REVIEW
from
Assoc. Prof. Dr. Ekaterina Georgieva Borisova, Institute of Electronics,
Bulgarian Academy of Sciences (IE-BAS)

for a competition for the academic position of "Professor"

Professional field: 4.1. Physical sciences
Scientific specialty: "Electrical, magnetic and optical properties of condensed matter", State Gazette, issue 12 of 11.02.2020, p. 40
Candidate: Assoc. Prof. Dr. Georgi Lalev Dyankov, Laboratory "Composite and Nanostructured Optical Materials", Department of "Optical Materials", Institute of Optical Materials and Technologies, Bulgarian Academy of Sciences (IOMT - BAS)

In implementation of the procedure, the applicant submitted:

1. Application for admission to the competition
2. Curriculum vitae according to the European CV blank
3. Diploma for the educational and scientific degree "Doctor"; certificate for the academic title "Associate Professor" (HAC)
4. Lists of publications, participations in conferences, projects, patents and other scientific and applied results, which do not repeat the presented for obtaining the educational and scientific degree "Doctor", the scientific degree "Doctor of Sciences" and for the academic position "Associate professor";
5. Preprints of publications equivalent to habilitation work;
6. Preprints of publications outside the habilitation work;
7. Preprints of patents and utility models;
8. Summaries of peer-reviewed publications in Bulgarian and English, which participate in the competition for "professor";
9. Certificates for a minimum of seven years of experience in the specialty:
    a. From ISSP-BAS
    b. From MASciR-Morocco
    c. From ITRI-Taiwan
10. Certificates for holding the academic position of "associate professor" for not less than 5 years in a university or scientific organization:
    a. From IOMT-BAS
    b. From Plovdiv University
    c. From ISSP-BAS
11. List of citations.
12. Summarized 'autoreferat' of defended doctoral students under the scientific guidance of the candidate
    a. by Ivan Ivanov
    b. by Katerina Zhelyazkova
13. Information for fulfillment of the minimal national requirements under art. 2b, p 2 and 3 of the Law for Academic Staff Development, the minimum requirements of BAS and respectively of IOMT, Regulations (according to the standard form of IOMT, Appendix 3-5);
14. Information in Bulgarian and English on the original scientific contributions with the relevant evidence (According to Article 25, paragraph 4, item 13 of the Regulations for

the acquisition of scientific degrees and for holding academic positions in IOMT-BAS), accompanied by an Opinion of the candidate.

15. References for teaching activities from;
    a. University of Plovdiv
    b. National Chiao Tung University, Taiwan
16. Other materials illustrating the qualification of the candidate: certificates for awards and qualifications;
17. Copy of the announcement for opening the competition in the State Gazette;

According to the presented evidences and documents for implementation of the minimal national requirements under Art. 2b, p.2 and 3 of ZRASRB, the minimal requirements of BAS and those of IOMT, the candidate has the following indicators:

group A - 50 (from a minimum of 50)
group B - 147 (from a minimum of 100)
group D - 320 (from a minimum of 220)
group D - 216 (from a minimum of 120)
group E - 326 (from a minimum of 150)
thereby fulfilling the necessary requirements for admission to the competition.

The publications submitted by the candidate for participation in this competition are not included in the procedures for holding the scientific and educational degree "Doctor" or for holding the academic position "Associate Professor", according to the requirements of the IOMT Regulations, Article 25 (3).

The scientific activity of the candidate is in the field of optical sensors, incl. biosensors in which the registration of molecular interactions is carried out by optical methods related to surface physics and specifically - with Surface Plasmon Resonance (SPR).

The interdisciplinary nature of this type of research requires in-depth knowledge and skills, reflecting the complexity of the studied object. I would characterize the scientific activity of the candidate as a process of consistent, purposeful and systematic scientific growth in the last years, as a result of which are the significant scientific achievements that we evaluate within the frames of this competition.

Transfer of this accumulation of knowledge and experience to young scientists, students and PhD students is a logical step forward: the candidate is a research supervisor of two successfully defended PhD students (in 2016 and 2017) and a supervisor of one PhD student currently, as well as a supervisor of six graduates students, defended until 2015. I would like to specifically mention his work on teaching high school students in the field of physics. The candidate worked as a part-time lecturer at the Technical School of Woodworking - Sofia and at the Sofia Mathematical High School in the period 1991-2002. He is a co-author of 7 textbooks and 8 exercise books in physics from 7th to 10th classes, which are used in the school network of Bulgaria. This is a significant amount of work, giving a very broad and in-depth experience not only in the field of research tasks solved by the candidate, within his scientific activity, but also in the whole research field of physics.

