Syllabus Europhotonics
AMU
2022

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Semestre 1

Curriculum

H	S1 - AMU	ECTS
80	Fundamentals in Optics & Tutorials	6
60	Physics for Photonics I	6
40	Light Emission & Laser sources	3
30	Imaging and Systems in Optics	3
50	Labs practice	3
40	Personal projects	6
24	FLE ou English	3
324	Total	30

Modules description - AMU

UE01 Fundamentals in Optics & Tutorials		*Semestre :* M1 – S1	
		Code : SPHAU58J	*ECTS : 6*
Total Workload	**CM : 40 h / TD : 40 h**	*Homework & self-studies : 60* h	

Module	Introduction Tutorials	*Code :* SPHAU58J	*ECTS : 0*
Person in charge	*P. Ferrand*		
Lecturer (s)	*P. Ferrand*		
Workload	TD : 20 h	*Homework & self-studies : variable*	
Objectives	The purpose of this series of tutorials is to remind the common background knowledge that is required in all the lectures of the Master.		
Content and organisation	A quick reminder about • Basic mathematical tools: complex numbers, derivatives, integrals, vector algebra, Fourier transforms, • Ray optics and wave optics: interferences, diffraction, polarization, introduction to coherence		
Acquired competencies	• Performing basic and advanced mathematical derivations, • Understanding the purpose of Fourier analysis, i.e. the effect of some transformation in one domain (shift, derivative, etc.) to the reciprocal domain • Drawing optical rays for an optical system, and to identify conjugated planes, • Knowing how to analyze a state of polarization, and how to modify it, • Writing formally the conditions for interferences (Young slits, Michelson interferometer).		
Performance Appraisal	Indirect as the competencies are needed for the final examination of parts below		
Prerequisites	Bachelor knowledge in physics, electrodynamicss Fundamentals in Mathematics		
Literature			

Module	Fundamentals of Optics **– Part I**	*Code :* SPHAU58J	*ECTS : 3*
Person in charge	*A. Nicolet*		
Lecturer (s)	*A. Nicolet, G. Soriano (tutorials)*		
Workload	CM : 20 h / TD : 10 h	*Homework & self-studies : 30* h	
Objectives	The students from different backgrounds refresh and elaborate their knowledge of basic electrodynamics and wave propagation. The course is also the opportunity to refresh the necessary math skills (vector analysis, Fourier transform, distribution theory…) for the understanding the physical concepts presented in the course. The course is pretty self-contained since it starts with electrostatics.		
Content and organisation	I. Electrostatics and distribution theory. II. Magnetostatics (and some special relativity). III. Fields with time variation : Maxwell's equations (Faraday's induction and Maxwell-Ampère theorem). Understanding the equations : a vector analysis synthesis. IV. Macroscopic Maxwell's equations in media. Integral form of the Maxwell's equations. Electromagnetic energy. V. Wave equations, EM plane waves, Snell-Descartes law and Fresnel coefficients. VI. Fourier transforms of functions and distributions. VII. Maxwell's equations in the frequency domain, dispersive materials and the Kramers-Kronig relations. VIII. Helmholtz equation, Green functions, and the integral integral theorem of Helmholtz-Kirchhoff. IX. Electromagnetic radiation.		

	Note : the mathematical tools are introduced in the chapters were they are relevant for electrodynamics.
Acquired competencies	• Understand the basic principles of electromagnetism and how they are interconnected. • Know how to perform computations using vector analysis, Fourier transformation, and distribution theory to set up and solve simple electromagnetic problems. • Understand that magnetism is a relativistic effect and that the observations do not depend on the inertial frame (velocity is relative) while the radiation is due to charge acceleration. • Understand the difference between general laws (macroscopic Maxwell's equations) and constitutive laws specific to materials. • Understand the concepts of electromagnetic energy, power density, and forces. • Understand how the electromagnetic waves are radiated and propagates, and the optics is the study of electromagnetic waves propagation with some simplifying assumptions. • Be able to perform dimensional analysis to get physical information with a minimum of work.
Performance Appraisal	Final examination Type of Examination: written exam
Prerequisites	Solid mathematical background, basic knowledge in physics and electrodynamics
Literature	D. J. Griffiths: Introduction to Electrodynamics G. van Dijk: Distribution theory, Convolution, Fourier transform, and Laplace transform J. I. Richards, H. K. Youn: The theory of distributions - A nontechnical introduction V. S. Vladimirov: Generalized Functions in Mathematical Physics

Module	Fundamentals of Optics **– Part II**	*Code :* SPHAU58J	*ECTS : 3*
Person in charge	*F. Zolla*		
Lecturer (s)	*F. Zolla, G. Soriano (tutorials)*		
Workload	CM : 20 h / TD : 10 h	*Homework & self-studies : 30* h	
Objectives	With the help of Part I, on the introduction to electrodynamics, this course is supposed to be as self-consistent as possible. It allows to make the link between two parts which are separated in the undergraduate courses: Optics on the one hand and Electromagnetism on the other hand. We address notions as essential as polarization, wave packets, lenses, always putting forward the wave aspect.		
Content and organisation	**1. Introduction to electromagnetism** 1.1. General introduction and preliminary remarks 1.2. From constitutive relations to dispersion equation 1.2.1. Generalities 1.2.2. A bit more about permittivity 1.2.3. Dispersion equation 1.3. Polarization of electromagnetic waves 1.3.1. General considerations 1.3.2. Some useful properties 1.3.3. Linear and circular polarization 1.3.3.1. Linear polarization 1.3.3.2. Circular polarization 1.4. Notions of spatial wave packets 1.4.1. Towards a 2D–problem 1.4.2. Packets of cylindrical waves 1.4.3. Packets of plane waves **2. Stratified media** 2.1. Introduction 2.2. Decoupling in TE and TM waves of an arbitrary polarized incident plane wave 2.3. Reflection and transmission of a plane wave at a plane interface 2.3.1. TE case 2.3.2. TM case		

