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REVIEW

By Prof. Valentin Nikolov Popov, D.Sc., Faculty of Physics of the University of Sofia "St. Kliment Ohridski"
of the application, submitted for participation in the competition for the academic position of "Professor" in the Field of Higher Education 4. Natural Sciences, Mathematics and Informatics, Professional Subfield 4.1. Physical Sciences, Scientific Speciality "Electrical, Magnetic and Optical Properties of the Condensed Matter (Multiferroic Properties of Bulk Samples and Nanomaterials), Discipline "Physics with Biophysics".

Assoc. Professor Iliana Naumova Apostolova, Department of Mathematics, Physics, and Informatics at the Faculty for Forest Industry of the University of Forestry is the sole candidate to submit documents for participation in the competition for "Professor", announced in the State Gazette, issue 108/08.12.2023 and on the internet site of the University of Forestry for the needs of the Department of Mathematics, Physics, and Informatics at the Faculty for Forest Industry of the University of Forestry.

1. Brief biographical data

The candidate Assoc. Prof. Apostolova graduated with the degree of Master of Solid State. Physics from the Faculty of Physics of the University of Sofia in 1993. There she qualified as a teacher of physics in 1994. She has been a Ph.D. student at the Department of Physics of the Solid State and Microelectronics. In 2013, she defended a PhD dissertation "Static and Dynamic Properties of Magnetic and Multiferroic Nanoparticles" and was awarded the degree "Doctor". The candidate's professional career starts as a physics and informatics teacher at the 54th Secondary School, Sofia, after which she has worked as an Assistant, Senior Assistant, Principal Assistant, and Assoc. Professor at the Department of Mathematics, Physics, and Informatics of the Faculty for Forest Industry of the University of Forestry for the last 27 years. At the University of Forestry, she has taught the disciplines of Physics with Basics of Biophysics, Physics with Biophysics, Physics, and Defence from Noise and Vibrations for different faculties of the University of Forestry.
The scientific interests of the candidate are in the field of the physics of condensed matter, the theoretical investigation of static and dynamical properties of complex systems with nonlinear interactions between their subsystems, investigations in the field of nanomaterials – magnetic and multiferroic nanoparticles, thin films and graphene using the method of Green's functions, more precisely that of Tserkovnikov, which has been modified for application in nanostructures.

2. General description of the submitted materials

The candidate participates in the competition with:
- Textbooks - 2 pcs;
- Published teaching aids - 1 pcs;
- Publications - 58 pcs.

The publications can be classified as follows:
By type:
- Articles in scientific journals - 58 pcs;

By language:
-Foreign language (English) -58 pcs;

By the number of the co-authors:
- Single author – 2 pcs;
- With one co-author – 1 pcs;
- With two co-authors – 46 pcs;
- With three or more co-authors – 12 pcs.

Citations of the publications:
- Total – 505 citations in journals with Q (quartile from Q1 to Q4);
- Of the publications for the competition – 404 citations in journals with Q;
- H index of all publications – 11.

3. Fulfilment of the minimum requirements for the position of professor

The candidate fulfils the minimum numerical criteria of the Law for the Development of the Academic Staff in the Republic of Bulgaria and the Regulation for its Implementation, as well as the Regulation for Development of the Academic Staff of the University of Forestry for the position of a professor as summarized in the Table:

Group of indicators	Required points	Points of the candidate
А	50	50
Б	-	-
В	100	190
Г	200	871
Д	100	828
Е	150	170

It has to be noted that the number of points of the candidate for indicator Г (publications outside the habilitation work) and Д (citations in the world databases with scientific information) exceeds many times the required number of points as specified in the mentioned Regulations.

4. General characteristics of the candidate's activity

4.1. Educational and pedagogical activity

The educational and pedagogical activity of the candidate as an Assoc. Prof. includes teaching students of the speciality Veterinary Medicine the discipline Physics with Basics of Biophysics – lectures and laboratory exercises, speciality EOOC the discipline Physics with Biophysics – lectures and laboratory exercises, speciality Defence from Noise and Vibrations – lectures, laboratory and seminary exercises. The candidate participates actively in preparing laboratory exercises, tests, and curricula of her courses. Especially, the candidate has submitted for the competition two published textbooks (Physics with Biophysics and Physics with Biophysics for Ecologists) and lecture notes (Tests on Physics and Physics with Biophysics), prepared for the needs of the University of Forestry. All this shows the active position and commitment of the candidate in the teaching process at the University of Forestry.

