MASTER PROGRAM

First year

First semester (in REIMS) — 30 ECTS

EUR01 — 6 ECTS

Mathematical and numerical tools for physicists

Mathematical and numerical tools for physicists :
Algorithmic and programming
Models and discretization with finite element method.
Numerical simulation for partial derivatives equation.
Practical work or demo: applications on numerical differential equations systems and numerical tools to solve problems in optics.
Probability, statistics and inverse problems.
Statistic physics: Introduction to Fermi-Dirac and Bose-Einstein statistics.

Main related text books:

GUM : Evaluation of measurement data — Guide to the expression of uncertainty in measurement, Joint Committee for Guides in Metrology.
Ramalho, L. Fluent Python: Clear, Concise, and Effective Programming
Tarantola, A. Inverse Problem Theory and Methods for Model Parameter Estimation. (https://doi.org/10.1137/1.9780898717921)

EUR02 — 6 ECTS

Wave optics

The objective of this course is to give students a solid background in optical wave propagation, with emphasis towards application to integrated optics and optoelectonic devices: diffraction, interferometry, polarization, lasers, optical fibers,..
- Wave optics and applications:
Includes Practical work or demo: Fourier optic (filtering), Michelson (refractive index measurement), Fabry-Perrot, ellipsometry.
- Gaussian Optics:
Propagation and properties of Gaussian beams, ABCD matrix, adaptation and focusing of Gaussian beams, application to integrated optoelectronic devices (coupling losses).
Practical work or demo: laser to optical fiber coupling.
- Dielectric waveguides:
Includes more advanced topics such as plasmonics.
Dielectric waveguides: Propagation in dielectric waveguides (planar waveguides, strip waveguides…), application to integrated optoelectronics, mode adapters. Introduction to plasmonics.
Practical work or demo: propagation in optical fibers, simulation of planar waveguides.

Main related rext books:

Saleh, B. E. A & Teich, M. C. Fundamental in Photonics
Ciarlet, P. G. The finite element method for elliptic problems
Ern, A. and Guermond, J.L. Theory and Practice of Finite Elements. Applied Mathematical Sciences, Vol. 159, Springer-Verlag, New York. http://dx.doi.org/10.1007/978-1-4757-4355-5
Quarteroni, A. Numerical models for differential problems. Modeling, Simulation & Applications Springer, Cham, Third edition (2020)

EUR03 — 6 ETCS

Solid state Physics

- Basis of solid state physics:
Crystal structures (Bravais network. Reciprocal network).
Experimental probes of real space (near field microscopy) and of reciprocal lattice (Diffraction methods, neutrons, or electrons).
Electrons in a periodic potential, Bloch's Theorem, band structure, Fermi surfaces and Brillouin zones, nearly free electrons model. Application to some metals.
Practical work or demo: XRD
- Lattice vibration:
Classical theory (normal mode with one- and three-dimensional monoatomic Bravais network), quantum theories of the Harmonic crystals, elementary theory of the phonon dispersion relation, electron-phonon interaction. Thermal properties in relation to phonons: specific heat of the network, Debye and Einstein models, inharmonic effects. Today's research trends: thermal transport at nanoscale, Phonon-phonon scattering, interaction phonon-e-, gap indirect, confinement in nanostructures, Phonon transport in phononic crystals, Ballistic heat conduction in semiconductor nanostructures, non-Fourier behavior. Practical work: introduction to molecular dynamics
- Optoelectronics:
Introduction (interest of semiconductors, application to electronic and optoelectronic devices, research industry and market perspectives). Band structure, occupation statistics, doping. Transport properties: mobility and velocity, drift and diffusion currents. Junctions: Schottky diodes and PN junction, current-voltage characteristics. Field effect transistors. Light/semiconductor interaction, introduction to optoelectronic devices: photodetectors, LED and lasers. Today's research trends.
Practical work or demo: Hall effect, XRD

Main related text books:

Ashcroft, N. W. & Mermin, N. D. Solid state physics
Kittel, C. Introduction to solid state physics
Sze, S. M. Physics of Semiconductor Devices
Chen, G. Nanoscale Energy Transport and Conversion: A Parallel Treatment of Electrons, Molecules, Phonons, and Photons.

