UNIVERSITÀ DI PAVIA

Anno Accademico 2020/2021

OPTOELECTRONIC DEVICES	
Enrollment year	2020/2021
Academic year	2020/2021
Regulations	DM270
Academic discipline	ING-INF/01 (ELECTRONICS)
Department	DEPARTMENT OF ELECTRICAL,COMPUTER AND BIOMEDICAL ENGINEERING
Course	ELECTRONIC ENGINEERING
Curriculum	Photonics
Year of study	1°
Period	1st semester (28/09/2020 - 22/01/2021)
ECTS	9
Lesson hours	74 lesson hours
Language	English
Activity type	WRITTEN TEST
Teacher	GIULIANI GUIDO (titolare) - 9 ECTS
Prerequisites	Knowledge of the advanced concepts in Physics and Optics, and in Electronics.
Learning outcomes	Students will learn the physics, the basic principles of operation, the operating characteristics, the materials, the fabrication technology, the application fields, of electro-optic and photonic devices intended to generate or manipulate or detect light. By the end of the Course, students are expected to develop skills in the identification of the most suited electro-optic or photonic device for a given application or required performance.
Course contents	Part I - semiconductor light sources * World semiconductor laser market * Light generation from direct-band semiconductor materials: principle

* LEDs (Light Emitting Diodes): materials; structures; operating characteristics; optoisolators; Solid-state lighting; RGB LED and White LED lighting systems; LEDs for displays and video projection; OLEDs; analysis of RGB LED datasheets
* LUMENTILE European Project: Electronic Luminous tile
* Introduction to LASER: the laser as an oscillator; optical amplification; threshold condition; pumping methods; oscillation frequency.
* Semiconductor laser basics: structure; electrical and optical confinement; single- and double-heterostructure; optical waveguides (rib, ridge, buried)
* Historical evolution of semiconductor lasers
* Materials for semiconductor lasers: heterojunctions; lattice matching; III-V AlGaAs ternary system and InGaAsP quaternary system; II-VI material systems, active region: bulk, Multi-Quantum Well, Quantum Dots; optical gain
* Technologies for semiconductor laser fabrication: epitaxial growth (Liquid Phase Epitaxy, Vapor Phase Epitaxy, Molecular Beam Epitaxy, Metal-Organic Chemical Vapor Deposition); growth of quantum dots; definition of optical waveguides; photolithography and electron beam lithography; masking; wet chemical etching and dry plasma etching; metallization; regrowth; details of transversal semiconductor lasers sections; bonding; cleaving; packaging
* Operating characteristics of Fabry-Perot semiconductor lasers: light-current curve; emission spectrum; temperature effects (on threshold and emission wavelength); output beam characteristics (spot size, angular divergence, polarization); laboratory instrumentation for the characterization of semiconductor lasers; constant current electronic circuit; high-frequency direct current modulation; laser safety (at a glance); reliability (at a glance); analysis of semiconductor lasers datasheets
* Simplified theory of the operation of semiconductor lasers: rate-equations; spontaneous recombination (radiative and non-radiative); stimulated recombination; waveguide losses; equivalent mirror losses; threshold current calculation; differential and quantum efficiency; frequency response; relaxation frequency; relative intensity noise
* Experimental techniques for the characterization of semiconductor lasers: internal losses; optical spectrum; linewidth; relative intensity noise; modulation bandwidth; linewidth enhancement factor
* Effects of optical backreflections in semiconductor lasers (at a glance): Lang-Kobayashi equations; weak feedback regime; coherence collapse; chaotic regime; master-slave injection and locking
* Distributed-feedback (DFB) semiconductor lasers: optical Bragg gratings; fabrication techniques; types of gratings; ?/4- DFB lasers; performance; analysis of datasheets of commercial DFB lasers; DBR semiconductor lasers
* VCSELs (vertical cavity surface-emitting lasers): principle; materials and fabrication techniques; light-current curve; optical spectrum; temperature effects; polarization; applications
* VECSELs (vertical extended-cavity surface-emitting lasers), aka semiconductor disk lasers (at a glance)
* Tunable semiconductor lasers: external cavity lasers (Littman and Littrow configurations); monolithic edge-emitting tunable lasers (DBR,

