Drohobych Ivan Franko State Pedagogical University

APPROVED
Vice-Rector for Scientific, Pedagogical Work and Informatization
__________ Voloodymyr HALYK
15 листопада 2023

SYLLABUS

NANOTECHNOLOGIES AND NANOMATERIALS

Field of Study: 10 Natural sciences
Progrmme Subject Area: 105 Applied physics and nanomaterials
Educational Programme Applied physics and nanomaterials
Discipline status: Obligatory
Faculty of Physics, Mathematics, Economics and Innovative Technologies
Department of Physics and Information Technologies
Language of instruction: English

Information on the Study of the Discipline

Mode of study	Year of study	Semester	Total scope of the discipline: hours/ECTS credits	Number of hours							Type of semester control	
				Auditory classes					Individual work	Term paper		
				Total	Lectures	Laboratory work	Practical classes	Seminars			Credit	Exam
Full-time	2	3	90/3	30	14	16	-	-	60	-	-	+
Part-time	2	4	90/3	8	4	4	-	-	82	-	-	+

The Sullabus is based of the Educational Programme and the Curriculum for the specialists of the third (Educational and Scientific) level of higher education (3 Credit)

Autor:
__________ **Ihor VIRT,** Doctor of Physical and Mathematics Sciences, Professor;

Approved by the guarantor of the Education Programme : __________ Ihor VIRT,
Doctor of Physical and Mathematics Sciences, Professor.

Approved at the meeting of the Departament of Physics and Information a Technologies
Protocol № 3 dated 26 10 2023.
Head of the Departament __________ Vitaly HOLSKYI

Approved at the meeting of the Scientific and Methodical Council of the Faculty of Physics, Mathematics, Economics and Innovative Technologies
Protocol № 3 dated 31 жовтня 2023.

Approved at the meeting of the Scientific and Methodical Council of the University
Protocol № 9 dated 14 листопада 2023.

1. THE PURPOSE OF STUDYING THE EDUCATIONAL DISCIPLINE

Purpose: training of specialists who have modern theoretical and applied knowledge in the field of nanophysics and nanoelectronics; acquisition of knowledge, skills and abilities about semiconductor materials, nanomaterials and nanostructures used in electronics, their main physical properties, methods of obtaining and research.

Subject: nanoscale physical phenomena, nanomaterials, nanoelements and nanodevices.

Tasks: analysis of physical problems of obtaining nanomaterials and nanodevices for the electronic industry; study of issues of modeling of technological processes, in particular nano-sized objects; gaining experience to effectively apply the acquired knowledge in the practical use of functional semiconductor materials and nanomaterials.

2. PREREQUISITES FOR STUDYING THE EDUCATIONAL DISCIPLINE

The educational discipline is taught after studying the disciplines "Higher Mathematics", "Physics", "Materials Science TCM", "Electrical Engineering and Electronics", "Fundamentals of Heat Engineering and Hydraulics", "Modern Materials Science in Engineering" and is the basis for studying the disciplines of the cycle of professional training of specialists of the third (educational and scientific) level of higher education.

3. EXPECTED LEARNING OUTCOMES

According to the educational programme, higher education applicants must

know: basic principles and regularities of solid-state electronics and optoelectronics; physical principles of operation of microelectronic devices and the connection of their parameters with structural features; technology of devices and materials used for their creation; the main technological processes of creating microstructures.

be able:

Integral competence: to solve complex problems in the field of professional, including research and innovation activities, which involves a deep rethinking of existing and the creation of new integral knowledge and professional practice.

General competences: to operate with scientific terminology and to build a hierarchy of scientific concepts according to the levels of their generalization; to navigate in the modern regulatory framework of education development, educational policy trends in Ukraine; to generalize innovative pedagogical experience in one's own scientific research; to prepare, plan, organize one's own scientific and pedagogical activities; to adequately apply scientific methods to fulfill the tasks of one's own research; to implement information and communication technologies to implement the scientific research plan; psychological readiness for scientific activity, development of scientific thinking; readiness for emotional self-regulation, development of willpower, self-organization and self-actualization; readiness for self-analysis of the results of scientific activity.

