Federal State Autonomous Educational Institution of Higher Education "Moscow Institute of Physics and Technology (National Research University)"

APPROVED
Head of Landau Phystech-School of Physics & Research
A.V. Rogachev

Work program of the course (training module)

course:	Nanomaterials Analysis and Research/Физические методы исследований наноматериалов
major:	Photonics and Optical Informatics
specialization:	Photonics, Quantum Technologies & 2D Materials/Фотоника, квантовые технологии и двумерные материалы
	Landau Phystech-School of Physics & Research
	Chair of Physics and Technology of nanostructures
term:	1
qualification:	Master

Semesters, forms of interim assessment:

1 (fall) - Grading test
2 (spring) - Exam

Academic hours: 60 AH in total, including:
lectures: 30 AH.
seminars: 0 AH.
laboratory practical: 30 AH.

Independent work: 45 AH.

Exam preparation: 30 AH.

In total: 135 AH, credits in total: 3

Authors of the program:

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The program was discussed at the Chair of Physics and Technology of nanostructures 01.02.2021

Annotation

The course of lectures "Nanomaterials Analysis and Research" is oriented to graduate students with basic training in physics and mathematics. The course provides an introduction to modern research methods for various nanomaterials and nanostructures, including two-dimensional materials, carbon nanotubes, quantum dots, van der Waals heterostructures, metasurfaces and metamaterials and other artificial nanomaterials. Among the methods considered in the lecture course are: optical microscopy, spectrophotometry, reflectometry, optical spectroscopy including terahertz, spectral ellipsometry, Raman and giant Raman scattering, scanning near-field optical microscopy, surface plasmon resonance spectroscopy, atomic force microscopy, scanning tunneling microscopy, scanning and transmission electron microscopy, as well as X-ray diffractometry, electrophysical measurements and a number of other experimental techniques. The course will also cover effective methods of numerical analysis of nanomaterials and nanostructures. Lectures are accompanied by laboratory sessions to reinforce practical skills in experimental characterization of nanomaterials and nanostructures.

1. Study objective

Purpose of the course

Training of the students on the experimental methods of researching natural and artificial nanomaterials, including materials such as graphene, other two-dimensional materials, carbon nanotubes, perovskites, as well as various metamaterials. Experimental techniques under study include optical research methods (optical microscopy, spectrophotometry, reflectometry, spectroscopy, including terahertz spectroscopy, spectral ellipsometry, Raman spectroscopy, Surface-enhanced Raman spectroscopy (SERS), scanning near-field optical microscopy, surface resonance spectroscopy and other plasmonic methods), atomic force microscopy, scanning tunneling microscopy, scanning and transmission electron microscopy, as well as X-ray diffractometry, electrophysical measurements and a number of other experimental techniques.

Students will receive basic skills in working with complex scientific equipment and will complete a series of practical exercises on educational experimental stands. It is planned to master the culture of modern experiment, as well as safety precautions when working with optical radiation and careful handling of optical equipment and other high-tech equipment. The consolidation of the lecture course materials is carried out within the framework of a laboratory workshop. All laboratory work is accompanied by lectures, where theoretical and practical aspects of equipment operation and measurements are considered. Within the framework of the lecture course and laboratory workshop, the features of the manufacture of nanostructures and the technique of working with two-dimensional materials (synthesis of materials - exfoliation and chemical vapor deposition, fabrication of nanostructures, including using optical and electron lithography), as well as measuring the main parameters of nanomaterials will be studied by various physical methods. When performing laboratory work, students will learn how to correctly formulate the results of experiments, their subsequent processing, as well as present the results for evaluation by the teacher. The tasks solved within the framework of the lecture course and laboratory workshop can be further adapted to study the properties of new nanostructures and nanomaterials for research activities of students. The laboratory work of the workshop will allow students to develop the skills of experimental work, which in the future will allow them to prepare for the implementation of research projects in scientific laboratories. The course is aimed at developing creative skills for setting promising scientific problems.

Tasks of the course

Study of the theoretical and practical foundations of various physical methods for investigating nanomaterials: optical microscopy, spectrophotometry, reflectometry, spectroscopy, including terahertz spectroscopy, spectral ellipsometry, Raman scattering and Surface-enhanced Raman spectroscopy, scanning near-field optical microscopy, surface plasmon resonance spectroscopy, atomic force scanning tunneling microscopy, scanning and transmission electron microscopy, X-ray diffractometry, electrophysical measurements and a number of other experimental techniques.

Experience in the characterization of nanomaterials, practice and study of the culture of working with nanomaterials. Study of safety precautions for working with nanomaterials.

Synthesis and manufacture of nanomaterials. Working with 2D materials - exfoliation and chemical vapor deposition. Transfer of nanomaterials to various substrates.

Determination of the most effective research methods for given nanomaterials and nanostructures.

