Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

Department of Applied Radio Electronics

[RE-127] MICROSYSTEMS ENGINEERING

Curriculum of the academic discipline (Syllabus)

Course details

Level of higher education	First (bachelor's)
Field of knowledge	17 - Electronics, Automation, and Electronic Communications
Specialization	172 - Electronic Communications and Radio Engineering
Educational program	All
Discipline status	Elective (F-catalog)
Form of higher education	Full-time
Year of training, semester	Available for selection starting from the 3rd year, fall semester
Scope of the discipline	4 credits (Lectures 18 hours, Practical classes 36 hours, Laboratory work 36 hours, Independent work 66 hours)
Semester Control/control measures	Credit
Class schedule	https://schedule.kpi.ua
Language of instruction	Ukrainian
Information about the course leader/teachers	Lecturer: Peregudov S. M., Lab: Peregudov S. M., Independent work: Peregudov S. M.
Course location	https://classroom.google.com/c/MjA5ODY1Nzc4MDAz?cjc=d22zvpr

Curriculum

1. Description of the academic discipline, its purpose, subject matter, and learning outcomes

The rapid development of modern technology for various purposes, in particular telecommunications and radio engineering systems, and the increase in their functional capabilities require the widespread use of microsystem technology devices. These are a further development of electronic microcircuits, which, in addition to processing electrical signals, perform the functions of various sensors and actuators: mechanical, thermal, optical, etc. This allows the development of compact and reliable equipment in various fields of science and technology.

The discipline "Microsystem Technology" belongs to the cycle of professional and practical training.

The aim of teaching the discipline is to develop knowledge about microsystems and their components, the physical principles of the functioning of microsystem technology devices, design features, and basic technological operations of the production process.

The subject of the discipline is the most important components and devices of microsystem technology: mechanical, magnetic, thermal, chemical, and optical sensors and actuators, their main technical characteristics, operating conditions, and field of application.

As a result of training, students will partially develop the following competencies: the ability to independently acquire and use new knowledge and skills in their subject area in practical activities; readiness to formulate tasks for the development of microsystem technology components; the ability to design elements and devices of microsystem technology using typical application software packages, taking into account the specified requirements.

Students should know: the physical basis of the functioning of MST components and devices; the main technical characteristics of the most important types of sensors and actuators; the main methods of modeling and stages of development of microsystem technology.

Students should be able to: use the acquired knowledge in the design, development, and operation of equipment that includes microdevices; analyze signal conversion by the nodes of such devices.

Students gain experience working with individual components of microsystem technology and their application in the creation of technical systems for various functional purposes.

2. Prerequisites and post-requisites of the discipline (place in the structural-logical scheme of training under the relevant educational program)

Interdisciplinary connections are determined by the place of the discipline "Microsystem Technology" in the training program for specialists in the field of microsystem technology. It is based on the general training of students in physics, chemistry, mathematics, and computer science. The professional disciplines that precede its study are: "Mechanics of Radio-Electronic Equipment and Mechatronics," "Fundamentals of Circuit Theory," "Electronic Devices and Microelectronics."

The discipline "Microsystem Technology" provides for the study of disciplines of the second (master's) level of higher education: "Modeling of Micro- and Nanostructures," "Computer Networks and Telecommunications."

3. Contents of the academic discipline

Names of sections and topics	**Number of hours**			
	Total	**including**		
		Lectures	**Laboratory work (Computer workshop**	**SRC**
Section 1 INTRODUCTION. FEATURES OF MICROSYSTEM DESIGN AND MANUFACTURING				
Topic 1.1 Content and structure of the discipline "Microsystem Technology." Stages and trends in the development of microsystem technology	1.5	1		0.5
Topic 1.2 Features of the development and manufacturing of microsystem devices	9.5	1	4	4.5
Total for Section 1	11	2	4	5
Section 2 SENSORS AND MICROSENSORS				
Topic 2.1 Micromechanical sensors and devices based on them	20	2	8	10

