REVIEW

of the dissertation for the acquisition of the educational and scientific degree "Doctor", Professional field: 4.1 Physical Sciences, scientific specialty: "Electrical, magnetic and optical properties of condensed matter"

Author of the dissertation: Petar Kolev, IOMT-BAS

Topic of the dissertation: "Sensors based on spectral polarimetric detection"

Reviewer: Vera Marinova Gospodinova, Professor, Ph.D., IOMT-BAS, member of the Scientific Council according to Order No. RD-15-959/16.12.2025 of the Director of IOMT-BAS

1. Brief biographical data about the doctoral student

Petar Kolev graduated with a bachelor's and master's degree from the Technical University, Sofia, Faculty of Power and Mechanical Engineering, Specialty Hydraulic and Pneumatic Engineering, respectively in 2009 and 2015. He has experience as a design engineer at Hidropnevmotehnika AD, Kazanlak. Since the beginning of 2022, he has been enrolled as a full-time doctoral student at the Institute of Mechanical Engineering and Technology-BAS.

2. Relevance of the problem developed in the dissertation work

The dissertation work is dedicated to the spectral analysis of the polarization state of light and, more specifically, to the design and development of a Channel Spectral Polarimeter for applications in sensors operating on the basis of surface plasmon resonance, as well as on the basis of the magneto-optical effect.

The dissertation addresses a very topical topic, since the spectral analysis of the polarization state of light plays a fundamental role in polarimetric research and is the basis of various types of sensors. The author skillfully identifies the main limitations of conventional optical sensors - for example, standard biosensors based on Surface Plasmon Resonance, which take into account the change in light intensity or the shift of the spectral minimum, i.e., work on the principle of traditional amplitude detection, which are characterized by a low signal-to-noise ratio and have limited sensitivity. In response to this challenge, the doctoral student proposes phase measurement as a solution to achieve higher sensitivity through the Channel Spectral Polarimetry Method, which allows the extraction of full polarization information (Stokes parameters) from just a single spectral record, which is critically important, for example, when monitoring fast chemical and biological processes in real time.

Undoubtedly, the topic is extremely relevant and interesting because it combines fundamental physical principles (polarimetry and plasmonics) with modern technological solutions to achieve higher accuracy, faster action, and lower cost in the detection of critical biological and chemical agents.

3.Knowledge of the state of the problem and analysis of the literature data

The literature review (Chapter 1) is written on the basis of 135 sources and examines in detail the two main approaches for optical excitation of Surface Plasmon Resonance: through a prism and through a diffraction grating. The main parameters describing the sensors based on Surface Plasmon Resonance, as well as the Channel Polarimetry Method, are defined. The doctoral student demonstrates knowledge of the current state of spectral polarimetry. The literature review covers fundamental works in the field of Stokes parameters and the Muller and Jones matrix apparatus, as well as the main publications related to the channel spectral polarimetry method. Key authors in spectropolarimetry are cited.

The analysis of the literature data regarding gas sensors and magneto-optical materials is also in-depth. The author examines the advantages and disadvantages of metal oxides such as $WO3$ and the optical activity of $Bi12SiO20$ (BSO) crystals.

Petar Kolev skillfully proves that while the theoretical foundations of the Channel Polarimetry Method are known, their integration into compact and instantaneous bio and gas sensors is still a challenge. Thus, Petar Kolev states the goal of the dissertation – to optimize the existing configuration and software algorithms for extracting phase information in real time.

4. Evaluation of the selected research methodology in relation to the set goals and objectives of the dissertation.

The goal of the dissertation is clearly formulated: to develop a Channel Spectral Polarimeter and study its application in various types of sensors. To achieve the goal, the doctoral student has set the following tasks:

Task 1. To design and manufacture a Channel Spectral Polarimeter by:

-optimizing the parameters of the main structural elements with the existing measuring equipment;

-investigating and minimizing the sources of error.

Task 2. To experimentally establish the advantages of the Channel Polarimetry Method:

-high signal-to-noise ratio: by detecting pathogens in Surface Plasmon Resonance biosensors based on a diffraction grating;

-high sensitivity by detecting $H2$ in gas sensors based on Surface Plasmon Resonance excited in a diffraction grating;

-by direct measurement of the phase difference during changes in the polarization state in magneto-optical sensors.

The selected methodology of Channel Spectral Polarimetry allows simultaneous extraction of all Stokes parameters, therefore it can be defined as the most accurate tool for achieving the set tasks. The methodology is precise, including Fourier analysis for extracting the Stokes parameters from the modulated spectrum. The experimental schemes are described in detail and calibrated. The fast axes of the phase retarders in the construction of the Channel Spectral Polarimeter (CSP) are determined, because the direct encoding of information about the polarization state in the spectrum depends on their orientation.