2. List of the planned results of the course (training module), correlated with the planned results of the mastering the educational program

Mastering the discipline is aimed at the formation of the following competencies:

Code and the name of the competence	Competency indicators
Gen.Pro.C-1 Gain fundamental scientific knowledge in the field of physical and mathematical sciences	Gen.Pro.C-1.1 Apply fundamental scientific knowledge in the field of physical and mathematical sciences
	Gen.Pro.C-1.2 Able to summarise and critically evaluate experiences and research results in the field of photonics and opto-informatics
	Gen.Pro.C-1.3 Understands the interdisciplinary links in mathematics and physics and is able to apply them to problems in photonics and opto-informatics
Gen.Pro.C-2 Acquire an understanding of current scientific and technological challenges in professional settings, and scientifically formulate professional objectives	Gen.Pro.C-2.3 Understand professional terminology used in modern scientific and technical literature and present scientific results in oral and written form within professional communication
Gen.Pro.C-3 Select and/or develop approaches to professional problem-solving with consideration to the limitations and specifics of different solution methods	Gen.Pro.C-3.1 Analyze problems, plan research strategy to achieve solution(s), propose, and combine solution approaches
	Gen.Pro.C-3.2 Employ research methods to solve new problems, and apply knowledge from various fields of science (technology)
	Gen.Pro.C-3.3 Gain knowledge of analytical and computational methods of problem-solving, understand the limitations for applying the obtained solutions in practice
Gen.Pro.C-4 Successfully perform a task, analyze the results and present conclusions, apply knowledge and skills in the field of physical and mathematical sciences and ICTs	Gen.Pro.C-4.1 Apply ICT knowledge and skills to find and study scientific literature and use software products
	Gen.Pro.C-4.2 Apply knowledge in the field of physical and mathematical sciences to solve problems, make conclusions, and evaluate the obtained results
	Gen.Pro.C-4.3 Justify the chosen method of scientific research
Pro.C-1 Assign, formalize, and solve tasks, develop and research mathematical models of the studied phenomena and processes, systematically analyze scientific problems and obtain new scientific results	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within a selected subject field
	Pro.C-1.2 Make hypotheses, build mathematical models of the studied phenomena and processes, evaluate the quality of the developed model
	Pro.C-1.3 Able to apply theoretical and/or experimental research methods in photonics and opto-informatics to a specific scientific problem and interpret the results obtained
Pro.C-2 Organize and conduct scientific research and testing independently or as a member (leader) of a small research team	Pro.C-2.1 Able to plan and carry out research in photonics and opto-informatics independently or as part of a research team
	Pro.C-2.2 Conduct tests of research results through scientific publications and participation in conferences
Pro.C-3 Professionally use research and testing equipment (devices and installations, specialized software) in a selected subject field	Pro.C-3.1 Understand the operating principles of the equipment and specialized software
	Pro.C-3.2 Conduct an experiment (simulation), using research equipment (software)
	Pro.C-3.3 Evaluate the accuracy of the experimental (numerical) results

3. List of the planned results of the course (training module)

As a result of studying the course the student should:

know:

- basic principles of spectroscopy and spectrophotometry
- basic principles of spectral ellipsometry
- basic principles of far-field optical microscopy
- basic principles of atomic force microscopy
- the basic principles of scanning tunneling microscopy
- basic principles of scanning near-field optical microscopy
- basic principles of Raman and Surface-enhanced Raman spectroscopy
- basic principles of surface plasmon resonance spectroscopy
- basic principles of scanning electron microscopy
- basic principles of transmission electron microscopy
- basic principles of terahertz spectroscopy
- basic principles of optical reflectometry
- basic principles of X-ray diffractometry
- basic principles of laser nanopolymerization (or two-photon polymerization)
- basic principles of photoluminescence microscopy
-basic principles of making samples (deposition of metal films, optical lithography (photolithography))
- the main objects and phenomena, the study of which is possible by optical methods
- safety precautions and rules for working with scientific equipment

be able to:

- work with a spectrophotometer
- work with an ellipsometer
- work with an atomic force microscope
- work with a scanning tunneling microscope
- work with a scanning near-field optical microscope
- work with a scanning Raman microscope
- work with a scanning electron microscope
- work with a photoluminescent microscope
- work with transmission electron microscopy
- work with a scanning electron microscope
- work with chemical solutions, determine the chemical composition of solutions.
- work with van der Waals materials. Determine the composition, properties, quality, and number of layers.
- to plan an experiment to solve a scientific problem using optical methods.
- collect, process and present the results of the experiment, taking into account possible errors and inaccuracies

master:

- methods of analysis and processing of experimental data.
-Skills in the presentation of experimental data.
- the skills of characterizing the manufactured samples using atomic force microscopy, scanning and transmission electron microscopy.
-the skills of solving scientific problems by experimental optical methods (Raman spectroscopy, Surface-enhanced Raman spectroscopy, spectrophotometry, near-field microscopy, ellipsometry, photoluminescence microscopy)

4. Content of the course (training module), structured by topics (sections), indicating the number of allocated academic hours and types of training sessions