Topic 2.2 Thermoelectric sensors and sensors based on them	5.5	1	4	0.5
Topic 2.3 Magnetoelectric and optical sensors and transducers based on them	1.5	1		0.5
Topic 2.4 Chemical and biochemical sensors	11	2	4	5
Total for Section 2	38	6	16	16
Section 3 ACTUATORS AND MICROMECHANISMS				
Topic 3.1 Micromechanical actuators	9.5	1	4	4.5
Topic 3.2 Microdrives in devices microdisplacement and micropositioning devices	9.5	1	4	4.5
Topic 3.3 Thermoactuators	1.5	1		0.5
Topic 3.4 Optical actuators	9	1	4	4.5
Topic 3.5 Electromechanical and optoelectromechanical controlled microcomponents	3	2		1
Total for Section 3	33	6	12	15
Modular test	2			2
Section 4 ANALYTICAL AND ROBOTIC MICROSYSTEMS				
Topic 4.1 Intelligent and multisensory systems	3	2		1
Topic 4.2 Miniature robotic systems	11	2	4	5
Total for section 4	14	4	4	6
Calculation and graphic work	16			16
Credit	6			6
Total hours	120	18	36	66

4. Teaching materials and resources

Basic literature

1. Lobur M. Fundamentals of Microsystem Devices: [Electronic resource]: textbook / M. Lobur, M. Melnyk - Electronic text data (1 file: 3.97 MB). - Lviv: Published by Lviv Polytechnic National University, 2015. - 258 p. - Access mode: http://cad.lp.edu.ua/project/b3.pdf. - Title from the screen.
2. Semenets V.V. Introduction to Microsystem Technology and Nanotechnology [Text]: textbook / V.V. Semenets, I.Sh. Nevlyudov, V.A. Palagin. – Kharkiv: SMHT Company LLC, 2011. – 416 p.
3. Kosobutsky P.S. Micro- and Nanoelectromechanical Systems: Basic Principles of Designing Phenomena, Materials, and Elements [Text]: textbook / Petro Kosobutsky, Mykhailo Lobur, Volodymyr Karkulovsky – L.: Lviv Polytechnic Publishing House, 2017. – 400 p.
4. Modeling of MST devices. Computer workshop [Electronic resource]: Textbook / Igor Sikorsky KPI; compiled by S. M. Peregudov. – Electronic text data (1 file: 3.38 MB). – Kyiv: Igor Sikorsky KPI, 2021. – 78 p. Access: https://ela.kpi.ua/handle/123456789/43058.
4. Dolia P. G. Fundamentals of Modeling in COMSOL Multiphysics [Electronic resource] / Dolia P. G.; Karazin Kharkiv National University. - Electronic text data (1 file: 14.58 MB). - Kharkiv: Karazin Kharkiv National University, 2019. – 529 p. – Access mode: http://geometry.karazin.ua/resources/documents/20191219182458_ 3cc8431d.pdf. - Title from the screen.

Supplementary literature

5. Teslyuk V.M. Advanced Design of Microsystem Devices [Text]: textbook / V. Teslyuk, A. Zelinsky, V. Karakulovsky, Ya. Vasilyuk - L.: Lviv Polytechnic Publishing House, 2016. -

