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

APPROVED
Проректор по учебной работе и экономическому развитию
D.A. Zubtsov

Work program of the course (training module)

course: Plasma Chemistry/Химия плазмы
major: Applied Mathematics and Physics
specialization: Beam-Plasma Systems and Technologies/Пучково-плазменные системы и технологии
Phystech School of Aerospace Technology
Chair of Logistics Systems and Technologies
term: 2
qualification: Master

Semester, form of interim assessment: 4 (spring) - Exam

Academic hours: 60 AH in total, including:
lectures: 30 AH.
seminars: 15 AH.
laboratory practical: 15 AH.

Independent work: 45 AH.

Exam preparation: 30 AH.

In total: 135 AH, credits in total: 3

Author of the program: T.M. Vasileva, candidate of biological sciences, associate professor

The program was discussed at the Chair of Logistics Systems and Technologies 09.02.2022

Annotation

The training course is targeted at student's familiarization with scientific and engineering principles concerning the physical and chemical foundations of plasma chemical technologies and fields of plasma chemical processes application, as well as at development of skills and abilities to apply this knowledge when working in scientific and practical activities related to plasma chemistry. Plasma chemical reactors based on electron beam and hybrid plasmas are considered in detail. Theoretical sections of the training course are supported by laboratory practice on real reactors.

1. Study objective

Purpose of the course

To acquaint students with scientific and engineering principles concerning the physical and chemical foundations of plasma chemical, areas of plasma-chemical technological processes application; to develop skills and abilities to apply this knowledge when working in various fields of scientific and practical activities related to plasma chemistry.

Tasks of the course

- To give students the necessary fundamental knowledge in the field of chemically active plasmas;
- To give students information about plasma-chemical technologies used in practice of functional materials production, coating deposition, in solving environmental problems, as well as promising plasma-chemical technologies based on the use of electron-beam plasma;
- Development of students' basic knowledge and initial practical skills when working with plasma chemical reactors of various types.

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-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)
Pro.C-3 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:

- general parameters of plasma chemical processes;
- kinetic and thermodynamic characteristics of plasma chemical reactions;
- features of processes in non-equilibrium plasmas;
- principles of operation and design of plasma-chemical reactors of various types;
- principles for calculating the main parameters characterizing the operating modes of plasma setups based on electron-beam plasma generators;
- plasma chemical reactors operation (beam-plasma reactors and hybrid-type reactors), features of their operation and maintenance;
- methods for measuring the main parameters characterizing the operating modes of plasma chemical reactors;
- basic parameters and target characteristics of plasma chemical reactors for technologies.

be able to:

- apply in practice the basic concepts used in the analysis and description of plasma-chemical processes in equilibrium and non-equilibrium plasmas;
- to predict the course of plasma-chemical transformations under various conditions, to choose the optimal method for obtaining products with the required properties and the required composition;
- to numerically estimate the key characteristics of plasma chemical processes and plasma-chemical reactors, as well as to numerically simulate plasma chemical processes in beam-plasma reactors, to optimize their operating regimes;
- to formulate the problem statement of the properties study for products of non-equilibrium plasma-chemical reactions;
- to determine (clarify) of obtaining products with desired properties by means of beam-plasma impact on mater;
- to master new subject areas, theoretical approaches and experimental techniques related to the analysis, design and application of industrial plasma systems based on electron-beam plasma

master:

- skills of mastering a large amount of interdisciplinary and special information;
- culture of setting goals in the field of design and application of plasma chemical reactors;
- initial skills in working on beam-plasma reactors, ensuring their reliable and safe operation.