4.1. The sections of the course (training module) and the complexity of the types of training sessions

№	Topic (section) of the course	Types of training sessions, including independent work			
		Lectures	Seminars	Laboratory practical	Independent work
1	Artificial nanomaterials. Manufacturing technologies	1		1	1
2	Natural nanomaterials. Synthesis and manufacturing technologies	1		1	1

3	Review of physical methods for studying nanomaterials	1		1	1
4	Optical properties of nanomaterials	1		1	1
5	Optical microscopy	1		1	1
6	Spectroscopy and spectrophotometry	1		1	1
7	Terahertz spectroscopy	1		1	1
8	Raman spectroscopy	1		1	1
9	Surface-enhanced Raman spectroscopy	1		1	1
10	Surface plasmon resonance spectroscopy	1		1	1
11	Spectral ellipsometry	1		1	1
12	Spectral ellipsometry of anisotropic materials	1		1	1
13	Scanning near-field optical microscopy (aperture)	1		1	1
14	Scanning near-field optical microscopy (apertureless)	1		1	1
15	Electrophysical methods for the study of nanomaterials	1		1	1
16	Atomic force microscopy	1		1	2
17	Scanning tunnel microscopy	1		1	2
18	Scanning electron microscopy	1		1	2
19	Transmission electron microscopy	1		1	2
20	Optical lithography (photolithography)	1		1	2
21	Electronic lithography	1		1	2
22	X-ray diffractometry	1		1	2
23	Laser nanopolymerization (or two-photon polymerization)	1		1	2
24	Photoluminescence microscopy	1		1	2
25	Raman spectroscopy of two-dimensional materials	1		1	2
26	Spectral ellipsometry of two-dimensional materials	1		1	2
27	Optical reflectometry	1		1	2
28	Far-field optical microscopy	1		1	2
29	Van der Waals materials	1		1	2
30	Review of synthesis technologies and research methods for nanomaterials	1		1	2
AH in total		30		30	45
Exam preparation		30 AH.			
Total complexity		135 AH., credits in total 3			

4.2. Content of the course (training module), structured by topics (sections)

Semester: 1 (Fall)

1. Artificial nanomaterials. Manufacturing technologies

Metamaterials, metasurfaces, photonic crystals. Hyperbolic metamaterials. Van der Waals heterostructures. Methods for the manufacture of artificial nanomaterials. Methods for the characterization of artificial nanomaterials.

2. Natural nanomaterials. Synthesis and manufacturing technologies

Graphene. Two-dimensional materials. Exfoliation of 2D materials. Synthesis methods using ultrasound and chemical vapor deposition. Transfer of nanomaterials to various substrates.

3. Review of physical methods for studying nanomaterials

Optical and electrophysical methods for studying nanomaterials. A review of methods of optical spectroscopy, atomic force, scanning tunneling, scanning electron and transmission electron microscopy.

4. Optical properties of nanomaterials

Optical properties of bulk substance. Classical theories of optical constants. Lorentz model. Multi-oscillator model. Model of anisotropic oscillators. Drude's model. Optical characteristics of the substance. Optical properties of particles. Extinction, absorption, scattering.

5. Optical microscopy

Modern microscopic technology. Confocal laser scanning microscopy. Multiphoton confocal microscopy. Quantitative fluorescence microscopy. Superresolution methods. Special optical methods.

6. Spectroscopy and spectrophotometry

Optical spectroscopy. Spectral analysis. Spectroscopic methods. Photocolorimetry. Spectrophotometry. Photoluminescence spectroscopy.

7. Terahertz spectroscopy

Continuous terahertz spectroscopy on backward-wave lamps (BWT). Time-resolved pulsed terahertz spectroscopy. Fourier transform infrared spectroscopy.

8. Raman spectroscopy

Raman spectroscopy (Raman effect). Classical theory. Quantum theory. Empirical laws of Raman spectroscopy. Stimulated Raman Scattering. Raman spectroscopy techniques. The structure of the Raman spectrometer. Getting skills in working with a Raman spectrometer.

9. Surface-enhanced Raman spectroscopy

Surface-enhanced Raman spectroscopy (SERS). Experimental techniques for obtaining spectra of SERS. Main characteristics and mechanisms of the effect of SERS. Application of SERS to the study of biological molecules. Possibilities and prospects for the development of the SERS method.

10. Surface plasmon resonance spectroscopy

Surface electromagnetic waves. Surface plasmon resonance. Surface plasmon resonance spectroscopy. Sensitivity methods. Limitations of the method. Compact circuits. Biosensors based on surface plasmon resonance spectroscopy.

11. Spectral ellipsometry

Light polarization. An introduction to spectral ellipsometry. Measurement scheme. Receiving data. Data analysis. Measurement of spectra of optical constants of materials, including thin films. Study of the structural properties of thin films and interphase boundaries. Determination of thicknesses and physical characteristics of multilayer structures.

12. Spectral ellipsometry of anisotropic materials

An introduction to spectral ellipsometry of anisotropic materials. Muller Matrix. Measurement of the spectra of optical constants of anisotropic materials. Analysis of the spectra of optical constants of anisotropic materials.

