COURSE OF STUDY *Physics (LM-17)*

ACADEMIC YEAR *2024-2025*

ACADEMIC SUBJECT *Optoelectronics and Nanotechnologies*

General information	
Year of the course	1st
Academic calendar (starting and ending date)	2nd semester: March – May 2025
Credits (CFU/ECTS):	6
SSD	FIS/03
Language	English
Mode of attendance	Compulsory

Professor/ Lecturer	
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Department and address	Physics Department, via Amendola 173
Virtual room	
Office Hours (and modalities: e.g., by appointment, on line, etc.)	Monday, 15:00 – 17:00; Wednesday, 16:00 – 18:00

Work schedule			
Hours			
Total	Lectures	Hands-on (laboratory, workshops, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
150	32	30	88
CFU/ECTS			
6	4	2	

Learning Objectives	Provide basic and advanced knowledge on the working principle of the main solid-state optoelectronic devices, such as LEDs, III-V heterostructures, lasers, photodetectors and optical fibers. Capability to follow the scientific and technological evolution in the optoelectronics field with related industrial applications.
Course prerequisites	Background knowledge on quantum physics, statistical physics and solid-state physics at the level of bachelor's degree in physics. Knowledge of condensed matter physics and optics.

Teaching strategies	Lectures in the teaching room with the aid of a laptop and a projector. Laboratory activities supervised.
Expected learning outcomes in terms of	
Knowledge and understanding on:	○ Understanding the scientific method, the nature, and the methods of research in Physics ○ Acquire knowledge on the structure of matter, with particular attention to condensed matter and photonics applications ○ Acquire knowledge on optical, electronic and thermal properties of solid state systems

	o Knowledge of opto-electronic devices and of the related applications o Explain fundamental physics and technical base of optoelectronics systems. o Identify relevant properties of semiconductor materials and their quantum structures for the design and fabrication of optoelectronic devices. o Classify optoelectronic devices and their state-of-the-art performance o Familiarize with the state-of-the-art knowledge on optoelectronics and photonics with emphasis on contemporary optoelectronic devices
Applying knowledge and understanding on:	o Ability to identify the essential elements of a phenomenon o Ability to use analogy to apply known solutions to new problems (problem solving) o Ability to design and implement experimental or theoretical procedures to solve problems in academic and industrial research or to improve existing results o Ability to use analytical and numerical mathematical computation tools o Acquire basic concepts for the design and fabrication of quantum heterostructures with desired properties. o Measure basic characteristics of devices o Conduct experiments and measurements in laboratory and on real components, devices and equipment of optoelectronic systems o Interpret the acquired data and measured results
Soft skills	● **Making judgments and choices** o Ability to work with increasing levels of autonomy, including taking responsibility in project planning and managing facilities. o Operate with optical components and laser source in a laboratory framework o Identify current research themes and technologies in the field of optoelectronic devices and integration, study the relevant literatures and present a critical analysis of the results. ● **Transferable communication skills** o Competence in communication in Italian and English in advanced fields of Physics o Explain basic operational principles of optoelectronic devices o Skills in the exposition of physical phenomena and communicating experimental results using appropriate scientific language. ● **Lifelong learning skills** o Acquisition of basic knowledge tools for continuous learning and knowledge updates o Ability to learn effective approaches from the critical analysis of crucial inventions in optoelectronics and photonics o Take part in teamwork and be able to independently present various professional materials. o Ability to present the results of a scientific work o Follow scientific and technological developments using the basic concepts acquired during the lessons
Syllabus	
Content knowledge	**III-V semiconductors.** Critical review of structural, electronic and optical properties of semiconductors: GaAs, $Al_xGa_{1-x}As$, In1-xGaxAsyP1-y, InP, GaN. Principles of bandgap engineering using quantum heterostructures. Interband and inter-subband transitions.

	Light emitting diodes (LEDs). Criteria for the choice of materials. Internal quantum efficiency. Spontaneous emission rates as a function of the injection regime. External efficiency. Heterojunction LEDs. L-I-V characteristics. Thermal effects. Temporal response. **Semiconductor lasers.** Stimulated emission in semiconductor structures. Optical gain. Conditions for population inversion. Double heterojunction laser diodes (LDs). Influence of electrical pumping on the dielectric function of a semiconductor active medium. Laser threshold. Current threshold. L-I-V characteristics. External efficiency. Spectral characteristics. Optical modes of a LD. Solution of the Helmholtz equation in the effective index approximation. Gain guiding and index guiding cavities. Single-mode LDs for telecommunications. Distributed feedback lasers. **Quantum well lasers**. Influence of Auger effect on the long wavelength limits of LEDs and LDs. Quantum cascade lasers. (QCLs). Quantum dot lasers. Vertical cavity surface emitting lasers (VCSELs). Self-mixing in laser diodes: principles and applications. Photolithographic fabrication of LDs. **Semiconductor photodetectors**. Quantum efficiency and detectivity. Photodiodes. Photoconductors. p-i-n photodiodes. Criteria for the choice of materials. Avalanche photodiodes. Quantum well IP. **Optical fibers.** Basic telecom systems. Wavelength and frequency division multiplexing. Classes of optical fibers. Modal dispersion. Index dispersion. **Laboratory activities.** Optical coupling between a diode laser and a hollow core fiber. Modal analysis of the beam profile at the fiber exit. Measurement of the optical loss and the divergence of the beam at the fiber exit.
Texts and readings	J. Singh, “Semiconductor optoelectronics”, Mc Graw Hill, 1995. G. P. Agrawal, N. K. Dutta, “Semiconductor lasers”, Van Nostrand Rehinhold, 1993. J. Faist, “Quantum Cascade Lasers”, Oxford University Press, 2013.
Notes, additional materials	Selected Chapters
Repository	Lecture notes at the website: http://polysense.poliba.it/index.php/optoelectronics-and-nanotechnologies/

Assessment	
Assessment methods	Oral exam with evaluation of the written report on laboratory activities
Assessment criteria	● *Knowledge and understanding:* o Knowledge of the optical and electronic properties of optoelectronic devices o Understanding the working principle of a diode laser and waveguides ● *Applied knowledge and understanding:* o Ability to apply the knowledge acquired on optoelectronic devices in a predictive and quantitative way it in the field of nanotechnologies ● *Making judgments and choices*: o Critical ability to select appropriate physical models to interpret phenomena involving optoelectronic devices ● *Communication skills*: o Clarity and conciseness in the expository and discussion of a physical phenomenon ● *Ability to learn:*

	o Ability to use fundamental concepts of classical and quantum mechanics to explain physical phenomena involving optoelectronic devices and their applications
Final exam and grading criteria	The final grade is expressed on a 30-point scale. The minimum passing grade is 18/30, the maximum grade is 30/30 cum laude. The final exam will consist of the discussion of the technical report drawn up by the student in the form of a scientific article regarding the laboratory activities (50% of the final grade), and an oral part with discussion of two topics among them covered during lessons (50% of the final grade).
Further information	