4.2. Scientific and scientifically applied activity

The candidate's research activity is in the multiferroics field and is related to their theoretical investigation. Multiferroics are materials, in which the magnetic, electrical, and structural parameters of ordering are strongly interconnected, which can lead to the simultaneous emergence of magnetic ordering, electrical ordering, and ferroelasticity. Such systems can have simultaneously magnetization and polarization, and they can be created and controlled by magnetic and electrical fields. The interest in multiferroics is due to the significant advance in their synthesis in bulk phase and as nanoparticles, as well as to the hope for their practical application in computer memory chips and cancer treatment by magnetic hyperthermia. The macroscopic description of these phenomena in these systems can be done using the Landau theory. The origin of many of the observed phenomena in multiferroics can however be explained only using the microscopic approach that has been applied in the proposed publications. In this approach, the Hamiltonian of the system is constructed from the Hamiltonians of the separate subsystems – spin, electronic, phonon, etc. – and their interactions, as well as interactions with external electric and magnetic fields. The static and dynamic properties of the multiferroics are calculated using the method of Green's functions in the formulation of Tserkovnikov. This method allows calculating the spin energy and attenuation and the average magnetization for the magnetic system; the energy of the pseudospin excitation and attenuation and the polarization for the ferroelectric system; the phonon energy and attenuation for the atomic system; an important quantity that is calculated in this approach is the dielectric function. The applied method has huge possibilities for a description of multiferroics with various atomic compositions, microscopic interactions, and external interactions. This advantage of the method has been used for the modelling of different multiferroics, for which the

interactions leading to definite macroscopic effects have been identified and qualitative agreement of the derived results with experimental data has been achieved.

A part of the publications is devoted to the clarification of the connection between the structure and the properties of the multiferroics and the magnetoelectric coupling at the microscopic level. Special attention is paid to the identification of the mechanisms for the emergence of spin-induced polarization in bulk samples, namely, the one-ion and two-ion magnetostriction mechanism, connected with non-relativistic exchange interactions [3 - 7, 27, 29, 32, 34], "inversion" Dzyalishinskii – Morya (DM) mechanism, connected with the exchange interaction of the DM accounting for the spin-orbit interaction [5-7, 31] and the mechanism of the spin-dependent p-d hybridization [10, 17, 27, 33]. The contributions of these mechanisms to the emergence of spin-induced polarization are analyzed [5, 6, 7, 29]. A large number of systems is considered, differing in structure and composition, which define the magnetic ordering in them and the different mechanisms of spin-induced polarization. As an example, the publications [7, 29] show that the spontaneous polarization in the polar magnetics BiFeO3 and LiFeP2O7 within the transverse Ising model depends on the magnetic ordering and can be controlled by a magnetic field. Another part of the publications is devoted to the study of the effect of doping in low-dimensional systems [1, 20, 22, 25, 26, 39, 41, 43, 45]. The doping deforms the systems, which leads to the change of the electric and magnetic ordering in them, and also changes the temperature of the ferroic phase transitions, magnetization, and polarization. As an example, the doping of nanoparticles of YCrO3 with Mn leads to an increase in the dielectric constant, while doping with Gd leads to a decrease in the dielectric constant because of the different radii of Y, Mn, and Gd atoms [20]. The size and surface effects are accounted for by the use of model nanoparticles, which are homogeneous in composition, heterogeneous in structure, and with different exchange interactions and magnetic anisotropy in the bulk and at the surface. The dependence of the magnetization, polarization, and temperature of the phase transitions on the size of the nanoparticles is studied within the latter model [20, 22, 25, 26, 45].

A part of the publications has applied character and concerns the investigation of magnetism and multiferroism at room temperature in doped magnetic and multiferroic nanoparticles [9, 12, 13, 16, 21, 30, 37, 38, 40, 44, 46, 47]. These phenomena are attractive with the possibility to manipulate the properties of the nanoparticles and opening possibilities for application in many areas of science and technology, for example in cancer treatment by local heating. In particular, decreasing the size of the nanoparticles of certain oxides and sulfides leads to the emergence of magnetization due to the presence of anionic vacancies [9, 13, 21, 38, 46, 47]. The magnetic properties of the nanoparticles depend also on the doping, which changes the interactions between the spins, the deformation of the crystal lattice, and the temperature of the magnetic transitions, which has been studied in the case of oxides [9, 12, 13, 16, 30, 37, 38]. Special

attention is paid to modelling the effect of doping with different ions on the band gap of the electronic structure of the nanoparticles [37, 40, 44, 46, 47].

In a part of the publications, the concrete application of the nanoparticles for cancer treatment by the method of magnetic hyperthermia is considered. This method is based on the local heating of the tumour cells in the temperature interval from 41°C to 46°C by applying an alternating magnetic field on nanoparticles with magnetic phase transition in this interval. The effectiveness of the method is determined by the degree of heating, which is connected with the area of the hysteresis curve, i.e., by the coercive force and the saturation magnetization. The principal aim of a part of the publications is to find nanoparticles, corresponding to these requirements by changing the size of the nanoparticles, and the type and degree of doping [11, 18, 24, 28, 36, 42]. For the studied oxides, the optimal parameters for application in the method of magnetic hyperthermia have been derived. It has been shown that the most suitable are the composite nanoparticles, which allow for achieving the effectiveness of the heating and fulfilment of the requirements for biocompatibility [28].