sampled-Grating DBR, Y-laser); VCSEL/MEMS tunable lasers; III-V on silicon lasers
* High power semiconductor lasers (at a glance): stacked lasers; master oscillator + power amplifier (MOPA); VCSELs array
* Semiconductor ring lasers (SRLs): structure; light-current characteristics; operating regimes (bidirectional and uni-directional) and directional bistability; application as all-optical set-reset flip-flop and toggle flip-flop; snail laser
* Quantum cascade lasers (QCLs): importance of mid-infrared emission for applications; principle (inter-subband transitions, quantum cascade); optical waveguide; materials and fabrication technologies; operating characteristics; single-frequency DFB QCLs; the THz gap and THz QCLs; analysis of datasheets of commercial MIR QCLs
* III-V on silicon lasers: introduction and motivation of silicon photonics; silicon photonics and III-V-on-silicon technologies; principle and performance of III-V-on-silicon Fabry-Perot lasers; III-V-on-silicon DFB lasers; III-V-on-silicon tunable and multi-wavelength lasers
* New semiconductor lasers emitting at fancy wavelengths (at a glance): blue; green; yellow-orange
* Mode-locked semiconductor lasers: mode-locking principle; saturable absorber; operating characteristics
* SLEDs (Superluminescent Light Emitting Diodes) (at a glance)
* Laboratory experimental sessions:
o Detailed microscope analysis of commercial lasers (Fabry-Perot, VCSELs); measurement of P-I curve and spectral characteristics of semiconductor lasers of different types (Fabry-Perot, DFB, tunable external cavity laser)

Part II - Photodetectors

* Classification of photodetectors
* Photocathodes: photoemission process; types of photocathodes; spectral responsivity; vacuum phototubes
* Photomultipliers: principle; structure; Single-Electron-Response (SER); charge gain; gain randomness; SER typical parameters; biasing circuits; applications: detection of optical weak signals, time measurements, photon counting, nuclear spectrometry
* Photodiodes: internal photodetection process; materials and structures; performance; p-n junction photodiode; spectral sensitivity; I-V characteristics; equivalent circuit; frequency response (intrinsic and extrinsic cut-off); p-i-n photodiode; types of packages; photodiode circuits (basic circuit, trans-impedance)
* Avalanche photodiodes: principle of avalanche multiplication; gain; SPAD (Single-Photon Avalanche Detector)
* Photoconductors: principle and structure; materials; spectral response; use in basic circuit
* Thermal detectors: principle; spectral response; equivalent circuit; types of temperature sensors; thermal imaging systems
* Quantum and Thermal detection regimes: the bandwidth/sensitivity trade-off; signal-to-noise ratio; graph of signal-to-noise ratio vs. Pin
* Coherent detection: principle; signal-to-noise ratio; phase-matching and phase coherence; applications
* Imaging detectors: principle; serialization of 2D image signal; analog

	and digital imaging; * Vidicon: structure; principle of operation; image read-out; lag * CCD and CMOS image detectors: concept; working principle of CCD and methods for image read-out; * Photovoltaics and solar cells: importance of energy production from renewable sources; solar panels; solar cells (principle, electrical characteristics, V-I characteristics, solar spectrum and solar cell response, materials, efficiency, poly-crystalline silicon, concentration systems); organic photovoltaics * Laboratory experimental sessions: o Photodiode: basic circuit, external bias, output voltage, effect of load resistance, photovoltaic operation o Photoconductor: basic circuit, output voltage, effect of load resistance, speed response
Teaching methods	The Course is based on lectures that illustrate the physics, the working principles, the operating characteristics, and the fabrication technology of the considered devices. Tutorial laboratory sessions provide a "hands-on" experience where students are requested to experimentally measure the operating characteristics of a semiconductor laser and of semiconductor photodetectors. Laboratory sessions on photomultipliers, Vidicon camera imaging system, and advanced semiconductor laser are also foreseen.
Reccomended or required readings	S. Donati, " Photodetectors. Devices, circuits and applications", Prentice Hall, 1999. Slides of the Course
Assessment methods	Written or oral test, with questions aiming at understanding which are the concepts acquired by the student and his/her ability to explain how the functional blocks of an optoelectronic device/instrument work. The minimum score to pass the exam is 18, the top one is 30 cum laude.
Further information	
Sustainable development goals - Agenda 2030	$lbl_legenda_sviluppo_sostenibile