13. Scanning near-field optical microscopy (aperture)

Diffraction limit. Introduction to scanning near-field optical microscopy. Resolution of scanning near-field optical microscopy. Schematic diagrams of scanning near-field optical microscopy. Practical measurements. Solution of applied problems.

14. Scanning near-field optical microscopy (apertureless)

Introduction to scattering scanning near-field optical microscopy. Resolution of scattering scanning near-field optical microscopy. Scheme. Practical measurements. Applied tasks. Plasmons in two-dimensional materials.

15. Electrophysical methods for the study of nanomaterials

Resistivity measurement methods. Four-probe method for measuring resistivity. Specific resistance and specific surface resistance. Measurement of surface resistance of relatively thin semiconductor wafers and thin conductive (semiconductor and metallic) layers isolated from conductive substrates. Two-layer structures. Self-compensation method for geometric effects. Modern installations for measuring surface resistance.

Semester: 2 (Spring)

16. Atomic force microscopy

Principle of operation. Construction of an atomic force microscope. Features of work. Processing of the received information and restoration of the received images. Current state and development of scanning probe microscopy. Practical measurements. Thickness of 2D materials. Roughness of thin metal films.

17. Scanning tunnel microscopy

Principle of operation. Construction of a scanning tunneling microscope. Features of work. Processing of the received information and restoration of the received images. Current state and development of scanning tunneling microscopy. Practical measurements.

18. Scanning electron microscopy

Principle of operation. Construction and main components of a scanning electron microscope. Features of work. Processing of the received information and restoration of the received images. Practical measurements. Surface morphology of ultrathin metal films.

19. Transmission electron microscopy

Principle of operation. Design and main components of a transmission electron microscope. Features of work. Processing of the received information and restoration of the received images. Practical measurements. Transmission electron microscopy of two-dimensional materials.

20. Optical lithography (photolithography)

Principle of operation. Photolithography process. Photopolymers. Manufacturing of microstructures. Cleaning and surface preparation. Photoresist application. Exposure. Manifestation. Surface treatment.

21. Electronic lithography

Principle of operation. Electronic lithography process. Resolution in electronic lithography. Principles of writing a drawing on a sample. Systems for electronic lithography. Writing drawings on a sample.

22. X-ray diffractometry

Theoretical foundations of the method. X-ray structural analysis. X-ray diffractometric method. Phase identification and quantification (phase analysis). Practical measurements for thin metal films.

23. Laser nanopolymerization (or two-photon polymerization)

Theoretical foundations of the method. Two-photon polymerization. Polymers. Manufacturing of two-dimensional and three-dimensional structures. Resolution in typical laser nanopolymerization experiments.

24. Photoluminescence microscopy

Photoluminescence microscopy at room temperature and mapping. Photoluminescence absorption microscopy at room temperature. Low-temperature photoluminescence microscopy.

25. Raman spectroscopy of two-dimensional materials

Raman spectroscopy technique for two-dimensional materials: graphene and transition metal dichalcogenides. Practical measurements and processing of spectra.

26. Spectral ellipsometry of two-dimensional materials

Effective spectral ellipsometry models for the analysis of the optical properties of two-dimensional materials: graphene and transition metal dichalcogenides. Practical measurements and extraction of optical constants.

27. Optical reflectometry

Theoretical foundations of the method. Models for analysis. Modeling. Practical measurements for thin and ultra-thin metal films.

28. Far-field optical microscopy

Scattering of nanoparticles. Dark-field microscopy. Method resolution. Applications. Hybrid nanostructures. Practical measurements.

29. Van der Waals materials

Physics of van der Waals materials. Assembly of van der Waals heterostructures. Methods for studying van der Waals heterostructures. Two-layer structures and moire.

30. Review of synthesis technologies and research methods for nanomaterials

Analysis of synthesis technologies and research methods for nanomaterials. Theoretical and practical foundations.

5. Description of the material and technical facilities that are necessary for the implementation of the educational process of the course (training module)

Lectures: a set of electronic presentations / slides; auditorium equipped with presentation equipment (projector, screen, computer / laptop); special technical means for trainees and persons with disabilities.

1. Confocal scanning Raman microscope Horiba JY LabRAM HR Evolution.
2 Near-field optical microscope Neaspec NeaSNOM with visualization modules and spectroscopy (working range 0.4 - 20 microns).
3. Spectroscopic ellipsometer (240-930 nm) SENTECH SE 800E with reflectometric probe FTPadvance.
4. Spectroscopic ellipsometer (250-3200 nm) Woollam VASE.
5. Biosensor based on surface plasmon resonance BiOptix 104sa.
6. Spectrophotometer (175-3300 nm) Agilent Technologies Cary 5000 UV-Vis-NIR.
7. Laboratory polarizing microscope Carl Zeiss Axio Scope.A1.
8. Spectrometer of IR range (900-2550 nm) Ocean Optics NIRQuest256-2.5,
9. Fourier spectrometer (900-2600 nm) Ocean Optics ANIR-900-2600, St.
10. Spectrometer (200-950 nm) Ocean Optics QE65000, St.
11. Compact spectrometers (350-700 nm) Thorlabs CCS100.
12. Vacuum infrared Fourier spectrometer BRUKER VERTEX 80V with a microscope HYPERION 2000.
13. Terahertz spectrometer, including the visualization (imaging) system Menlo Systems TERA K15 - All-
Fiberd THz Spectrometer and TeraLyzer Single THz software.
14. Installation of electron beam deposition in high vacuum NanoMaster Dual-E-beam evaporation system NEE-
4000.
15. System for applying solutions centrifugation Single-wire processor Laurell WS-650Mz-23NPP.
16. Plasma cleaning unit for samples Femto (Diener Electronic GmbH).
17. Installation for laser 3D lithography (Nanoscribe Photonic Professional).
18, Sets of modern optics (including fiber optics) and high-precision optomechanics from Thorlabs and Newport.