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	Introduction to plasma chemistry. Basic definitions and comments	4	2		3
2	Mechanisms of plasma chemical reactions I: ionization.	2	1		3
3	Mechanisms of plasma chemical reactions II: electron-ion recombination	2	1		3
4	Mechanisms of plasma chemical reactions III: elementary processes involving excited atoms and molecules.	2	1		3
5	Examples of known plasma chemical processes	2	1		3
6	Plasma-chemical modification of (bio)organic polymers in gas discharge plasma	2	1		4
7	Kinetics of reactions of polymers plasma chemical modification	2	1		4
8	Modification of various materials in the Electron-Beam Plasma: typical technological problems	2	1	4	3
9	Mechanisms of material modification in Electron-Beam Plasma I: main acting factors	2	1		4
10	Mechanisms of materials modification in the Electron-Beam Plasma II: modification process control	2	1		3
11	Main mechanisms of plasma interaction with living cells and tissues; application of gas discharge plasmas in biology and medicine	2	1	4	3

12	Prospects of beam-plasma technologies for solving biological and medical problems	2	1	4	3
13	Prospects of low-temperature plasmas for green chemistry and environment saving agro technologies, gas cleaning	2	1	3	3
14	Real plasma chemical reactors for industrial, agricultural and environment saving technologies	2	1		3
AH in total		30	15	15	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: 4 (Spring)

1. Introduction to plasma chemistry. Basic definitions and comments

Plasma as a state of matter. The main components of reactive plasma, the main mechanisms of plasma chemical processes: overview.

2. Mechanisms of plasma chemical reactions I: ionization.

Classification and types of ionization processes. Direct and stepwise ionization. Photo-ionization. Ionization under the action of high-energy electrons and in an electromagnetic field.

3. Mechanisms of plasma chemical reactions II: electron-ion recombination

Various mechanisms of electron-ion recombination. Plasma-chemical transformations and reactions involving positive and negative ions.

4. Mechanisms of plasma chemical reactions III: elementary processes involving excited atoms and molecules.

Processes involving excited atoms and molecules. Excited particles, resonant and metastable states. Dissociation of molecules under the influence of plasma, generation of radicals, radical plasma-chemical reactions. Reactive oxygen species, chlorine.

5. Examples of known plasma chemical processes

Ozone generation, nitrogen (II) oxide production, plasma-assisted etching of the material surface. Plasma catalysis, plasma-chemical fuel conversion and plasma-assisted hydrogen synthesis. Plasma-stimulated functionalization of carbon materials.

6. Plasma-chemical modification of (bio)organic polymers in gas discharge plasma

Plasma-stimulated polymers destruction, polymers oxidation under the plasma action, plasma-stimulated polymerization, copolymerization, functionalization and cross-linking of polymers. VUV-stimulated polymerization and degradation of polymers. Polymers aging as a result of plasma-chemical modification. Specific examples of plasma-chemical modification of synthetic and natural polymers, its effect on the physical and chemical resulting materials. Application of plasma-modified polymers in biology, medicine and technology.

7. Kinetics of reactions of polymers plasma chemical modification

Basic concepts, definitions, kinetic equations and mechanisms. Approaches to modeling and experimental study of plasma-chemical polymers modification kinetics.

8. Modification of various materials in the Electron-Beam Plasma: typical technological problems

Interaction of electron-beam plasma with proteins and polysaccharides. Synthesis of thin films and coatings in electron-beam plasma, surface functionalization of inorganic and organic materials in electron-beam plasma.

9. Mechanisms of material modification in Electron-Beam Plasma I: main acting factors

Main factors of the electron-beam plasma action on mater. Fast and secondary electrons, optical radiation, X-ray bremsstrahlung, active plasma particles. Mechanisms of interaction of these particles and radiations with (bio)organic molecules. Experimental approaches to differentiation of each factor effect on the material.

10. Mechanisms of materials modification in the Electron-Beam Plasma II: modification process control

Experimental and theoretical approaches to control the materials modification in the electron-beam plasma. Control of integral energy input, control of temperature distribution and fluxes of fast electrons and active plasma particles over the surface of samples of various geometry.

11. Main mechanisms of plasma interaction with living cells and tissues; application of gas discharge plasmas in biology and medicine

Basic information about the structure of the cell and the organization of body tissues. The main plasma-chemical factors affecting the structure and function of cells during treatment in plasma and the mechanisms of their action. The use of gas discharge plasmas for sterilization, inactivation of microorganisms, tissue engineering and cell technologies; stimulation of tissue regeneration. Plasma surgery, plasma-assisted coagulation, the use of gas-discharge plasma in dentistry and cosmetology. Plasma treatment of malignant cells.