Professional competencis of the specialty: the ability to study and modernize existing industrial electronic technologies, understanding the processes of the innovation environment, the problems of modern electronics and nanoelectronics; the ability to introduce the known physical properties of the research object and the physico-chemical phenomena occurring in it into modern technological processes.

Program me learning outcomes: knowledge of physical laws and known facts to describe the qualitative physical interpretation of the results of experimental measurements; knowledge of regularities of researched phenomena and physical objects in the knowledge system of this field of applied physics, assessment of their scientific novelty; knowledge of modern methods of interpretation of raw data for the synthesis of new materials, in particular nano-sized products and technological processes; the ability to evaluate the mechanical, technological, physical properties, structure and phase composition of substances and materials being studied or obtained, in particular nano-sized) using modern technical means and methods; the ability to effectively use standard devices, equipment and materials for the analysis of researched objects; the ability to master operations of analysis, synthesis, comparison, comparison of physical and chemical phenomena and processes to solve various scientific and research tasks; the ability to apply scientific methods to perform the tasks of one's own research.

4. CRITERIA FOR ASSESSMENT OF LEARNING OUTCOMES

Assessment is carried out according to the scales: ECTS, 100-point and national.

Grade "A" (90 - 100 points) - "excellent" (*excellent knowledge and skills with only a small number of minor errors*): receives a student who demonstrates deep system knowledge of software material and productively uses it in solving practical problems; competently formulates the tasks facing the electronic industry in the modern world; freely conducts an analytical description of modern technologies for the production of materials for electronics; is able to explain the technology of obtaining nano-sized materials for electronics, substantiate the physico-chemical bases of the alloying process, determine the effect of impurities on the balance of their own defects, describe the physico-chemical bases of obtaining pure materials; clearly explains the processes that take place during adsorption, ion exchange, chromatography, extraction, distillation, rectification, crystallization methods of cleaning materials, physicochemical processes that take place when growing nanomaterials, heterostructures based on them and nanostructures; knows how to determine defects in epitaxial structures and methods of obtaining structures with a low content of defects; is able to determine the technological defects of the crystal structure introduced during the manufacture of electronic devices, to explain the structural and technological features of electronic devices; completed all types of educational work.

Grade "B" (82 - 89 points) - "good" (*above average with few errors*): is awarded to a student who shows good knowledge of the software material, tries to use it when solving practical problems independently, even though he makes minor mistakes; for the most part competently formulates the tasks facing the electronic industry in the modern world; freely conducts an analytical description of modern technologies for the production of materials and nanomaterials for electronics; which take place during adsorption, ion exchange, chromatography, extraction, distillation, rectification, crystallization methods of material purification, physicochemical processes which take place during the growth of nanomaterials, heterostructures based on them and nanostructures; knows how to determine defects in epitaxial structures and methods of obtaining structures with a low content of defects; basically knows how to determine the technological defects of the crystal structure introduced during the manufacture of electronic devices and to explain the structural and technological features of electronic devices; completed all types of educational work.

Grade "C" (75-81 points) - "good" (*in general, thorough system knowledge with a small number of significant errors*): is awarded to a student who shows mostly good knowledge of the software material, tries to use it when solving practical problems independently, although he makes a small number of significant mistakes; tries to formulate the tasks facing the electronic industry in the modern world and conduct an analytical description of modern technologies for the production of materials for electronics; is able to explain the technology of growing nano-sized materials for electronics; tries to substantiate the physico-chemical bases of the alloying process, to describe the physico-chemical bases of obtaining pure materials; mainly explains the processes that take place during adsorption, ion exchange, chromatography, extraction, distillation, rectification, crystallization methods of cleaning materials, physicochemical processes that take place when growing nanostructures, homo- and heterostructures, nanostructures; with the help of the teacher can determine the technological defects of the crystal structure introduced during the manufacture of electronic devices; tries to explain the structural and technological features of electronic devices; completed all types of educational work.

