Approved at the Academic Council meeting
of the college of New Materials and Nanotechnologies
№ 8-25 from 23.10.2025

ENTRANCE EXAMINATION CONTENT

FOR THE MASTER'S DEGREE PROGRAM

CODE 22.04.01 Advanced Materials / Перспективные материалы

Moscow 2025

PROGRAM
admission test
«Materials Science and Technology»

Master's programs
«Advanced Materials»

I. Explanatory Note

The purpose of the entrance examination is to assess the candidate's knowledge of subject-specific academic and research materials and their compliance with the requirements for higher education in the "Advanced Materials" program for admission to master's programs.

The entrance examination is conducted through an interview using remote technology.

The entrance examination should not exceed 40 minutes.

The maximum score for the interview is 100. The interview primarily consists of questions related to the program content. If the answer is correct and complete, the applicant receives the maximum number of points; if the answer is incomplete or contains errors, the examination committee awards points proportional to the portion of the question answered correctly.

To be admitted, a candidate must score at least 40 points.

II. Examination Content Outline

1. Basic concepts of solid state physics. Electronic shells of atomic orbitals and types of chemical bonds in solids, strongest and weakest bonds, criteria of the bond strength. Amorphous and crystalline solids. Geometry of crystal lattices: symmetry of crystals, periodicity of crystal structures. The reciprocal lattice, lattice vibrations, phonons. Electron in a periodic field, the model of near-free electrons, tight binding approximation. Electric current in a Bloch state, concept of holes. Classification of materials. Anisotropy of solids.

2. Defects in the crystal structures. Point defects. The equilibrium concentration of point defects. Nonequilibrium defects and their origins. Linear defects. Dislocations, types of dislocations, parameters of the dislocations. The interaction of dislocations. The sources of dislocations. Stacking faults. Intraphase and interphase boundaries. Interaction of intrinsic defects with each other and impurity atoms. Neutral and electrically active defects, their influence on conductivity and mobility. Interaction between the dislocations. Internal phase boundaries and boundaries between phases. Types of impurities, their electrical activity.

3. The concept phase. The structure of the pure elements and solid solutions. Classification of solid solutions. Phase equilibrium in multicomponent systems. Gibbs phase rule. Chemical Equilibrium. Equilibrium constant for chemical reaction. Effect of pressure and temperature. Chemical potential. Phase transitions of type I and type II. The main types of phase diagrams of binary systems. Classification of phase transformations. Polymorphic transformation. Diffusion and martensitic transformations. Decomposition of supersaturated solid solutions. Chemical reaction rate. Dependence on concentration and temperature.

4. Crystallization. Thermodynamics and kinetics of crystallization. Homogeneous and heterogeneous nucleation of crystals in the melt. Mechanisms of crystal growth. Directional solidification. Epitaxial growth.

5. Diffusion. Phenomenological laws of diffusion. Self-diffusion and heterodiffusion. Atomic diffusion mechanisms. The role of vacancies, dislocations and grain boundaries. Diffusion in the concentration gradient. Effects of temperature and duration in the process of diffusion. Reactive diffusion.

6. Physical properties of solids. Methods of investigation of the physical properties of materials. Microscopic probe methods and materials research. Basic methods of X-ray analysis. Electron diffraction and neutron diffraction. The notion of spectroscopic methods of investigation.

7. The mechanical and physical properties of materials. Hardness and microhardness. Plasticity of Solids. Mechanical testing.

8. Normal metals and semiconductors.

9. Classical dc transport, specific heat of crystal lattice and electron system. The Boltzmann equation for electrons. Conductivity and thermoelectric phenomena. Neutral and ionized impurities. Electron-Electron scattering, scattering by lattice vibrations. Electron-Phonon interaction in semiconductors. Generation and recombination of nonequilibrium charge carriers. Kinetic equation of recombination. Life time, diffusion free length.

10. Electrodynamics of Metals. Skin effect. Cyclotron resonance. Time and spatial dispersion. Waves in a magnetic field.

11. Optical Properties of Semiconductors. Photon-material interaction. Intraband transitions. Excitons, excitonic states in semiconductors, interband light absorption. Photo conductance. Radiation recombination.

12. Methods for fabrication and modification of materials.Thermodynamics and kinetics of crystallization. Homogeneous and heterogeneous nucleation of crystals. Role of supercooling during the crystallization process. The mechanisms of crystal growth. Directional crystallization. The distribution coefficient of impurity during crystallization, crystallization cleaning material. Epitaxy. Mechanisms of growth of the epitaxial layer. Methods of growing bulk crystals of semiconductors and dielectrics, epitaxial layers and hetero-epitaxial multilayer heterostructures. The dependence of material properties on its composition and structure. Changing the properties by increasing temperature. Methods for controlling the properties of materials.

13. Nanocrystalline state and nanoparticles. Main types of materials in nanocrystalline state: structure, electron structure of nanocrystals, basics of physical-chemical theory of nanoparticle nucleation. Kinetic laws for modeling the processes of nanomaterial synthesis. Diffusion and kinetic processes of reactions of nanoparticle synthesis. Specifics of physical and chemical methods of obtaining nanoparticles. Kinetic rules for calculating the processes of nanoparticle synthesis. Determination of parameters of different stages for nanoparticle synthesis (quasi-equilibrium, diffusion, and kinetics).

14. Characterizations methods. Characterization methods of micro and nano scaled materials. Microscopic and probe characterization methods. X-ray diffraction in periodic structures. Evaluation of defect concentration.

III. Recommended Reading

1. William D. Callister, David G. Rethwisch. Fundamentals of Materials Science and Engineering: An Integrated Approach, 4th Edition. Wiley. 2012.
2. Ashby, M. F. and D. R. H. Jones, Engineering Materials 1, An Introduction to Their Properties and Applications, 3d edition, Elsevier, Oxford, 2005.
3. Ashby, M. F. and D. R. H. Jones, Engineering Materials 2, An Introduction to Microstructures, Processing and Design, 3d edition, Elsevier, Oxford, 2006.
4. ASM Handbook, Volume 9, Metallography and Microstructures. ASM International. 2004