252 p.
6. Voytovich I.D. Intelligent Sensors / I.D. Voytovich, V.M. Korsunsky. - K.: V.M. Glushkov Institute of Cybernetics, 2007. – 513 p.
7. Nevlyudov, I. Sh. Microsystem Technology and Nanotechnology [Text]: monograph / I. Sh. Nevlyudov, V. A. Palagin. - Kyiv: VYDANNYA, 2017. - 528 p.
8. Nevlyudov I. Sh. Microsystem Technology [Electronic resource] / I. Sh. Nevlyudov, V. A. Palagin, E. A. Chalaia // Instrument Engineering Technology. - 2014. - No. 3. - P. 7-10.- Access mode: http://nbuv.gov.ua/UJRN/Tp_2014_3_4.
9. Nevlyudov I. Sh. Microsystem technology (part II) [Electronic resource] / I. Sh. Nevlyudov, V. A. Palagin, E. A. Chalaia // Instrument Engineering Technology. – 2015. – No. 2. – P. 5-10.- Access mode: http://nbuv.gov.ua/UJRN/Tp_2015_2_4.
10. Varadan V.K. RF MEMS and Their Applications / Vijay K. Varadan, K. J. Vinoy, K. A. Jose – John Wiley & Sons, Ltd, 2003. – 408 p.
11. Theodore S. Rappaport. Millimeter Wave Wireless Communications / Theodore S. Rappaport, Robert W. Heath Jr., Robert C. Daniels, James N. Murdock. – Prentice Hall, 2014. – 657 p.
12. Yavorskyi, N.B. Computer Methods in Microelectromechanical Systems Engineering [Text]: textbook / Nazarii Yavorskyi, Vasyl Tesliuk, Yevheniia Lytvynova. - Lviv: Lviv Polytechnic Publishing House, 2015. – 280 p.

Information resources

I. Microsystems science, technology & components [Electronic resource] - Access mode: http://www.sandia.gov/mstc/index.html.
II. COMSOL, Inc. ; official website [Electronic resource] - Access mode: http://www.comsol.com.

Educational content

5. Methodology for mastering the academic discipline (educational component)

Lectures

No	Lecture topic and list of main questions (list of teaching aids, references to literature, and assignments for independent study)
	Chapter 1 INTRODUCTION. FEATURES OF DESIGN AND MANUFACTURING MICROSYSTEMS
1	**Content and structure of the discipline "Microsystem Technology".** The role and place of the discipline in training specialists in the field of intelligent technologies of microsystem radio-electronic engineering. Main sections and topics of the course. Types of classes, individual assignments, assessment system. **Features of the development and production of microsystem devices** Microsystem technology is a new technical field. History and main stages of development. Advantages of MST. Main elements and devices of microsystem technology, physical processes in them, design and technological features. Connection with microelectronics and nanoelectronics. Reliability of MST devices. Independent work assignment: review the lecture material, pay attention to the topics of the classes, types of assignments, and the student assessment system. Literature: [1, pp. 15-17]; [5, pp. 6-11].
	Section 2 SENSORS AND MICROSENSORS
2	**Micromechanical sensors and transducers based on them** Classification of sensors. Sensor characteristics: measurement range, sensitivity, accuracy, linearity, selectivity. Standardization and certification of sensors. Designs of micromechanical sensor elements. Types of transducers: piezoelectric, strain gauge, capacitive. Sensors based on micromechanical transducers: accelerometers and microgyroscopes, pressure, ripple, and displacement sensors. Independent work assignment: review the lecture material and study the literature; memorize the main types of micromechanical sensors and their operating principles. Literature: [3, pp. 213-239]; [5, pp. 13-25]

