REVIEW

of the dissertation for awarding of the scientific degree

“Doctor of the Physical Sciences”

in the Professional Field 4.1. Physical Sciences (Condensed Matter Physics)

submitted for defence at the Faculty of Physics (FP)

of the University of Sofia (SU)

The review is prepared by Prof. Valentin Nikolov Popov, D.Sc., retired < 5 y., FP of SU, in his capacity of a member of the Scientific Committee according to Order RD-38-464/ 27.07.2022 by the Rector of SU.

Title of the dissertation: “Surface photovoltage spectroscopy of semiconductor optoelectronic materials and nanostructures”
Author of the dissertation: Assoc. Prof. Vesselin Todorov Donchev, Ph.D.

I. General description of the submitted materials

1. Data on the submitted documents

The documents submitted for the defence by the candidate Assoc. Prof. Vesselin Todorov Donchev meet the requirements of ЗРАСРБ, ППЗРАСРБ и ПУРПНСЗАДСУ.

The candidate has submitted in electronic format the dissertation and an abstract, as well as the other documents required by Art. 78(5) of the Regulations on the terms and conditions for acquiring scientific degrees and occupying academic positions at SU “St. Kliment Ohridski (ПУРПНСЗАДСУ), except for a similarity report required by Art. 78(5)9.

The obligatory tables for FP from Appendix 1 of the aforementioned regulations are also presented: Table for meeting the minimum requirements based on Table D.1 for required points by groups of indicators and Table D.2 for the number of points by indicators. Table D.3, containing a report on the compliance of the publications with the additional requirements of the FP, and Table D.4, containing a reference on the compliance of the citations (according to Scopus) with the additional requirements of the FP, are also presented.

2. Candidate data

The candidate graduated as a physicist with specialization in Solid State Physics from the FP in 1985. He was awarded the scientific degree “Candidate of the Physical Sciences” (educational and scientific degree “Doctor of Physics”) after defending a thesis titled “Investigation of Electrical and Optical Properties of Point Defects in Gallium Arsenide” in 1991.

The candidate has worked as a physicist at FP from 1991 to 1992, Senior Assistant Professor from 1993 to 1997, Chief Assistant Professor from 1997 to 2004, and Associate Professor from 2004 till present at the Department of Condensed Matter Physics and Microelectronics of the FP. He has been Head of this department since 2013.

The candidate has taught undergraduate students in the discipline “General Physics” (“Mechanics” and “Molecular Physics”) and Master’s students in “Nanostructured materials and devices for information technologies” and “Physical foundations of optoelectronics”. He is Head of a student’s laboratory of electricity and magnetism, he has supervised 6 and has consulted 4 Diploma students. He has consulted 2 Ph.D. students, has supervised 1 graduated Ph.D. student and is currently supervising 1 Ph.D. student.

The candidate has realized 8 scientific visits to France, Germany, Great Britain, Switzerland, and Brazil. The candidate declares expert activity in the field of Physics and participation in the organization of scientific events.

3. General characteristics of the scientific achievements of the candidate

The candidate's scientific interests are in the field of the study of electronic and optical properties of semiconductor materials and structures using photoelectric and optical methods, and performing computer simulations. In particular, they cover the use of Surface Photovoltaic Spectroscopy (SPS) to study materials for photovoltaic applications (Ga(In)As(Sb)N, Si, perovskites) as well as semiconductor materials and nanostructures for optoelectronic applications (emitters, detectors), and secondly, calculation of reflection and transmission spectra of multilayer structures taking into account the roughness of the interfaces.

The materials, presented for the defence, cover and in some cases even exceed the minimum requirements of ЗРАСРБ, ППЗРАСРБ, and ПУРПНСЗАДСУ, as shown in Table 1.

Table 1. Implementation of the minimum requirements of ЗРАСРБ, ППЗРАСРБ, and ПУРПНСЗАДСУ.

