General information		
Academic subject	Optoelectronics and Nanotechnologies	
Degree course	Physics	
Academic Year	1st	
European Credit Transfer and Accumulation System (ECTS)		6
Language	English	
Academic calendar (starting and ending date)		2nd semester, first week of March – Last week of May
Attendance	Attending the lectures is strongly recommended. Attending the laboratory sessions is compulsory.	

Professor/ Lecturer	
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Department and address	Dipartimento Interateneo di Fisica, room 224
Virtual headquarters (Microsoft Teams code)	
Tutoring (time and day)	The students are invited to send an e-mail to arrange a meeting

Syllabus	
Learning Objectives	The objective of the course is to provide the basis for understanding the main physical properties of optoelectronic devices. An important goal is the understanding of relevant structural, electronic and optical properties of III-V semiconductors and how to design and modify such properties using heterostructures and quantum well structures to achieve specific device functionalities. Special attention will be posed to assess the figures of merit and the physical limits of various approaches for the design and fabrication of advanced optoelectronic devices. A relevant objective is also the hands-on learning of advanced experimental techniques for the fabrication and characterization of materials and devices using research-grade instrumentation such as clean-room facilities, atomic force microscopy (AFM), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR) and microprobe Raman scattering.
Course prerequisites	Background knowledge of solid state physics, quantum physics, statistical physics at the level of bachelor degree in physics. Basic knowledge of condensed matter physics and laser physics.
Contents	Critical review of structural, electronic and optical properties of relevant III-V semiconductors (GaAs, AlxGa1-xAs, In1-xGaxAsyP1-y, InP, GaN). Principles of bandgap engineering using quantum heterostructures. Inter-band and inter-subband transitions. Laboratory activity: micro-probe Raman and FTIR characterization of materials and heteroctructures for optoelectronics. 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). Photolithography and nanotechnologies for the fabrication of optoelectronic devices in clean room.

	Laboratory activity: e-beam thin-film deposition and characterization. Semiconductor photodetectors. Quantum efficiency and detectivity. Photodiodes. Photoconductors. p-i-n photodiodes. Criteria for the choice of materials. Avalanche photodiodes. Quantum well IP. Basic telecom systems. Wavelength and frequency division multiplexing. Classes of optical fibers. Modal dispersion. Index dispersion.
Books and bibliography	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.
Additional materials	Lecture notes. Laboratory setups manuals

Work schedule			
Total	Lectures	Hands on (Laboratory, working groups, seminars, field trips)	Out-of-class study hours/ Self-study hours
Hours			
150	40	15 (laboratory)	95
ECTS			
6	5	1	

Teaching strategy	
	Lectures in the teaching room with the aid of a laptop and a projector or a blackboard. Laboratory activities supervised in research grade setups.

Expected learning outcomes	
Knowledge and understanding on:	• basic and advanced aspects of optoelectronic device physics • proper choice of materials and structures for the realization of optoelectronic devices • proper choice of optoelectronic devices for applications
Applying knowledge and understanding on:	• the essential description and the assessment of physical limits of phenomena involving radiation-matter interaction
Soft skills	• **Making informed judgments and choices** ○ ability to describe and quantitatively model relevant structural, vibrational, optical and surface properties of relevant semiconductors. ○ ability to choose suitable experimental methods to fabricate and characterize optoelectronic devices • **Communicating knowledge and understanding** ○ communication skills in English; ○ skills in the exposition of physical properties and characteristics of optoelectronic devices using appropriate scientific language • **Capacities to continue learning** ○ ability to learn and to transfer the design of the optical properties of semiconductor structures and experimental methods for their assessment

Assessment and feedback	
Methods of assessment	
Evaluation criteria	• **Knowledge and understanding** ○ basic principles of different classes of optoelectronic devices and related figures of merit. ○ experimental methods to study the properties of heterostructures. ○ successful models describing the optoelectronic devices. • **Applying knowledge and understanding** ○ capability to discuss the development of efficient optoelectronic devices with desired functionalities based on the physical properties of relevant material structures, design and fabrication strategies. • **Autonomy of judgment**

	○ Identify and compare fundamental physical facts and their applications • **Communicating knowledge and understanding** ○ Master physics and scientific communication • **Communication skills** ○ Capability of support statements with relevant examples, and demonstrate understanding • **Capacities to continue learning** ○ Capability to exploit the achieved knowledge and concepts to further studying advanced physical and technological topics
Criteria for assessment and attribution of the final mark	Oral exam (75%). Laboratory report (25%).
Additional information	