12. Prospects of beam-plasma technologies for solving biological and medical problems

Technologies for bioactive peptides and oligosaccharides production. Biocompatible hybrid materials and coatings formation. Electron Beam Plasma for nanobiotechnologies and biosensors production. Beam Plasma modification and doping of carbon materials.

13. Prospects of low-temperature plasmas for green chemistry and environment saving agro technologies, gas cleaning

Plasma-chemical water and wastes treatment, plasma-assisted synthesis of phytostimulators and phytoprotectors. Application of plasma-chemical methods in the production of catalysts, processing of oil and oil products. Gas cleaning by gas discharge plasmas. Exhaust gases cleaning from hazardous and toxic pollutions by means of the electron beam plasma. EBARA-process.

14. Real plasma chemical reactors for industrial, agricultural and environment saving technologies

Plasma installations used for plasma chemical modification of various materials and solving biological and medical problems: plasma needle, plasma pencil, plasma torch, etc. Electron beam reactors for the production of bioactive compounds and materials.

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

Experimental complex "Beam-plasma systems and technologies" as part of the ELU-1 and ELU-2 installations, the PPT-2 plasma torch, RF gas-discharge plasma generators, hybrid plasma systems, diagnostic equipment, auxiliary and special technological equipment (room 222 of the UPM building) . Necessary equipment for practical exercises: computer and multimedia equipment (projector, marker board, Internet connection).

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

Main literature

1) A. Fridman (2011). Plasma chemistry. Cambridge university press: Cambridge, UK
2) J. Meichsner (2013). Non-thermal plasma chemistry and physics. CRC Press. Boca Raton, FL.
3) F.F. Chen, J.P. (2002). Chang Lecture notes on principles of plasma processing. Plenum/Kluwer Publishers: LA

Additional literature

1) Bychkov, V.; Vasiliev, M.; Koroteev, A. Electron-Beam Plasma: Generation, Properties, Applications; Moscow State Open University Publishers: Moscow, Russia, 1993.
2) Encyclopedia of low-temperature plasma. Chief editor V. Fortov. Moscow. Nauka, 2001. V. XI, sections XI-2, XI-4.9, XI-5.
3) Fridman (2013). Plasma medicine. John Wiley & Sons Ltd.: Chichster, West Sussex, UK.

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

Not used

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

Microsoft Office. Internet access.

9. Guidelines for students to master the course

The discipline presenting and studying are implemented in the following forms of activity:

• lectures aimed at obtaining the necessary information and how to use it in solving practical problems;

• practical classes aimed at enhancing the cognitive activity of students and acquiring skills for solving practical problems;

• independent extracurricular work is aimed at acquiring the skills of discipline problem self solving and is implemented in the form of special practical tasks in all discipline sections;

• consultations on lectures materials and self tuition.

The training course program provides for the acquaintance of students with the equipment and instruments used in the experiments, the features of the operation of the main and auxiliary systems of the experimental complex and a number of independent measurements on operating setups.

Successful mastering of the discipline requires intense student's self tuition. It includes:

- reading the recommended basic and additional literature;
- study of technical descriptions and manuals for the equipment used in experiments;
- preparation of proposals for setting up experiments within the framework of individual and group projects;
- familiarity with publications on the subject of studied topics.

The main indicators of knowledge of the material are the ability to demonstrate knowledge obtained from the materials of lectures, practical and laboratory classes, as well as recommended literature.