Group of indicators	Indicators	Total point (required minimum total points by ЗРАСРБГ/FP)
А	1. Dissertation for the award of ONS "Doctor"	50 (50)
Б	2. Dissertation for the award of NS "Doctor of Sciences"	100 (100)
В	3. Habilitation work – monograph 4. Habilitation work – Scientific publication in editions that are referenced and indexed in world-famous databases of scientific information (Web of Science and Scopus)	0 (0) 9 publ. в Q1 x 25 4 publ. в Q2 x 20 2 publ. в Q3 x 15 = 335 (0 /100)
Г	7. Scientific publication in editions that are referenced and indexed in world-famous databases of scientific information (Web of Science and Scopus)	8 publ. в Q1 x 25 7 publ. в Q2 x 20 6 publ. in other x 10 = 400 (100 /200)
Д	11. Citations in scientific editions, monographs, collective volumes and patents that are referenced and indexed in world-famous databases of scientific information (Web of Science and Scopus)	2 x 176 cit. = 352 (100 /200)

Group of indicators	Indicators	Number (required minimum number by FP)
Additional requirements of the FP of SU	24. Number of publications of group I in groups of indicators В and Г 27. Number of publications of groups of indicators В and Г with essential contributions by the candidate 28. h-factor	15 (14) 14 (9) 9 (6)

The presented scientific papers do not repeat those of previous procedures for acquiring a scientific title and an academic position. My opinion is that there is no plagiarism in the presented dissertation and the publications on which it is based.

4. Characteristics and evaluation of the teaching activity of the candidate (if there is a requirement in ПУРПНСЗАДСУ for this)

There is no requirement in ПУРПНСЗАДСУ to evaluate the candidate's educational and pedagogical activities.

5. Content analysis of the scientific and scientific-applied achievements of the candidate contained in the materials for participation in the competition

The dissertation contains 6 pages numbered in Roman numerals and 166 pages numbered in Arabic numerals. It is written in English and includes text, 85 figures, 5 tables and 300 references. The contributions have been published in 15 publications in journals with IF, 6 publications in journals with SJR, and 3 publications in other journals. The text is divided into Introduction, Chapter 1 presenting the structures and experimental methods, Chapter 2 with details of the experimental method used, Chapters 3 and 4 with results, a chapter with description of the contributions, a list of candidate's publications used and a list of literature sources. Overall, the dissertation shows a thorough understanding of the physics of the research field, and the results are presented with the necessary degree of detail. The abstract presents the material of the dissertation in Bulgarian (88 pages) and English (82 pages), in the same way divided into chapters.

The research of the dissertation is positioned in the field of new materials for optoelectronic components for light generation and detection, as well as for solar cells for light capture, finding application in many areas of human society. The relevance of such studies is sufficiently substantiated in the Introduction, citing proper literature sources. The necessity of the precise study of the electronic properties of the synthesized materials is well-argued. One of the methods for their investigation is SPS, which is based on the measurement of the surface photovoltage (SPV), arising upon illumination of the materials. This method has been shown to have a number of advantages over other experimental methods routinely applied in studying these properties, while at the same time before it there is a number of open questions.

The dissertation successfully addresses some of these issues by presenting an experimental setup and a procedure for measuring SPV, and developing a new approach for extracting information from it, as well as applying the setup and procedure to the study of semiconductor materials for application in optoelectronic components and solar cells.

Nanomaterials came into the focus of the researchers more than half a century ago in the quest to create structures such as thin films on a substrate, superlattices, quantum wells, quantum wires, quantum dots, etc., for application in components with suitable electronic properties for the emerging electronics.

Chapter 1 briefly but meaningfully introduces the various nanostructures that are investigated in the dissertation, as well as the methods for their synthesis, with appropriate citation of literature sources in the field. Of primary importance in the research of nanostructures is the precise measurement of such electronic characteristics as the band gap width and transport properties of charge carriers, for which the SPS is adopted in the dissertation. The processes occurring during illumination of the nanostructure and the creation of PFN, as well as the techniques for measuring SPV, are described in sufficient detail. Various such techniques are critically discussed and the advantages of the adopted SPV measurement technique using a metal-insulator-semiconductor structure with a fixed metal electrode are indicated, for which an experimental setup has also been constructed. It is shown that, in addition to determining the SPV, the SPS can also be used to determine the diffusion length of the minority carriers by two methods.

