



# UNIVERSITÀ DI PAVIA

Anno Accademico 2021/2022

## OPTOELECTRONIC DEVICES

<b>Anno immatricolazione</b>	2021/2022
<b>Anno offerta</b>	2021/2022
<b>Normativa</b>	DM270
<b>SSD</b>	ING-INF/01 (ELETTRONICA)
<b>Dipartimento</b>	DIPARTIMENTO DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE
<b>Corso di studio</b>	ELECTRONIC ENGINEERING
<b>Curriculum</b>	Photonics
<b>Anno di corso</b>	1°
<b>Periodo didattico</b>	Primo Semestre (27/09/2021 - 21/01/2022)
<b>Crediti</b>	9
<b>Ore</b>	74 ore di attività frontale
<b>Lingua insegnamento</b>	English
<b>Tipo esame</b>	SCRITTO
<b>Docente</b>	GIULIANI GUIDO (titolare) - 9 CFU
<b>Prerequisiti</b>	Knowledge of the advanced concepts in Physics and Optics, and in Electronics.
<b>Obiettivi formativi</b>	<p>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.</p> <p>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.</p>
<b>Programma e contenuti</b>	<p>Part I - semiconductor light sources</p> <ul style="list-style-type: none"><li>* World semiconductor laser market</li><li>* Light generation from direct-band semiconductor materials: principle</li></ul>

- \* 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;  $\pi/4$ -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

#### Metodi didattici

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.

#### Testi di riferimento

S. Donati, " Photodetectors. Devices, circuits and applications", Prentice Hall, 1999.

Slides of the Course

#### Modalità verifica apprendimento

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.

#### Altre informazioni

#### Obiettivi Agenda 2030 per lo sviluppo sostenibile

[Gli obiettivi](#)