MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
Sumy State University

APPROVE
Head of the admissions committee
_____ I.S. Kozii
26.09 2024

PROGRAM
entrance exam during admission to study for the degree of «Doctor of Philosophy» in the specialty 105 «Applied Physics and Nanomaterials»

1. GENERAL PROVISIONS
The purpose of the entrance exam for admission to graduate school is to assess the readiness of the applicant to obtain the degree of Doctor of Philosophy in section 105 "Applied Physics and Nanomaterials".
The entrance exam is conducted in the form of tests in written form for 80 minutes.

2. TYPICAL QUESTIONS FOR THE ENTRANCE EXAM

The entrance exam for admission to studies for the degree of the Doctor of Philosophy includes questions on the following topics.

Topic 1. The structure of solid state
1. Crystalline and amorphous state.
2. Translational symmetry. Elementary cell.
3. Types of crystal syngonias and Brave lattices.
4. Miller indices.
5. Edge and screw dislocations.

Topic 2. Energy spectrum of crystals
7. Description of the energy state of crystals using a gas of quasiparticles.
8. Examples of quasiparticles: phonons, magnons, excitons, plasmons, etc.
9. Electrons in metal as quasiparticles. Quasi-impulse.
10. Zone theory of crystals.
11. Zone scheme and types of solids.
12. Degenerate electron gas. Electronic heat capacity, Fermi energy.
13. Statistics of quasiparticle gas. Bosons and fermions.

14. Heat capacity of the grid. Experimental temperature dependence of heat capacity of crystals.
15. Einstein and Debye models for heat capacity of crystals.

Topic 3. Magnetic phenomena in solid bodies
16. Classification of magnets. Diamagnetism and paramagnetism of solid state. Antiferromagnets.
17. The nature of ferromagnetism. Domains.
18. Antiferromagnetism and ferrimagnetism.
19. Curie's law. Ferromagnetism. Weiss molecular field. Exchange interaction. Ferromagnetic domains.
20. Anisotropy energy. Domain walls.

Topic 4. Thermodynamics and phase transitions
21. Equilibrium of phases. Gibbs phase rule.
22. Phase transitions of type I and II.
23. Equilibrium diagrams of the "Cigar" type.
24. Equilibrium diagrams of the eutectic type.

Topic 5. General characteristics of semiconductors
25. General characteristics of semiconductor materials of electronic equipment.
26. Intrinsic electron and hole conductivity. Mobility of charge carriers.
27. Quasi-two-dimensional systems in semiconductors: MON-structures (metal-oxide-semiconductor) and MDN-structures (metal-dielectric-semiconductor): concepts of breakdown voltage and threshold voltage, depth of leakage and drain regions, channel length.

Topic 6. Physical properties of semiconductors
28. Electrical and thermal conductivity: ratio for total specific conductivity, mechanisms of thermal conductivity.
29. Mechanisms of electron scattering in semiconductors.
30. Scattering of electrons on impurities and defects.
31. Electron-phonon collisions in semiconductors.
32. Classical Hall effect in semiconductors: physical nature of the effect and devices based on it.

Topic 7. Elements of functional electronics
33. Contact phenomena in microelectronic structures: classification and characteristics of contacts of integrated microcircuits.
34. The Hann effect: physics of the process, current-current characteristic.
35. Schottky diode: structure, physical processes.
36. Film elements of hybrid integrated circuits: types, configuration, main parameters of film resistors, capacitors and inductors.

Topic 8. Devices of magneto- and optoelectronics

37. Optoelectronic devices: classification, structure, physical principles of operation.
38. Volt-ampere characteristics of a photodiode, phototransistor and photothyristor.
38. Structural diagram of an optocoupler: radiation source and receiver, optical medium.
39. Magnetoelectronic devices: physical principles of operation, design, electrical characteristics.
41. Structural and technological parameters and principles of operation of fiber-optic communication lines.

Topic 9. Materials of spintronics

42. Film nanostructures used in electronics.
43. Granular film alloys: methods of formation and properties.
44. Spin-valve structures: features of the structure and properties.

Topic 10. Spin-dependent effects in magnetic nanostructures and devices based on them

45. Giant magnetoresistance (GMR): experimental studies and theoretical provisions.
46. Conditions for the implementation of GMR in multilayer film materials.
47. Tunnel and giant tunnel magnetoresistance.
48. Spin transistors: structure, principle of operation.
49. Sensors based on the GMR effect: principles of operation, structure of the sensitive element.
50. Application of GMR materials: instrumentation, sensor equipment and information technologies.