	2.4. Energetic considerations – Coefficients of reflection and transmission in energy 2.5. Reflection and transmission of a plane wave by a slab 2.5.1. Complex coefficients of reflection and transmission 2.5.2. A first approach of lenses 2.5.3. Introduction 2.5.4. Transfer function for a plano-convex lens 2.5.5. Transfer function for other thin lenses **3. From Fresnel to Fraunhofer** 3.1. Introduction 3.2. Fresnel transform 3.2.1. Packets of plane waves : a second approach 3.2.2. Fresnel approximation 3.3. Properties of the Fresnel transform 3.3.1. The Fresnel transform is an operator of convolution 3.3.2. Fresnel vs Fourier 3.4. A first approach of Fraunhofer optics : Fresnel at "infinite" distance 3.5. A second approach of Fraunhofer optics : Fresnel Optics in using a convergent thin lens
Acquired competencies	• The students understand the origin of dispersion and leakage • The students have a clear idea on polarization • They can derive the Fresnel's coefficients and understand their consequences • They have a clear idea about thin lenses • They have some notions on wavepackets • They know the frame of Fresnel's and Fraunhofer's Optics and their numerous consequences on the study of images.
Performance Appraisal	Final examination Type of Examination: written exam
Prerequisites	Solid mathematical background, basic knowledge in Physics, Electrodynamics and Optics
Literature	1. Gbur, 2011, Mathematical Methods for Optical Physics and Engineering. As mentioned in the title, this textbook tackles the realm of Optics with a rather mathematical flavour. Available at the library on request. 2. Novotny and Hecht, n.d., Principles of Nano-Optics. All fashionable topics. . . Available at the library on request. 3. Hecht, 2002, Optics. Well suited for beginners. Available at the library on request. 4. Goodman, n.d., Introduction To Fourier Optics. For students interested in classical optics and especially Fresnel and Fourier optics. Outstanding monography but for complementary readings. 5. Marcuse, n.d., Light Transmission Optics. For the students interested in classical optics, waveguides, lenses, etc. . . Complemenrary readings (About 400 pages). Available at the library on request. 6. Sharf, n.d., From Electrostatics To Optics : A Concise Electrodynamics Course. For master students : Chapters I to IV. Available at my office on request. 7. Jackson, n.d., Classical Electrodynamics. For master students : Chapters VI, VII and IX partly (Too) comprehensive book in Optics (about 800 pages !). Available at my office on request. 8. Born and Wolf, 2002, Principle of Optics. For master students : Chapters I and II. (Too) comprehensive book in Optics (about 1000 pages !). 9. Saleh and Teich, 2007, Fundamentals of Photonics. Very comprehensive book (About 1200 pages!!) suited for master students. This monograph tackles the main topics in Photonics in a very pedagogical fashion with its abundant and well-illustrated coloured figures with a minimum of mathematical background. (See amongst other Ch. I to VI) Available at library on request.

UE06 Physics for photonics - part 1		*Semestre : M1 – S1*	
Module		*Code :* SPHAU63	*ECTS : 6*
Person in charge	*Marie Houssin*		
Lecturer (s)	*Marie Houssin, Michael Kuzmin, Voicu Dolocan*		
Workload	CM : 40 h / TD :20 h	*Homework & self-studies :*	
Objectives	Photonics is based on the interaction between light and matter. A knowledge of the atom structure and matter physics is needed to understand different types of interaction processes. The main objective of this course is to give students basic notions on atomic physics, statistical physics and condensed matter physics.		
Content and organisation	**Atomic Physics** 1. Atom. 2. Basics of quantum mechanics. Light quanta. Emission and Absorption. Duality wave-particle. Uncertainty relation. 3. The atom picture of Bohr, Rutherford and Sommerfeld (and its limits). 4. The hydrogen atom. Fine and hyperfine structure. 5. Atoms in external fields. 6. Interactions of atoms with light. Spectroscopy and High-resolution spectroscopy 7. Laser cooling. Traps. Atomic clocks. **Statistical physics** 1. Quantum states. Closed system. Equal probabilities. Microcanonical ensemble. 2. Systems in thermal contact. Temperature and entropy. Canonical ensemble. 3. Systems in diffusion contact. Chemical potential. Grand canonical ensemble. 4. Fermi-Dirac's distribution. Fermions. Metals. 5. Bose-Einstein's distribution. Bosons. Bose-condensation. Photons, Planck's distribution. 6. Boltzmann's distribution. Ideal classical gaz. **Introduction to condensed matter physics** Introduction to the properties of solids. Crystal structures and bonding in materials. Beyond the crystalline state: soft matter (polymers, membranes, liquid crystals).		
Acquired competencies	The students • can describe atomic models • are familiar with basic microscopic models of light-matter interaction • know order of magnitude of quantum processes • understand the role of environmental conditions to atomic spectrum • should be familiar with the basic concepts of equilibrium statistical physics • have knowledge of the Bose-Einstein and Fermi-Dirac distributions • understand the different matter states and theirs particularities		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites	Solid mathematical background basic knowledge in physics		
Literature	W. Demtröder, *Atoms, Molecules and Photons*, Springer, Heidelberg (2006). C.J. Foot, *Atomic Physics*, Oxford (2005) M.Marder, Condensed Matter Physics		