EUR04	**Communication, bibliography, conferences**	3 ECTS
EUR05	**Foreign Language (including FLE: French as a foreign langage)**	3 ECTS
EUR06	**Lab Project 1 (1 day/week in a laboratory within the NANO-PHOT consortium)**	6 ECTS

Second Semester (in TROYES) — 30 ECTS

3 courses to be chosen among :

	LM01	**Classical and quantum light-matter interaction** The main objective is to lay the foundations for the interaction between light and matter: the bases of classical light-matter electrodynamic interactions, a semi-quantum model and finally a completely quantum model will be studied. - Classical light-matter interaction - Black-body radiation - Einstein coefficients - Optical amplification and lasers - Optical non-linear Optical non-linear processes - Quantum mechanics essentials I - Quantum mechanicsessentials II - Semi-classical approach to light-matter interaction - Rabi oscillation and the dressed state picture - Density matrix, Pauli operators and Bloch sphere - Optical Bloch equations - Applications of the Optical Bloch equations: saturation, optical pumping, dark resonances and EIT **Main related text books:** Weneir, J., Nunes, F. Light-Matter Interaction - Physics and Engineering at the Nanoscale. Oxford University Press Keeling, J. Light-Matter Interactions and Quantum Optics. CreateSpace Independent Publishing Platform Loudon, R. The Quantum Theory Of Light. Oxford Science Publication	6 ECTS
	OPTM01	**Materials and devices in optics and optoelectronics** The objective is to study the various optical properties of solid state materials and structures involved in optics and optoelectronics through technological examples in key fields, including sensing, photovoltaics, security and telecommunications. Program: - Understand and describe optical properties of solid state materials and systems (dielectric, anisotropic, metallic, semiconductor, gratings, multilayers, waveguides, photonic crystals, metamaterials, laser materials) - Select materials and systems to meet identified needs regarding: absorption, transmission, reflection, filtering, confinement, guiding, dispersion, emission, detection, polarization states - Practical skills: setting a solid-state laser, using a laser diode and a detector for gas sensing, using a CAD software to design multilayer filters and waveguides, playing with polarization states of light. **Main related text books:** Singleton, J. Band theory and electronic properties of solids Fox, M. Optical properties of solids. Yeh, P. Optical waves in layered media Snyder, A. W. & Love, J. Optical waveguide theory	6 ECTS
	EUR10	*High resolution microscopies and spectroscopies (to be opened)*	6 ECTS
	FAB01	*Nanofabrication and nanomaterials (to be opened)*	6 ECTS
	NOPH01	**Nano-optics and nanophotonics** The objective is to acquire basic knowledge and know-how in the field of nano-optics, from concepts to applications: subwavelength imaging, plasmonics and optical (bio)sensing, photonic circuitry... Notably through simulation and experimental workshops. Program: - Understanding and describing the basics of nano-optics and related applications (imaging, biochemical sensing, lithography, telecommunications, spectroscopy...): - Far-field and near-field imaging: evanescent waves, dipole emitter, nanoantenna... Application: subwavelength imaging (nanoscopy). - Plasmonics: localized and delocalized SPR. Enhancing optical sensing ... - Integrated photonic circuits. - Design (Simulation) and characterization of nanodevices. -Practical skills: oriented toward optical characterization and simulation **Main related text books:** Hohenester, U. Nano and Quantum Optics. Novotny, L. & Hecht, B. Principles of nano-optics	6 ECTS
	Mandatory and in addition to the courses above:		
	LAB02	**Lab Project 2 (1 day/week in a laboratory within the NANO-PHOT consortium)**	6 ECTS
		Foreign Language (including FLE: French as a foreign language)	3 ECTS