It can be argued that the selected methodology is fully adequate to the set goals.

5. A brief analytical description of the nature and reliability of the material on which the contributions of the dissertation are built.

The dissertation consists of 106 pages and includes: Relevance of the topic with the stated Aim and objectives of the dissertation, Literature review, two Experimental chapters dedicated to the construction of a channel polarimeter and its application in 3 types of sensors. The dissertation ends with a conclusion, a summary of the main contributions, a list of figures, a list of publications included in the dissertation and a list of participation in scientific forums, as well as a list of literature sources.

The dissertation is written on the basis of four articles indexed in Web of Science and Scopus, one of them is in the first quartile Q1, two in the second quartile Q2 and one with an impact rank SJR.

The dissertation contains 64 figures, 11 tables and 135 cited literature sources.

The literature review (**Chapter 1**) is structured as a theoretical basis. The author examines in detail the Stokes parameters (S0, S1, S2, S3), which are at the heart of the quantitative description of partially and fully polarized light. The mathematical methods for describing the passage of light through various optical elements are presented.

The review also critically reviews three main types of sensor technologies that are the subject of research:

• Surface Plasmon Resonance (SPR): The physics of plasmons is described and why phase detection (via polarimetry) is more sensitive than standard intensity detection is discussed.

• Metal-oxide gas sensors: The properties of materials such as WO_3 and their reaction when interacting with hydrogen molecules are examined.

• Magneto-optical effects: The Faraday effect in crystals and the possibility of precise measurement of magnetic fields and electric current are analyzed.

The review concludes with an analysis of the limitations of existing systems. This logically leads to the formulation of the goal and objectives of the dissertation, namely: creating a faster, more sensitive and more stable system through spectral polarimetry.

Chapter 2 describes in detail the steps in the Design of a Channel Spectral Polarimeter, with three tasks to be solved (1): Spectral resolution of the modulations with the highest spectral frequency (2): Precise orientation of the optical elements in the system, using two main techniques to minimize systematic errors - polarimetric orientation (a He-Ne laser and a commercial polarimeter (Thorlabs PAX 1000 VIS) were used to measure the output Stokes vector after each element) and polarimetric-spectral orientation (fine tuning of the azimuths was applied, comparing the Stokes parameters measured by the Channel Spectral Polarimeter with the reference values from a commercial polarimeter (3) Determination of the fast axes of phase retarders. Here, the author conducts a series of tests, summarized in Table 11 of the dissertation, establishing that Option 3 achieves the best match between the measured polarization state of the reference polarimeter and the demodulated state. An additional check with input elliptical polarization was also performed. As a result, the fabrication of two phase retarders with thickness ratios of 1:2

and 1:3 is presented, as well as the orientation of all optical elements in the system is described, which helps to minimize systematic errors. It is concluded that the configuration with a ratio of 1:3 (R1 = 3.4 mm, R2 = 10.2 mm) is more efficient, since it provides an additional channel for more accurate extraction of the Stokes parameters S2 and S3.

Chapter 3 is experimental and is dedicated to sensors based on surface plasmon resonance. In it, the author demonstrates the practical application of the channel spectral polarimetry method he developed for highly sensitive biological detection, presenting in more detail the applications in three types of sensors, the first two of which are sensors based on a diffraction grating: a biosensor and a gas sensor; and the third - a magnetic field sensor. In summary, Chapter 3 confirms the theoretical developments presented in Chapter 2 in an applied way, proving that spectral polarimetry can be successfully used for diagnostic purposes with a sensitivity superior to traditional optical methods.

6. Scientific and applied contributions of the dissertation:

I agree with the contributions of the dissertation formulated as follows, which can be classified as applied and summarized as follows:

A method of channel spectral polarimetry has been designed and experimentally developed, which includes the manufacture of structural elements with optimal parameters, consistent with the accompanying measuring equipment.

Phase retarders have been manufactured with pre-calculated thicknesses and ratios between them, and two design options have been implemented: with a thickness ratio of 1:2 (R1 = 4.4 mm and R2 = 8.8 mm) and with a ratio of 1:3 (R1 = 3.4 mm and R2 = 10.2 mm). For their design and manufacture, values obtained through calculations consistent with the resolution of the AvaSpec-ULS2048-CL-EVO spectrometer were used.

The effectiveness of the channel spectral polarimetry method has been experimentally proven in:

- Biosensors- Detection of the bacterium Helicobacter pylori has been successfully demonstrated, with an improvement of about 35% compared to the amplitude method achieved by phase measurement.
- Gas detection- A hydrogen ($H2$) sensor using WO_3 has been developed, in which the sensitivity in phase measurement is two orders of magnitude higher than that in conventional amplitude measurement.
- The channel polarimetry method has been applied for the first time to magneto-optical sensors based on BSO crystal, which allowed temperature-independent direct measurement of the phase difference generated by the Faraday effect.