UE02 - Light emission and Lasers		*Semestre :* M1 – S1	
Module	Light emission and Lasers	*Code :* SPHAU59	*ECTS : 3*
Person in charge	Nicolas Sanner		
Lecturer (s)	Nicolas Sanner and Kamal Belkebir		
Workload	CM : 30 h / TD : 10 h / TP : 0 h	*Homework & self-studies : 50* h	
Objectives	This course is an introductory lecture about light and lasers, providing comprehensive description of the physics underlying the operation of lasers. The first part, "Light emission" (10h), introduces the three main processes responsible for light emission (thermal, spontaneous, stimulated). In the second part, "Laser sources" (30h), a comprehensive treatment is provided for the fundamental concepts of lasers physics and the basic operation principles. Detailed example and tutorials are included.		
Content and organisation	**Part 1 – Light emission (10h)** In this part, we focus on several processes responsible for light emission with some practical examples. 1. Thermal emission. 2. Luminescence and spontaneous emission. 3. Stimulated emission **Part 2 – Laser sources (30h)** 1. Introduction 2. Photon-atom interaction 3. Light amplification 4. The laser oscillator 5. Laser cavities and laser beams 6. Pulsed regimes		
Acquired competencies	At the end of this module, the student will possess knowledge on light emission and the principles and operation of laser sources as well as resulting characteristics of laser light. They will be able to: - Study population inversion for various spectroscopic systems - Determine the amplification gain and the saturation of a laser medium - Assess the threshold for laser oscillation - Design stable cavities - Understand and calculate spatial and spectral characteritics of a laser beam		
Performance Appraisal	Final examination Type of Examination: written exam (without documents)		
Prerequisites	Basic physics background		
Literature	"Laser fundamentals", W. Silfvast, Cambridge University Press "Lasers", A.E. Siegman, Science Books		

UE03 - Imaging and Instrumentation in optics		*Semestre :* M1 – S1	
Module	Imaging and Instrumentation in optics	*Code :* SPHAU60	*ECTS : 3*
Person in charge	*Guillaume Maire*		
Lecturer (s)			
Workload	CM : 20 h / TD : 10 h / TP : 0 h		
Objectives	The students from different backgrounds refresh and elaborate their knowledge of the principles of optical imaging. The course starts with a reminder of the Huygens-Fresnel principle and of the Fresnel and Fraunhofer theories of diffraction. Then, a more general and rigorous approach, based on the resolution of Maxwell's equations, is adopted. The principles of image formation are studied using this approach. In particular, the link between the object defined by its permittivity distribution and the data collected for a given illumination (coherent or non coherent) is studied. The role of otical lenses, mirrors and the limitations of the performances of optical imaging systems (telescopes, far-field microscopes, near-field microscopes) in terms of resolution, accuracy are discussed. Applications in astronomy, biology, nanotechnology… and solutions implemented for increasing the performances are studied. Recent advances in optical imaging are presented throughout this course.		
Content and organisation	I – Introduction I.1 – Image-vision I.2 – Brief description of the main imaging systems II – Interaction between electromagnetic waves and heterogeneous objects II.1 – Maxwell's equations II.2 – Calculation of the scattered field II.3 – Total field inside the object II.4 – Numerical calculation II.5 – Fourier transform of the Green function II.6 – Green function in far-field III – Optical imaging III.1 – Accessible data III.2 – Optical microscopes III.3 – Telescopes		
Acquired competencies	The students •can determine the link between the object (described by its permettivity distribution) and the diffracted field using an electomagneic approach •know what are the main approximated theories of diffraction with their limitations and domains of validity •understand the difference between near field imaging and far field imaging •understand the difference between coherent and incoherent imaging •know what are the characteristics of the main imaging systems in optics (telescopes, microscopes in near field, far field, fluorescence microscopes…) •know what are the origins of the limitations of optical systems in terms of resolution and accuracy •are familiar with the main applications of optical imaging •know the solutions implemented in order to overcome the main limitations of classical imaging systems in optics •know the principles of digital imaging •have a good vision of recent advances in optical imaging		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites	Geometrical optics, optical interferences, optical coherence, diffraction, electromagnetism		
Literature	For the prerequisites: E. Hecht: Optics		

UE04 – Lab Practice		Semestre : M1 – S1	
Module	Lab Practice	Code : SPHAU61	ECTS : 3
Person in charge	Julien Duboisset		
Lecturer (s)	J Duboisset, A Escarguel, M Houssin, B Stout, P Ferrand, G Soriano		
Workload	CM : 0 h / TD : 0 h / TP : 40 h	*Homework & self-studies :* 20-60 h	
Objectives	The students from different backgrounds refresh and elaborate their knowledge of basic fields of optics and some other useful neighboring fields: Ray optics, interferences, diffraction, spectroscopy, metrology and electronics, data analysis by computer. The objective to the Lab practice is to given them skills, reflexes, automatisms in manipulating experimental optical data …		
Content and organisation	List of experiments: (4h each) 1. Geometrical optics — 2. Coherence 3. Fourier optics — 4. Polarization 5. Monochromator — 6. Michelson interferometer 1 7. Michelson interferometer 2 — 8. Spectroscopy 9. Photodetectors — 10. Holography We apply a working methodology which is close to the one used in research or in industrial R&D. First all experiments are carried out and notes are taken in a lab book. Quantitative measurments are performed, supplemented by comments on the methodology as well as on the measurement errors. Experimental work is done in teams of 2 students. There is one setup for each experiment, so everybody does a different experiment and the group rotates for the next session.		
Acquired competencies	The students • can align the different setups • can carry out a measurement and evaluate its statistical uncertainties • can write a scientific report • can communicate precisely on complex experimental setups • understand how interferometers work and what they can be used for • understand how spectrometers work and what they can be used for • understand basic optical instruments and the aberrations therein • realized a precise alignment of the Michelson interferometer • realized holograms and used them in applications • know the different electronic circuits used in combination with photdiodes • know how to caracterize the polarization of light.		
Performance Appraisal	An oral exam allows to check comprehension of the different experiments. The student must present a quantitative measurment on one of the experiments studied. The students have some time of preparation before the presentation. The Lab book is evaluated in the same time		
Prerequisites	Basic knowledge in physics / optics / electronics / programming		
Literature	"Laser fundamentals", W. Silfvast, Cambridge University Press "Lasers", A.E. Siegman, Science Books		

