БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ
ИНСТИТУТ ПО
МИНЕРАЛОГИЯ И КРИСТАЛОГРАФИЯ
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СОФИЯ

REVIEW

on a competition for the academic position of "Associate Professor" in the professional field 4.1 Physical Sciences (Electronic Properties of Nanoscale Thin-Layer Systems) for the needs of the field "Structural Crystallography and Materials Science" at the Institute of Mineralogy and Crystallography-BAS, announced in the "State Gazette", issue 36 / 29.04.2025.

Candidate: Asst. Prof. Dr. Petar Yordanov Yordanov, IMC-BAS
Reviewer: Prof. DSc. Miroslav Vergilov Abrashev, Faculty of Physics, Sofia University "St. Kliment Ohridski"

1. General description of the submitted materials – under the competition the candidate has submitted 0 monographs, 17 articles, 0 book chapters, 0 textbooks, 2 certificates and patents, a list of 2 research projects. All works are accepted for review. According to the attached table, compiled from the information from the files given in directory 17 "Report on fulfillment of the minimum criteria" and directory 09 "Report on citations" from the list of documents of the candidate

Group of indicators	Content	PhD		Assoc. Prof.	
		Minimum requirement	Achieved	Minimum requirement	Achieved
A	Indicator 1	50	50	50	50
Б	Indicator 2	-	-	-	-
B	Indicator 3 or 4	-	-	100	100
Г	Sum of indicators 5 to 10			200	210
Д	Sum of points in indicator 11	-	-	50	100
E	Sum of indicators from 12 to the end	-	-	-	-

I can conclude that the quantitative indicators of the requirements of the IMC-BAS for occupying the academic position of "associate professor" have been met.
The science metric indicators of the articles submitted for participation in the competition cover the new minimum requirements for professional field 4.1. Physical Sciences, published in the State Gazette 23/18.03.2025 (Decree No. 17 of March 14, 2025).
13 publications with quartile Q1 x 25 pts. – 325 pts.
2 publications with quartile Q2 x 20 pts. – 40 pts.
2 publications with quartile Q3 x 15 pts. – 30 pts.

0 publications with quartile Q4 x 12 pts. – 0 pts.
0 posts with SJR; 10 pts. – 0 pts.
0 in books x 15 pts. – 0 pts.
0 journal publications in Web of Science and Scopus without IF and SJR x8 pts. – 0 pts.
0 publication in other peer-reviewed journals in another database - 0 pts.
0 publications in non-indexed journals - 0 pts.
2 published patents 2 pcs. x 25 pts. – 50 pts.
Total: 445 pts.

3. The candidate's scientific, applied and pedagogical activities can be characterized as follows: Dr. Yordanov is a researcher in the field of materials science - synthetic materials with strongly correlated different physical properties, i.e. the so-called multiferroics. The groups of materials studied are the following: various types of oxides ($Ca_3Co_4O_9$, $PdCoO_2$, $YTiO_3$, $CaMnO_3$, $CaRuO_3$, $RBa_2Cu_3O_{7-\delta}$ (R=Y, Nd, La), $YNiO_3$ as well as other dielectrics (SiAlON and SiC) and semiconductors. The studied samples are ceramics, epitaxial layers grown on various substrates ($SrTiO_3$, $LaAlO_3$, $[LaAlO_3]_{0.3}[Sr_2AlTaO_6]_{0.7}$, $LaSrAlO_4$, MgO, and Al_2O_3), superlattices or composite systems. In addition to performing their synthesis, the candidate is familiar with and has used in his research numerous experimental methods: IR and UV-VIS spectroscopy, scanning electron microscopy, X-ray structural analysis, measurement of transport properties (specific electrical resistance) and thermoelectric properties (Seebeck coefficient). In addition to the measurements, the candidate also participates in the discussion of the results and the formulation of conclusions.

The candidate's pedagogical activity is not presented.