As a result of the extensive scientific capacity built by the candidate, he is a successful leader of 7 research projects and a participant as a team member of 22 more projects funded at national (19) and international (10) level, including Horizon2020 programs (1), FP7 (1), operational programs of the Republic of Bulgaria (4).

His professional growth was supported by trainings and specializations in prestigious international research centers, in Russia (as a doctoral student), Germany (guest scientist), Taiwan (post-doctoral student and guest professor), Morocco (researcher). In Taiwan he has

spent about 5.5 years as a guest researcher, and the results of his work have been highly praised with silver and bronze medals - awards for inventions at the Innovation Exhibitions - Taipei, in 2016 and 2017, respectively, which is a significant recognition of scientific and the applied capacity of the candidate. The applicant has significant by numbers applied developments, which are reflected through a total of 7 patents, utility models and patent applications, with 5 of which he participates in the current competition.
To promote the results of his research, the candidate has presented reports from his research activities for evaluation to the scientific community at 25 international and 12 national scientific conferences, as well as on 5 invited lectures in other organizations.

Main scientific and applied scientific contributions/achievements

The candidate has submitted a habilitation certificate description for his research and scientific-applied contributions. The problems that are the subject of this procedure are in the field of optical sensors, incl. Surface Plasmon Resonance (SPR) biosensors, which detect optical signals when registering molecular interactions.

The registration and monitoring of biological or biochemical processes is extremely important for medicine, biology and for the registration of current health status and ability to work. The development of highly sensitive, specific and cost-effective biosensors is extremely important, as they contribute to the implementation of accurate diagnostics and development of approaches for theranostics and individualized medical care. Therefore, research in the field of development of new detection and / or monitoring sensor systems is very intensive, which is confirmed by the trend of exponential growth of publications in this scientific and applied field, which has been maintained for many years. The market for biosensors in the world is estimated at billions and the average annual growth is estimated at 6-8%, which stimulates research and development activities for the development and optimization of biosensors, and makes them highly competitive.

The significance of the issue on which the candidate is working is not in doubt. I explicitly want to emphasize the interdisciplinary nature of his research, which is binding in terms of the amount of knowledge and experimental techniques necessary and mandatory to achieve significant results. SPR-related biosensor research is multidisciplinary and requires knowledge in various scientific fields such as surface physics and chemistry, electrochemistry, biochemistry, solid state physics, optics and laser technology, and more.

The scientific contributions presented by the applicant in the present procedure are related to the solution of the problem of non-specific molecular reactions specific to SPR biosensors. SPR sensors are based on the conversion of the change in the effective refractive index of the recognition layer into an optical response. Thus, SPR sensors measure both the physical and chemical effects that affect the refractive index of the layer within the penetration of the plasmon wave field into it. Therefore, SPR sensors are not inherently specific to the measurement process.

The candidate has divided his contributions into two main thematic areas, which cover different aspects of the optimization of SPR biosensors. The first thematic area is related to solving the problems of non-specificity of this type of sensors by optimizing the recognition layer. The main scientific contributions belonging to the first thematic area are entirely the result of experimental research, including the following:

- direct immobilization - without a built-in matrix - of the bio-molecules of the recognition layer is proposed, whereby a nanostructured such layer is created;

- direct immobilization was experimentally realized by matrix-assisted pulsed-laser evaporation (MAPLE) - a method used for deposition of layers of bioactive substances;

- the effectiveness of direct immobilization has been experimentally proven.

The second thematic area, in which the candidate has contributions, is related to solving the problems of differentiation of specific from non-specific molecular interactions. Because the SPR signal is generated by a change in the refractive index occurring in the plasmon wave field, it contains information about both - the specific molecular reactions in the recognition layer and the effects behind that layer, generally in the solution containing the analyte. As a result, there is always a background signal generated by the non-specific response in the SPR sensors. In order to minimize the influence of the non-specific response on the measured parameters, a typical measurement of the SPR signal is performed as a differential between the reference and signal channels.

The main scientific contributions of the candidate within the second thematic area are the result of his theoretical research, and include the following:

- Theoretically, three new methods have been proposed for the realization of two-wave SPR:

• Through a new type of biochip based on a bimetallic layer;

• By assisted from chiral smectic / nematic liquid-crystal layer, excitation of SPR;

• By assisted from a highly dispersed medium, excitation of SPR.

