R E V I E W

Application for the academic position "Professor" in the Central Laboratory of Applied Physics, Bulgarian Academy of Sciences - professional field 4.1. "Physical Sciences", specialty "Condensed Matter Physics", advertised in the State Gazette, issue 26, p. 136, 04/01/2022.

Candidate: Liliana Petrova KOLAKLIEVA, PhD, Assoc. Professor in the Central Laboratory of Applied Physics BAS.

Reviewer: Ivan NEDKOV Ivanov, DSc, Professor, IE BAS.

1. General characteristics of the submitted materials.

The documents of assoc. prof. PhD L.P. KOLAKLIEVA for this competition are in accordance with the requirements of the Implementing Regulations of the Law on Development of the Academic Staff in the Republic of Bulgaria (LDAS RB), the Regulations for the Application of Bulgarian Academy of Sciences (BAS) and Requirements of the Institute of Solid State Physics (ISSP) BAS (updated on 04.18.2019) for the Professional field 4.1. The subject of this review are the documents that the candidate has attached in the Author's reference for scientific and scientific applied contributions (Tables 1 and 2) and accompanying documents, including diplomas for higher education and for the educational and scientific degree "doctor", scientific works, inventions, citations, data on participation in scientific projects, contracts, implementations with economic effect, training of doctoral students, etc. The attached materials meet the documentary requirements for participation in a competition for the academic position of "Professor" and are adequate to the professional field and specialty (topic) of the announced competition, respectively 4.1. "Physical Sciences", specialty "Condensed Matter Physics".

Assoc. prof. PhD L.P.Kolakliieva graduated from SU "St. Kl. Ohridski", in 1980, the Faculty of Physics, with excellent results in the state exam with the specialization "Physics of Semiconductors". She successfully defended her PhD doctoral thesis in 2000 with the scientific specialty 01.03.25 "Electronic, optical and magnetic properties of condensed matter" (Tabl.2 indicator **A1**). Her scientific career began at the Central Laboratory of Applied Physics (CLAP) and went through the classic path of scientist at the BAS, respectively a physicist, a research assistant from the 3rd to the 1st degree and in 2011 she was elected an Associate professor at the CLAP. She specialized in leading world scientific centers under the leadership of Prof. Sinitsa at the Russia Academy of Science (1986), in Sweden-Linkoping University under the leadership of Prof. Jansen (2002-2004), in the Greek research center FORT-Hellas in 2000, program "NATO-Science and Peace".

Her administrative growth is a recognition of her high competence and accumulated experience and knowledge. PhD Kolaklieva has worked as Group leader, Deputy Director, as logistically her development has reached her election as Director of CLAP in 2012 with completed two mandates.

2. Publication activity (according to the submitted reference).

Assoc.prof. PhD L. Kolaklieva submitted for participation in the competition: an abstract of a dissertation work, documents for 2 book chapters, 22 publications in scientific journals (of which 10 with IF) and 3 reports at scientific forums published in full text in refereed collections. The candidate's works are in the field of materials science, in particular condensed matter physics and semiconductor physics. The presentation of the scientific publications for participation in the competition is organized in two sections **A** and **B**, where in section **A** the publications for habilitation work are presented. The remaining publications are summarized in section **C**.
The doctoral thesis of Assoc. prof. PhD Kolaklieva is at a high scientific level. The results have been published in highly rated scientific journals, respectively: 1 paper in *IEEE Trans.on Electron Devices, 2 in Materials Science and Engineering, 2 in Materials Science Forum and 1 in Semiconductor Science and Technology*. She has presented papers also published at more than 10 conferences proceedings.

The scientific works of the candidate for participation in the competition under indicator **B4** (Habilitation work) are numbered from **A1** to **A8** in table 2 and include works published in the period 2009 - 2021. Their distribution by districts is respectively: **Q1 -** 1 piece; **Q2** – 6 pcs.; **Q3** – 1 pcs. In 5 of the works, the candidate is the first author, and in 3 the corresponding author. Her contributions to published research are indisputable and well distinguished. Her publication activity is rated **160** points, which exceeds the requirements for the academic position of "professor" of **100** points. In the author reference, there are data on 19 participations with reports published in full text in materials of conferences (Appendix 1).