6. List of the main and additional literature, that is necessary for the course (training module) mastering

Main literature

1. Физическая оптика [Текст] : учебник для вузов / С. А. Ахманов, С. Ю. Никитин .— М : Изд-во МГУ, 2004 .— 656 с.

2. Основы нанооптики [Текст] / Л. Новотный, Б. Хехт ; пер. с англ. А. А. Коновко, О. А. Шутовой ; под ред. В. В. Самарцева - М.Физматлит,2009, 2011

3. Наноплазмоника и метаматериалы [Текст] : учеб. пособие для вузов / В. А. Астапенко ; М-во образования и науки Рос. Федерации, Моск. физ.-техн. ин-т (гос. ун-т .— М. : МФТИ, 2011 .— 180 с.

4. Оптика и фотоника. Принципы и применения [Электронный ресурс]. В 2 т. Т. 1, учеб. пособие / Б. Салех, М. Тейх . — Долгопрудный, Интеллект, 2012.— URL: http://books.mipt.ru/book/301340 (дата обращения: 22.12.2020). - Полный текст (Режим доступа : из сети МФТИ / Удаленный доступ)

5. Оптика и фотоника. Принципы и применения [Электронный ресурс]. В 2 т. Т. 2, учеб. пособие / Б. Салех, М. Тейх . — Долгопрудный, Интеллект, 2012.— URL: http://books.mipt.ru/book/301342 (дата обращения: 22.12.2020). - Полный текст (Режим доступа : из сети МФТИ / Удаленный доступ)

Additional literature

1. Наноплазмоника [Текст]/В. В. Климов, -М., Физматлит, 2010

2. Квантовая наноплазмоника [Текст] : [учебное пособие] / Е. С. Андрианов [и др.] .— Долгопрудный : Изд. дом "Интеллект", 2015 .— 368 с.

3. Квазичастицы в физике конденсированного состояния [Электронный ресурс] / Н. Б. Брандт, В. А. Кульбачинский. — М., Физматлит, 2010.— URL: https://e.lanbook.com/book/59598 (дата обращения: 21.01.2021). - Полный текст (Режим доступа : из сети МФТИ / Удаленный доступ)

4. Основы оптики [Текст] : [учеб. пособие для вузов] / М. Борн, Э. Вольф ; пер. с англ. С. Н. Бреуса, А. И. Головашкина, А. А. Шубина ; под ред. Г. П. Мотулевич .— М. : Наука, 1970 .— 855 с.
Literature fund of the basic departament:
5. Б. А. Колесов, «Прикладная КР-спектроскопия», Москва, РАН, (2018)
6. С. П. Кэри, «Применения спектроскопии КР и РКР в биохимии», Москва, Мир, (1985)

7. List of web resources that are necessary for the course (training module) mastering

https://mipt.ru/education/chairs/physics_and_technology_of_nanostructures/study.php

8. List of information technologies used for implementation of the educational process, including a list of software and information reference systems (if necessary)

When preparing and conducting lectures, the Internet is used.
In addition, Libre Office is used, as well as the Ink Scape graphics package.

9. Guidelines for students to master the course

A student studying the discipline must, on the one hand, master the general conceptual apparatus, and on the other hand, must learn to apply theoretical knowledge in practice.
As a result of studying the discipline, the student must know the basic definitions and concepts, be able to apply the knowledge gained to solve various problems.
Successful completion of the course requires:
- attendance of all classes provided for by the curriculum for the discipline;
- keeping a synopsis of classes;
- student's intense independent work.

Independent work includes:
- reading recommended literature;
- study of educational material, preparation of answers to questions intended for independent study;
- solving problems offered to students in the classroom;
- preparation for the performance of tasks of the intermediate certification.

An indicator of mastery of the material is the ability to answer questions on the topics of the discipline without a synopsis.
It is important to achieve an understanding of the material being studied, not its mechanical memorization. If a student finds it difficult to study certain topics, questions, he/she should seek advice from a teacher.
Intermediate control of students' knowledge is possible in the form of solving problems in accordance with the topic of classes.

