COURSE DESCRIPTION

1. Program identification information

1.1 Higher education institution	**National University of Science and Technology Politehnica Bucharest**
1.2 Faculty	**Electronics, Telecommunications and Information Technology**
1.3 Department	**Electronic Devices, Circuits and Architectures**
1.4 Domain of studies	Electronic Engineering, Telecommunications and Information Technology
1.5 Cycle of studies	Masters
1.6 Programme of studies	Microsystems

2. Date despre disciplină

2.1 Course name (ro) (en)				Procese nanotehnologice avansate			
2.2 Course Lecturer				Colaborator Dr. Adrian Dinescu,			
2.3 Instructor for practical activities				Colaborator Dr. Adrian Dinescu			
2.4 Year of studies	2	2.5 Semester	I	2.6. Evaluation type	E	2.7 Course regime	Ob
2.8 Course type		DA	2.9 Course code	UPB.04.M3.O.03-13		2.10 Tipul de notare	Nota

3. Total estimated time (hours per semester for academic activities)

3.1 Number of hours per week	3	Out of which: 3.2 course	2.00	3.3 seminary/laboratory	1
3.4 Total hours in the curricula	42.00	Out of which: 3.5 course	28	3.6 seminary/laboratory	14
Distribution of time:					hours
Study according to the manual, course support, bibliography and hand notes Supplemental documentation (library, electronic access resources, in the field, etc) Preparation for practical activities, homework, essays, portfolios, etc.					20
Tutoring					0
Examinations					24
Other activities (if any):					0

3.7 Total hours of individual study	58.00
3.8 Total hours per semester	100
3.9 Number of ECTS credit points	4

4. Prerequisites (if applicable) (where applicable)

4.1 Curriculum	Fundamental Courses of Electronic Devices, MCEMI

4.2 Results of learning	General knowledge of physics, electronic devices and software simulation of electronic circuits

5. Necessary conditions for the optimal development of teaching activities (where applicable)

5.1 Course	The course will take place in a room equipped with a video projector or on the MSTeams platform
5.2 Seminary/ Laboratory/Project	The project will take place in a specific room, which must include: computers, Internet connection, SPICE electronic circuit simulator or MSTeams platform, etc, students with computers with a SPICE simulator installed.

6. General objective *(Reffering to the teachers' intentions for students and to what the students will be thought during the course. It offers an idea on the position of course in the scientific domain, as well as the role it has for the study programme. The course topics, the justification of including the course in the currcula of the study programme, etc. will be described in a general manner)*

This discipline is studied within the field of Electronic Engineering, Telecommunications and Information Technologies, the specialization Microelectronics and nanoelectronics and aims to familiarize students with the main approaches, the, methods and technologies used in the field of nanofabrication of nanoelectronic devices.

The course presents the main technologies in the field of nanofabrication as well as several nanoelectronic devices that can be made with their help. Large chapters addressed:

Introduction to micro-nanofabrication

Additive processing methods: CVD (vapor phase chemical deposition)

PVD (evaporation: thermal and electron beam)

MBE (molecular beam epitaxy)

Lithographic methods : optical lithography, electron beam lithography

Substractive processing methods: plasma corrosion (RIE, DRIE)

Doping methods: diffusion and ion implantation

Methods of characterization of nanostructures: optical microscopy, electron scaling microscopy, transmission electron microscopy, EDX, X ray diffraction, Raman spectroscopy, atomic force microscopy

Manufacturing technology of nanotransistors based on 2D materials and silicon nanowires

7. Competences *(Proven capacity to use knowledge, aptitudes and personal, social and/or methodological abilities in work or study situations and for personal and proffesional growth. They refflect the empolyers requirements.)*

Specific Competences	Demonstrates advanced knowledge of fundamental elements relating to devices, circuits, systems, instrumentation and electronic technology. It correlates knowledge related to the design, simulation and testing of devices, integrated circuits, micro and nanoelectronic systems with modern software tools. Apply in practice the knowledge regarding the modeling and processing of integrated devices and circuits using advanced technologies. Arguments and analyses consistently and correctly the context of applying basic knowledge on the design, simulation and testing of optoelectronic devices, circuits and systems with modern micro-and nanoelectronic software tools and technologies. Oral and written communication in Romanian: use the scientific vocabulary specific to the field. Oral and written communication in a foreign language (english): it dominates the understanding of the vocabulary related to the field.
Transversal (General) Competences	Analytical and synthesis capability: summarises the knowledge acquired on new technologies following a systematic review process. Autonomy and critical thinking: the ability to think in scientific terms, to search and analyze data independently, as well as to present/identify solutions in a new context. Work in a team and communicate effectively by coordinating efforts with others to solve problem situations of average complexity.