According to indicator **G7** (Scientific publications), 14 works are presented, numbered from **B1** to **B14** in the attached table 2. The distribution by neighborhoods is: **Q2** – 4 units; **Q3** – 4 pcs.; **Q4** – 3 pcs. and **Q-3** publications without **IF** – 10 pcs. PhD Kolaklieva is the first author in 6 of the works, in one of the works she is the second author and in the others she is in third and after third place, and for 3 of them she is the corresponding author. The contribution of the candidate in the works presented clearly stands out. Rated points are **206**. According to indicator **G8** (Published book chapter), 2 book's chapter are published by American and English publishing houses in 2009 and 2012 are included. The authors are two, with PhD Kolaklieva being the first author. Rated points are **30**. According to indicator **G9** (Inventions) – **75** poins. Publication activitiy for indicator **G** is rated **311** points which exceeds the requirement **220** points.

It is noteworthy that the candidate publishes in leading scientific journals (*Semiconductor Science and Technology, Coatings, Surface Engineering, Journ. of Thermal Analysis and Calorimetry* and new one *Journal of Nano Research*) in the field of its activity, which have high scientific recognition.

I have no notes and recommendations on the works presented.

3. General assessment of the candidate's scientific, applied scientific and pedagogical activities

Assoc. prof. PhD L. Kolaklieva has a well-formed profile as a scientist in the field of "Physics of Condensed Matter" with specialization in the creation of ohmic contacts to new wide band-gap semiconductor structures and nanostructured coatings for surface modification, technologies for their preparation and the study of physical interactions in thin-film and nanostructured coatings for application in high temperature and high powers devices for the needs of electronics and microelectronics. They are considered as a third generation materials in the semiconductor industry. Assoc. prof. PhD Kolaklieva submitted documents for participation as a member of the team in 2 national (2007-2010) and 3 international projects (1998-2007), which were successfully completed. She is the head of 1 project with National Scientific Research Fund, 1 with the Ministry of Education and Science and 1 with the Ministry of Economy. She is the head of the CLAP teams that participate in 2 Centers of Competence and Excellence, financed by the Ministry of Education and Science. The projects were carried out with the indisputable participation of CLAP and the candidate's contribution is noticeable, both in terms of scientific experiments and in terms of the organization of research work.

Pedagogical activity. During the last 12 years of her career, assoc.prof. PhD Kolaklieva has been the supervisor of three doctoral students, two of which have the status of "ready to defend", and the third one was enrolled in 2020.

4. Basic scientific and applied scientific contributions

The contributions of assoc. prof. PhD L. Kolaklieva can be summarized in two thematic areas: 1. Ohmic contacts for high-powers and high-temperature microelectronics; 2. Nanostructured coatings for surface modification. The main scientific contributions has reflected in the scientific publications equivalent to habilitation work (works marked with **A**) and those, extra-habilitation work (marked with indices **B** and **C**).

- ***Thematic area.*** *Ohmic contacts for high-power and high-temperature microelectronics:*

An optimized technology for depositing and forming ohmic contacts to an AlGaN/GaN HEMT structure including (Ti/Al)TiAu and (Ti/Al)MoAu contact structures has been developed. The determining influence of the forming temperature, the ratio of the elements in the first contact layer (Ti/Al), and the barrier metal (Ti, Mo) on the ohmic properties of these contacts has been proven [A1.1, A1.2]. The formation mechanism of ohmic properties and the role of the (Ti/Al) ratio in the first contact layer as well as the barrier layer (Ti or Mo) in (TiAl) contact structures are explained. [A1.1, A1.3]. A Mo-barrier layer was found to reduce the intensity of Au and Al diffusion in forming ohmic properties [A1.3].
New data were obtained on the influence of the (Ti/Al) ratio and the barrier layer on the surface morphology and composition and edge sharpness. By means of a precise analysis of the morphology and composition of the surface, the presence of a metal with a higher melting point as a barrier layer, in the case of Mo, has been proven. which greatly reduces the diffusion of aluminum to the surface, therefore these contacts have a smoother surface compared to those with a Ti barrier layer. In addition to the surface morphology, the barrier layer affects the edge sharpness [A1.2].

A thermostability test methodology was developed and the reliability of (Ti/Al) contacts to AlGaN/GaN HEMT structures was investigated, which allows in-situ to investigate the contact resistance under conditions corresponding to the operating conditions of HEMTs [A1.1, A1. 2]. Comparative analysis of contacts with the same ratio (Ti/Al) and different barrier layers showed that the presence of Mo as a buffer layer in the contact structure provides high temperature stability [A1.2].

New data have been obtained on the influence of the Ti:Al ratio on the morphology and composition of low ohmic contacts Au/Ti/Al to 4H-pSiC. It was found that the diffusion of Al during annealing can limit the interactions at the interface with SiC [B1.3,B1.4]. The binary compounds Au_2Ti and Al_3Ti were identified for the first time and shown to contribute to charge transfer and thus improve ohmic properties [B1.6]. Improved ohmic contacts are implemented in a high-speed modulator in the Q-band range on 4H-SiC p-i-n diodes [B1.2].

