UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Ingegneria
ACADEMIC YEAR	2021/2022
SECOND CYCLE (7TH LEVEL) COURSE	ELECTRONICS ENGINEERING
SUBJECT	OPTOELECTRONIC DEVICES
TYPE OF EDUCATIONAL ACTIVITY	C
AMBIT	20925-Attività formative affini o integrative
CODE	20512
SCIENTIFIC SECTOR(S)	ING-INF/01
HEAD PROFESSOR(S)	MOSCA MAURO Professore Associato Univ. di PALERMO
OTHER PROFESSOR(S)	
CREDITS	6
INDIVIDUAL STUDY (Hrs)	102
COURSE ACTIVITY (Hrs)	48
PROPAEDEUTICAL SUBJECTS	
MUTUALIZATION	
YEAR	1
TERM (SEMESTER)	1° semester
ATTENDANCE	Not mandatory
EVALUATION	Out of 30
TEACHER OFFICE HOURS	**MOSCA MAURO** Monday 18:00 19:00 IMPORTANTE! Il docente riceve sempre alla fine della lezione e per appuntamento. Giorno e orario sono stati inseriti in modo fittizio perche richiesti dal sistema!

DOCENTE: Prof. MAURO MOSCA

PREREQUISITES	Physics, Electronics, Electronic devices
LEARNING OUTCOMES	Knowledge and Understanding The course aims to provide the student some advanced topics in the field of optoelectronic devices (light sources and photodetectors). It will be provided the basic theoretical principles, the characterization methodologies, and the applications of each device. Particular emphasis will be given to the commercial devices and their applications. Students will be also required to carry out some experimental experiences in the Photonics Teaching Laboratory. On successful completion of the module students will have gained a comprehensive knowledge of the modern light sources and photodetectors. They will understand the basic principles of operation and their applications. Applying Knowledge and Understanding Thanks to a dynamic approach towards the applications of the devices, it is expected that the students are able to apply knowledge of what they have learned into practice. Laboratory exercises will provide a fundamental support for this purpose. Making Judgements The aim of the course is not only to enhance knowledge of modern optoelectronic devices, but also to give the students the methods and the tools to characterize them. Students will thus be able to understand and justify the behavior of the devices. On completion of the course they will also have acquired their own methodology for the analysis and characterization of the devices, in order to solve a problem as effective as possible. For a typical optoelectronic system they will be able to match the suitable devices. Communication Skills Students will gain the ability to communicate and express the issues concerning optoelectronic devices and their applications. In particular they will be able to sustain a debate or an interview on modern photonic sources (coherent and incoherent) and photodetectors. Learning Skills Students will be given the means to complete and refine the topics acquired during the module. In particular they will be able to deal independently problems related to the physical understanding and characterization of modern optoelectronic devices. This competence will allow them to access easily to high-technical sectors of the industry, as well as doctoral courses in electronics and photonics.
ASSESSMENT METHODS	Oral exam The oral exam consists of an interview, aimed at ascertaining the possession of the skills and the knowledge required by the course. In general, the interview focuses on the discussion of three topics: - an article written by the student and sent by email to the teacher at least two days before the exam (maximum score: 10); - an oral PowerPoint presentation, chosen from two possible ones (slides provided by the teacher on a topic of the course) (maximum score: 15); - a multiple-choice questionnaire on various topics covered during the course (maximum score: 7). The subject of the article, chosen by the student and communicated to the teacher before the beginning of the writing, must be a topic concerning the optoelectronic devices (physics, engineering, applications, and/or characterizations), not covered during the course; this in order to stimulate the student's scientific curiosity, to test his autonomy in the analysis of documents and to evaluate his choice and processing skills. Furthermore, the interview tends to verify a) the knowledge acquired, b) the processing skills, c) the possession of adequate expository skills. The evaluation criteria are as follows: EXCELLENT (30-30 cum laude): Excellent knowledge of the topics and excellent understanding and developing ability, excellent command of the language. The student is able to apply knowledge to solve proposed problems. The article is original and is written in good and proper style. The discussion of the paper highlights the full understanding of the subject matter. GOOD (28-29): Very good knowledge of the topics and very good understanding and developing ability, full command of language. The student is able to apply knowledge to solve proposed problems. The article is original and is well written in a proper style. The discussion of the paper highlights the good understanding of the subject matter VERY GOOD (26-27): Good knowledge of the topics and good understanding and developing ability, decent command of language. The student is able to apply knowledge to solve proposed problems, although not always in complete