UE05 – Personal Project		*Semestre :* M1 – S1	
Module	Personal project	*Code :* SPHAU62	*ECTS : 6*
Person in charge	F Wagner, A Litman		
Lecturer (s)	Frequently changing		
Workload	CM : 0 h / TD : 0 h / TP : 40 h	*Homework & self-studies : 60* h	
Objectives	This lab work aims to make a first contact of the students with research work. Independent work on a specific topic is expected. Reading the litterature. Discussing with the supervisor to clear remaining questions. Start learning usage of an experimental setup or a computer code. Do some measurements or simulations and analyze them. Doing everything in a logical systematic way. Finally, present the topic and your work on it in an oral presentation, similar to what is done at conferences.		
Content and organisation	Depends on the project and on the supervisor.		
Acquired competencies	At the end of this module, the student will: - Have knowledge how researchers work in the lab - Be able to acquire specific knowledge on a research project - Get some hands-on experience in the chosen field.		
Performance Appraisal	Final examination Type of Examination: oral presentation followed by questions		
Prerequisites	Basic physics background		
Literature	Depends on the project and on the supervisor.		

UE07 Français Langue Etrangère – French as a Foreign Language		*Semestre :* M1 – S1	
Module	French as a Foreign Language	*Code :* SPHAU65	*ECTS : 3*
Person in charge	Cécile THIRION		
Lecturer (s)	Cécile THIRION		
Workload	TD : 24h	*Homework & self-studies :* 24-48 h	
Objectives	For students to acquire a competency in communication in the French language and an understanding of French society and culture so that they may express themselves, write directly, and express comprehension when communicating with French speakers.		
Content and organisation	I. Four areas of language competency will be covered – oral and written comprehension, oral and written communication – but emphasis will be placed on oral competency, therein integrating pragmatic, socio-cultural and strategic proficiencies according to the Common European Framework of Reference for Languages (CEFR). II. The lesson plans for this class will be communicative and action-oriented. As the approach will be centered on students engaging in communicative tasks, there will be flexibility in the choice and duration of the class activities. The course program will therefore be adapted to best fit the linguistic needs of each level. The topics covered may vary depending on local, national or international news and the time of year. The course is not a lecture and its success depends greatly on student participation. Class attendance is strongly recommended. In the case of an absence, the student is invited to make up the work done in class and any homework given during the student's absence. Documents from class will be available on a digital workspace. III. Resources and training materials: authentic documents, articles, photos, songs, videos, playful material from the publisher or made by the teacher and written or audio documents from manuals, methods or sites.		
Acquired competencies	Varies according to the level of each group.		
Performance Appraisal	Continuous assessment: oral comprehension, written comprehension, exercises relating to grammar and vocabulary lessons, oral presentation.		
Prerequisites	Adapted according to the level of each group.		
Literature	*La Grammaire des premiers temps* (PUG) *Grammaire Progressive du Français* (Clé International)		

Semestre 2

Curriculum

H	S2 - AMU	ECTS
30	Guided Optics	3
20	Nonlinear Optics	2
20	Physics for Photonics II	2
30	Optoelectronic Devices	3
15	Photon Spectroscopy	2
15	Molecular Cell Biology	2
30	Advanced Elm - Numerical	3
30	Labs Practice	3
30	Signal and Image Analysis	3
24	FLE ou English	2
> 7w	Internship	5
214	Total	30