Grade "D" (67 - 74 points) - "satisfactory" (*not bad, but with a significant number of shortcomings*): is awarded for knowledge and understanding of the main program material; reproduces the material in a simplified form; can demonstrate the connection between individual theoretical regularities and solves simple applied problems; is able to formulate basic conclusions and make generalizations, but at the same time makes significant mistakes and inaccuracies; focuses on the technology of growing nano-sized materials for electronics, on the physico-chemical bases of the alloying process, obtaining pure materials, on the processes that take place during adsorption, ion exchange, chromatography, extraction, distillation, rectification, and crystallization methods of material purification; with significant difficulties tries to determine the technological defects of the crystal structure introduced during the manufacture of electronic devices and to explain the structural and technological features of electronic devices; completed all types of educational work.

Grade "E" (60 - 66 points) - "satisfactory" (*knowledge and skills meet the minimum criteria*): is awarded to an applicant whose knowledge and skills satisfy the minimum criteria according to the program; which can reproduce more than half of the educational material at the reproductive level with elements of logical connections; has elementary skills and abilities; can perform a simple applied task; is poorly oriented in the technology of growing nano-sized materials for electronics, in the physico-chemical bases of the alloying process, obtaining pure materials, in the processes that take place during adsorption, ion exchange, chromatography, extraction, distillation, rectification, crystallization methods of material purification, with significant difficulties tries explain structural and technological features of electronic; completed all types of educational work, but with significant shortcomings.

Grade "FX" (35 - 59 points) - "unsatisfactory" (*unsatisfactory knowledge with the possibility of retaking the exam*): the recipient receives for superficial knowledge and understanding of the main program material; inconsistent presentation of material with significant errors; does not know how to make generalizations and conclusions; does not know how to apply theoretical knowledge when solving applied problems; does not focus on modern technological processes of nanoelectronics; cannot explain the structural and technological features of electronic devices; did not complete all types of educational work.

Grade "F" (1-34 points) - "unsatisfactory" (*with a mandatory repeat course*): it is presented in the case when the acquirer possesses only separate concepts, fragmentary knowledge of the software material without any relationship between them; does not know how to apply theoretical knowledge when solving applied problems; does not focus on modern technological processes of nanoelectronics; cannot explain the structural and technological features of electronic devices; did not complete all types of educational work.

5. MEANS OF DIAGNOSIS OF LEARNING OUTCOMES

1) protection and performance of laboratory work;
2) final control work;
3) interview with the lecturer;
4) exam.

6. CONTENT OF EDUCATIONAL DISCIPLINE

1. Nanotechnologies for nanoelectronics.

1.1. The main trends in the development of nanoelectronics. Classification of nanoobjects. Low-dimensional structures, nanotechnology. Classification of nanomaterials is based on size. Different types of nanomaterials. Characteristics of nanomaterials.

1.2. Methods of creating nanoscale materials. Mechanisms of formation of nanoparticles. Manufacturing technologies of nanomaterials. Various methods of obtaining nanoparticles. Top-down and bottom-up nanotechnologies.

1.3. Obtaining quantum-sized layers, superlattices, quantum threads and quantum dots. Production of nano-sized particles of semiconductors and biological materials.

1.4. Technology of nanostructures. Liquid phase synthesis. Colloid methods. Sol-gel technique. Nanostructures with matrix insulation. Porous silicon technology.

1.5. Methods of controlling the parameters of nanosized materials and nanopowders.

2. Quantum mechanical phenomena in nanostructures.

2.1. Quantum confinement. Quantum film, quantum wire, quantum dot. Ballistic transport of charge carriers. Average free run length. The quantum of resistance.

2.2. Tunneling of charge carriers. Tunnel transparency coefficient. Effect of tunnel resonance. Coulomb Blockade. Electro-optical effects in quantum structures. Quantum Hall effect.

2.3. Spin effects. Spin-polarized materials. Elements of nanoscale structures. Free surface and boundaries of the interphase separation.

2.4. Superlattice. Strained and relaxed nanostructures. Simulation of quantum configurations.

3. Materials of nanoelectronics.

3.1. Materials of nanoelectronics. Fullerenes. Carbon nanotubes. Nanosized heterostructures. Graphene. Nanotechnology of creating functional elements.

3.2. Methods of molecular dynamics and molecular mechanics. Structures with quantum confinement due to the internal electric field. Quantum well. Anderson's rule.