Topic 11. Fullerenes, nanotubes and nanowires

51. Thin-film technologies: methods of physical and chemical deposition from the vapor phase of materials related to diamond-like materials.
52. Fullerenes and materials based on them, methods of their production, fullerides.
53. Crystal structure and properties of C60 fullerite.
54. General characteristics of carbon nanotubes and methods of their synthesis.
55. Photonic crystals, nanomembranes and nanowires: characteristic properties.
56. Photonic crystals: structure and physical properties.
57. Two-dimensional nanocomposites: nanowires, nanofibers, nanotubes in nanochannels and layered nanocomposites.
58. Study of nanomaterials by scanning electron microscopy.
59. Study of nanomaterials by transmission electron microscopy.

Topic 12. Diamond-like and related nanomaterials

60. Diamond-like materials based on carbon.
61. Methods of obtaining diamond-like films.
62. Materials related to diamond: chemical composition and crystal structure.

Topic 13. Spectrometric measurements
63. Physical foundations of mass spectrometry.
64. Mass spectrometers, mass spectra, mass analyzers.
65. Use of mass spectrometry for gas analysis.

Topic 14. Fundamentals of qualitative and quantitative microanalysis
66. Physical basis of mass spectrometry of secondary ions.
67. Application of the secondary ion mass spectrometry method for the analysis of the elemental composition of films.
68. Fundamentals of qualitative and quantitative X-ray microanalysis.
69. Peculiarities of microanalysis of free films (foils) and films (coatings) on a substrate.
70. Physical foundations of Auger-electron spectroscopy.

Topic 15. Electron beam and diffraction methods
71. Types of microscopic contrasts (shadow, diffraction, amplitude and phase).
72. The principle and modes of operation of a raster electron microscope. Types of microscopic contrasts.
73. Principle of operation of an electronograph. Diffraction of fast electrons.
74. Fundamentals of electronographic analysis: diffraction contrast and its varieties. Shadow, amplitude and phase contrasts.
75. Fundamentals of X-ray analysis: calculation of the type and parameters of the crystal lattice.

3. STRUCTURE OF TASKS

The examination task of the entrance exam consists of six theoretical and practical tasks. Each task includes three questions, each of which has three possible answers, one of which is correct. (A sample exam task is given in Appendix 1).
Answers are entered by the entrant to the postgraduate course in written form in the answer sheet. (A sample answer sheet is given in Appendix 2).

4. EVALUATION CRITERIA

General requirements
The commission evaluates the entrant's written answers to test tasks on a 200-point scale. Entrants who scored less than 100 points receive an "unsatisfactory" rating and are not allowed to further participate in the competitive selection. Entrants who scored 100 or more points are allowed to participate in the competitive selection.

To receive a positive grade from the entrance test, the applicant must pass the minimum acceptable test threshold at the level of 0.3 or 30% of the total number of test points.

Test points are awarded for each correct answer to the task, 0 points are awarded for an incorrect answer. The obtained test points for the entrance test are

calculated on a 200-point scale (with rounding to the nearest integer, according to the rules of mathematical rounding) according to the following algorithm:

$$O = O_{min} + k \times (N - r \times T), \text{ where}$$

O – grade from the entrance exam on a scale of 200 points;
O_{min} – the minimum score from the entrance test on a scale of 200 points, at which the entrant is allowed to participate in the competitive selection;
k – the coefficient of transfer of test scores to a scale of 100-200 points, while:

$$k = 100 / (T \times (1 - r));$$

r – the minimum acceptable test threshold with an accuracy of up to 0.01, which is set in the range from 0 to 1, but not less than 0.10;
T – is the total number of test points that an entrant can receive during the entrance test;
N – is the number of test points that the applicant received during the entrance test.

Provided that the number of test points that the entrant received during the entrance exam (N) is "0", then the entrant receives an "unsatisfactory" grade and is not allowed to further participate in the competitive selection.

Calculation of test points

A maximum of 30 points can be obtained for one task №1-4, and a maximum of 40 points for tasks №5,6. The assessment of the answer within the task is carried out as follows: for the first question - 8 points, for the second - 10 points and for the third question - 12 points (for tasks №1-4) and for the first question - 12 points, for the second - 12 points and for the third question - 16 points (for tasks № 5, 6). Weighting coefficients in question evaluation are related to its complexity. Incorrect answer - 0 points.

The total number of test points (T) that an applicant can receive during the entrance exam is 200 test points.

The number of test points for the entrance exam (N) is calculated as the sum of test points excluding the test points removed for correcting the answer sheet.