The developed experimental setup is described in sufficient detail in Chapter. 2. In the dissertation, for the first time, the zero value of the SPV phase is defined, which is important for the correct interpretation of the amplitude and phase SPS spectra. Two original approaches are proposed when working with phase spectra – one of them allows determining the type of the semiconductor under study, and the other allows determining the rate of generation of free carriers. In the second approach, the observed decrease in phase with increasing free carrier generation rate is explained by a decrease in the effective lifetime of non-equilibrium carriers through three different mechanisms leading to nonlinear recombination. As an original result, a vector model is proposed to facilitate the analysis of the magnitude and phase of the SPV signal.

Chapters 3 and 4 present a pioneering application of the amplitude and phase SPS in combination with the vector model for the analysis of the electronic characteristics of complex structures. Chapter 3 contains specific results of the application of SPS to the study of the electronic properties of specific nanostructures. In the case of AlAs/GaAs superlattices with one or two embedded GaAs quantum wells, the obtained exciton transition energies are in very good agreement with the photoluminescence data, and in addition the phase spectra allowed conclusions about the band bending and the doping of the structure, as well as the dominance of free excitons recombination.

SPS studies of InAs/InGaAlAs quantum-dashes-in-quantum-well structures with possible application in light emitters with wavelengths above 1 µm are also presented. The analysis of the obtained amplitude and phase spectra allows the determination of the optical transitions, the doping of the layers, and the direction of the bending of the zones depending on the method of deposition of the layers, the degree of annealing and the bombardment with nitrogen ions. A similar use of the SPS and the vector model in the case of InAs quantum dot-in-quantum-well structures with possible application in infrared detector components allows finding the electronic transitions for two different methods of structure growth.

The reported in the dissertation SPS studies of multilayer structures with InP/GaAs type II quantum dots, with possible application for optical memories and optical communication devices, are among the first ones for such structures. The special thing in this case is that a signal was measured only in measurements at the liquid nitrogen temperature. The origin of the two peaks in the SPS spectrum and the mechanisms of carrier separation in the structure were determined.

In Chapter 4, SPS studies of structures with possible application in solar cells are presented. Silicon nanowires are promising structures for increasing cell efficiency. The results of the studies using SPS on silicon nanowires prepared by chemical etching show that subsequent chemical treatment allows to remove structural defects on their surface and to improve their quality. An alternative way to increase cell efficiency is by constructing multijunction cells using diluted III-V-N nitrides to achieve tunable band gap widths. In the dissertation, such structures grown by liquid phase epitaxy were investigated using SPS. In many respects, the obtained results are of a pioneering nature.

The scientific contributions of the dissertation can be summarized as a detailed study by SPS of the optical and electronic characteristics of nanomaterials promising for application in nanotechnology. The use of the obtained amplitude and phase spectra in combination with the proposed vector model allows improving the analysis of the experimental data and facilitating the characterization of the nanomaterials.

The dissertation is based on 21 publications in editions with IF/SJR, in 12 of which the candidate is first and in 9 he is second in the list of authors, which confirms his leading contribution to these publications. Altogether 176 citations of the publications are found and the h-factor is equal to 9, indicating the wide interest in the candidate's work.

6. Critical remarks and recommendations

There are no essential critical comments.

7. Personal impressions of the candidate

I have wonderful impressions of the candidate from our joint work in the administration of the FP.

8. Conclusion

After getting acquainted with the submitted dissertation, abstract, and the other documents, and based on the analysis of their importance and the scientific and applied scientific contributions contained in them, I confirm that the scientific achievements of the candidate meet the requirements of ЗРАСРБ, ППЗРАСРБ, and ПУРПНСЗАДСУ for awarding to the candidate of the scientific degree “Doctor of the Physical Sciences”. In particular, the candidate satisfies the minimum national requirements in the professional field and no plagiarism has been established in the dissertation, abstract, and publications, submitted for the competition.

I give my positive assessment of the dissertation.

II. OVERALL CONCLUSION

Based on the above, I recommend to the Scientific Committee to award the scientific degree “Doctor of the Physical Sciences” in the Professional Field 4.1. Physical Sciences (Condensed Matter Physics) to Assoc. Prof. Vesselin Todorov Donchev

07/09/2022 Reviewer: ....

Sofia (Prof. Valentin Nikolov Popov, D.Sc.)