The candidate's scientific and teaching capacity is based on and proven by his following participation in various scientific programs, workshops and summer schools of the institute where the candidate worked from 2004-2022 - the Max Planck Institute for Solid State Physics - Stuttgart, Germany:

- Participation in the traditional annual scientific meeting with presentations, organized by the Max Planck Institute - Stuttgart, in Ringberg - Germany, with international participation.
- Participation with presentations and poster presentations in Kloster Irsee - Germany, related to the international scientific project "TRR 80: From Electronic Correlations to Functionality" of the Max Planck Institute - Stuttgart, funded by the German State Science Foundation.
- Participation with presentations of scientific reports and workshops in connection with the implementation of a scientific-applied project with international participation of an industrial company Max-Planck Institute - Stuttgart and Coherent Inc., OR (USA) (Wilsonville, US): "High Operating Temperature Transverse Thermoelectric Materials for use in Laser Power Sensors".
- Numerous participations with presentations and poster presentations at small forums and summer schools, organized and held at the Max Planck Institute - Stuttgart.
- participation in two major projects:

a) international scientific and applied project with the participation of the Max Planck Institute for Solid State Research, Stuttgart and an industrial company - Coherent Inc., OR (USA) (Wilsonville, US): "High Operating Temperature Transverse Thermoelectric Materials for use in Laser Power Sensors" (successfully completed with the publication of scientific articles in

journals with a high impact factor and the introduction of a series of commercial products - Ultrafast broadband sensors for high-power laser radiation)
b) international scientific project Max Planck Institute for Solid State Research, Stuttgart and the German Research Foundation (DFG): "TRR 80: From Electronic Correlations to Functionality" (successfully completed with a discovery, patent, and publication of scientific articles in journals with a high impact factor - Generation of terahertz radiation using the ultrafast transverse thermoelectric effect).

3. Impact of the candidate's scientific publications in the Bulgarian and foreign literature: - science metric indicators (total number of articles - 17, of which articles with JCR-IF impact factor - 17, visible in SCOPUS - 16, number of citations according to SCOPUS - 403, h-index (SCOPUS, Web of Science) - 12). It should be noted that a significant part of the candidate's articles has been published in extremely reputable journals in the physical sciences - 1 in Adv.Mater., 1 in Phys.Rev.Lett, 1 in ACS Applied Materials & Interfaces, 5 in Phys.Rev.B, 2 in Phys.Rev.Materials.

4. Main scientific and/or scientific-applied contributions:
The main scientific contributions in the candidate's publications submitted for participation in the competition are: synthesis of polycrystalline samples, epitaxial growth of nanoscale thin-film systems - layers and heterostructures on single-crystal substrates, performance of X-ray structural characterization, spectroscopic studies, study of transport properties - electrical conductivity (respectively electrical resistance), Seebeck coefficient (thermoelectric properties), measurement of time characteristics in the ultrafast transverse thermoelectric effect, generation of electromagnetic radiation in the terahertz region, model analysis.

Here I will comment on the results obtained (chronologically), distributed according to the scientific issues and the specifics of the research object (the numbers in parentheses are the numbers of the publications in the list for participation in the competition):

In the period 2000 - 2004, the candidate worked as a physicist in the Department of Semiconductor Physics of the Faculty of Physics of Sofia University "St. Kliment Ohridski", where, in addition to laboratory demonstrations for students, he was actively involved in scientific research, and in particular - IR and UV-VIS spectroscopy of semiconductor materials. During this period, two scientific articles were published [No. 1,2], for which the candidate performed spectroscopic measurements of thin layers of β-FeSi2 and Mg2Si, obtained by the ion implantation method, and participated in the processing and interpretation of the results.