No.	Lecture topic and list of main questions (list of teaching aids, references to literature, and tasks for independent work)
3	**Thermoelectric sensors and transducers** Thermoresistive and thermoelectric sensors, thermomechanical and pyroelectric transducers. Temperature, flow, liquid level, and vacuum sensors. Thermocouples, bolometers, thermistors, and conductometers. **Magnetoelectric and optical sensors and transducers** Inductive transducers. Hall effect magnetic field sensors. Magnetoresistors, magnetodiodes, and magnetotransistors. Photoresistors, photodiodes, phototransistors. Light flux and optical absorption sensors. Displacement and position sensors based on optical sensors. Independent work assignment: review the lecture material, study the basic principles of thermoelectric, magnetoelectric, and optical sensors. References: [1, pp. 32-40]; [7, pp. 11-25].
4	**Chemical and biochemical sensors** Electrochemical sensors. Thermocatalytic sensors. Adsorption transducers. Liquid and gas composition sensors. Humidity sensors. Biosensors, their main types and principles of operation... Independent work assignment: review the lecture material, memorize the classification and areas of application of chemical and biological sensors. References: [1, pp. 107-129]; [5, pp. 28-50].
	Chapter 3 ACTUATORS AND MICROMECHANISMS
5	**Micromechanical actuators** Micromechanical motion drives, their classification and principle of operation. Piezoelectric, capacitive, thermomechanical, electromagnetic, and pneumatic actuators. Micro-motion drives based on the "shape memory" effect. **Microdrives in microdisplacement and micropositioning devices** Microlevers. Light reflectors. Vibration generators. Fixing devices Independent work assignment: review the lecture material, explain the principle of operation of micromechanical actuators and microdrives. References: [1, pp. 216-218]; [6, pp. 95-115].
6	**Thermoactuators** Microheaters and microcoolers. Miniature devices with thermal connections. **Optical actuators** Microemitters: light-emitting diodes, semiconductor lasers. Infrared emitter. Miniature devices with optical connections. Independent work assignment: review the lecture material, examine the operation of thermal and optical actuators References: [6, pp. 136-158].
7	**Electro-radio-mechanical and opto-electro-mechanical controlled microcomponents** Resistors. Inductors. Controlled capacitors. Microantennas and resonators. Microrelays and switches. Micromechanical components in radio frequency and ultra-high frequency devices. Optical resonators. Micromirrors and lenses. Optical gates, switches. Electrically controlled optical band filters, their classification and principle of operation. Independent work assignment: review the lecture material, examine the operation of electro-radio-mechanical and opto-electro-mechanical controlled components. Literature: [6, pp. 166-178].
	Section 4 ANALYTICAL AND ROBOTIC MICROSYSTEMS
8	**Intelligent and multisensory systems** Artificial nose. Artificial speech, multisensory matrices. Biometric sensors. Miniature analytical devices. Chromatographic process. Microchromatographs. Miniature medical and biological devices. Matrix microsystems. Capillary-fluid microsystems. Independent work assignment: review the lecture material; determine the principles of operation of analytical microsystems. References: [6, pp. 348-414].

No.	Lecture topic and list of key questions (list of teaching aids, references to literature, and assignments for independent study)
9	**Miniature robotic systems** Miniature autonomous transport systems: ground, air, and space. Mini and micro robots for medicine and technical diagnostics. Robots with dynamically changing structures. Bio-like robots. Prospects for the development and application of microsystems. Nanotechnology and nanosystem engineering. Independent work assignment: review the lecture material; identify the principles of operation and areas of application of micro-robotic systems. Literature: [6, pp. 415-457].

Computer workshop

The discipline "Microsystem Engineering" belongs to the cycle of professional and practical training, therefore, special attention is paid to the practical component of the learning process.

The main objectives of the practical classes are:

- to deepen and consolidate theoretical knowledge;
- mastering methods and means of modeling microsystem devices and acquiring skills in their development;
- mastering methods for calculating the parameters of basic MST elements;
- acquiring skills in preparing graphic and text documentation accompanying microsystem technology products.

Most tasks involve the use of the COMSOL Multiphysics software package.

No.	Name of the lesson topic and list of main questions (list of teaching aids, references to literature, and assignments for independent study)
1	Topic 1.2 Features of the development and production of microsystem devices **Modeling of MST elements and devices. Features of software support** Assignments for independent work: review the material from the practical class, familiarize yourself with the principles of the COMSOL Multiphysics package [4], learn how to build basic elements of geometric models of MST devices. References: [6, pp. 9-54], [4, pp. 45-69].
2	Topic 2.1 Micromechanical sensors and transducers based on them **Calculation of piezoresistive pressure sensor parameters** Independent work assignment: review the material from the practical class, simulate the MPX100 piezoresistive pressure sensor in the COMSOL Multiphysics environment, calculate the main parameters of the sensing element, and plot graphs of the calculated characteristics. References: [1, pp. 56-59], [4, pp. 477-484].
3	Topic 2.2 Thermoelectric sensors and sensors based on them **Resistive heating of a metal plate** Independent work assignment: review the material from the practical class – simulate the resistive heating of a metal plate in COMSOL Multiphysics and calculate the linear dimensions of the plate using the method described in [8]. References: [4, pp. 439-462]; [8, pp. 3-12].
4	Topic 2.4 Chemical and biochemical sensors **Determination of cantilever resonance frequencies** Independent work assignment: review the material covered in class – calculate the resonance frequencies of the microdevice cantilever beam and investigate their dependence on load using the COMSOL Multiphysics package. References: [1, pp. 95-107]; [4, pp. 12-16, 357-368].