New data on the processes in the Au/Pd/Ti/Pd/SiC system during annealing were obtained and the mechanisms of formation of ohmic properties were explained, as well as their thermostability during thermal treatment in nitrogen and air. Thermal treatment of the Pd/SiC interface was found to result in partial dissociation of the SiC surface into silicon and carbon [B1.1]. This study showed that the presence of Ti and Au in the contact composition strongly limits palladium agglomeration and improves the surface morphology [B1.5]. At the same time, the titanium in the contact layer reacts completely with the dissociated carbon atoms to form TiC. The absence of free carbon in the Au/Pd/Ti/Pd ohmic contact was found to be the reason for its improved temperature stability under prolonged heat treatment and high operating temperatures [B1.1, B1.4].

For the first time, contacts to an AlGaN/GaN HEMT structure that do not contain Al have been developed in order to improve the surface morphology and sharpness of the contact periphery after formation of ohmic properties. The study of ohmic contacts to wide band-gap semiconductors proves that when metal/semiconductors are deposited, they commonly result in rectifying Schottky contacts which barrier height inhibits curr ent flow across the metal/semiconductor interface. Two new contact structures Ti/M/Au and Ti/M/Ti/Au were developed, where M is the hard-melting metals Mo, Ni and Pd [B1.7, B1.8].

- ***Theme area.*** *Nanostructured coatings for surface modification:*

Thermal and corrosion resistance of nanocomposite gradient TiAlSiN film was developed with the aim of its high-temperature application in the metalworking industry [A2.1, A2.2]. The coating is made of a Ti-TiN gradient adhesion layer, a TiAlSiN gradient nanolayer and a TiAlN/SiN nanocomposite layer and its causes a high hardness (40 GRa). The coating has a low coefficient of friction and has very good adhesion and stability at high temperatures [A2.1,A2.2]. This coating has been transferred to industry and is applied to metalworking cutting tools and dies.

An original gradient CrAlSiN nanostructured coating was created and a technology for its application was developed. The coating was found to consist of $Cr_xAl_{1-x}N$ solid solution nanocrystals embedded in an amorphous SiNx matrix. The coating has shown high temperature stability [A2.3].

A new type of CrAlSiN-AlSiN nanocomposite coating with a periodically modulated composition, combining superhardness and high resistance to elastic and plastic deformations, was created [A2.4]. It has been shown that to obtain the improved properties it is necessary to technologically achieve a modulated composition, each period consisting of Cr-enriched ($Cr_{0.51}Al_{0.41}Si_{0.08}N$) and Al-enriched ($Al_{0.82}Cr_{0.04}Si_{0.14}N$) regions, the transition between which is gradient. This study

proposes a new approach to improve the mechanical properties of nanocomposite coatings and combine superhardness with very good strength [A2.5].

A range of low-temperature (<200 ºC) technologies for deposition by unbalanced magnetron sputtering of multicomponent (triple and quadruple) nitrides of Ti, Cr, Al was created and their mechanical properties, morphology, composition and structure were studied [B2.3-B2.7]. As a result, structures with high hardness [B2.3-B2.7] has been received, which is a very good achievement for coatings produced at low temperatures. The influence of the adhesion-transition gradient layer system (Ti-TiN and Cr-CrN) on the adhesion-cohesion properties of the developed coatings was also characterized [B2.4-B2.7].

New data on the mechanical properties of an AlN coating deposited by pulsed laser deposition depending on the process conditions have been obtained [B2.8]. In this study, it was found that high deposition temperatures stimulate reactions occurring on the substrate surface and help to form the crystal structure as the layer grows. As the deposition temperature increases, crystallites with a hexagonal structure grow in the amorphous matrix and causes the hardness increases. The temperature dependence of the resistance to elastic and plastic deformations was determined.

- ***Scientific-applied contributions in useful models*** *that are not included in the habilitation work are as follows*:

The composition and structure of a TiAlSiN [C2-1] multilayer nanocomposite coating is proposed for the first time. The utility model (Certificate of Invention No. 1464 dated 17.08.2011) relates to a multi-layer nanocomposite coating to modify the surface of cutting, drilling and forming tools used in the metalworking industry. The subject matter of protection is the structure and composition, including the percentage content of each element, of the TiAlSiN multilayer nanocomposite coating, as well as the sequence of application of the composite layers and their thickness.

Planetary mechanism ensuring continuous and uniform movement of devices intended for application of single- and multi-layer wear-resistant coatings - Certificate No. 1631 dated 17.10.2012 [C2-2]. The subject of protection is the construction of the planetary mechanism.