Modules description - AMU

UE02 - Guided Optics		Semestre : M1 – S2	
Module	Guided Optics	Code : SPHBU94	ECTS : 3
Person in charge	*Prof. G. Renversez*		
Lecturer (s)	*Prof. G. Renversez*		
Workload	CM : 15 h / TD : 15h / TP : 0 h	*Homework & self-studies :*	
Objectives	The students from different backgrounds elaborate their knowledge in guided optics. They get also a know-how in the theoretical study of waveguides that can be used for more general optical devices. They become familiar with the concept of modes and are able to manipulate them.		
Content and organisation	1 Main introduction 2 Maxwell's equations 2.1 Maxwell's equations 2.2 Continuity relations 2.2.1 General case 2.2.2 Perfect conductor case 2.3 Constitutive equations 2.3.1 General cases 2.3.2 Frequency domain 2.3.3 Our pratical case: a very 2.4 Plane waves 2.5 Poynting vector 3 Slab waveguide 3.1 Introduction 3.2 Geometry and indices 3.3 TE/TM splitting 3.4 Propagation equations 3.4.1 Transverse E waves (TE) 3.4.2 Transverse M waves (TM) 3.5 Dispersion equation 3.5.1 Conditions to obtain a guided wave 3.5.2 Form of the electric field profile in the guiding layer 3.5.3 Obtaining of the dispersion equation for the TE case 3.5.4 field profile in the TE case 3.5.5 Comments on the dispersion equation 3.5.6 Discussion of the dispersion equation 3.6 General properties of modes 3.6.1 Mode orthogonality 3.7 The symmetric case 3.7.1 Symmetry properties (parity) 3.7.2 Even TE modes in the symmetric slab waveguide 3.7.3 Odd TE modes in the symmetric slab waveguide 3.7.4 Mode numbering 3.7.5 Dispersion curves 3.7.6 Quantization of mode localization in waveguide: confinement factor 4 Propagation of a signal	4.1 Introduction 4.2 Wave-packet and co 4.3 Signal enlargement 4.3.1 Extent of a signal 4.3.2 Distortion of a signal during the propagation 5 Optical fiber 5.1 Definition 5.2 Technological aspects 5.2.1 Attenuation in optical fibres 5.2.2 Transmission windows 5.2.3 Materials for optical fibres 5.3 Initial equations 5.4 Form of the solutions 5.4.1 Forms of the propagating modes 5.4.2 Transverse components of the fields 5.4.3 Azimuthal dependency 5.5 The circular step-index fiber 5.5.1 Recap equations for the radial dependency 5.6 Solutions in the core fibre 5.7 Solutions in the cladding 5.7.1 Orthoradial components 5.7.2 Consequences of the continuity relations 5.8 Guided modes of the circular SIF 5.8.1 Transverse modes 5.8.2 Hybrid modes HE ν,μ and EH ν,μ 5.9 Cut-Off frequencies 5.9.1 Cut-Off frequencies of TE $0,\nu$ and TM $0,\nu$ transverse modes 5.9.2 Cut-Off frequencies of EH ν,μ and HE ν,μ hybrid modes 5.10 Scalar modes 5.10.1 Introduction 5.10.2 Scalar wave equation 5.10.3 Forms of the solutions 5.10.4 Dispersion equations 5.10.5 Mode profiles 5.10.6 Power fraction in the core Several tutorials are realized during the semester including one on surface plasmon polaritons and one for graded index waveguide.	
Acquired competencies	The students • can derive the dispersion equation for simple waveguides including slab waveguides and step-index optical fibers • can analyse the dispersion properties of waveguides		

	• understand the generalization of the waveguide studies for more complex configurations • manipulate the waveguides guided modes as the solutions of eigenvalue problems • understand the link between waveguide symmetries and mode classification • understand the link between waveguide dispersion properties and signal propagation • know the main technological aspects of optical fibers • have the knowledge and know-how to understand and use the standard textbooks on this field including for new photonic structures
Performance Appraisal	Final examination Type of Examination: 3h written exam
Prerequisites	Mathematical background, fundamentals in Mathematics including basic linear algebra, and vector analysis, basics of wave physics, Maxwell's equations, electromagnetic plane waves
Literature	K. Okamoto: Fundamentals of optical waveguides A. W. Snyder & J. D. Love: Optical waveguide theory H. Kogelnik: Integrated Optics, D. Marcuse: Light Transmission Optics D. Marcuse: Theory of Dielectric Optical Waveguides C.-L. Chen: Foundations for guided-wave optics

UE10 - Nonlinear optics		*Semestre :* M1 – S2	
Module	**Nonlinear optics**	*Code :* SPHBU93	*ECTS : 2*
Person in charge	Frank WAGNER		
Lecturer (s)	Frank WAGNER, Konstantinos ILIOPOULOS		
Workload	CM : 20 h / TD : 0 h / TP : 0 h	*Homework & self-studies : 15* h	
Objectives	This course		
Content and organisation	**Part 1 – Introduction, general definitions and chi2 effects** *1. Introduction* Explaining the name - The origin of the nonlinearity in P(E) The polarization density and the susceptibility tensors - For time-invariant, local and homogeneous materials - P^((n)) induced by a superposition of monochromatic waves List and classification of NLO effects The symmetries of higher order susceptibilities - Symmetries of material tensors in crystalline materials - Contracted notation for chi2-tensors Simplified photon picture of NLO effects - Three-wave interaction: Energy conservation - Three-wave interaction: Momentum conservation (= phase-matching) *2. Linear but anisotropic optics* Propagation in an anisotropic medium - Principal axes and principal indices - Propagative plane wave solutions: normal indices and normal modes Optical axis and material classification Graphical representation of the normal indices as k-surfaces Back to phase-matching: The "types" of phase matching *3. The nonlinear wave equation* The exact version - The approximated version for three wave interaction - Energy conservation and the Manley-Rowe relations *4. Practical aspects of three wave interaction* Second harmonic generation (SHG) - Conversion with negligible pump depletion - Comparing phase-matched conversion to mismatched conversion - Tolerated phase mismatch and crystal length - Noncritical phase matching - Phase matched conversion with pump depletion. - Experimental realization of high efficiency SHG - The importance of the phase if more than one beam is incoming Phase matched optical parametrical amplification (OPA) in the non-depleted pump approximation Influence of the crystal anisotropy: effective nonlinearity parameter deff - The example of collinear type I SHG in KDP. **Part 2 – Third order nonlinear optical response** *5. Intensity dependent refractive index (optical Kerr effect),* nonlinear optical parameters, physical origin of the nonlinear refractive index. *6. The Z-scan technique* A single beam setup allowing the determination of the nonlinear refraction and absorption of appropriate materials. *7. Temporal studies of the optical nonlinearities* *8. Applications* Nonlinear optical microscopy, applications related to nonlinear refraction and absorption			
Acquired competencies	At the end of this module, the student will be able to: - Understand the formalism of the classical description of nonlinear optics - Find directions of phase matching in a nonlinear optical crystal - Establish the system of differential equations describing a chi2 effect. - Understand the physics of frequently encountered nonlinear optical phenomena - Know some basic applications of NLO			

