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	**9952**	**SEMESTER**	**1**
COURSE TITLE	PHYSICS OF SEMICONDUCTING MATERIALS AND 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	4	7.5
Laboratory	1	
(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*	GENERAL BACKGROUND (for Core Courses)
PREREQUISITES:	[REQUIRED BACKGROUND KNOWLEDGE]: Quantum Mechanics, Statistical Physics, Condensed Matter Physics, Electromagnetism
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/course/view.php?id=3004

(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 focuses on the physical properties (structural, electrical, crystallodynamic, optical, and optoelectronic) of semiconductor materials and related devices. Beginning with the band structure of materials, it explores the phenomena of intrinsic and extrinsic carriers in homogeneous solid materials. The course then examines phenomena in heterogeneous systems and interfaces, such as p-n junctions, metal-semiconductor contacts, MOS structures, and transistors. The latter part of the course (over 50%) is dedicated to the study of low-dimensional systems, and quantum effects and systems, combining semiconducting, superconducting and topological materials ad effects including quantum wells, quantum wires, two-dimensional electron gases, layered materials, and semiconductor-superconductor contacts. Emphasis is placed on the electronic/electrical, optical, and magnetic properties of these low-dimensional systems, providing an in-depth understanding of advanced semiconductor physics and applications.

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

- Understand the concept of different charge carriers in a semiconductor (electrons and holes), their dispersion relations, and their effective masses.
- Comprehend the concept of density of states and its dependence on the topology (dimensions) of the system.
- Explain the difference between intrinsic and extrinsic semiconductors and their behavior as a function of temperature.
- Calculate the Fermi level in intrinsic and extrinsic systems, as a function of temperature and other system parameters.
- Determine electrical characteristics of a given semiconductor device, including contact potential, carrier concentrations, and currents.
- Generate characteristic voltage-current curves in semiconductor circuits.
- Understand the role of artificial boundary/periodic conditions in low-dimensional systems and the coexistence of continuous and discrete energy spectra.
- Recognize the interaction of low-dimensional electronic systems with a static electric or magnetic field or with an electromagnetic wave of optical frequencies.

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 in teams, encouraged by collaborative problem-solving exercises).
- Select Appropriate Physical Parameters/Variables that define a physical/scientific problem.
- Formulate a Physical/Scientific/Technological Problem in Mathematical Terms, translating complex concepts into mathematical language.
- Search, Analyze, and Synthesize Data and Information, adapting them to specific scientific problems with necessary and reasonable approximations.
- Combine Knowledge and Skills for the analysis of complex problems, often using suitable approaches and approximations.

(3) COURSE CONTENT

Course Modules

Unit-A Bulk semiconductors. Band structure: Direct – indirect energy gap. Electron-hole dispersion relations and the effective mass at band-extreme points. Excitons. Density of States in 1-, 2-, 3-dimensions and carrier concentration. Fermi level of intrinsic semiconductors. Fermi level of extrinsic semiconductors. Majority and minority carriers. Fermi level of heterogeneous systems and band- alignment. Build-in contact potential. Coupled quantum wells. Super-lattices. Mini-bands mini-gaps and density of states. Quantum wires and Density of States **Unit-B** Carrier Transport phenomena. P-n junction: electrostatics, current-voltage characteristic and modeling. Metal-semiconductor junction: Ohmic and Schottky contacts. MOS two-terminal device: electrostatics, capacitance-voltage characteristic and modeling. Transistor MOSFET: current-voltage characteristics and modeling. **Unit-C** Low-dimensional systems and characteristic-length-time scales. Band alignment in heterogeneous systems and the formation of quantum wells. Tetragonal-trigonal-parabolic quantum wells. Continuous spectrum of quantum wells and transport properties. Reflection and Transmission matrices. Electric and Magnetic field in low-dimensional systems. Quantum Hall effect. Bohm-Aharonov effect. Optical absorption in quantum wells. Fullerenes. Carbon nanotubes. Graphene (structural and electronic properties, Dirac particles). Magnetic properties, spin transport, applications. Superconductivity: basic properties, Josephon junctions (DC and AC), type I and II superconductors, theories London, Ginzburg-Landau and BCS, high temperature superconductors, applications. Topological materials and Berry phase

(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
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*	**Language of Assessment:** Greek (for Erasmus students: English) **Home Assignments:** 10% of the final grade **Written Examination (problem-solving):** 80% of the final grade **Completion/Presentation of Project** 10% of the final grade Explicit mention of these assessment criteria will be available on the Helios platform.

Activity	*Semester Workload*
Lectures	13x4=52 hours
Study	13x4=52 hours
Home Assignments/Exercises	10x3=30 hours
Laboratory	0
Completion/Presentation of Project	10x3=30 hours
Educational Visits	0
Examinations	3 hours
Total Course Load	167 hours

accessible through the course's online platform where students can review them at any time.	

(5) RECOMMENDED BIBLIOGRAPHY

Recommended Bibliography

Review Literature – Properties of Semiconductors

- S. M. Sze, *Semiconductor Devices, Physics and Technology*, Wiley, NY, 1985
- B. G. Streetman, S. Banerjee, *Solid State Electronic Devices*, Prentice Hall, UK, 2000
- S. O. Kasap, *Principles of Electronic Materials and Devices*, McGraw Hill, NY, 2002 [Also available in Greek translation from Papasotiriou Publications]
- H. Ibach, H. Luth, *Φυσική Στερεάς Κατάστασης* (Solid State Physics), Ziti Publications, 2012

Bibliography for Low-Dimensional Semiconductor Systems

- M. J. Kelly, *Low-Dimensional Semiconductors (Materials, Physics, Technology, Devices)*, Oxford University Press, 1995
- P. K. Basu, *Theory of Optical Processes in Semiconductors – Bulk and Microstructures*, Oxford University Press, 1997
- D. K. Ferry, S. M. Goodnick, *Transport in Nanostructures*, Cambridge University Press, 1997
- J. H. Davies, *The Physics of Low-Dimensional Semiconductors – An Introduction*, Cambridge University Press, 1998
- V. M. Mitin, V. A. Kochelap, M. A. Stroscio, *Quantum Heterostructures – Microelectronics and Optoelectronics*, Cambridge University Press, 1999
- P. Harrison, *Quantum Wells, Wires, and Dots: Theoretical and Computational Physics*, John Wiley & Sons, 2001
- E. L. Wolf, *Nanophysics and Nanotechnology*, Wiley, 2004
- Z. Gaburro, L. Pavesi, *Nanostructured Silicon for Photonics*, Trans Tech Publications, 2005
- G. W. Hanson, *Fundamentals of Nanoelectronics*, Pearson Prentice Hall, 2008