Corrections Policy

For each correction, 2 test points are deducted from the total number of test points (T) that the applicant can obtain in the entrance examination.

5. LIST OF RECOMMENDED LITERATURE

1. Maurizio Di Pado Emilio Microelectronis from fundamentals to applied design. – Springer Book. – 2016. – 118 p. http://dx.doi.org/10.1007/978-3-319-22545-6

2. John Wilson, John Hawkes, Optoelectronics. An introduction (third edition). – Prentce Hall Europe. – 2007. – 575 p. https://ia600307.us.archive.org/30/items/OptoelectronicsAnIntroduction/OptoelectronicsAnIntroduction_text.pdf

3. Nouailhat Alain. An introduction to nanoscience and nanotechnology. – UK: Willey. – 2008. – 229 p.
https://web.pdx.edu/~pmoeck/phy381/intro-nanotech.pdf

4. Theoretical methods of investigation of thin film materials properties : study guide / I. M. Pazukha, I. Yu. Protsenko. – Sumy : Sumy State University, 2017. – 102 p.
https://essuir.sumdu.edu.ua/bitstream-download/123456789/59581/1/Pazukha_theoretical.pdf;jsessionid=2FAEA5FEB791DC4E594463E5F244F45C

5. Ray F. Egerton Physical Principles of Electron Microscopy. – USA: Springer. – 2005. – 211 p.
http://ndl.ethernet.edu.et/bitstream/123456789/ 76942/1/75.pdf

6. Basics of spintronics: materials, devices and devices / Yu. A. Kunytskyi, V.V. Kurylyuk, L.V. Odnodvorets, I.Yu. Protsenko. – Sumy: SSU, 2013. – 127 p. http://www.essuir.sumdu.edu.ua/ handle/ 123456789/31807.

7. Protsenko I.Yu., Chornous A.M., Protsenko S.I. Devices and methods of film materials research. – Sumy: SSU, 2007.–198 p.
http://essuir.sumdu.edu.ua/handle/123456789/1632.

8. Odnodvorets L.V., Pazukha I.M. Materials and components of functional electronics. – Sumy: SSU, 2020. – 196 p.
https://essuir.sumdu.edu.ua/bitstream-download/123456789/79527/1/Odnodvorets.pdf;jsessionid=FBCEDEF07028BB968B0D748D4208E284

Approved at a meeting of the admissions committee.

Protocol № 11 from 08.04.2024

Responsible secretary
admissions committee — Igor Roy

Head of the subject commission — Yurii Shkurdoda

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

Sumy State University

APPROVE
Head of the admissions committee

_____

_____ _____ 2024

EXAMINATION TASK
entrance exam during admission to study
for the degree of «Doctor of Philosophy»
from specialty 105 «Applied Physics and Nanomaterials»
Educational and scientific program – Applied physics and nanomaterials

Variant № 6

Task 1. Solid state physics.

1.1 Edge and screw dislocations. Choose the correct statement:

a) the axes of edge and screw dislocations have the same nature and structure;

b) a screw dislocation can be represented as the result of a lattice period shift of one part of the crystal in relation to the other;

c) the dislocation model of plastic deformation is based on the concept of dislocation slip

1.2 Statistics of a gas of quasiparticles: fermions. Choose the correct statement:

a) Fermi-Dirac distribution for electrons $f(\varepsilon)=\left(e^{\frac{\varepsilon-\varepsilon_\phi}{kT}}+1\right)^{-1}$

b) Fermi-Dirac distribution for electrons $f(\varepsilon)=\left(e^{\frac{\varepsilon-\varepsilon_\phi}{kT}}-1\right)^{-1}$

c) the value of the Fermi-Dirac distribution function at T = 300K is $f(\varepsilon)=\frac{1}{2}$

1.3 Ferromagnetism, molecular Weiss field, exchange interaction, ferromagnetic domains. Choose the correct statement:

a) the Weiss molecular field hypothesis made it possible to explain the nature of ferromagnetism;

b) since the molecular Weiss field has a relatively small value, only the hypothesis of exchange interaction between ferromagnetic atoms allows to correctly explain the nature of ferromagnetism;
c) ferromagnetic domains completely block the magnetization/remagnetization processes of ferromagnetic materials

Task 2. Physics of semiconductors. Choose the correct statement:

2.1 Thermal conductivity of semiconductors (SC). Choose the correct statement:
a) the main contribution to thermal conductivity in SC is made by non-degenerate electron gas and phonons, and thermal conductivity can occur during the movement of electrons in the impurity zone;
b) thermal conductivity occurs due to the transfer of heat by phonons;
c) in SC, as in metals, the main contribution to thermal conductivity is given by conduction electrons