Performance Appraisal	Final examination Type of Examination: written exam
Prerequisites	Complex numbers, Electromagnetics, Linear Algebra, Tensor calculus, Differential equations
Literature	"The Elements of Nonlinear Optics", Butcher & Cotter, with the (few) corrections given in: Fredrik Jonsson, "Nonlinear Optics" (KTH, Stockholm, Sweden). Full text available at: https://kth.diva-portal.org/smash/record.jsf?pid=diva2%3A25333&dswid=3719 (See also page 9 (p.15 of the pdf) for more books and comments on them.) "Nonlinear Optics", Robert W. Boyd

UE03 - Physics for photonics part 2		*Semestre :* M1 – S2	
Module		*Code :* SPHBU95	*ECTS : 2*
Person in charge	*Voicu Dolocan*		
Lecturer (s)	*Voicu Dolocan*		
Workload	CM : 13 h / TD :7 h	*Homework & self-studies :*	
Objectives	Photonics is based on the interaction between light and matter. A knowledge of the atom structure and matter physics is needed to understand different types of interaction processes. The main objective of this course is to give students fundamental notions on condensed matter physics.		
Content and organisation	• Mechanical properties: cohesion, elasticity and lattice dynamics (phonons) • Electronic structure: single electron model, Schrodinger equation and symmetry, nearly-free and tightly bound electrons, electron-electron interaction and band structure • Electron dynamics and basic transport properties. Semiconductors • Magnetic properties, magnetotransport • Optical properties		
Acquired competencies	The students • understand the different states of matter and what give materials their properties • can describe the different models that explain these properties • are familiar with the electronic structure of materials		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites	Physics for Photonics 1 Introductory Quantum Mechanics Solid mathematical background		
Literature	M. Marder, Condensed Matter Physics		

UE04 - Properties, fabrication and characterization of optoelectronic devices		*Semestre :* M1 – S2	
Module		*Code :* SPHBU96	*ECTS : 3*
Person in charge	*Jean-Yves Natoli*		
Lecturer (s)	*Jean-Yves Natoli, Judikaël De Rouzo*		
Workload	CM : 20h / TD : 10h	*Homework & self-studies :*	
Objectives	Optoelectronic devices and circuits are now core technologies for several key technical areas such as telecommunications, information processing, optical storage, lighting, and sensors. Objectives of this course is to give firstly to students fundamental notions in semiconductors for optoelectronics phenomenon, secondly details on components (emitters and detectors). A third part will describe the process of fabrication and characterization of devices.		
Content and organisation	**Part 1** 1. Basis of semiconductors physics: (band structure/Ek diagram/Junction theory/ hetero-junction structure) 2. electroluminescence phenomenon 3. Light-emitting diode (LED) and applications 4. Laser LED: structures and properties (edge, MQW, DFB, tunable, VCSEL) **Part2** 1. Fundamental for detection 2. Photodetectors 3. Imaging sensors 4. Solar cells **Part 3:** Fabrication and characterization (Main difference between electronic and optoelectronic fabrication processes		
Acquired competencies	The students • understand the properties of semiconductors for optoelectronic applications. • can describe the different models that explain these properties • are familiar with the electronic structure of materials • can chose materials and devices regarding applications • have knowledge on process technology for the fabrication of a range of optoelectronic devices		
Performance Appraisal	Oral Presentation (chosen topic) + Final examination (written exam)		
Prerequisites	Introduction to Material Science - Basis in electronics systems		
Literature	-Optoelectronics & Photonics: Principles & Practices, 2nd Edition, Safa O. Kasap,Univ of Saskatchewan -A. Rogalski, Infrared Detectors, 2nd edition, CRC Press, Boca Raton, Florida (2010). -Wei-Chic Wang, “Optical detectors” & “Radiometry”, teaching lessons, National, Tsing Hua University		

UE06 - Photon Spectroscopy		*Semestre :* M1 – S2	
Module	Photon Spectroscopy	*Code :* SPHBUA2	*ECTS : 2*
Person in charge	*Julien Duboisset*		
Lecturer (s)	*Julien Duboisset*		
Workload	CM : 15 h	*Homework & self-studies :*	
Objectives	Photonics Spectroscopy is based on the interaction between light and matter. A knowledge of the molecule structure and matter physics is needed to understand different types of interaction processes. The main objective of this course is to give students a fundamental basic understanding of the light-matter interaction processes used in spectroscopy.		
Content and organisation	• Molecular structure • InfraRed absorption • Raman scattering – point group symmetries • Fluorescence • Nonlinear optics: second harmonic and sum frequency generation, coherent Raman scattering		
Acquired competencies	The students • understand the different states of matter and what give materials their properties • can describe the different processes, their usefulness, their advantages, drawbacks for spectroscopy or imaging purpose. • are familiar with light matter interaction		
Performance Appraisal	Final examination Type of Examination: written exam based on the lecture – usually no document is allowed		
Prerequisites	Physics for Photonics 1 Introductory Quantum Mechanics Solid mathematical background Imaging		
Literature	Principles of Fluorescence Spectroscopy, Lakowicz, Nonlinear optics, Boyd Symmetry and spectroscopy, Bertolucci		

