PdSe_2$, since convincing evidence is provided by the polarized Raman spectroscopy results presented in Section IV.9.2.

2. Regarding the analysis of the thin films (Figures 20 and 29), I believe that the diffractograms clearly indicate the formation of textured films with a preferred orientation close to <001> in both cases. This observation does not affect the principal conclusion of the dissertation, namely that the corresponding thin films were successfully synthesized.

I would also like to make one recommendation regarding the presentation of crystallographic structures. Whenever such structures are discussed, it would be beneficial to provide more detailed crystallographic information directly in the dissertation text rather than requiring the reader to consult external references.

It is also worth noting that the dissertation contains remarkably few typographical errors. Most appear to result from automatic text processing; for example, in three instances the Bulgarian letter "и" is used instead of "й" in the word "silicon" (pages 40, 64, and 66).

The above comments do not affect the scientific value of the dissertation, which, I reiterate, is of a very high standard.

Conclusion

In conclusion, I find that the dissertation of Nikolay Minev fully satisfies the requirements of the Development of the Academic Staff Act in the Republic of Bulgaria (ЗРАСРБ), its implementing regulations, and the corresponding regulations of the Bulgarian Academy of Sciences, and the internal regulations of the Institute of Optical Materials and Technologies "Academician Yordan Malinovsky" of the Bulgarian Academy of Sciences for the award of the educational and scientific degree of "Doctor" (PhD).

Therefore, I strongly recommend that the esteemed members of the Scientific Jury vote in favor of awarding Nikolay Diyanov Minev the educational and scientific degree of Doctor (PhD) in Professional Field 4.1 "Physical Sciences", Scientific Specialty "Electrical, Magnetic and Optical Properties of Condensed Matter".

Date: Signature:

/ Prof. Teodor I. Milenov/