2.2 Mechanisms of electron scattering in semiconductors (SC). Choose the correct statement:

a) those defects that form local energy levels have the greatest influence on the mobility of conduction electrons (scatter electrons);
b) electrons in SCs are scattered only by phonons;
c) electrons in SC are scattered only on Schottky and Frenkel defects

2.3 Electron-phonon collisions in semiconductors (SC). Choose the correct statement:
a) during electron-phonon interaction in SC, conduction electrons and holes interact with quanta of acoustic and optical vibrations of the crystal lattice;
b) during electron-phonon interaction in SC, electrons interact only with acoustic phonons;
c) during electron-phonon interaction in SC, electrons and holes interact only with optical phonons

Task 3. Functional electronics.

3.1 Classification of optoelectronic devices. Choose the correct statement.

a) the main groups of optoelectronic devices include the following: emitters (light-emitting diodes and lasers); radiation receivers (photoresistors, photodiodes, phototransistors, photothyristors); radiation control devices (modulators, deflectors); devices for displaying information (indicators); devices for optical isolation - (optocouplers); optical storage devices.
b) the main groups of optoelectronic devices include the following: emitters (light-emitting diodes and lasers); signal receivers (magnetoresistors, magnetodiodes, magnetotransistors); devices for displaying information (indicators); transistor logic.

c) the main groups of optoelectronic devices include the following: emitters (incandescent lamps, LED, lasers); signal receivers (semiconductor diodes and transistors); devices for displaying information (indicators and indicator panels); magneto-optical storage devices.

3.2 Magnetoelectronic devices: physical principles of operation. Choose the correct statement.

a) magnetoelectronics - a branch of electronics that is devoted to the theory and practice of creating devices based on magnetic phenomena (magnetization, remagnetization, demagnetization);
b) magnetoelectronics - a branch of electronics that is devoted to the theory and practice of creating devices based on the phenomena of electromagnetism and magnetic induction (magnetization, remagnetization, demagnetization of cores by pulsed or continuous current, EMF generation in a moving conductor under the influence of a magnetic field)
c) magnetoelectronics - a branch of electronics that is devoted to the theory and practice of developing magnetic materials for the construction of devices whose action is based on the phenomena of magnetization, remagnetization, and demagnetization.

3.3 Structural and technological parameters of fiber-optic communication lines. Choose the correct statement:

a) for the needs of fiber optic communication, the visible part of the optical spectrum in the wavelength range from 380 to 780 nm is used. The effect of total internal reflection is used in optical fibers made of quartz glass with the refractive index of the core n_1 lower than the refractive index of the shell n_2;
b) for the needs of fiber-optic communication, the visible part of the optical spectrum in the wavelength range from 380 to 780 nm is used. The effect of total internal reflection is used in optical fibers that are made of quartz glass with the refractive index of the core n_1 slightly greater than the refractive index of the shell n_2;
c) for the needs of fiber-optic communication, the invisible part of the optical spectrum in the wavelength range from 800 to 1625 nm is used. The effect of total internal reflection is used in optical fibers that are made of quartz glass with a refractive index of the core n_1 slightly greater than the refractive index of the shell n_2.

Task 4. Fundamentals of spintronics and nanomaterials and nanotechnology.

4.1 Physical characteristics of a giant magnetoresistance (GMR). Choose the correct statement.
a) the isotropicity of the GMR effect (independence from the measurement geometry) is a sufficient physical sign of the effect;

b) the isotropic effect of the GMR (independence from the measurement geometry) and the monotonous decrease in the resistance of the conductor as the induction of the external magnetic field increases are signs of the GMR effect;
c) the GMR effect is based on the interaction of delocalized conduction electrons with localized ones, provided that the difference in free path lengths of delocalized electrons with different spin directions in relation to the localized magnetic moment is very insignificant, i.e. $\lambda\uparrow \cong \lambda\downarrow$

4.2 Concepts of photonic crystals (PC). Choose the correct statement.
a) FC consist of quasi-one-dimensional air nanochannels;
b) the usual Doppler and Cherenkov effects and the law of refraction of light take place in FC;
c) photonic crystals are 2D – nanocomposites in which the dielectric constant changes periodically, resulting in high localization of light

4.3 Concepts of nanomembranes (NM) and nanowires (NW). Choose the correct statement.
a) NM is obtained by anodizing Al to the composition of corundum (Al_2O_3) or by bombarding a certain material with accelerated ions (so-called track membranes);
b) anodization both in the process of nucleation and growth is random;
c) NW can be formed only in corundum NM

Task 5. Nanomaterials and nanotechnologies. Choose the correct statement.

