COURSE OUTLINE

(1) GENERAL INFORMATION

SCHOOL	SCHOOL OF APPLIED MATHEMATICAL AND PHYSICAL SCIENCES		
DEPARTMENT	SCHOOL OF APPLIED MATHEMATICAL AND PHYSICAL SCIENCES		
LEVEL OF STUDIES	POSTGRADUATE		
MSc PROGRAM	MICROSYSTEMS AND NANODEVICES		
COURSE CODE	**9954**	**SEMESTER**	**1**
COURSE TITLE	NANOELECTRONIC DEVICES		

INDEPENDENT TEACHING ACTIVITIES *In cases where credits are awarded to discrete parts of the course (e.g., Lectures, Laboratory Exercises, etc.), specify them. If credits are awarded as a whole, specify weekly teaching hours and total credits.*	**WEEKLY TEACHING HOURS**	**ECTS**
Lectures – Exercises	2	4
Laboratory	0.5	
Assignments	0.5	
(Additional rows may be added if necessary. Detailed descriptions of teaching organization and methods are provided in section (d).)		

COURSE TYPE *general background, specialized background, specialization, skill development*	SPECIALIZATION (for Stream or Specialization Compulsory Courses)
PREREQUISITES:	[REQUIRED BACKGROUND KNOWLEDGE]: Physics of Semiconductor Devices, Technological Processes for Integrated Circuit Fabrication, and Electronics
LANGUAGE OF INSTRUCTION and EXAMINATION:	GREEK
COURSE AVAILABLE TO ERASMUS STUDENTS	YES (offered in English as a reading course).
COURSE WEBSITE (URL)	https://helios.ntua.gr/enrol/index.php?id=3010#section-1

(2) LEARNING OUTCOMES

Learning Outcomes

This section describes the learning outcomes of the course, specifying the knowledge, skills, and competencies at the appropriate level that students will acquire upon successful completion of the course.

Refer to Appendix A:

- *Description of the Level of Learning Outcomes for each cycle of studies according to the European Higher Education Area Qualifications Framework*
- *Descriptive Indicators for Levels 6, 7, & 8 of the European Qualifications Framework for Lifelong Learning and Appendix B.*
- *Concise Guide to Writing Learning Outcomes*

Knowledge:

This course provides a comprehensive overview of the global field of nanoelectronic devices, with a specific focus on MOSFET transistors, the integration of innovative materials to enhance transistor properties, and the introduction of alternative devices for both data processing and storage. The course thoroughly examines the fundamental operation of the MOSFET transistor and explores various phenomena that arise during device miniaturization. Detailed explanations are provided for the extraction and analysis of essential electrical characteristics of these devices.

Additionally, the course delves into the neuromorphic properties of nanoelectronic devices, discussing their potential applications in brain-inspired computing systems. The course also covers nanoparticle sensor technologies, addressing their relevance and applications in the context of nanoelectronics.

Skills:
Upon completion of the course, students will be able to:

- **Differentiate between various types of transistors** and understand the physical mechanisms underlying their operation.
- **Outline the steps required to characterize a transistor**, detailing the procedure and necessary measurements.
- **Explain experimental performance characteristics** of electronic devices by selecting the most appropriate physical models.
- **Calculate the electrical characteristics of nanodevices** (e.g., current as a function of applied voltages) based on the device's technology and materials.
- **Identify the role of new materials** (such as 2D materials, carbon nanotubes, and nanoparticles) in enhancing device functionality.
- **Recognize different types of gate dielectrics** used in transistors and their impact on performance.
- **Understand the various types of memory and sensor devices**, along with their applications.
- **Identify neuromorphic properties** in nanoelectronic devices and their implications for brain-inspired computing.

General Competencies

Considering the general competencies that graduates are expected to acquire (as stated in the Diploma Supplement), which competencies does this course aim to develop?.

Data search, analysis, and synthesis, utilizing necessary technologies *Adaptability to new situations* *Decision-making* *Independent work (primarily through assignments completed at home)* *Teamwork* *Working in an international environment* *Working in an interdisciplinary environment*	*Generation of new research ideas* *Project design and management* *Respect for diversity and multiculturalism* *Respect for the natural environment* *Exhibiting social, professional, and ethical responsibility and sensitivity to gender issues* *Critical and self-critical thinking* *Promotion of free, creative, and inductive thinking*

Competencies:
Upon successful completion of the course, students will develop the ability to:

- **Work Independently** (and, secondarily, collaboratively through group assignments).
- **Classify various nanoelectronic devices** and identify their specific properties.
- **Formulate a technological problem** and determine the most suitable approach for solving it.
- **Design innovative systems** using electronic devices tailored to address specific technological challenges.
- **Integrate knowledge** to analyze complex technological problems and identify optimal solutions.
- **Evaluate the technological capabilities of microelectronics** for the purpose of designing appropriate semiconductor devices.