	EIP01	**Innovative companies: entrepreneurship, economic intelligence and intellectual properties** Goals: allow students to understand the economic and legal environment of innovative companies. Through the theoretical study of the protection and development of scientific innovations (or in other fields) applied to the business. The student will be able to address the practical aspects through participation and observation of the creation of an innovative business. Program: Management of a business creation project (theoretical course and discussion with creators of innovative businesses). Protecting an innovation: national and international legal system, alternative strategies for the protection of ideas Collect competitive information, market analysis methods and their evolution Establish in the company a culture and tools ensuring efficient and differentiating economic intelligence.	3 ECTS
		Third semester (in TROYES)	**30 ECTS**
	2 courses to be chosen among:		
	MC01	**Multi-scale characterization** The objective is to provide theoretical and practical training in physico-chemical and mechanical characterization techniques, from macroscopic to nanoscopic scale. Students will be asked to synthesize their own sample. Program: Five themes are addressed in order to acquire experimental skills in the following areas: - Surface analysis and technique (pro lometer, atomic force microscope and indentation) - Analysis of the crystallinity of materials (X-ray diffraction) - Optical spectroscopy (Absorption and dynamic scattering of light) - Mechanical tests (hardness, tensile and shear strength) - Optical and scanning electron microscopy **Main related text books:**	6 ECTS
	QO01	**Quantum Optics and Nano-Optics** The objective is to study the behavior of light at the quantum level. Quantum optics deals with single photons or countable photons and their properties. Applications of quantum optics for nano-optics and quantum technologies will be seen Program: At the end of this course, the student would have acquired: - The basic principles of light quantization - The standard formalism of Quantum Optics with examples taken in single photon phenomena, including applications to quantum technologies - The formalism to describe the notion of entangled photons - The quantum optical formalism for describing classical light, either coherent such as laser light, or incoherent such as thermal radiation. The student will see concrete applications from quantum optics such as: - Quantum metrology: thanks to the notion of standard quantum limit (SQL) and squeezed states of light - Quantum communications & quantum cryptography for quantum technologies using quantum teleportation and based on single photons & entangled photons applications of quantum optics in nano-optics will also be addresses **Main related text books:** Loudon, R. The Quantum Theory Of Light. Oxford Science Publication Gryngberg, G.; Aspect, A.; Fabre, C; Cohen-Tannoudji, C. Introduction to Quantum Optics: From the Semi-classical Approach to Quantized Light. Cambridge University Press Gerry, C. Introductory Quantum Optics. Cambridge University Press Meystre, P. Quantum Optics. Springer	6 ECTS

Second year	NOPH02	**Hot topics in nano-optics and nanophotonics** The objective is to get knowledges and skills on the main current topics in nano-optics and nanophotonics, including science, technologies and applications, in collaboration with world-class experts, laboratories and companies. The selected topics can vary each year depending on current topicalities. The expected fall 2021 program is: - Deep learning for nano-optics key words: machine learning, inverse problem, optimization, applications - 2D-nanomaterials key words: optical and transport properties, semiconductor nano-platelets, graphene, transition-metal dichalcogenide - Optical nanosources key words: single photon, nano-emitters, hybrid configuration based on weak/strong coupling, nanolasers, integration of sources - Far-field fluorescence nanoscopy key words: Imaging, Epi-fluorescence confocal and 2-photon microscopy TIRFM, PALM, STORM, (STED) nanoscopy - Nanoscale heat and charge transfer key words: nanoIR, hot electrons, phonons, plasmon-assisted chemistry, ultrafast optics **Main related text books and key articles:** Mertz, J. Introduction to optical microscopy, Roberts and Company Publishers Lelek, M. et al. Single-molecule localization microscopy. Nature Review - Methods Primers (2021)1:39 Hell, S. Far-field optical nanoscopy. Science (2007) 316:1153 Zhang, X. et al. Plasmonic photocatalys. 2013 Rep. Prog. Phys. 76 046401	
	LAB03	**Lab Project 3 (2 days/week in a laboratory within the NANO-PHOT consortium)**	12 ECTS
		Foreign Language (including FLE: French as a foreign language)	4 ECTS
	MRPROJ	**Management of research projects–** based on various real cases and practical examples Training on different issues: Identifying a subject and the type of the project: personal interest, challenge for science, technology, society. Fundamental or applied project? With or without industry? State of the art: positioning the subject! Definition of workpackages Definition of a schedule (Gantt Chart.) with milestones Definition of partners: complementarity, skills,.. Definition of the needs and means: people, instruments, consumables...what does one already have? What should be got? What is the cost of the project? Can the project earn money? How to finance the project? (sponsoring, calls to be identified) The funding organizations Writing a good project to efficiently response to official calls for projects Implementation of the project: Team to be set-up/hired, projects meetings, project reports: actual achievements, to be compared with the expected milestones, real time assessments, eople managements, Communication and outcomes: publications, conferences, patents, prototypes, complying with the expectation of the funders, Intellectual property: patents and others, efficient use of the available platforms/facilities	2 ECTS
		Fourth semester	**30 ECTS**
	ST30	**6-month master internship --> master thesis, master diploma**	30 ECTS

PhD PROGRAM		
	PhD thesis in a laboratory within the NANO-PHOT consortium	**3-4 years**
	Courses at UTT (SPI doctoral school):	
	multiscale fabrication and characterization of materials	38h
	nano-optics and photonics	38h
	Entrepreneurship	25h
	Scientific information and communication	25h
	Valorization and professional insertion	20h
	Scientific ethics and integrity	15h