5.1 Fundamentals of qualitative microanalysis. Choose the correct statement:
a) materials related to diamond-like materials include nitrides, borides and carbides of Ti, Zr, W, Nb and other transition metals;
b) materials related to diamond-like materials, most often thermal conductivity occurs due to the transfer of heat by phonons;
c) only metal cathodes and the reactive medium $Ar+C_nH_m$ are used in the magnetron production of materials related to diamond-like materials

5.2 Crystal structure of materials related to diamond:
a) materials related to diamond-like materials have a crystal lattice similar to pure metal;
b) in most cases, the synthesis of diamond-like films is accompanied by the formation of nonstoichiometric or superstoichiometric MeN_x or MeC_yN_x compounds;
c) when deviating from stoichiometry in MeN_x compounds in a smaller direction ($x < 1$) leads to a decrease in resistance, as in the case of $x > 1$

5.3 Physical properties of photonic crystals (PC):
a) a characteristic property of FC is a strong interaction of light with a lattice of 1D elements, as a result of which an optical band structure with an optical band gap is formed;

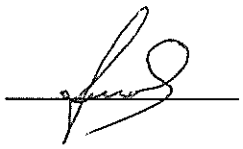
b) the forbidden optical zone is a frequency interval in which the propagation of electromagnetic waves is somewhat weakened;
c) in FC, the relative dielectric (ε) and magnetic (μ) permeability are always positive values

Task 6. Physics of measurements. Choose the correct statement.

6.1 Fundamentals of qualitative microanalysis. Qualitative microanalysis can be carried out using:
a) energy dispersive analyzer or crystal diffractometer;
b) method of three amendments;
c) method of a-coefficients

6.2 Features of microanalysis of films (coatings):
a) in the case of microanalysis of films or coatings that are on the substrate, the method of three corrections can be used;
b) in the case of microanalysis of films or coatings that are on the substrate, the relative sensitivity method of H. Cliff and H. Lorimer can be used;
c) the most effective method of analysis is modeling of possible trajectories of primary electrons using the Monte Carlo method

6.3 Principle of operation of the electronograph. Diffraction of fast electrons:
a) the electronograph is used in the fast electron diffraction mode when the thickness of the samples $d \leq 200$ nm and the size of the crystallites $L \leq 100$ nm;
b) an electronograph is an electron microscope that works in the mode of electron diffraction;
c) the diffraction angles of fast electrons 2Θ are up to 100°

Head of the subject commission  Yurii Shkurdoda

SUMY STATE UNIVERSITY Addition 2

Code _____

ANSWER SHEET

entrance exam during admission to study
for the degree of «Doctor of Philosophy»
from specialty 105 «Applied physics and nanomaterials»

Variant № ___

№ Task	№ Question	a	b	c	№ Question	a	b	c	№ Question	a	b	c
1	1.1	□	□	□	1.2	□	□	□	1.3	□	□	□

№ Task	№ Question	a	b	c	№ Question	a	b	c	№ Question	a	b	c
2	2.1	□	□	□	2.2	□	□	□	2.3	□	□	□

№ Task	№ Question	a	b	c	№ Question	a	b	c	№ Question	a	b	c
3	3.1	□	□	□	3.2	□	□	□	3.3	□	□	□

№ Task	№ Question	a	b	c	№ Question	a	b	c	№ Question	a	b	c
4	4.1	□	□	□	4.2	□	□	□	4.3	□	□	□

№ Task	№ Question	a	b	c	№ Question	a	b	c	№ Question	a	b	c
5	5.1	□	□	□	5.2	□	□	□	5.3	□	□	□

№ Task	№ Question	a	b	c	№ Question	a	b	c	№ Question	a	b	c
6	6.1	□	□	□	6.2	□	□	□	6.3	□	□	□

WARNING!!! TASKS HAVE SEVERAL ANSWER OPTIONS, AMONG WHICH ONLY ONE IS CORRECT. CHOOSE THE OPTION THAT YOU THINK IS CORRECT AND MARK IT AS SHOWN IN THE SAMPLE. **THE NUMBER OF CORRECTIONS AFFECTS THE OVERALL RATING OF THE WORK!**

a	b	c
x	□	□

Number of correct answers – _____; The number of points for them – _____;
Number of corrections – _____; Deduct points for corrections – _____;
Total points including withdrawals – _____

Head of the subject commission _____ (signature) _____ (name)

Members of the commission _____ (signature) _____ (name)

_____ (signature) _____ (name)