UE07 - Introduction to molecular cell biology		*Semestre :* M1 – S2	
Module	Introduction to molecular cell biology	*Code :* SPHBUA3	*ECTS : 2*
Person in charge	*Loic Le Goff*		
Lecturer (s)	*Loic Le Goff/Manos Mavrakis/Julien Savatier*		
Workload	CM : 16 h		
Objectives	The course will provide basic knowledge in molecular and cell biology, and describe the molecular tools that biologists use in order to study and label molecules and structures of interest, in particular using fluorescence microscopy.		
Content and organisation	I – Introduction • What is life ? • Biomolecules (carbohydrates, lipids, proteins, nucleic acids) • Cell organization, types and structures (organelles, sizes, functions) • DNA, RNA and proteins, genetic code • Cell division (mitosis) II – Experimental model systems and methodology • Cell and animal model systems in biology • Experimental approaches for studying biology • Molecular cloning, Polymerase chain reaction (PCR, RT-PCR) III – Fluorescent labeling • Chemical labeling of proteins, immunofluorescence • Green Fluorescent Protein (GFP), genetic fusions IV – Cells in organs • Cell types • Cell differentiation • Stem cells V – Gene regulation • The central Dogma of molecular Biology • The basic mechanisms of genetic regulation: enhancers, promoters, transcription factors • Gene regulatory networks		
Acquired competencies	• Know the different families of biomolecules and their role • Recognize different organelles and cytoskeletal filaments of a cell, and differentiate cell types • Know the link and mechanisms between DNA, RNA and proteins • Summarize stages of mitosis and know what dividing cells look like • Being able to choose the proper model system and experimental approach for addressing a biological question • Being able to use PCR for molecular cloning and detection of viral infection • Being able to fluorescently label specific proteins of interest in fixed and living cells and tissues • Understand the basics of gene regulation, its importance in the context of animal development, and know about the techniques associated		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites	None		
Literature	Molecular Biology of the Cell, Bruce Alberts et al		

UE08 - Advanced Electromagnetics 1 – Num. Approach		*Semestre :* M1 – S2	
Module	**Advanced Electromagnetics 1 Numerical Approach**	*Code :* SPHBU97	*ECTS : 3*
Person in charge	Amelie Litman		
Lecturer (s)	Amelie Litman		
Workload	CM : 0 h / TD : 0 h / TP : 30 h	*Homework & self-studies : 30* h	
Objectives	This course introduces students to MATLAB programming and visualization of electromagnetic fields. The students will acquire an operational knowledge and firm grasp of electromagnetic fundamentals by teaching them "hands on" electromagnetics through a series of computer exercises solving optical phenomena on rigorous grounds. The first part, "Discovering Matlab", serves as an introduction to programming languages, numerical schemes and the Matlab environment. In the second part, "Electromagnetic simulations", several examples of light matter interactions will be numerically explored by the students, ranging from diffraction to the optical responses from stratified media.		
Content and organisation	**Part 1 – Discovering Matlab** 1. Arrays and operators in Matlab 2. Working with files and functions 3. Graphs, 2D and 3D plots 4. Minimization and optimization **Part 2 – Electromagnetic simulations** 1. Diffraction and interferences (scalar theory, Huygens-Fresnel principle, Fraunhofer) 2. Reflection/Transmission of a plane wave at a planar interface 3. Reflection/Transmission of a plane wave on a multilayer system (anti-radar coating, Bragg mirror, …) 4. Color rendering 5. Solar cells		
Acquired competencies	At the end of this module, the student will be able to: - Solve real-time complex physical problems using MATLAB-based short scripts - Implement numerical strategies to model optical multilayered media and improve their performances - Generate graphs to illustrate and analyse electromagnetic phenomena for articles and reports		
Performance Appraisal	Final examination Type of Examination: computer exam		
Prerequisites	Electromagnetics, Linear Algebra		
Literature	"Classical Electrodynamics" John David Jackson "Introduction to Fourier Optics" Joseph W. Goodman "Computational Electromagnetics with MATLAB " Matthew N.O. Sadiku "Fundamentals of Electromagnetics with MATLAB " Karl E. Lonngren		

UE09 - Laboratory project and practice work		*Semestre :* M1 – S2	
Module	**Laboratory project and practice work**	*Code :* SPHBU98	*ECTS : 3*
Person in charge	Frank WAGNER		
Lecturer (s)	Frank WAGNER, Amélie FERRE		
Workload	CM : 0 h / TD : 0 h / TP : 30 h	*Homework & self-studies : 16* h	
Objectives	Knowledge of avanced optical elements and simulations		
Content and organisation	All students will make 4 experimental projects of 2x4h: 1. *Nd:YAG lasers:* Learn about laser safety, Make the laser work (see alignment procedure), Explore the limits of the stability of the cavity, Explore the transverse modes, Create nanosecond pulses, Show the existence of multiple longitudinal modes, Convert the laser to another wavelength, Explore the conversion efficiency. 1. *Diode lasers:* Learn about laser safety. Explore the wavelength changes that you can obtain. Discuss the changes observed in the coherence of the emitted light when changing the pump current. Measure the slope efficiency. Describe the 'optical power' as function of 'pump current' curve. Explore beam profile and divergence of the laser diode emission. What is the orientation of the p-n-junction? What is the polarization state? *3. Optical modulation* *Acousto Optical Modulator:* Understand your modulator. Can it modulate phase? Can it modulate amplitude? Which additional elements are needed to an optical free space transmission setup (for music)? What is the best modulation contrast you can obtain? This modulator is used for frequency stabilization of lasers. How is this done? *Electro Optical Modulator:* Understand your modulator Can it modulate phase? Can it modulate amplitude? Which additional elements are needed to create an optical free space transmission setup (for music)? Realize the setup. Understand the limits of the setup, distortions… *4. Simulations for optics* *Using Matlab or Pyhton* for *assessing an imaging setup within a diffraction formalism*. Implement two coherent point sources that irradiate through a round aperture. What is seen on a screen after the aperture? Is there a particular (best) location for the screen? Implement a plano-convex les in the aperture. How does this change the pattern on the screen? Is there a particular (best) location for the screen? Find and discuss the resolution of your imaging system. *Using Oslo* to compare the performance of optical components, *design and optimize a simple zoom objective*. Explain how it works. Explain its limitations. Describe its performance.		
Acquired competencies	At the end of this module, the student will be able to: - Understand how lasers work including Q-switching, and frequency conversion - Understand how AOMs and EOMs work. - Make a electromagnetic simulation based on the Fresnel diffraction - Have some experience with optical design software.		
Performance Appraisal	Evaluation of the reports Type of Examination: written reports		
Prerequisites	Independent learning capacities, laser theory, basic physics, programming in Matlab or Python, basics of ray tracing, solid state physics, anisotropic optics		
Literature			