Another area of research of the candidate is the development of optical sensors based on known optical methods of registration, as well as the application of such methods in conventional sensors. As a result, new qualities and properties of optical sensors of physiological and biometric parameters, as well as optical sensors of various physical impacts have been achieved. The discovered new qualities and properties of optical sensors represent scientific and applied contributions of the candidate, namely:

- Non-invasive detection of blood alcohol concentration, carried out with simultaneous personal identification;

- Simultaneous, constant and real-time detection of temperature, smoke and CO in a fire protection sensor;

- High temperature stability and accuracy of detection at current sensor (magnetic field) through the realized reference and signal channels with the same optical path.

The scientific and scientific-applied contributions are presented in detail by the candidate in the habilitation reference. I will briefly note the more significant ones as follows:

I. Scientific achievements:

- **For a first time, the effectiveness of direct immobilization in a biosensor has been experimentally proven**. Immobilization of hemoglobin was performed on a diffraction grating created in an optical fiber. The reaction hemoglobin + glucose = glycated hemoglobin was performed for the first time in order to detect glucose. Although this reaction is specific and well known, it has not been used for detection up to date. So-called low level of reliable detection was achieved **(low detection limit) of concentration - 0.1 mmol / L, which is lower than the clinically significant concentration of blood sugar in saliva**, repetitive concentration dependences were observed for analyte concentrations in the range greater than one order of magnitude, and stability of the applied recognition layer - very good adhesion is achieved. Thus, the directly immobilized hemoglobin on the transducer is a laboratory prototype of a biosensor for non-invasive detection of blood sugar by saliva analysis.

- **For a first time, direct immobilization of metalloproteins was performed**. For a first time, an SPR biochip was developed by direct immobilization, performed entirely by a

physical method - by matrix-assisted pulsed-laser evaporation (MAPLE). A specific problem for creating an SPR biochip is the need for strict control of the thickness of the deposited layer. A technological installation has been developed, which implements the MAPLE method, as well as the sets of technological parameters have been established, which guarantee the immobilization of hemoglobin and myoglobin while preserving their biological activity and with a controllable thickness of the recognition layer.

- **an SPR biochip based on a diffraction grating has been developed**. A methodology for creating diffraction gratings with gold coating has been developed;

- **A methodology for determining the bioactivity of the deposited layers has been developed**, which is realized by checking the bioactivity of different functional groups, performed by SPR detection of the interaction with CO, CO_2, NO, O_2. The efficiency of the technology is proven by the achieved minimum reliably detectable concentrations of gases;

- **A new medium has been developed with application in biosensors** - a binary mixture of rhodamine 6G and rhodamine B embedded in an epoxy matrix. It differs in principle from those used for SPR. These types of media are highly dispersible, while at the same time being active and enhancing optical radiation. They are used for chaotic generation of laser radiation (random lasing). Recognizing molecules can be incorporated into such an environment, as molecular reactions change it, respectively the conditions for generation. The advantages of biosensorics are: i) the ability to generate several laser modes, each of which is affected differently - multi-channel detection; (ii) the detection is not complex (resonance conditions do not need to be met); coherence detection can be used as criteria for molecular response (including image detection); iii) the recognition molecules are immobilized relatively easily - by diffusion in a bulk medium.

- **A new structure of SPR biochip is proposed based on a bimetallic layer** composed of silver and gold sub-layers. The different dispersion characteristics of the two metals are used to excite two or more plasmon modes with different mode distribution but with the same propagation constants. This allows distinguishing the specific from the non-specific effects, as well as the background noise by one spectral measurement;

- **A new quality of the bimetallic plasmon structure has been revealed** - to support the spread of the so-called long-range (LR) and short-range (SR) plasmon modes. Their function is to distinguish specific from non-specific effects by a spectral measurement. The required refractive index of the buffer, at which the LR mode is excited at the desired wavelength, is theoretically established.

- It has been theoretically proven that the **new plasmon structure is the most efficient of those currently known in terms of selectivity**. This is due to the proven characteristics of the structure: (1) the highest "junction" between the signal and the reference channel, realized by conventional plasmon modes and (2) the mode field, excited at a longer wavelength, penetrates deeper ; for comparison: to achieve this, standard chips use complex optical schemes;

- **For the first time, the phenomena of the metal-chiral smectic boundary were theoretically studied**, as the liquid crystal (LC) layer is located after the metal layer under the conditions of SPR excitation. It was found that the increase in the angle of inclination leads to a shift of the SPR to longer wavelengths as a result of the change of the refractive index in the adjacent to the metal layer LC, in the direction of propagation of the plasmon wave.