8. Learning outcomes *(Synthetic descriptions for what a student will be capable of doing or showing at the completion of a course. The learning outcomes reflect the student's acomplishments and to a lesser extent the teachers' intentions. The learning outcomes inform the students of what is expected from them with respect to performance and to obtain the desired grades and ECTS points. They are defined in concise terms, using verbs similar to the examples below and indicate what will be required for evaluation. The learning outcomes will be formulated so that the correlation with the competences defined in section 7 is highlighted.)*

Knowledge	*The result of knowledge aquisition through learning. The knowledge represents the totality of facts, priciples, theories and practices for a given work or study field. They can be theoretical and/or factual.* List types of nanotechnologies Defines the characteristics of nanostructures Describe/classify lithographic techniques Highlights the peculiarities of special constructive solutions

Skills	*The capacity to apply the knowledge and use the know-how for completing tasks and solving problems. The skills are described as being cognitive (requiring the use of logical, intuitive and creative thinking) or practical (implying manual dexterity and the use of methods, materials, tools and intrumentation).* Select and group relevant information about nanostructures Arguably uses specific principles . Work productively in a team to carry out the project. Elaborates a scientific text in the drafting of the project Experimentally check the solutions of the threshold voltage extraction by several methods. Solves practical applications within the project. Adequately interprets causal relationships between extracted values. Analyzes and compares the value of the threshold voltage. Identifies solutions and elaborates the discipline project. Conclusions on the experiments carried out. Arguments the solutions identified in the project .
Responsability and autonomy	*The student's capacity to autonomously and responsably apply their knowledge and skills.* **Select appropriate bibliographic sources and analyze them.** **Respect the principles of academic ethics, correctly quoting the used bibliographic sources.** **Demonstrate responsiveness for new learning contexts.** **Demonstrates collaboration with other colleagues and teachers in carrying out teaching activities** **Demonstrates autonomy in organizing the learning process/context or problem-solving situation** **Promotes/contributes through new solutions, related to the specialty field.** **Awareness of the value of its contribution to the field of engineering in identifying viable/sustainable solutions** **Apply ethical principles**

9. Teaching techniques *(Student centric techniques will be considered. The means for students to participate in defining their own study path, the identification of eventual fallbacks and the remedial measures that will be adopted in those cases will be described.)*

Building on the analysis of students' learning characteristics and their specific needs, the teaching process will explore teaching methods both expository (lecture, exposure) and conversational-interactive, based on learning by discovery models facilitated by direct and indirect exploration of reality (experiment, demonstration, modeling), but also on action-based methods such as exercise, exercise, and, practical activities and problem solving.

Lectures will be used in the teaching activity, based on PowerPoint presentations or different Internet pages that will be made available to students. Each course will start with the recapitulation of the chapters already covered, with an emphasis on the notions taken at the last course.

The presentations use images and schemes so that the information presented is easily understood and assimilated.

This discipline covers information and practical activities designed to support students in their learning efforts and to develop optimal relationships of collaboration and communication in a climate conducive to learning through discovery.

The practice of active listening and assertive communication skills, as well as feedback building mechanisms, will be considered, as ways of behavioral regulation in various situations and of adapting the pedagogical approach to the learning needs of the students.

The ability to work in teams to solve different learning tasks will be practiced.

The attention of students will be checked by rapid tests (quizz type) during or at the end of the course at certain courses.

10. Contents

COURSE		
Chapter	**Content**	**No. hours**
1	Chapter 1. Introduction 1.1 Course theme 1.2. Overview of specific objectives 1.3. Project overview	2
2	Chapter 2. Additive processing technologies/submission of thin layers with nanometric thickness: 2.1. Elements of vacuum technique 2.2. CVD (vapor phase chemical deposits) at both low pressure (LPCVD) and plasma-assisted (PECVD) or metal-organic (MOCVD) deposition, 2.3. PVD - physical vapour deposition (thermal evaporation and electron beam evaporation) and cathode spraying (sputtering) 2.4. Epitaxial deposits from liquid phase and molecular beam (MBE)	6
3	Chapter 3. Lithographic nanoscale configuration technologies: 3.1. Introduction to lithography and nanolithography (including SPM and NIL methods) 3.2. Optical lithography including DUV and EUV 3.3. Electron beam lithography	4
4	Chapter 4. Substractive processing technologies of nanostructures and devices. 4.1. Wet corrosion 4.2. Corrosion in plasma 4.3. RIES 4.4. DRIEFS 4.5. Ion beam corrosion.	4
5	Chapter 5. Nanometric scale characterization methods: 5.1. Optical microscopy 5.2. SEM-electronic scanning microscopy 5.3. TEM-electronic transmission microscopy 5.4. AFM - atomic force microscopy 5.5. EDX X ray spectroscopy in SEM 5.6. XRD-ray diffraction X 5.7. Raman Spectroscopy	4
6	Chapter 6. Semiconductor junction manufacturing technologies (doping): diffusion method and ion implantation method.	4