No.	Lesson topic and list of key questions (list of teaching aids, references to literature, and assignments for independent work)
5	Topic 3.1 Micromechanical actuators **Calculation and analysis of the characteristics of a piezoelectric beam-type actuator type** Independent work assignment: review the material covered in class, calculate the dependence of the actuator displacement on temperature and lever length using the method described in [5], and plot graphs of the calculated characteristics. References: [1, pp. 40-51]; [4, pp. 137-141, 297-301].
6	Topic 3.2 Microdrives in micro-placement and micro-positioning devices **Modeling of steady microfluidic flows in a micropump. Construction of a geometric model, setting equations and boundary conditions. Determination of the main characteristics and parameters of a micropump** Independent work assignment: review the material from the practical class, build a geometric model of a micro pump in the COMSOL Multiphysics package, set the physical models of the device and boundary conditions. References: [8, pp. 408-416].

Laboratory classes

The main purpose of the laboratory classes:

- to test the acquired theoretical knowledge in practice;
- acquiring skills in working with measuring instruments and equipment;
- mastering methods of measuring parameters and recording characteristics; •
acquiring skills in evaluating experimental data and drawing conclusions.

No.	Name of laboratory work	Number Class hours
1	**Determination of parameters and characteristicsof a piezoresistive pressure sensor** Independent work assignment: review the material from lectures 9 and 10 and prepare for the lab work; write a report on the work and prepare answers to the test questions.	3
2	**Research on the characteristics of a microelectromechanical accelerometer** Independent work assignment: review the material from lectures 7, 8, and 11 and prepare for the lab work; write a report on the work and prepare answers to the test questions.	3
3	**Determination of the characteristics of a micro-mirror oscillographic galvanometer** Independent work assignment: review the material from lecture 17 and prepare for the lab work; write a report on the work and prepare answers to the test questions.	3
4	**Investigation** of **the MPX100 pressure sensor's sensing element** Independent work assignment: review the material from lectures 5 and 6 and prepare for the lab work: build a model piezoresistive sensing element in COMSOL Multiphysics [6], perform simulations; prepare a report on the work and prepare answers to the test questions.	3
5	**Analysis of the operation of an electroosmotic micropump** Independent work assignment: review the material from lectures 4 and 8 and prepare for the lab work: build a model of a micropump in COMSOL Multiphysics [6], perform simulations; prepare a work report and prepare answers to test questions.	3

No.	Name of laboratory work	Number Class hours
6	**Investigation of the properties of a dichloromethane sensor on surface acoustic waves** Independent work assignment: review the material from lectures 12 and 13 and prepare for the laboratory work; build a model of a dichloromethane sensor in COMSOL Multiphysics [6] and perform simulations; write a report on the work and prepare answers to the test questions.	3

6. Independent work by students

Students complete the independent work assignments listed in section 5, as well as the methodological recommendations for the computer workshop and laboratory classes in accordance with the academic calendar. During the semester, they must complete a home control work (HCW). The approximate topics of the HCW tasks are given in the appendix to section 9.

Policy and control

7. Academic discipline (educational component)

policy Class attendance rules

Lab classes are mandatory to attend and complete assignments. If you miss them, you have to make up for it either during consultation hours or with other groups by prior agreement with the teacher.

If a student misses a lecture or practical class, they must complete the assigned tasks and attend an interview with the lecturer on the material covered in the missed class. The interview is conducted during scheduled consultations. Lecture and practical class materials with assignments are posted on Google Classroom, which students will have access to at the beginning of the semester.