SUPPLEMENT

Assessment funds for course (training module)

major:	Photonics and Optical Informatics
specialization:	Photonics, Quantum Technologies & 2D Materials/Фотоника, квантовые технологии и двумерные материалы
	Landau Phystech-School of Physics & Research
	Chair of Physics and Technology of nanostructures
term:	1
qualification:	Master

Semesters, forms of interim assessment:

1 (fall) - Grading test

2 (spring) - Exam

Authors:

V. Volkov, phd (candidate of physics and mathematical sciences)

S. Novikov, candidate of physics and mathematical sciences

G.I. Tselikov, candidate of physics and mathematical sciences

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
Gen.Pro.C-1 Gain fundamental scientific knowledge in the field of physical and mathematical sciences	Gen.Pro.C-1.1 Apply fundamental scientific knowledge in the field of physical and mathematical sciences
	Gen.Pro.C-1.2 Able to summarise and critically evaluate experiences and research results in the field of photonics and opto-informatics
	Gen.Pro.C-1.3 Understands the interdisciplinary links in mathematics and physics and is able to apply them to problems in photonics and opto-informatics
Gen.Pro.C-2 Acquire an understanding of current scientific and technological challenges in professional settings, and scientifically formulate professional objectives	Gen.Pro.C-2.3 Understand professional terminology used in modern scientific and technical literature and present scientific results in oral and written form within professional communication
Gen.Pro.C-3 Select and/or develop approaches to professional problem-solving with consideration to the limitations and specifics of different solution methods	Gen.Pro.C-3.1 Analyze problems, plan research strategy to achieve solution(s), propose, and combine solution approaches
	Gen.Pro.C-3.2 Employ research methods to solve new problems, and apply knowledge from various fields of science (technology)
	Gen.Pro.C-3.3 Gain knowledge of analytical and computational methods of problem-solving, understand the limitations for applying the obtained solutions in practice
Gen.Pro.C-4 Successfully perform a task, analyze the results and present conclusions, apply knowledge and skills in the field of physical and mathematical sciences and ICTs	Gen.Pro.C-4.1 Apply ICT knowledge and skills to find and study scientific literature and use software products
	Gen.Pro.C-4.2 Apply knowledge in the field of physical and mathematical sciences to solve problems, make conclusions, and evaluate the obtained results
	Gen.Pro.C-4.3 Justify the chosen method of scientific research
Pro.C-1 Assign, formalize, and solve tasks, develop and research mathematical models of the studied phenomena and processes, systematically analyze scientific problems and obtain new scientific results	Pro.C-1.1 Locate, analyze, and summarize information on current research findings within a selected subject field
	Pro.C-1.2 Make hypotheses, build mathematical models of the studied phenomena and processes, evaluate the quality of the developed model
	Pro.C-1.3 Able to apply theoretical and/or experimental research methods in photonics and opto-informatics to a specific scientific problem and interpret the results obtained
Pro.C-2 Organize and conduct scientific research and testing independently or as a member (leader) of a small research team	Pro.C-2.1 Able to plan and carry out research in photonics and opto-informatics independently or as part of a research team
	Pro.C-2.2 Conduct tests of research results through scientific publications and participation in conferences
Pro.C-3 Professionally use research and testing equipment (devices and installations, specialized software) in a selected subject field	Pro.C-3.1 Understand the operating principles of the equipment and specialized software
	Pro.C-3.2 Conduct an experiment (simulation), using research equipment (software)
	Pro.C-3.3 Evaluate the accuracy of the experimental (numerical) results

2. Competency assessment indicators

As a result of studying the course the student should:

know:

- basic principles of spectroscopy and spectrophotometry
- basic principles of spectral ellipsometry
- basic principles of far-field optical microscopy
- basic principles of atomic force microscopy
- the basic principles of scanning tunneling microscopy
- basic principles of scanning near-field optical microscopy
- basic principles of Raman and Surface-enhanced Raman spectroscopy
- basic principles of surface plasmon resonance spectroscopy
- basic principles of scanning electron microscopy
- basic principles of transmission electron microscopy
- basic principles of terahertz spectroscopy
- basic principles of optical reflectometry
- basic principles of X-ray diffractometry
- basic principles of laser nanopolymerization (or two-photon polymerization)
- basic principles of photoluminescence microscopy
-basic principles of making samples (deposition of metal films, optical lithography (photolithography))
- the main objects and phenomena, the study of which is possible by optical methods
- safety precautions and rules for working with scientific equipment

be able to:

- work with a spectrophotometer
- work with an ellipsometer
- work with an atomic force microscope
- work with a scanning tunneling microscope
- work with a scanning near-field optical microscope
- work with a scanning Raman microscope
- work with a scanning electron microscope
- work with a photoluminescent microscope
- work with transmission electron microscopy
- work with a scanning electron microscope
- work with chemical solutions, determine the chemical composition of solutions.
- work with van der Waals materials. Determine the composition, properties, quality, and number of layers.
- to plan an experiment to solve a scientific problem using optical methods.
- collect, process and present the results of the experiment, taking into account possible errors and inaccuracies

master:

- methods of analysis and processing of experimental data.
-Skills in the presentation of experimental data.
- the skills of characterizing the manufactured samples using atomic force microscopy, scanning and transmission electron microscopy.
-the skills of solving scientific problems by experimental optical methods (Raman spectroscopy, Surface-enhanced Raman spectroscopy, spectrophotometry, near-field microscopy, ellipsometry, photoluminescence microscopy)

3. List of typical control tasks used to evaluate knowledge and skills

Not provided.