SUPPLEMENT

Assessment funds for course (training module)

major:	Applied Mathematics and Physics
specialization:	Beam-Plasma Systems and Technologies/Пучково-плазменные системы и технологии
	Phystech School of Aerospace Technology
	Chair of Logistics Systems and Technologies
term:	2
qualification:	Master

Semester, form of interim assessment: 4 (spring) - Exam

Author: T.M. Vasileva, candidate of biological sciences, associate professor

1. Competencies formed during the process of studying the course

Code and the name of the competence	Competency indicators
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)
Pro.C-3 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

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know:

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- features of processes in non-equilibrium plasmas;
- principles of operation and design of plasma-chemical reactors of various types;
- principles for calculating the main parameters characterizing the operating modes of plasma setups based on electron-beam plasma generators;
- plasma chemical reactors operation (beam-plasma reactors and hybrid-type reactors), features of their operation and maintenance;
- methods for measuring the main parameters characterizing the operating modes of plasma chemical reactors;
- basic parameters and target characteristics of plasma chemical reactors for technologies.

be able to:

- apply in practice the basic concepts used in the analysis and description of plasma-chemical processes in equilibrium and non-equilibrium plasmas;
- to predict the course of plasma-chemical transformations under various conditions, to choose the optimal method for obtaining products with the required properties and the required composition;
- to numerically estimate the key characteristics of plasma chemical processes and plasma-chemical reactors, as well as to numerically simulate plasma chemical processes in beam-plasma reactors, to optimize their operating regimes;
- to formulate the problem statement of the properties study for products of non-equilibrium plasma-chemical reactions;
- to determine (clarify) of obtaining products with desired properties by means of beam-plasma impact on mater;
- to master new subject areas, theoretical approaches and experimental techniques related to the analysis, design and application of industrial plasma systems based on electron-beam plasma

master:

- skills of mastering a large amount of interdisciplinary and special information;
- culture of setting goals in the field of design and application of plasma chemical reactors;
- initial skills in working on beam-plasma reactors, ensuring their reliable and safe operation.

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

The list of laboratory works, the implementation and delivery of which is required to be admitted to the exam.

- Materials modification by the Electron-Beam Plasma
- Polymers and biopolymers modification by RF discharge plasma.

• Powder materials treatment in Electron-beam plasma.
• Plasma chemical reactors of hybrid type.

4. Evaluation criteria

1. Classification and types of ionization processes. Direct and stepwise ionization.
2. Classification and types of ionization processes. Ionization under the action of high-energy electrons and electron beams.
3. Mechanisms of electron-ion recombination. Plasma-chemical transformations and reactions involving positive and negative ions.
4. Elementary processes involving excited atoms and molecules.
5. Excited particles, resonant and metastable states.
6. Dissociation of molecules under the influence of plasma, generation of radicals, radical plasma-chemical reactions.
7. Plasma-stimulated etching of the material surface.
8. Plasma-stimulated ozone generation.
9. Plasma-stimulated oxidation of nitric oxide (II).
10. Plasma-chemical fuel conversion
11. Plasma-chemical modification of (bio)organic polymers in the plasma of gas discharges: plasma-stimulated destruction of polymers, plasma-stimulated polymerization.
12. Plasma-stimulated oxidation of polymers under the action of plasma.
13. VUV-stimulated polymerization and degradation of polymers.
14. Approaches to modeling and experimental study of the kinetics of plasma-chemical modification of polymers.
15. Mechanisms of interaction of electron-beam plasma with proteins.
16. Mechanisms of interaction of electron-beam plasma with polysaccharides.
17. Synthesis of thin films and coatings in electron-beam plasma.
18. The main operating factors realized in electron-beam plasma during the modification of materials.
19. Mechanisms of interaction of high-energy beam electrons with biopolymers.
20. Mechanisms of interaction of X-ray bremsstrahlung generated in an electron-beam plasma with biopolymers.
21. Experimental approaches to differentiation of the effect of each of the factors on the material.
22. Experimental and theoretical approaches to controlling the modification of materials in an electron-beam plasma. Control of the integral energy input.
23. Control of temperature distribution and fluxes of fast electrons and active plasma particles over the surface of samples of various geometries.
24. The use of gas discharge plasma in biology and medicine: the use of gas discharge plasma for sterilization, inactivation of microorganisms. Mechanisms of interaction of chemically active plasma particles with cellular structures.
25. Application of gas discharge plasma in biology and medicine: tissue engineering and plasma surgery.
26. Beam-plasma technologies for obtaining bioactive peptides and oligosaccharides.
27. Beam-plasma technologies for the synthesis of biocompatible hybrid materials and coatings.
28. Application of plasma-chemical methods in the production of chemical catalysts.
29. Application of plasma-chemical methods in the processing of oil and oil products.
30. Possibilities and application of low-temperature plasma in chemistry, ecology and agricultural technology: plasma-chemical treatment of water and industrial waste.
31. Plasma installations used for plasma-chemical modification of various materials and solving biological and medical problems.
32. Electron-beam reactors for obtaining bioactive compounds and materials.
33. The main plasma-chemical factors affecting the structure and function of cells during treatment in plasma and the mechanisms of their action.