(3) COURSE CONTENT

- **MOSFET Devices**: Extraction of fundamental characteristics for long-channel MOSFETs, subthreshold operation, and channel mobility.
- **Short-Channel Effects**: Speed saturation, scaling theory, and ballistic transport phenomena.
- **Ballistic Transistors**: Landauer formalism, propagation, operation, and characteristics of ballistic transistors; transitioning from ballistic to semiclassical transistors.
- **Quantum Devices**: Tunnel diodes, single-electron transistors, Coulomb blockade, and double quantum dot systems (qubits).
- **MOSFET on Silicon on Insulator (SOI)**: Partially and fully depleted devices, multi-gate devices, FinFETs, nanowire devices, tunnel FETs, and neuromorphic properties.
- **High-K Dielectrics in Transistors**: High-k dielectric materials, new gate materials, and high-

mobility substrates (e.g., germanium, 2D materials, carbon nanotubes). • **Electronic Memory Devices**: Volatile and non-volatile memories, single-electron memories. • **Resistive Switching Memories and Neuromorphic Applications**: Analysis of resistive switching memories and their use in neuromorphic systems.

(4) TEACHING AND LEARNING METHODS - ASSESSMENT

TEACHING METHOD *In person, Distance Learning etc.*	In person
USE OF INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT) *Use of Information and Communication Technologies (ICT) in Lecturing, Laboratory Training, Communication with Students*	Course Notes, Assignments for Home Study **(**Assignments are provided by the lecturer, and students are required to submit completed work.)
ORGANIZATION OF TEACHING *A detailed description of the teaching methods and approaches used in the course, which may include:* *Lectures, Seminars, Laboratory Exercises, Fieldwork, Study and Analysis of Bibliography, Tutorials, Internships, Clinical Exercises, Art Workshops, Interactive Teaching, Educational Visits, Project Development, Report Writing/Assignments, Artistic Creation.* *The student's study hours for each learning activity, as well as hours of independent study, are outlined in accordance with ECTS principles.*	see table below

Activity	***Semester Workload***
Lectures	3x11=33 hours
Study	3x11=33 hours
Home Assignments/Exercises	3x2=6 hours
Laboratory	3x2=6 hours
Completion/Presentation of Project	25x1=25 hours
Educational Visits	0
Examinations	2 hours
Total Course Load	115 hours [ECTS×13×2,2]

STUDENT ASSESSMENT *Description of the Assessment Process* *Language of Assessment, Assessment Methods, Formative / Summative Assessment Methods, Multiple-choice tests, Short-answer questions, Essay-style questions, Problem-solving exercises, Written assignments, Reports, Oral examinations, Public presentations, Laboratory work, Clinical patient examinations, Artistic interpretations, Other methods, as appropriate* *The assessment criteria are clearly defined and provided to students, ensuring transparency in the evaluation process. These criteria are accessible through the course's online platform where students can review them at any time.*	**Language of Assessment:** Greek (for Erasmus students: English) **Home Assignments:** 10% of the final grade **Written Examination (problem-solving):** 50% of the final grade **Laboratory**: 10% of the final grade **Completion/Presentation of Project** 30% of the final grade Explicit mention of these assessment criteria will be available on the Helios platform.

(5) RECOMMENDED BIBLIOGRAPHY

Recommended Bibliography

- D. K. Schroder: "Semiconductor Material and Device Characterization", Wiley and Sons, (2005).
- https://www.amazon.com/Modern-Semiconductor-Devices-Integrated-Circuits/dp/0136085253
- https://www.amazon.com/Integrated-Microelectronic-Devices-Physics-Modeling/dp/0134670906
- S. M. Sze: "Physics of Semiconductor Devices", Willey Interscience, 3rd edition (2007).
- R. M. Warner, Jr. and B. L. Grung: "MOSFET Theory and Design", Oxford University Press, Oxford, (1999).
- Marius Grundmann: "The Physics of Semiconductors - An Introduction Including Nanophysics and Applications", Second Edition, Springer-Verlag Berlin, (2010).
- David L. Pulfrey: "Understanding Modern Transistors and Diodes", Cambridge University Press, (2010).
- D. Ielmini and R. Waiser: "Resistive Switching: From Fundametals of Nanoionic Porcesses to Memristive Device Applications", Wiley and Sons, (2016).

- Mark Lundstrom and Jung Guo, Nanoscale Transistors: Physics, Modeling, and Simulation, Springer, New York, USA, 2006
- Single Charge Tunneling, Coulomb Blockade Phenomena in Nanostructures, eds. H. Grabert and Michel H. Devoret, NATO ASI Series B 294 (Plenum Press, New York, 1992).
- Quantum Transport in Ultrasmall Devices, eds. D. K. Ferry, H. L. Grubin, C. Jacoboni, and A. Jauho, NATO ASI Series B 342 (Plenum Press, New York, 1995).

Relevant Scientific Journals

- Applied Physics Letters
- IEEE Transactions on Electron Devices
- IEEE Electron Device Letters