4. Evaluation criteria

Checklist:

First term

1. What are metamaterials, metasurfaces, photonic crystals. What are hyperbolic metamaterials and van der Waals heterostructures? What are the methods for making artificial nanomaterials?
2. What two-dimensional materials do you know. What 2D materials can be transferred to other substrates and what is the transfer technique?
3. What methods of research of nanomaterials do you know? What are the optical properties of bulk matter7 Classical theories of optical constants. Lorentz model. Multi-oscillator model. Model of anisotropic oscillators. Drude's model. Optical characteristics of the substance. Optical properties of particles. Extinction, absorption, scattering.

4. Modern microscopic technology. Confocal laser scanning microscopy. Multiphoton confocal microscopy. Quantitative fluorescence microscopy. Superresolution methods. Special optical methods.

5. What spectroscopic methods do you know? Spectral analysis. Photocolorimetry. Spectrophotometry. Photoluminescence spectroscopy. What is photoluminescence and what is the difference between this process and Raman scattering of light? Draw a diagram of Yablonsky's energy transitions.

6. What is the principle of the spectrophotometer? Bouguer-Lambert-Beer law.

7. Terahertz spectroscopy of continuous action on backward-wave lamps (BWO). Time-resolved terahertz pulsed spectroscopy. Fourier transform infrared spectroscopy.

8. What is the essence of the Raman effect? What is the Stokes and Anti-Stokes scattering? Types of Raman scattering of light, differing mechanisms of interaction of light with matter. Classical theory. Quantum theory. Empirical laws of Raman scattering of light. Stimulated Raman Scattering. Raman spectroscopy techniques. What is the principle of operation of the Raman microscope?

9. What is the Surface-enhanced Raman spectroscopy (SESR)? What kind of concentrations does it resolve? Experimental techniques for obtaining spectra of SERS. Main characteristics and mechanism of the effect of SERS. Application of SERS to the study of biological molecules. Possibilities and prospects for the development of the SERS method.

10. What are surface electromagnetic waves. Surface plasmon resonance. Surface plasmon resonance spectroscopy. Sensitivity and method of the method. Compact circuits. Biosensors based on surface plasmon resonance spectroscopy.

11. What is the principle of the ellipsometer. What is the measurement scheme and data acquisition?

12. What is a Mueller matrix?

13. Scanning near-field optical microscopy (aperture): Diffraction limit. Introduction to scanning near-field optical microscopy. Resolution of scanning near-field optical microscopy. Schematic diagrams of scanning near-field optical microscopy.

14. Scanning near-field optical microscopy (apertureless): An introduction to scattering scanning near-field optical microscopy. Resolution of scattering scanning near-field optical microscopy. Scheme. Plasmons in two-dimensional materials.

15. Four-probe method for measuring resistivity. Specific resistance and specific surface resistance. Measurement of surface resistance of relatively thin semiconductor wafers and thin conductive (semiconductor and metallic) layers, built up from conductive substrates. Two-layer structures. Self-compensation method for geometric effects. Modern installations for measuring surface resistance.

Second term

16. What is the principle of operation and design of an atomic force microscope? What are the features of the work. Current state and development of scanning probe microscopy.

17. What is the working principle and design of the scanning tunneling microscope? Features of work? Current state and development of scanning tunneling microscopy.

18. The principle of operation of raster electronic electronic. Construction and main components of a scanning electron microscope. Features of work

19. The principle of operation of the transmission electron microscope. Design and main components of a transmission electron microscope. Features of work.

20. What is optical lithography (photolithography)? Describe the photolithography process step by step.

21. What is electronic lithography? Electronic lithography process. Resolution in electronic lithography. Principles of writing a drawing on a sample.

22. Tell us about the theoretical foundations of the X-ray diffractometry method. X-ray structural analysis. X-ray diffractometric method. Identification and definite determination of phases (phase analysis).

23. What is two-photon polymerization? Operating principle. Polymers. Manufacturing of two-dimensional and three-dimensional structures. Resolution in typical laser nanopolymerization experiments.

24. Photoluminescence microscopy at room temperature and mapping. Photoluminescence absorption microscopy at room temperature. Low-temperature photoluminescence microscopy.

27. Optical reflectometry: theoretical foundations of the method. Models for analysis.

28. Scattering of nanoparticles. Dark-field microscopy. Method resolution. Applications. Hybrid nanostructures. Practical measurements. Mee theory.

29. Physics of van der Waals materials. Assembly of van der Waals heterostructures. Methods for studying van der Waals heterostructures. Two-layer structures and moire.