The contributions of the dissertation represent a complete cycle - from the fundamental understanding of phase information extracted through spectral polarimetry to the creation of prototypes of sensors with real applications in medicine, ecology and energy.

The results presented in the dissertation are original and reliable.

7. Assessment of the personal contribution of the doctoral student

I have known Petar Kolev since the beginning of his doctoral studies at the Institute of Optical and Photonics-BAS in 2022. Later, Petar Kolev successfully passed the course "Fundamentals of Photonics" led by me, and he also coped excellently with the practical tasks assigned to him for the course, related to the construction of various optical circuits, and he showed strong interest until he solved every practical problem that arose on his own. For the years that I have known him, I can say that I am impressed by his professional growth. This gives me reason to believe that the activities carried out on the dissertation are mainly his personal work.

Here I would like to note that over the years Petar Kolev has been very actively involved in various scientific projects at the Scientific Research Fund. Also, according to the attached documents, Petar Kolev is also involved in a Biophotonics center.

8. Publications on the dissertation

The dissertation is written on the basis of 4 publications in journals, of which 3 with an impact factor (e.g. *Optics Communications, Sensors*) and 1 with SJR. Despite the fact that Petar Kolev is not the first author in the publications with quartiles, separation protocols from the first authors are attached, with which they certify that the main contribution related to the development and construction of the channel spectral polarimeter, the creation of a module for precise temperature control in magnetic field conditions, the conduct of measurements, the establishment of experimental errors, as well as the interpretation of the results, are the work of the doctoral student. Also, Petar Kolev is a corresponding author in one of the articles.

11 citations have been noted on the topic of the dissertation, 9 of which are to the publication in *Optics Communications* from 2023.

The results of the dissertation are also presented in the form of one report and 8 poster presentations at the scientific forums. The high publication activity of the doctoral student, as well as the number of 11 citations noted, are an indicator of a high level of scientific production, the relevance of the scientific problem and the significance of the achieved results. There is no evidence of plagiarism.

9. Evaluation of the abstract

The abstract is very well-formed and meets the requirements for volume and content. The main activities, results obtained and contributions to the dissertation are reflected.

10. Critical notes and questions

I have the following questions:

1. How do you distinguish the phase signal generated by hydrogen from that of water vapor in the atmosphere (it is known that WO_3 is associated with sensitivity to moisture)? Is a hysteresis dependence observed after removing hydrogen and how stable is this process over repeated cycles?

2. Regarding the magneto-optical sensor - In the BSO crystal there is a superposition of two effects: natural optical activity (self-dispersion) and induced Faraday effect (Verde number as a function of λ). How does your model distinguish the cumulative effect of the dispersion of natural optical activity and that of the Verde number in the crystal to ensure invariance of the measured magnetic field with respect to the wide spectrum of the source?
3. Considering that the phase sensitivity is extremely high only in a narrow range around the resonance point, how does a spectral-polarimetric system guarantee measurement accuracy in biological samples with variable turbidity? How does the algorithm distinguish the phase signal from the changes in the amplitude and contrast of the bands caused by the inhomogeneity of the analyte?

Technical comments:

--Optical elements are missing in Fig. 21 and 22, while they are placed in Fig. 20.

--Figure 45, AFM image of the deposited W03 nanostructured layer on a diffraction grating – what are a) and b)?

In places the text of the dissertation is written in an overly technical or "telegraphic" style, often lacking expected physical explanations or subsequent discussion. Also, many grammatical inaccuracies and errors are noticeable. All the technical remarks above do not belittle the contributions of the dissertation.

10. Motivated and clearly formulated conclusion

The presented dissertation is original, with contributions of a scientific and applied nature. Important results have been achieved, published in journals with quartiles Q1 and Q2. Part of the results have also been presented at scientific forums. To date, 11 citations have been noted, which proves the relevance of the topic being developed. Undoubtedly, Petar Kolev's contribution is significant.

The dissertation submitted to me for review and Petar Kolev's scientometric data meet and even exceed the national requirements for awarding the ONS "doctor" in the Act on the Development of the Scientific Staff in the Republic of Bulgaria, as well as the requirements for defending a dissertation in the Regulations on the Terms and Procedure for Acquiring Scientific Degrees and for Holding Academic Positions at the Institute of Optical Materials and Technologies (IOMT)-BAS.

In conclusion, I declare my agreement and recommend to the esteemed Scientific Jury to award the educational and scientific degree "Doctor" in the professional field 4.1 Physical Sciences, scientific specialty ""Electrical, magnetic and optical properties of condensed matter"" to Petar Kolev.

27 Feb 2026 Reviewer:

/Prof. DSc Vera Marinova /