Admission to laboratory classes and defense of the report on the work performed

Before laboratory work, students are interviewed by the instructor, based on the results of which a decision is made on admission to the work.

The defense of the report on the laboratory work is held during the next scheduled laboratory class. The grade that the student receives for the laboratory class consists of the points received during admission and defense. The number of points is indicated in the rating system (item 8).

Defense of the home control work

The defense of the homework assignment takes place during consultations according to the schedule in the last two weeks of the semester or, by prior agreement with the teacher, at another time. The grade for the homework assignment has two components: for the explanatory note and for the answers during the defense. The final grade is announced during the defense.

There is no provision for retaking the homework assignment.

Bonus and penalty points and academic integrity policy

The most active students, in particular those who perform exemplary tasks based on the course materials, can receive from 1 to 10 points to their semester rating.

Penalty points are applied if a student submits someone else's work as their own. In this case, they must redo the assignment.

Deadline and resit policy

The deadline for submitting individual assignments (DCA), tests, and resits is determined by the schedule approved by the dean of the faculty. In case of violation, the grade is reduced by 10%.

8. Types of control and rating system for assessing learning outcomes (RSO)

Before the second assessment, students complete a modular control work (MCW). The MCW assignment consists of questions that are included in the semester control (clause 9), with the exception of those that were not covered in class.
The curriculum for the discipline "Microsystem Technology" provides for the following rating system for assessing student performance.
The student's rating consists of points (on a 100-point scale) that they receive for:

1. ongoing assessment of lecture material mastery (an average of 5 answers per student);
2. answers in practical classes (an average of 5 answers per student);
3. completion and defense of 5 laboratory works;
4. homework assignment (HA);
5. modular test (MT).

The number of points and assessment criteria are determined as follows.

Rating (weighted) point system and assessment criteria

1. Current assessment during lectures

Weighted score - 2. The maximum number of points for 16 lectures is: 2 points × 5 = 10 points.
Assessment criteria:

- complete answer 2 points;
- satisfactory answer 1 point;
- unsatisfactory answer 0 points.

2. Practical work

Weighting score - 2. The maximum number of points for all practical classes (except for the first one) is equal to:
2 points × 5 = 10

points. Assessment

criteria:

- complete answer 2 points;
- satisfactory answer 1 point;
- unsatisfactory answer 0 points.

3. Laboratory work

Weighting - 6. The maximum number of points for all laboratory work is: 5 points × 6 = 30 points.
Each laboratory work is assessed on the following criteria:

a) preparedness for work:

- free command of theoretical material, availability of a prepared protocol 2 points;
- unpreparedness for laboratory work (failure to pass) 0 points;

b) performance of laboratory work:

- report formatted according to requirements 1 point;
- work performed with errors or sloppily 0 points;
- work not completed on time (due to absence from class without a valid reason) -2 points;

c) defense of the work:

- full answer during defense 3 points;
- satisfactory answer during defense - 2 points;
- incomplete answer during defense - 1 point;
- work defended on another day 0 points.

4. <u>Modular control work (MCW)</u> Weighted score – 20.

Assessment criteria:

- complete answers to all test questions: 17 to 20 points;
- correct answers to most test questions 10 to 16 points;
- incorrect answers to most test questions 0 to 9 points.

5. <u>Home test (HT)</u> Weighted score – 30. Assessment criteria:

- full disclosure of the topic of the assignment and mastery of it, reflecting one's own
- position and appropriate formatting of the work from 25 to 30 points;
- sufficient disclosure of the topic of the task with minor errors from 16 to 24 points;
- sufficient coverage of the topic, errors,
- poor presentation of the work, 7 to 15 points;

- incomplete or superficial coverage of the topic, poor presentation of the work. 1 to 6 points;

- the topic is not covered, the task is not completed 0 points.