Several publications report studies of systems with strong spin-phonon interaction [8, 14, 15, 19, 35, 38]. In one of these publications, the anomaly of the phonon spectra and the attenuation of the phonons below the temperature of the magnetic phase transition of oxides RCrO3 has been studied for different rare-earth element R, which has been explained with competing magnetic orderings [8]. The effect of the doping and size effects on the phonon spectra of the nanoparticles has been studied in detail in [14, 15, 19, 35, 38].

List of the publications submitted for the competition:

[1] Phys. Stat. Sol. B 252, 8, 1839 (2015); [2] Phys. Lett. A 379, 7, 743-746 (2015); [3] Mod. Phys. Lett. B 29, 17, 1550086 (2015); [4] Phys. Stat. Sol. B 252, 12, 2667 (2015); [5] Mod. Phys. Lett. B 29, 1, 1550251 (2015); [6] Eur. Phys. J. B 88, 328 (2015); [7] Phys. Stat. Sol. B 254, 4, 1600433 (2017); [8] Mod. Phys. Lett. B 31, 3, 1750009 (2017); [9] Mod. Phys. Lett. B 31, 36 1750351 (2017); [10] Eur. Phys. J. B 90, 236 (2017); [11] Phys. Stat. Sol. B 255, 6, 1700587 (2018); [12] Physica E 99, 202 (2018); [13] J. Magn. Magn. Mat. 456, 263 (2018); [14] Solid State Commun. 279, 17 (2018); [15] Mod. Phys. Lett. B 32, 21, 1850250 (2018); [16] Phys. Stat. Sol. B 255, 8, 1800179 (2018); [17] Solid State Commun. 292, 11 (2019); [18] Eur. Phys. J. B 92, 58 (2019); [19] Mod. Phys. Lett. B 33, 1950141 (2019); [20] Eur. Phys. J. B 92, 105 (2019); [21] Phys. Stat. Sol. B 1900201 (2019); [22] Phys. Stat. Sol. B 2000046 (2020); [23] J. Magn. Magn. Mat. 513, 167101 (2020); [24] Physica E 124, 114364 (2020); [25] Phys. Stat. Sol. B 258, 2000482 (2020); [26] J. Alloys and Compounds 852, 156885 (2020); [27] Solid State Commun. 323, 114119 (2021); [28] J. Magn. Magn. Mat. 522, 167504 (2021); [29] Mod. Phys. Lett. B 33, 2150158 (2021); [30] Eur. Lett. 133, 47003 (2021); [31] Phase Trans. 94, 527 (2021); [32] Phys. Lett. A 407, 127480 (2021); [33] Phys. Stat. Sol. B 258, 2100136 (2021); [34] Phase Trans. 94, 705 (2021); [35] J. Appl. Phys. 130, 175103 (2021); [36] Phys. Stat. Sol. B 259, 2100545 (2022); [37] Magnetochem. 8, 122 (2022); [38] Magmetochem. 8, 169 (2022); [39] Nanomaterials 13, 79 (2022); [40] Nanomaterials 13, 145 (2022); [41] Int. J. Mod. Phys. B 37, 2355021 (2022); [42] Materials 16, 2353 (2023); [43] Phys. Stat. Sol. B 260, 2300077 (2023); [44] Phys. Stat. Sol. (RRL) 2300159 (2023); [45] Magnetochem. 9, 142 (2023); [46] Eur. Phys. J. B 96, 77 (2023); [47] Appl. Sciences 13, 6411 (2023).

4.3. Implementation activity:
The research activity of the candidate does not include implementation.

4.4. Contributions
The analysis provided above of the publications submitted for the competition shows that in them the candidate has a deep understanding and has used systematically a microscopic approach for investigation and analysis of the magnetoelectric interactions leading to multiferroism. In particular, in the publications, the mechanisms for the emergence of spin-induced polarization are considered in detail, and it is shown that it can give rise to the antisymmetric magnetic interaction of the Dzyaloshinskii – Morya type. The change in the properties of multiferroics upon doping and the emergence of multiferroism at room temperatures are investigated in detail. Models of nanoparticles, accounting for the effects of size and doping are introduced. The application of nanoparticles with optimized characteristics for the method of magnetic hyperthermia is proposed. The concrete results in the presented publications can be used for further theoretical and experimental studies of multiferroics.

5. Evaluation of the personal contribution of the candidate
The personal contribution of the candidate is the use of specially constructed model Hamiltonians and the method of Green's functions for the calculation of static and dynamical properties of magnetic materials and multiferroics.

6. Critical notes
None.

7. Personal impressions
My impressions of the candidate are only from the defence of her Ph.D. dissertation, where she showed that she had solid knowledge in the field of multiferroics and the method of Green's function, and can defend her viewpoint.

8. Conclusion:
Given the above, I propose Assoc. Professor Iliana Naumova Apostolova to be elected "Professor" in the Field of Higher Education 4. Natural Sciences, Mathematics and Informatics, Professional Subfield 4.1. Physical Sciences, Scientific Speciality "Electrical, Magnetic and Optical Properties of the Condensed Matter (Multiferroic Properties of Bulk Samples and Nanomaterials), Discipline "Physics with Biophysics".

08/04/2024 Reviewer:
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