3.3. Tools for measuring the parameters of nanostructures. Methods of studying nanostructures. Atomic force microscope.

4. Film deposition methods.

4.1. Methods of deposition of thin and ultrathin films. Molecular beam epitaxy. Methods of manufacturing nanostructures using scanning probes.

4.2. Deposition methods: PVD, CVD, PLD, MOCVD. Compounds III-V on silicon. Plasma spraying. Surface analysis.

4.3. Formation of modulation-doped quantum structures. Formation of delta-doped quantum structures. Metal–dielectric–semiconductor structures. Structures with a split shutter.

4.4. Atomic engineering. Parallel and perpendicular processes. electron beam lithography. Resist profiling with scanning probes. Nanoprinting Comparison of nanolithographic methods.

4.5. Self-managing processes. Self-regulation. Self-assembly in bulk materials. Nanocrystallites in inorganic and organic materials.

5. Nanoelectronic devices.

5.1. Nanoelectronic devices and devices. Production of electronic nanodevices and electronic nanoelements. Chip technology. Design of functional structures.

5.2. Modern structure of BJT. Modern MOSFET and FinFET technology. NEMS nanoelectromechanical systems.

5.3. Bipolar transistors on heterojunctions. Transistors on hot electrons.

5.4. Single-electron transistors and devices based on them. Transistors with resonant tunneling. Modulation-doped transistors.

6. Plasma and ion technologies in nanoelectronics.

6.1. Ion implantation. Physical basis of ion implantation. Ion implantation technology. Technological equipment for ion implantation.

6.2. Plasma etching technology of electronic structures. Physico-chemical basics of vacuum plasma etching. Classification of methods of plasma etching technology.

6.3. Electron beam and laser technologies. Basic devices for electron beam processing. Basic technological processes of electron beam processing in electronic engineering. The formation of radiation defects and their influence on the surface structure of materials.

7. Devices based on quantum wells.

7.1. Spintronic devices. Interference transistors.

7.2. Light sources based on quantum heterostructures. Light sources on quantum dots. Modulation devices based on quantum wells.

7.3. Quantum point cage automata and wireless electronic logic. Nanocomputers.

7.4. Engineering nanomaterials and nanocomposites. Classification of various types of composites. Structural composites. Nanoscale engineering. Magnetic nanoparticles. Magnetic micro/nano robots.

Approximate topics of laboratory works

1. Thermodynamic parameters of systems;
2. Characteristics and properties of molecules;
3. LeoMonteCrystal program;

4. Characteristics of nanoparticles (computer simulations);
5. Characteristics of the DNA molecule;
6. Study of quantum states in solids;
7. Tunneling processes and wave packets;
8. Properties of a translucent membrane.

7. TASKS FOR INDEPENDENT WORK

The student's independent work in the discipline involves studying theoretical material in preparation for laboratory classes, writing a test paper, an interview with a lecturer and a semester exam.

Approximate topics of independent work

1. Describe the methods of growing nanoscale materials, films and heterostructures;
2. Provide an analysis of the main methods of researching the structural properties of nanoscale materials and heterostructures;
3. Find out the technology of obtaining epitaxial layers of a high degree of purity, homo- and heterostructures with given;
4. Describe the technology of ion-plasma and plasma-chemical production of nanomaterials;
5. Describe the growth mechanisms of graphene films and graphene-like materials;
6. Determine the main technological processes in the manufacture of nanoelectronics devices.

8. FORMS OF CURRENT AND FINAL CONTROL

Current control of knowledge is carried out in laboratory classes, control work and an interview with a lecturer.

Performing laboratory work involves theoretical preparation for work (working on theoretical material), the ability to analyze the researched processes and explain their physical essence, the structure and operation of the researched objects; writing a report for laboratory work, quality design of the report; defense of the report (interview with the teacher). Each laboratory work is valued at 10 points - 5 points for admission and 5 points for drawing up a report and defense. The student must make up the missed laboratory session within the set time.

The test is performed in a written form and is valued at 20 points.

The interview with the lecturer is held in the second half of the semester on the topics of the material covered according to the pre-announced schedule.

Final control is conducted in the form of a written exam. Examination tickets contain two theoretical questions and two practical tasks.