	autonomy. The article is original and is satisfactorily written. The discussion of the paper highlights the good understanding of the subject matter. GOOD (24-25): Good knowledge of the topics and satisfactory understanding and developing ability, satisfactory command of the language with a limited ability to independently apply the knowledge to the solution of the proposed problems. The article is quite original and is satisfactorily written. The discussion of the paper highlights some uncertainties in the understanding of the subject matter. SATISFACTORY (21-23): The student has not full command of the topics of the course but he has the knowledge, satisfactory command of the language with poor ability to independently apply the acquired knowledge. The subject of the article is not original and is passingly written. The discussion of the paper highlights several gaps in the understanding of the subject matter. PASSING GRADE (18-20): Minimum basic knowledge of both topics and technical language. Very poor, or no ability, to independently apply the acquired knowledge. The subject of the article is not original and is just passingly written. The discussion of the paper highlights several gaps in the understanding of the subject matter. UNSATISFACTORY: The student does not have an acceptable knowledge of the topics and/or has not studied at all some of them.
EDUCATIONAL OBJECTIVES	Knowledge of physical principles of operation of modern optoelectronic devices, their applications, and characterization methodologies.
TEACHING METHODS	Lectures, laboratory exercises
SUGGESTED BIBLIOGRAPHY	- Teaching material (notes and slides) provided by the lecturer - R. Karlicek • C.-C. Sun, G. Zissis, R. Ma (Eds.): Handbook of Advanced Lighting Technology (Springer International Publishing, Switzerland, 2017) - available free of charge on the UNIPA network of libraries - T. Erdem • H. Volkan Demir: Color Science and Photometry for Lighting with LEDs and Semiconductor Nanocrystals (Springer Nature, Singapore, 2019) - available free of charge on the UNIPA network of libraries - J. Li, G. Q. Zhang (Eds.): Light-Emitting Diodes - Materials, Processes, Devices and Applications (Springer Nature, Switzerland, 2019) - available free of charge on the UNIPA network of libraries - F. Träger (Ed.): Springer Handbook of Lasers and Optics (Springer Science +Business Media, LLC New York, 2007) - available free of charge on the UNIPA network of libraries - J. Singh: Semiconductor Optoelectronics: Physics and technology, Mc-Graw-Hill, Inc. (1995) - S. M. Sze, M. K. Lee: Semiconductor Devices. Physics and Technology (3rd edition), John Wiley & Sons, Inc. (2012) - C. W. Wilmsen, H. Temkin, L. A. Coldren: Vertical-Cavity Surface-Emitting Lasers: Design, Fabrication, Characterization, and Applications, Cambridge University Press (2001) - E. F. Schubert: Light-Emitting Diodes, Cambridge University Press (2006) - D. Sands: Diode lasers, IoP Publishing (2005) - S. D. Gunapala, D. R. Rhiger, C. Jagadish: Advances in Infrared Photodetectors (Semiconductors and Semimetals, Vol. 84), Elsevier (2011) - M. Henini, M. Razeghi: Optoelectronic devices: III Nitrides, Elsevier (2005) - A. Buckley: Organic Light-Emitting Diodes (OLEDs): Materials, devices and applications, Woodhead Publishing (2013)