6. Penalty points for:

- non-admission to laboratory work due to unsatisfactory initial assessment -1 point;

- Absence from a lecture, practical or laboratory class

- without a valid reason -1 point;

- late completion (more than a week late) of an MT -2 points.

The total number of penalty points shall not exceed Rs = 10 points.

Calculation of the semester rating

The maximum possible number of points for control measures (items 1-5) during the semester is:
R = 10 + 10 + 30 + 20 + 30 = 100 points.

Conditions for a positive interim assessment

- To receive a "pass" on the first interim assessment (week 8), the student must score at least 16 points ("ideal" student – 32 points).

- To receive a "pass" on the second interim assessment (week 14), the student must earn at least 32 points (an "ideal" student would earn 64 points).

The maximum number of points is 100. A prerequisite for admission to the exam is the completion of all laboratory work and HCW.
To receive a credit for the credit module "automatically," you must have a rating of at least 60 points and have all laboratory work and RGRs completed.

Students who have a rating of less than 60 points at the end of the semester, as well as those who want to improve their grade, take a final exam. In this case, the points for the final exam and laboratory work should be added to the points for the final exam, and this rating is final. The test consists of four questions from different sections of the work program from the list provided in the methodological recommendations for completing the credit module.

For each question, the student can receive points according to the assessment system:

- "excellent", complete answer (at least 90% of the required information) 9-10 points;
- "good," sufficiently complete answer (at least 75% of the required information) 7-8 points;
- "Satisfactory," incomplete answer (at least 60% of the required information) 5-6 points;
- "sufficient," incomplete answer (at least 50% of the required information) 3-4 points;
- "unsatisfactory," unsatisfactory answer (less than 50% of the required information) 0-2 points.

The sum of the student's points in the case of receiving a credit for the credit module "automatically", or the sum of points for DCR, laboratory work and credit control work should be transformed into a credit grade according to the table:

Table of correspondence between rating points and grades on the university scale

Number of points	Grade
100-95	Excellent
94	Very good
84	Good
74-65	Satisfactory
64-60	Sufficient
Less than 60	Unsatisfactory
Admission requirements not met	Not admitted

9. Additional information on the discipline (educational component)

1. Approximate topics of assignments for the final qualifying examination

A microsensor is used to determine the parameters of the mechanical signal. The primary sensing element consists of an inertial mass suspended above the substrate by means of cantilever beams fixed to the surface of the substrate in the anchor area. The base of the inertial mass is parallel to the surface of the substrate and has dimensions *axa*, and its height is h. The length of each beam is *l*, and its cross- section is a rectangle with a width *w*, parallel to the substrate surface, and a thickness *t*. A fixed electrode of a capacitive transducer is located next to the sensing element on the substrate surface. The design options for the sensing element are shown in Fig. 1, and the geometric dimensions are given in Table 1. The material is polycrystalline silicon.

The type of microsensor in the even-numbered variants is a MEMS accelerometer, and in the odd- numbered variants, a MEMS gyroscope. Complete the following task.

1. Describe the functional purpose of the microsensor, its structure, and the design of the primary sensing element according to the option received. Explain how the corresponding mechanical signal is converted into an electrical signal and how it depends on the parameters and characteristics of the sensing element.

2. Build a model in the *COMSOL Multiphysics* package environment, justify it, and use it to study the characteristics of the sensing element, namely:

- determine the frequencies of the element's natural mechanical vibrations;
- select those that correspond to vibrations in the direction of the stationary electrode of the capacitive transducer;
- analyze the effect of such vibrations on the characteristics of the microsensor, in particular on the operating frequency range of the measured signal.

3. Based on the obtained design of the sensitive element, describe the main technological stages of its manufacture using MUMPs technology, using lecture notes, the manual [1] and other sources of information.