Multi-layer coating for dental instruments with a high degree of hardness, elasticity and low coefficient of friction [C2-3] - Certificate No. 1988 dated 02.12.2014 The utility model relates to a multi-layer superhard coating with diamond-like layers for using in the construction and manufacture of dental instruments.

According to this indicator **G**, as I noted in point 2 the candidate's points are **311** and significantly exceed the required for "professorship" - **220** points.

The scientific contributions of assoc. prof. L. Kolaklieva combine in a unique and useful way high scientific achievements and a quick orientation to the possibilities of applying the scientific result. According to the contracts discussed in point 2, with her direct management, funds were attracted which, according to the candidate's data, provided her with **785** points in the group of indicators **E**.

5. **<u>Reflection of the candidate's scientific publications on the national and foreign literature</u>**

The list of citations presented by the candidate shows high interest from the scientific societie is a natural result of the publication activity of the candidate. Such as the significant number of citations

in reputable scientific journals - *IEEE Trans. on Plasma Science, Solid-Stsate Electronics, Journ. of Applied Physics, Semiconductor Science and Technology* and etc.

According to indicator **D11** (Citations), the candidate presented **296** independent citations to 58 works. Here I would point out two examples of highly rated informal citations that well illustrate the effect of the candidate's works.

1)Y.H., Liang et all., **Semiconductor Science and Technology**, Volume 28, Issue 12, December 2013, Article number 125010. DOI:10.1088/0268-1242/28/12/125010, quotes positively L. Kolaklieva, R. Kakanakov, **Ohmic Contacts for High Power and High Temperature Microelectronics**, Chapter 18 in "Micro Electronic and Mechanical Systems", Edit. Kenichi Takahata, ISBN 978-953-307-027-8, p. 293-318, 2009.
2)Baijun Xiao et all., **Surface and Coatings Technology**, Available online 10 January 2022, 128094. https://doi.org/10.1016/j.surfcoat.2022.128094, quotes very positively L. Kolaklieva et all., **Mechanical, Structural and Thermal Properties of Multilayered Gradient Nanocomposite Coatings,** Journal of Nano Research**, 17**, 193-203 (2012). *ISSN: 1662-5250*

The candidate's data in Scopus due to changes in her life status appear under two names - L. Kasamakova and L. Kolaklieva (she attached a document for the identity of the names), this makes it difficult to determine the **h-index** (for the first name it is **h7** at the second **h5**). The formal addition of the two numbers is not authoritative and calculation according to existing Scopus methodology is necessary for such case. At my request, the candidate, based on the list of her citations, presented me with graphical data summarized by this methodology, which coincide with my processing with resulting in h9.5. Given this coefficient the whole number of Scopus value of **h9** was assumed for evaluation.

In the total the points in the group indicators **D** are **592** at minimum of **200** points.

6. General characteristics of the candidate's scientific and scientific-applied activity

The specificity of assoc. prof. PhD L. Kolaklieva's scientific activity in a rapidly developing field, such as the physics of semiconductors, creates conditions for shortening the path from scientific research to the application. The candidate has an active scientific work and visible scientific contributions resealing in successful application of new solutions. Based on the summary analysis made above, in the total the points of assoc. prof. PhD L.P. Kolaklieva in the group of indicators exceed the minimum national requirements for the selection of the academic position "professor". My overall assessment of the candidate's publication activity is positive and I believe that her data fit the requirements for the position.

The sum of points according to indicator **E** for the candidate is **965** points with a required minimum of **150** points.

7. Critical Notes

Formally speaking, the candidate meets the pedagogical requirements of the position. However, I believe that she needs to pay more attention for the training of students and graduating, as they are the natural source of lab staff renovation. Of course, this is more a recommendation that does not affect my positive impression of her candidacy.

8. **Personal impressions of the candidate**

My personal impressions can be summarized as positive. Our contacts were in connection with administrative problems and scientific consultations in the field of application of semiconductor materials.

9. **Conclusion**

The analysis presented above shows that, in terms of indicators, the candidate significantly exceeds the requirements in the Regulations for the LDAS of RB, the BAS and the IFTT BAS Requirements for the position. The presented materials, the formulated contributions and my personal impressions of the candidate give me a reason to **strongly support** assoc. prof. PhD L.P. Kolaklieva's application for the academic position of "Professor" at the Central Laboratory of Applied Physics at the BAS in the professional direction 4.1. "Physical Sciences" with the scientific specialty "Physics of Condensed Matter".

03.08.2022

Prepared by: **(п)**
/Prof. DSc Ivan NEDKOV/