30. Review of synthesis technologies and research methods for nanomaterials.

Examples of test tasks:
1. Criterion for the spatial resolution of the photolithographic method for creating nanostructures?
2. In what elementary quantum nanostructure is the energy spectrum of electrons discrete?
3. How does the size quantization energy change with an increase in the size of the nanostructure?
4. How many and what elementary processes occurring in the growth zone does the method of molecular beam epitaxy involve?
5.Basic methods for the characterization of photonic crystals?

Examples of exam tickets:

Ticket 1.
1. Principles of operation of atomic force microscopy. Resolution.
2. Methods for characterizing two-dimensional materials.
Ticket 2.
1. Principles of operation of transmission electron microscopy. Sample preparation. Resolution.
2. Methods for determining the optical properties of materials.
Ticket 3.
1. Principles of scanning electron microscopy. Resolution.
2. Measurement of the conductivity of two-dimensional materials.
Ticket 4.
1. Principles of spectral ellipsometry. Method capabilities.
2. Electronic lithography. Principle of operation. Electronic lithography process. Resolution in electronic lithography.
Ticket 5.
1. Electrophysical methods for the study of nanomaterials.
2. Raman scattering of light (Raman effect). Classical theory. Quantum theory.

Assessment “excellent (10)” is given to a student who has displayed comprehensive, systematic and deep knowledge of the educational program material, has independently performed all the tasks stipulated by the program, has deeply studied the basic and additional literature recommended by the program, has been actively working in the classroom, and understands the basic scientific concepts on studied discipline, who showed creativity and scientific approach in understanding and presenting educational program material, whose answer is characterized by using rich and adequate terms, and by the consistent and logical presentation of the material;

Assessment “excellent (9)” is given to a student who has displayed comprehensive, systematic knowledge of the educational program material, has independently performed all the tasks provided by the program, has deeply mastered the basic literature and is familiar with the additional literature recommended by the program, has been actively working in the classroom, has shown the systematic nature of knowledge on discipline sufficient for further study, as well as the ability to amplify it on one’s own, whose answer is distinguished by the accuracy of the terms used, and the presentation of the material in it is consistent and logical;

Assessment “excellent (8)” is given to a student who has displayed complete knowledge of the educational program material, does not allow significant inaccuracies in his answer, has independently performed all the tasks stipulated by the program, studied the basic literature recommended by the program, worked actively in the classroom, showed systematic character of his knowledge of the discipline, which is sufficient for further study, as well as the ability to amplify it on his own;

Assessment “good (7)” is given to a student who has displayed a sufficiently complete knowledge of the educational program material, does not allow significant inaccuracies in the answer, has independently performed all the tasks provided by the program, studied the basic literature recommended by the program, worked actively in the classroom, showed systematic character of his knowledge of the discipline, which is sufficient for further study, as well as the ability to amplify it on his own;

Assessment “good (6)” is given to a student who has displayed a sufficiently complete knowledge of the educational program material, does not allow significant inaccuracies in his answer, has independently carried out the main tasks stipulated by the program, studied the basic literature recommended by the program, showed systematic character of his knowledge of the discipline, which is sufficient for further study;

Assessment “good (5)” is given to a student who has displayed knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, who while not being sufficiently active in the classroom, has nevertheless independently carried out the main tasks stipulated by the program, mastered the basic literature recommended by the program, made some errors in their implementation and in his answer during the test, but has the necessary knowledge for correcting these errors by himself;

Assessment “satisfactory (4)” is given to a student who has discovered knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, who while not being sufficiently active in the classroom, has nevertheless independently carried out the main tasks stipulated by the program, learned the main literature but allowed some errors in their implementation and in his answer during the test, but has the necessary knowledge for correcting these errors under the guidance of a teacher;

Assessment “satisfactory (3)” is given to a student who has displayed knowledge of the basic educational program material in the amount necessary for further study and future work in the profession, not showed activity in the classroom, independently fulfilled the main tasks envisaged by the program, but allowed errors in their implementation and in the answer during the test, but possessing necessary knowledge for elimination under the guidance of the teacher of the most essential errors;

Assessment “unsatisfactory (2)” is given to a student who showed gaps in knowledge or lack of knowledge on a significant part of the basic educational program material, who has not performed independently the main tasks demanded by the program, made fundamental errors in the fulfillment of the tasks stipulated by the program, who is not able to continue his studies or start professional activities without additional training in the discipline in question;

Assessment “unsatisfactory (1)” is given to a student when there is no answer (refusal to answer), or when the submitted answer does not correspond at all to the essence of the questions contained in the task.

5. Methodological materials defining the procedures for the assessment of knowledge, skills, abilities and/or experience

The course is graded at a credit (9th term) and an exam (10th term). The questioning starts with a random task assigned to each student and time given for completion of the task. No aids are allowed. The student then proceeds to a chat with the examiner, at which he/she presents his/her solution to the assigned task. The examiner then asks the student several questions that evenly cover the course content. A final grade is assigned based on the quality of answers and demonstrated level of understanding.