In the period 2004 - 2009 the candidate continued his research activity with work on the dissertation “Spectroscopic study of CaMnO3/CaRuO3 superlattices and YTiO3 single crystals”, at the Max Planck Institute for Solid State Physics – Stuttgart, Germany, related to the construction of a laboratory for spectroscopic studies of complex oxides of transition metals, including in an applied external magnetic field. The laboratory was successfully built. Two systems were studied: single-crystal ferromagnetic insulating YTiO3 and superlattices consisting of thin layers of the paramagnetic metal CaRuO3 and the antiferromagnetic dielectric CaMnO3. In the case of YTiO3, the IR (50 - 700 cm^{-1}) and UV-VIS (1-5.5 eV) ranges, including the phonon spectrum and high-energy electronic transitions, have been studied in detail as a function of temperature, crystallographic direction and the magnitude of the applied magnetic field. In the case of the CaRuO3/CaMnO3 superlattices, a detailed spectroscopic study has been carried out to establish the profiles of free electron carrier redistribution and the magnetic state. The following experimental methods have been used: IR spectroscopy, X-ray absorption spectroscopy and scattering, as well as circular polarization dichroism, with the candidate actively participating in the acquisition of the spectra, processing and analysis of the data. The results of the studies of these two systems have been published in several scientific papers [№ 3,5,7,8]. The detailed studies of the magnetization of YTiO3 help to further clarify the magnetic anisotropy and structural deformations accompanying the transition to a ferromagnetic state (with T_c = 27 K) in YTiO3 [№ 6]. The candidate actively participates in studies of other systems, successfully applying various experimental optical methods. In the article [№ 4], a detailed study of the optical conductivity σ(ω) (70-4000 cm^{-1}) along the c-axis of a series of single crystals of incompletely doped high-temperature superconductors RBa2Cu3O7-δ (R = Y, Nd, La) is presented. The results were obtained using ellipsometry, with the range corresponding to the far-IR region being recorded with a spectrometer based on a synchrotron source.

In the period 2011 – 2023, the candidate continues his scientific career at the Max Planck Institute – Stuttgart as a postdoctoral fellow. The areas of research include:

1. Synthesis of complex transition metal oxides in the form of polycrystalline samples, thin layers and heterostructures grown on single-crystal substrates;

2. Measurement and model analysis of thermoelectric properties – Seebeck coefficient S, and specific electrical conductivity at direct current σ (specific electrical resistance ρ = 1⁄σ);

3. Measurement of amplitude and time characteristics – magnitude of generated voltage U and generation time τ, of thin nanoscale systems (d ≈ 10-100 nm) for the realization of ultrafast transverse thermoelectric effect.

A large volume of scientific research activity was carried out as part of the implementation of two projects – one with the participation of a private industrial company, aimed at the development of ultrafast (nanosecond), thermally stable laser radiation detectors, and another – of the national German Science Foundation, aimed at identifying fundamental mechanisms applicable in devices with new functionalities. Both projects were successful, with the first ending with a marketed product, and the work on the second – with publications in prestigious scientific journals, a discovery and patents. The results were published in a total of nine scientific articles, and the discovery was protected by two separate patents – European and world. It should be noted that the specificity of the work on the first project (2012 - 2017) does not allow the publication of many of the results. In article [№ 9], a study of the thermoelectric properties – Seebeck coefficient S, electrical conductivity σ, and thermal conductivity κ, constituting the so-called “figure of merit” $ZT = S^2\sigma T/\kappa$ – a measure of the conversion efficiency of SiAlON and