The mark is excellent 10 points - given to a student who has shown comprehensive, systematized, deep knowledge of the curriculum of the discipline, who is interested in this subject area, who has demonstrated the ability to confidently and creatively apply them in practice in solving specific problems, free and correct justification of the decisions made.

An excellent mark of 9 points is given to a student who has shown comprehensive, systematized, in-depth knowledge of the curriculum of the discipline and the ability to confidently apply them in practice in solving specific problems, free and correct justification of decisions made.

An excellent grade of 8 points is given to a student who has shown comprehensive, systematized, in-depth knowledge of the curriculum of the discipline and the ability to confidently apply them in practice in solving specific problems, the correct justification of the decisions made, with some drawbacks.

A good score of 7 points is given to a student if he firmly knows the material, expresses it competently and to the point, knows how to apply the knowledge gained in practice, but does not adequately substantiate the results obtained.

A good score of 6 points is given to a student if he firmly knows the material, expounds it competently and to the point, knows how to apply the knowledge gained in practice, but makes some inaccuracies in the answer or in solving problems.

A good score of 5 points is given to a student if he basically knows the material, expresses it competently and to the point, knows how to apply the knowledge gained in practice, but makes a large number of inaccuracies in the answer or in solving problems.

The mark is satisfactory 4 points - given to a student who has shown a fragmentary, scattered nature of knowledge, insufficiently correct formulations of basic concepts, a violation of the logical sequence in the presentation of the program material, but at the same time he has mastered the main sections of the curriculum necessary for further education and can apply the acquired knowledge in sample in a standard situation.

The mark is satisfactory 3 points - given to a student who has shown a fragmented, scattered nature of knowledge, makes mistakes in the formulation of basic concepts, disruptions in the logical sequence in the presentation of program material, poorly knows the main sections of the curriculum necessary for further education and hardly applies the acquired knowledge even in standard situations.

The score is unsatisfactory 2 points - given to a student who does not know most of the main content of the curriculum of the discipline, makes gross errors in the formulation of basic principles and does not know how to use the knowledge gained when solving typical problems.

The mark is unsatisfactory 1 point - given to a student who does not know the main content of the curriculum of the discipline, makes gross errors in the formulation of the basic concepts of the discipline and generally does not have the skills to solve typical practical problems.

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

The main indicators of the materials assimilation for discipline "Plasma Chemistry" are the assessments of the teacher during the midterm control, and on the final (exam) certification of the ability to demonstrate the knowledge gained from the study of lecture materials и practical exercises, answering basic and additional questions of the examination ticket.

Boundary control is applied in the following forms:

- assessment of answers to questions in the process of a short (up to 5 minutes) selective oral survey before the start of each practical lesson based on the materials of the previous lesson;
- assessment of the ability to solve at the blackboard and / or in writing typical examples and / or tasks considered in practical classes;

- assessment of activity and answers to questions when solving typical problems in accordance with the program of practical classes.

The exam in the discipline is the final stage of studying of the entire course. It is aims to check the knowledge of students in theory and identify the skills of their application in solving practical problems, as well as the skills of self tuition with the recommended basic and additional literature.

The exam is carried out orally on tickets approved by the head of the department. The examiner is given the right, in addition to the theoretical questions of the ticket, to give students tasks and examples, typical options of which were considered in practical classes. Students with the permission of the examiner can use lecture notes, seminars, reference books only during the preparation for the exam. Time is allotted for preparation for the exam and the survey in accordance with the approved standards.