SYLLABUS

Hrs	Frontal teaching
1	INTRODUCTION TO THE COURSE
1	LIGHT - ITS NATURE AND ITS PROPERTIES: Electromagnetic spectrum. Speed of light and refractive index. Dispersion. Photon energy. Time and spatial coherence. Gratings. Monochromators. Optical activity. Electro-optic effect. Optical modulators
3	PHOTODETECTORS: Thermoelectric detectors. Bolometers. Pyroelectric detectors. Photomultipliers. Semiconductor-based photodetectors: Parameters, Photoconductors and related circuits, Photovoltaic detectors and related circuits. Multi-quantum well detectors. Junction detectors: p-n and p-i-n photodiodes, phototransistors. Avalanche photodiodes. Charge-Coupled Devices (CCDs).
3	LIGHT-EMITTING DIODES (LEDs): Injection Luminescence. Radiative recombination. Exciton recombination. Non-radiative recombination. Emission linewidth. LED construction. Light extraction. Radiation pattern. Electrical properties. LED drive circuitry. Efficiencies. ADVANCED STRUCTURES FOR HIGH-EFFICIENCY LEDs : Reasons that impede the fabrication of high-efficiency LEDs and their solutions. Double heterostructure. Quantum-wells. Separate confinement heterostructure: SCH and GRINSCH. Carrier loss. Electron-blocking layer. Light emission cone: extraction efficiencies. Optimization of geometries. Thick window layer and transparent substrate. Additional techniques to increase efficiency: TIP geometries, reflecting mirrors (epitaxial lift-off), rough surfaces (GaN etching, natural lithography), buried microreflectors, tapered structures (photoresist reflow technique)

SYLLABUS

Hrs	Frontal teaching
3	LASERS: Emission and absorption of radiation. Stimulated emission. Einstein relations. Three- and four-levels lasers. Gain and optical feedback. Longitudinal modes and Doppler shift. Transverse modes. Q-switching. Argon laser. Nd:YAG laser. Semiconductor laser diode.
2	HETEROSTRUCTURES AND EPITAXY: Semiconductor crystal structure. The Miller index notation. The diamond, zinc-blende, and wurtzite semiconductor cells. Epitaxial-growth techniques: Chemical-Vapor Deposition (CVD), Metal-Organic CVD (MOCVD), Molecular-Beam Epitaxy (MBE). Semiconductor alloys. Heterostructure band diagrams: Anderson's rule. Bandstructure engineering: heterojunctions and quantum wells. Semiconductor defects. Lattice-mismatched structures. Strained structures and dislocations. Buffer layers and virtual substrates.
3	MATERIALS FOR OPTOELECTRONIC DEVICES: Elements and alloys used in optoelectronics. Indirect gap materials and their transitions. The GaAsP system, GaP, GaAsP: N, and GaP: N. The AlGaAs / GaAs systems. The AlGaInP / GaAs systems. The silicon carbide (SiC). The GaN, AlGaN, InGaN, AlGaInN systems: problems, dislocations, methods to reduce the dislocations, ELOG growth. Spontaneous and piezoelectric polarization in nitrides. Thin and thick active regions in nitrides: Quantum Confined Stark Effect (QCSE). Ohmic contacts and polarization effects in nitrides. GaN p-doping. Recombination effects in dislocations. Theories to explain the high efficiency of nitrides. The "green-gap".
3	UV DETECTION AND SOLAR BLIND DETECTORS: Ultraviolet detection. Classification of UV detectors. Parameters of UV photodetectors. NEP and detectivity. Materials for UV detection. UV Silicon photodiodes ("UV-enhanced"): inversion layer, other types. SiC photodetectors. GaN and AlGaN photodetectors: photoconductors, photodiodes, Schottky and MSM. Gain, responsivity and noise in photoconductive and photovoltaic nitride-based detectors. Window layer in photoconductors and in MSM. Applications in biophotonics (erithema-weighted detectors). Application as a "solar blind" flame detector. Commercial devices
3	IR DETECTION AND QWIP (QUANTUM-WELL INFRARED PHOTODETECTORS): Historical background. IR detection overview. IR detection systems. BLIP (background-limited infrared photodetection). FPA (focal-plane arrays): first-generation, second-generation, hybrids. HgCdTe photodiodes. Intersubband absorption and physical principle of QWIP. Classification of QWIP: n-doped bound-to-bound, n-doped bound-to-continuum, n-doped bound-to-quasibound, n-doped broadbound, n-doped bound-to-bound miniband, n-doped bound -to-continuum miniband, n-doped bound-to-miniband, n-doped step bound-to-miniband. Dark current in QWIP. Spectral response of QWIP. Light coupling in QWIP: random reflector, 2D grating. Dual-band vision: MWIR and LWIR bands. Applications: night vision, surface roughness detection, minefields detection. Commercial devices