SiC composite systems, with 5 and 10 vol. % TiCN added, respectively. The candidate's contribution to this work is expressed in the measurement of S and ρ, of the samples in the temperature range 300-1000 K, as well as in active participation in the discussions. Article [№ 10] presents a study of the thermoelectric properties S and ρ, constituting the so-called power factor $P = S^2/\rho = S^2\sigma$, of thin layers of Ca3Co4O9, grown epitaxially on various single-crystal substrates, such as SrTiO3, LaAlO3, [LaAlO3]0.3[Sr2AlTaO6]0.7, LaSrAlO4, MgO, and Al2O3. An X-ray structural analysis of the degree of deformation of the thin layer was performed. The data include the temperature dependence of S and ρ on T in the range 300 - 1000 K, the dependence on the thickness of the layers d and on the oxygen pressure in the environment. The observed anomaly – extreme increase of the Seebeck coefficient S at T>700 K, in layers on SrTiO3 and LaAlO3 substrates, is explained by the inclusion of a parallel mechanism of thermoelectric voltage generation with an extremely high coefficient (S ≈ 1200-1600 μV/K) in these crystalline substrates. The results are described qualitatively and quantitatively with a parallel electrical model. The candidate has a leading role and contribution in all presented results, including the synthesis of the polycrystalline material Ca3Co4O9, the growth of thin layers of Ca3Co4O9 with laser-pulsed deposition on the different substrates, the experimental measurements of S and ρ, the model description, and the conclusions and inferences made. In the article [No. 11], a complete experimental and theoretical description of the thermoelectric properties of polycrystalline samples of the compound Ag6Ge10P12 is presented, which, due to its specific electronic and structural characteristics, exhibits an extremely low thermal conductivity κ, and a correspondingly high value of $ZT = S^2\sigma T/\kappa$. The candidate's contribution is in the detailed measurement of the parameters S and ρ in a wide temperature range, as well as in the active participation in the discussion and conclusions made. Articles [№ 12, 14] discuss the establishment of the dependence between the thermoelectric properties of heterostructures of the LaNiO3 / La2CuO4 type on the thickness of the building layers and the precise chemical composition of the boundaries between the two materials. Measurements of the parameters S and ρ were made, as well as a scanning electron microscopic study. In article [№ 13], a significant amount of work was carried out, related to the synthesis and measurement of the thermoelectric parameters S and ρ of nanoscale thin layers of the highly anisotropic delaphosite PdCoO2, grown on single-crystal substrates of Al2O3 with different angles of the vicinal planes. The goal is to establish the degree of spatial anisotropy in the Seebeck coefficient S_{ab}/S_c, as well as a comparison with the theoretically obtained results. Except for the theoretical part - estimation of the electron-electron interaction parameter, and the transmission microscopy analysis, the candidate has a leading role and contribution to this work, including the synthesis of the nanoscale layers, measurement of thermoelectric parameters, X-ray structural analysis, the fit-correction procedure, the calculation of the potential amplitude of the generated voltage in the laser-induced ultrafast thermoelectric effect, the discussion and conclusions. This work is the first published experimental confirmation of the theoretical predictions for a strongly pronounced and ambipolar spatial anisotropy in PdCoO2. The developed protocol for measuring the Seebeck coefficient along the main crystallographic directions of PdCoO2, using thin layers with different inclination angles, is universal and can also be used for other anisotropic materials where sufficiently large single crystals are not available. Article [№ 15] presents a supplement to the study on establishing spatial anisotropy in the Seebeck coefficient in PdCoO2. In this work, based on the results obtained from the thin layers, the temperature course of S(T) and ρ(T) in the range T = 300 - 1000 K of polycrystalline samples obtained by optimized synthesis, allowing for an extremely pure phase, is described in a model. A detailed X-ray structural analysis, microscopic images to confirm the morphology, and the specific thermal conductivity were also measured, which allowed for an estimate of ZT. The candidate's contributions are in the acquisition of the thermoelectric characteristics and the model description of the measured effective values of S(T), ρ(T) and κ(T). The model description in this case is non-trivial, as it is the result of a chaotic spatial distribution of a large number of highly anisotropic microscopic single-crystal particles constituting the polycrystalline samples. The results of the study are fully consistent with a large and ambipolar ratio S_{ab}/S_c. The limiting stability temperature of PdCoO2 in an inert (helium) atmosphere has also been established. Article [№ 16] is a review of the scientific work carried out in the implementation of the project "TRR 80: From Electronic Correlations to Functionality", and the candidate's contribution is accounted for by the works in two directions. The first concerns the mechanism of effective increase in the Seebeck coefficient S, and respectively the power factor $P = S^2/\rho = S^2\sigma$), of thin layers deposited on crystalline substrates of materials with ionic mobility at high temperatures. In such substrates, a small number of mobile p-carriers are generated through a process of reversible recombination of oxygen atoms in the crystal defects - oxygen vacancies. In turn, these small number of carriers generate gigantic values S_substrate, which drastically change S_{film}. An example of a thin-film system based on LaNiO3 is demonstrated, which has a metallic character and a negative S_film, but due to the influence of the substrate at T > 700 K, the S_film drastically changes its value and sign from about -30 µV/K to 90 µV/K. This mechanism has not been fully studied and provides opportunities for future original scientific developments, practical applications and patents, including for effective recycling of thermal energy, fabrication of fast and precise oxygen sensors, etc. The results of the studies of the anisotropic metal delafosite PdCoO2, described in detail above, are also included in the review of the article. The work on this extremely interesting material has made significant progress with the experiments on determining the response time for voltage generation τ_r in nanoscale (d ≈ 10 nm) thin layers of PdCoO2 grown on vicinal surfaces of single-crystal Al2O3 substrates with different inclination angles θ - article [№ 17]. The inclined growth of a layered material with a strong spatial anisotropy of the Seebeck coefficient $\Delta S = S_{ab} - S_c$ leads to the appearance of a special thermoelectric effect - the so-called transverse thermoelectric effect, in which the directions of the temperature gradient and the generated voltage are perpendicular $U_x = l \sin 2\theta \, \Delta S \Delta T_z / 2d$. The effect not only makes it possible to use thin layers, but also introduces a parameter (response time) that is fundamentally uncharacteristic for the thermoelectric effect. The response time here depends on the thickness of the thin film to the second degree and is inversely proportional to the thermal diffusivity of the material, $\tau_\mathrm{r} \approx 0.4\, d^2/D_z$. In this situation, with nano-sized layers and precise material selection, response times of the order of $\tau_\mathrm{r} \approx 10^{-12}$ s become fully achievable. Typically, the response time is tested with short nanosecond (10^{-9} s) laser pulses directed at the thin layer, and the shape and magnitude of the voltage are measured with an oscilloscope. The study shows that the electrons in the thin layers of PdCoO2 are so mobile that they are able to respond to femtosecond laser pulses (10^{-15} s) by generating an ultrafast current pulse, leading in turn to the emission of electromagnetic radiation in the terahertz region. With the exception of the physical implementation of the experiment to detect the generated terahertz radiation, the candidate has a leading role and main contribution to all presented concepts, results, model description, discussions and conclusions in this work. In addition to publication in a prestigious scientific journal, the discovery also led to the registration of a European and world patent [P1,P2], in which the candidate is the main inventor.