4. Present the results of the work in the form of an explanatory note.

Option	Sketch	a	h	l	w	t
1	Fig. 1a	200	10	200	3	3

2	Fig. 1b	200	10	200	5	5
3	Fig. 1c	250	10	280	4	5
4	Fig. 1d	200	10	150	5	3
5	Fig. 1a	250	12	250	5	5
6	Fig. 1b	250	10	300	3	5
7	Fig. 1c	300	10	350	3	5
8	Fig. 1d	300	10	300	5	3
9	Fig. 1a	250	15	300	7	5
10	Fig. 1b	280	15	300	5	6
11	Fig. 1c	280	15	280	5	5
12	Fig. 1d	280	15	300	10	5
13	Fig. 1a	300	12	250	6	3
14	Fig. 1b	300	15	250	8	5
15	Fig. 1c	280	12	300	7	6
16	Fig. 1d	300	12	280	8	6
17	Fig. 1a	300	20	300	5	5
18	Fig. 1b	300	20	300	10	5
19	Fig. 1c	300	15	300	7	7
20	Fig. 1d	300	10	250	10	6
21	Fig. 1a	400	7	250	7	7
22	Fig. 1b	400	7	250	7	7
23	Fig. 1c	350	10	350	10	10
24	Fig. 1d	400	10	300	7	6
25	Fig. 1a	450	8	300	8	6
26	Fig. 1b	450	8	250	10	6
27	Fig. 1c	400	10	400	5	5
28	Fig. 1d	480	7	240	7	8
29	Fig. 1a	500	10	300	15	10
30	Fig. 1b	500	10	300	10	8
31	Fig. 1c	500	15	450	10	10
32	Fig. 1d	500	8	250	10	8

2. List of questions for semester assessment:

1. Features of the design and technology of MST devices.
2. Basic principles of MST device modeling.
3. Similarity criteria and their application in modeling MST devices
4. Silicon volume micromachining
5. Surface micromachining technologies
6. Main stages and features of LIGA technology
7. MUMPs technology
8. Basic principles of elastic media mechanics
9. Silicon as a mechanical material for microdevice elements
10. Principle of operation and application of electrostatic actuators
11. Natural vibrations of a mechanical system
12. Forced mechanical oscillations and resonance
13. Damping of vibrations of MST elements
14. Physical fundamentals and principle of operation of electromechanical MST devices
15. Basic parameters of MST piezoelectric transducers
16. Use of the piezoelectric effect for receiving acoustic waves
17. Piezoelectric actuators
18. Types of mechanical sensors.
19. Displacement microsensors
20. Pressure and strain microsensors
21. Linear and angular micromechanical accelerometers
22. Design features and applications of MST accelerometers
23. Principle of operation of micromechanical gyroscopes (MMG)
24. Classification and design features of MMGs
25. Micromechanical gyroscopes based on iMEMS technology
26. Switching devices for microsystems
27. Microdevices based on surface acoustic waves
28. Resistive, capacitive, and impedance-sensitive microelements and devices

29. Voltaic devices of MST on diodes and bipolar transistors
30. Electrochemical devices for microsystem technology.
31. Principle of operation of electrochemical sensors.
32. Potentiometric electrochemical sensors
33. Conductometric and impedance sensors.
34. Amperometric and coulometric sensors
35. Chemically sensitive MST devices on field-effect transistors
36. Integrated micromirrors
37. MOEMS technologies for generating and scanning optical information
38. Prospects for MEMS technology for microwave applications.
39. MST components for RF and microwave ranges

Description of material, technical, and informational support for the discipline

Practical classes, which involve the use of the COMSOL Multiphysics software package, are held in computer classrooms (402-17, 404-17), which have 18 workstations with a demo version of the program installed. A manual and methodological recommendations have been developed for the practical classes and are available on Google Classroom.

Laboratory classes are held in the training laboratory (408-17) with models for performing the tasks specified in paragraph 5. Methodological recommendations for the tasks are posted on Google Classroom.

Work program for the academic discipline (syllabus):
Compiled by Peregudov S. M.;
Approved by the PRE Department (Minutes No. 06/2024 dated 06/27/2024)
Approved by the methodological commission of the faculty/research institute (protocol No. 06/2024 dated 28.06.2024)