7	Chapter 7. Production fluxes of nanotransistors with a field effect based on single and two-dimensional materials (carbon nanotubes, graphene, MoS2, SnS) and silicon nanowire base, based on, on SOI type substrate.	4
	Total:	28

Bibliography:

1. M.A. Dinescu Procese Nanotehnologice Avansate https://curs.upb.ro/2023/enrol/index.php?id=9679
2. https://curs.upb.ro/2021/enrol/index.php?id=9507
3. Scanning Microscopy for Nanotechnology: Techniques and Applications,Weilie Zhou (Editor), Zhong Lin Wang (Editor),Hardcover (November 2006
4. M.Dragoman and D.Dragoman, 2D Nanoelectronics: Physics and devices of atomically thin materials, Springer, 2017
5. Semiconductor Micromachining : Fundamental Electrochemistry and Physics, H.- J. Lewerenz (Editor), S. A. Campbell (Editor),Paperback (April 1998),John Wiley & Sons; ISBN: 04719668
6. Thin Film Deposition : Principles and Practice,Donald L. Smith, Hardcover (May 1994)
7. Handbook of Microlithography, Micromachining, and Microfabrication : Micromachining and Microfabrication,P. Rai-Choudhury (Editor),Hardcover Vol 002 (September 1997)

LABORATORY

Crt. no.	Content	No. hours
1	Increases and deposits of thin layers by chemical methods: thermal oxidation, CVD, ALD	2
2	Deposits of thin layers by physical methods: electron beam evaporation and cathodic spraying	2
3	Plasma corrosion:RIE and DRIE	4
4	Deotolitography	4
5	Electron beam lithography	4
6	Electronic scanning microscopy: SEM and Spectroscopic methods: EDX, Raman, XRD	8
7	Final verification	4
	Total:	28

Bibliography:

1. M.A. Dinescu Procese Nanotehnologice Avansatehttps://curs.upb.ro/2023/enrol/index.php?id=9679
2. https://curs.upb.ro/2021/enrol/index.php?id=9507
3. Handbook of Microlithography, Micromachining, and Microfabrication : Microlithography,P. Rai-Choudhury (Editor),Hardcover Vol 001 (June 1997),SPIE Press; ISBN: 081942378
4. Semiconductor Micromachining : Techniques and Industrial Applications,H.- J. Lewerenz (Editor), S. A. Campbell (Editor),Paperback Vol 2 (April 1998),John Wiley & Sons; ISBN: 0471966827
5. The Science and Engineering of Microelectronic Fabrication,Stephen A. Campbell,Hardcover - 536 pages (March 1996),Oxford University Press; ISBN: 0195105087

11. Evaluation

Activity type	11.1 Evaluation criteria	11.2 Evaluation methods	11.3 Percentage of final grade
11.4 Course	Theoretical knowledge of advanced nanotechnology processes	Theoretical knowledge of advanced nanotechnology processes	30%
	Assessment of the knowledge presented on the basis of the arguments in the various issues	Exam	50%
11.5 Seminary/laboratory/project	The evaluation shall be cumulative to an intermediate project verification period (midterm) and to a final verification deadline.	Oral verification of the solutions chosen for the project	20%
11.6 Passing conditions			
Ability to develop an elementary technological flow of FET manufacturing on 2D materials. Obtaining 50% of the total score. Obtaining 50% of the activity score during the semester. Compliance with the UNSTPB regulation on promotion conditions.			

12. Corroborate the content of the course with the expectations of representatives of employers and representative professional associations in the field of the program, as well as with the current state of knowledge in the scientific field approached and practices in higher education institutions in the European Higher Education Area (EHEA)

- Through the activities carried out, students develop skills to provide solutions to problems and propose ideas for improving the situation of existence in the field of nanofabrication of nanoelectronic devices

– In the development of the content of the discipline, knowledge, phenomena described by the literature and their own published research were taken into account .

- Through activities related to the presentation of the main technologies in the field of nanofabrication and manufacturing of nanoelectronic devices, the development of the graduate's skills to manage practical situations that can be faced in real life is envisaged in order to increase its contribution to the improvement of the socio-economic environment.

Date	Course lecturer	Instructor(s) for practical activities
09.09.2024	Colaborator Dr. Adrian Dinescu	Colaborator Dr. Adrian Dinescu

Date of department approval	Head of department
31.10.2024	Prof. Dr. Claudius DAN
Date of approval in the Faculty Council	Dean
01.11.2024	Prof. Dr. Mihnea Udrea