In summary, I define the contributions of the candidate according to the required classification as:

- Proving with new means significant new aspects of already existing scientific fields, problems, theories, hypotheses;
- Creating new classifications, methods, constructions, technologies, preparations, etc.;
- Obtaining and proving new facts;
- Obtaining confirming facts;
- Contributions to implementation: methods, constructions, technologies, preparations, schemes, etc.;
- Application of scientific achievements in practice, realized economic and other effect.

5. In collective publications, the candidate's contribution should be highlighted. I evaluate the contribution in the publications by:
- The candidate's place among the co-authors of a given publication: in publications 8, 10, 13, 15, 17 Petar Yordanov is in first place in the list of authors.
- For all articles, the candidate has given a detailed description of his individual contribution in the file "10 Reference for scientific contributions Petar Yordanov". From this description, I leave the impression that in all of them the candidate's contribution is significant, and in a significant part of them - leading.

6. I have no critical comments on the submitted works, including the candidate's literary awareness.

7. Based on the above, I recommend that the scientific jury propose to the competent body for the selection of the IMC-BAS to select Petar Yordanov Yordanov, who fully meets the requirements of the IMC-BAS Regulations, to occupy the academic position of "associate professor" in the professional field 4.1 Physical Sciences (Electronic properties of nanoscale thin-film systems).

Date: 03.09.2025 Reviewer: Заличено съгласно чл. 2 от ЗЗЛД

/ Prof. DSc. Miroslav Abrashev /