Scientific contributions formulated in scientific publications outside the habilitation thesis:

- **For a first time, the idea of "colored" plasmon was proposed and theoretically analyzed**, as (1) the excitation of SPR at different wavelengths belonging to the spectrum of "colored" plasmon will be excited and detected at the same angle; (2) the field distribution of these plasmons penetrates at different distances; covers the recognition layer and the space

behind it; (3) resonance analysis of "colored" plasmon at short and long wavelengths could separate specific from non-specific molecular reactions.
- For the first time, the idea of polarimetry based on "vortex" polarization was proposed. It is theoretically shown that three vortex polarizers, oriented in a certain way, guarantee the creation of a complete set of polarization states. Solving the inverse problem by the simplex method allows the detection of the introduced (from the plasmon structure) phase change.

II. Scientific applied achievements

- **For a first time, a device is offered that realizes non-invasive detection of alcohol concentration in the blood of a person with simultaneous personal identification**, based on the venocode of the fingers. The method for non-invasive detection of alcohol concentration in human blood is based on a photothermal effect, as the innovation is the way of detecting optical absorption in spectral regions characteristic of ethyl alcohol or its derivatives due to metabolism in the body.
- **A method has been developed for the organization of a system providing access through remote control** to the performance of functions after personal identification based on biometric data provided by optical methods.
- **For a first time, a fire sensor has been proposed, completely safe for use in rooms with the highest fire risk and explosive objects**. The subject of protection are the methods of simultaneous detection of CO, temperature and smoke by optical methods, as well as the optical communication with the sensor, realized through optical fibers. This development was awarded the Bronze Medal for Invention: Exhibition for Innovation - Taipei, September, 2017.
- For a first time, an optical sensor for measuring current (magnetic field) in high voltage conditions with reference channels having the same optical path has been proposed. This ensures amplitude and temperature stability of the sensor. This development was awarded a silver medal for invention: Exhibition of Innovation - Taipei, September, 2016.

Products and scientific publications

The scientometric indicators with which the candidate participates in the competition are proof of the significance of the achieved results:

- articles in magazines with impact factor and / or impact rank - 22;
- noticed quotes: 108;
- projects: 3 - as a leader and 9 - as a team member;
- patents and utility models: 5 (2- patent applications, 3- utility models);
- Conference reports: 21 (17 international, 4 national).

The character of the citations also shows the significance of the published results - no citations with a negative assessment or expressed doubt about authenticity were noticed.
The candidate has submitted a report, which **clearly distinguishes the scientific contributions submitted for this procedure** from the contributions with which he has already participated in the procedures for obtaining the educational and scientific degree "Doctor" and the academic position of "Associate Professor".
I have **no critical remarks** on the scientific activity of the candidate or on the quality and significance of the scientific results and contributions presented.

My personal impressions date back to the stat of an initiative for practical training of students from the University of Plovdiv, majoring in Medical Physics, which was held in a laboratory of Biophotonics of IE-BAS in the academic year 2012-2013. Assoc. Prof. Dyankov

was the initiator of this practical training, which could expand the opportunities and knowledge of students in this specialty, as well as their access to modern medical and optical equipment. Assoc. Prof. Dyankov proved to be a very serious, well-organized and working teacher for the training of his students, as well as a highly qualified specialist in the field of optical technologies and the interaction of optical radiation with condensed matter.
The evidences prepared for the current competition, the volume and quality of the research metrics indicators, as well as their order and visibility also make a very good impression, revealing a well-organized and serious scientist at a high professional level.

Conclusion
Given the above analysis, I believe that the candidate fully meets the minimal national requirements of the Law for Academic Staff Development and the Rules for its implementation.

Therefore, I propose with deep a conviction to the members of the scientific jury for election of "Professor" in professional field 4.1 "Physical Sciences", scientific specialty "Electrical, magnetic and optical properties of condensed matter", according to the competition procedure published in State Gazette, issue 12 of 11.02.2020, p. 40, to elect to the academic position "Professor" Assoc. Prof. Dr. Georgi Lalev Dyankov.

Date: 10.08.2020

Signature:

Assoc.prof. Dr. Ekaterina Borisova
Institute of Electronics - BAS