5	WHITE LED (WITH ELEMENTS OF RADIOMETRY, PHOTOMETRY, AND COLORIMETRY): Human vision. Radiometric and photometric quantities: radiant and luminous intensity, radiant and luminous flux, irradiance and illuminance, radiance and luminance. Human eye sensitivity curve. Luminous efficacy and efficiency. Color-matching functions. Tristimulus values. Chromaticity coordinates. Chromaticity Diagram (CIE - 1931). MacAdam ellipses. Uniform chromaticity diagram (CIE - 1976). Uniform chromaticity coordinates. Dominant wavelength and color purity. LED in the chromaticity diagram. Color and chromaticity. Planck's blackbody radiation. Planck locus in the chromaticity diagram. Color temperature and correlated color temperature. Additive color synthesis. Color gamut. Color rendering. Color rendering index (Color Rendering Index - CRI). Generation of white light with LEDs: dichromatic, trichromatic and tetrachromatic sources, discrete and monolithic. Color mixing of two LEDs. Luminous efficacy of dichromatic and trichromatic LEDs. Temperature dependence (for trichromatic LEDs). Generation of white light by frequency-down conversion: phosphors. Efficiency of phosphors. Materials used for down-conversion: phosphors, dyes, semiconductors. LED PRS (photon recycling semiconductors). Phosphors based on rare earths-doped garnets. Ce:YAG: emission spectrum, gamut in chromaticity diagram. Phosphor-conversion white LEDs based on Ce: YAG: first generation, high CRI. Color uniformity. Spatial distribution of the phosphors. Comparison among luminous efficiencies of various white LEDs. Commercial devices
5	ORGANIC LED (OLED): Elements of organic chemistry. Conductive polymers. Bonding and antibonding orbitals. Sigma and pi molecular orbitals. Delocalization of the electrons. Conjugated polymers. Energy band in organic compounds: HOMO (Highest Occupied Molecular Orbital) and LUMO (Lowest Unoccupied Molecular Orbital). Amorphous materials: density of states and mobility. Materials for OLEDs: low molecular weight (monomers and oligomers), and polymers. Glass transition. Techniques of deposition of organic films: OMBE, Thermal evaporation, spinning, dipping, inkjet printing. Purification of the material: gradient sublimation. Emissive materials: Alq3. Energy levels of Alq3 . Physical structure of an OLED: the emissive layer (EML), the electron carriers layers (ETL), and the hole carriers layers (HTL). Injection and transport in OLED: position of the energy levels. Polarization of OLEDs: injection and recombination. TCL (trapped charge-limited) model. Emission by excitons. Franck-Condon relaxation. Recombination mechanisms. Singlet and triplet states. Doping of the emissive materials. Lifetime and image burning. OLED-based displays: Passive-Matrix OLED (PMOLED), Active-Matrix OLED (AMOLED), Flexible OLED, Transparent OLED (TOLED).
4	VERTICAL CAVITY LASER (VCSEL): Edge-emitting and surface-emitting laser. Structure of a VCSEL cavity. Dielectric mirrors. Threshold condition. Longitudinal field distribution inside the cavity. Gain and threshold current as a function of reflectivity (for GaAs and GaN). DBR (Distributed Bragg Reflectors): effective length of the cavity, effects of absorption losses, effect of gradual interfaces, resistance of the mirrors, gradual mirrors. Differential efficiency. Wall-plug efficiency. Lateral confinement. AlAs lateral oxidation. AlGaAs lateral oxidation. Nitrides lateral oxidation. VCSEL fabrication steps. VCSEL applications.

SYLLABUS

Hrs	Frontal teaching
2	QUANTUM-CASCADE LASERs (QCLs): Historical background. Conduction band in a QCL: injection and active regions, ULL, LLL, DPL levels. Relaxation by longitudinal optical phonons. Wannier-Stark ladder: electron transport and recycling. Differences and similarities with traditional lasers. Gain in a QCL and in a conventional laser. Diagonal transitions: anti-crossing. Minibands in superlattices: the Kronig-Penney model. Superlattice states in a periodic structure GaAs/AlGaAs.

Hrs	Workshops
3	EXPERIMENTS WITH LIGHT
3	CHARACTERIZATION OF A PHOTODETECTOR
3	REALIZATION OF A PHOTOLITHOGRAPHIC MASK LAYOUT FOR LEDS
3	FABRICATION AND CHARACTERIZATION OF WHITE LEDs BY DYE DOWN-CONVERSION