The generalized number of points in the discipline is defined as the total score of the current performance with a weighting factor of 0.6 and grades for the exam in a 100-point scale with a weighting factor of 0.4. The assessment of the discipline is given according to the assessment scales: 100 point, national and ECTS.

Distribution of 100 points between types of works:

CURRENT PERFORMANCE			SUM OF POINTS	EXAMINATION
Performing laboratory work	Final control work	Interview with the lecturer	$S_{current}$	S_{final}
60 (6×10)	20	20	100	100
Weight factor			0,6	0,4
				$S_{summary} = 0,6 \cdot S_{current} + 0,4 \cdot S_{final}$.

9. TOOLS, EQUIPMENT, SOFTWARE

Multimedia presentations in Microsoft PowerPoint, posters, and demonstration samples are used in lectures. In laboratory classes, students acquire skills in research work and practical application of theoretical knowledge. The performance of laboratory work requires the presence of a laboratory equipped with specialized laboratory equipment and the necessary measuring 1 control instrument. Consumables - specially prepared samples are provided for conducting research in laboratory classes. Excel, MatLab, GNU-Octave, Mathcad software are used for calculations, data processing, and diagram construction.

10. RECOMMENDED SOURCES OF INFORMATION

a) main

1. Springer Handbook of Electronic and Photonic Materials.– Edited S. Kasap, P. Capper, Springer. – 2017. – 898p.
2. Nano-Semiconductors Devices and Technology.– Edited K. Iniewski.– CRC Press.– 2017. – 599 p.
3. Mitin V.V., Kochelap V.A., Stroscio M.A. Introduction to Nanoelectronics: Science, Nanotechnology, Engineering, and Applications.– Cambridge University Press.– 2008. – 347p.
4. Ramsden J.J. Nanotechnology: An Introduction, Elsevier, Amsterdam. – 2011. – 344 p.
5. Kang Y.H. Semiconductor Technologies in the Era of Electronics.– Springer, New York London.– 2014. – 156p.
6. Zant P.V. Microchip Fabrication, A Practical Guide to Semiconductor Processing.– McGraw-Hill.– 2014. – 979 p.
7. Balasinski A. Semiconductors : integrated circuit design for manufacturability.– CRC Press.– 2012. – 236p.

b) additional

1. Freund L.B., Suresh S. Thin film materials: stress, defect formation and surface evolution.– Cambridge University Press.– 2003. – 820 p.
2. Yoo C.S. Semiconductor Manufacturing Technology.– World Scientific Publishing.– 2008. – 484p.
3. Majumder M.K., Kumbhare V.R., Japa A., Kaushik B.K. Introduction to Microelectronics to Nanoelectronics.– Taylor & Francis Group, CRC Press.– 2020. – 328p.
4. Comprehensive Nanoscience and Technology.– Edited D. Andrews Cambridge, MA: Academic Press. – 2010. – 169 p.
5. Anantram M.P. and Leonard F. Physics of carbon nanotube electronic devices//Rep. Prog. Phys. 69. – 2006. – p. 507–561.
6. Осадчук В.С. Фізична наноелектроніка : навчальний посібник / Осадчук В.С., Осадчук О.В. – Вінниця: ВНТУ. – 2015. – 146 с.
7. Наноелектроніка. За ред. З. Ю. Готри. – Львів: Ліга-прес. – 2009. –342 с.
8. Заячук Д.М. Нанотехнології і наноструктури. – Львів: Львів. політехніка.– 2009. – 581с.

c) information resources

1. https://medium.com/tag/nanophysics
2. https://www.nanotechetc.com/nanotechnology-nanomaterials-and-the-purple-mattress/
3. https://www.niehs.nih.gov/health/topics/agents/sya-nano/index.cfm
4. https://www.britannica.com/technology/nanotechnology/Overview-of-nanotechnology
5. http://www.differencebetween.net/technology/difference-between-nanotechnology-and-nanoscience/
6. https://www.scientificworldinfo.com/2020/01/nanotechnology-in-electronics-and-communication.html
7. https://ehs.utexas.edu/working-safely/chemical-safety/nanomaterials
8. https://lotusarise.com/nanotechnology-upsc/
9. https://www.intechopen.com/subjects/17