UE01 - Signal and image analysis		*Semestre :* M1 – S2	
Module	Signal and image analysis	*Code :* SPHBU92	*ECTS : 3*
Person in charge	*Jean-Marc Themlin*		
Lecturer (s)	*Jean-Marc Themlin, Laurent Nony*		
Workload	CM : 20 h / TP : 10 h or 10h/20h TP	*Homework & self-studies : 25h*	
Objectives	The students will learn a significant number of basic "*Signals and systems*" concepts, tools and theory. They will develop awareness of a number of problems/tasks that signals and systems engineering commonly addresses, and will be capable of resolving realistic signals and systems problems using GNU Octave or MatLab®, a widespread tool used in R&D worldwide.		
Content and organisation	We start with 9 hours of lectures and then go on to 8 laboratory sessions based on MatLab® (or GNU Octave) and implement their own solutions, *e.g.* in signal estimation and identification, ubiquitous issues in signal processing. Short introductory lectures treat : Part A : **Signals** : Present the essential tools commonly used to describe continuous-time (analog) and discrete-time signals, images and noise, mostly from a deterministic waveform point of view. Continuous-time waveforms are represented by direct mathematical expressions or by the use of orthogonal series representations such as the Fourier series. Properties of these waveforms, such as their DC value, root-mean-square (RMS) value, energy and power, magnitude and phase spectrum (through the Fourier transform), power spectral density, and bandwidth, are recalled or established. In the frequency-domain, analog and digital signals are represented by their Fourier transform. The Discrete Fourier Transform (DFT), when properly applied, allows the computation of spectra. Part B : **Systems** : Used to manipulate analog or digital waveforms, exploiting various operations like scalar product, convolution and correlation. In addition, effects of linear filtering is introduced. Actual systems used in signal storage, transmission and modulation, multiplexing, video signal coding, lossy signal compression (principle of JPEG standard) will be explained. • **Lab 1** : Signal representation using GNU-Octave: Introduction to Octave scripts and functions, application to the *sinc* signal. • **Lab 2** : Representation of analog signals by discrete-time signals: Introduction to discrete sinusoids, discrete frequency and sampling, empirical discovery of the Shannon-Nyquist theorem. • **Lab 3** : Signal Parameter Estimation – Part A: Estimation of the parameters of a sinusoidal signal (of known frequency f_0) using the scalar product; dependence on S/N ratio and on the precise knowledge of f_0. • **Lab 4** : Signal Parameter Estimation – Part B: Estimation of the parameters of a sinusoidal signal (of unknown frequency), an empirical introduction to the Discrete Fourier Transform (DFT). • **Lab 5** : Signal recognition through Correlation: Retrieve the occurrence of replicas of a reference signal hidden in a noisy signal using sliding scalar product and "running" ("real-time") correlation; application to Radar/Sonar signals. • **Lab 6** : FIR Filtering: From running correlation to convolution, to implement various digital filters, used *e.g.* to extract a sinusoid of known frequency in a composite signal. • **Lab 7** : Discrete Fourier Transform: Empirical and extensive self-paced exploration of the DFT tool, supported by a complete and specifically-designed "active" reference (a Jupyter notebook). • **Lab 8** : Image Processing and Filtering: Generalizes the convolution to 2D signals (images), digital filtering of images.		

Acquired competencies	The students will be able to : • Exploit *Matlab*® (or its open-source equivalent *GNU-Octave*) to develop useful and realistic "*expert systems*" in digital signal and image processing, *e.g.* signal estimation and identification. • Become accustomed to modern means of performing personal or team work on scientific calculations and novel ways of sharing data, programs and results (through the use of the *CoCalc*® platform). • Practice personal exploration through trials and enquiries, and thus develop adequate research skills in digital signal and image processing.
Performance Appraisal	30% Lab marks + 70% Final examination (on PC)
Prerequisites	Basic programming knowledge, basic mathematical background in signal theory (Fourier transform).
Literature	• Richard J.Tervo, *Practical Signals Theory (with MatLab Applications)*, Wiley (2014) • Hwei Hsu, *Signals and Systems (2nd edition)*, Schaum's Outline Series, Mac Graw Hill (2011) • Steven W. Smith, *The Scientist and Engineer's Guide to Digital Signal Processing*, www.dspguide.com.

UE11 - French as a Foreign Language		*Semestre :* M1 – S2	
Module	French as a Foreign Language	*Code :* SPHBUA5	*ECTS : 2*
Person in charge	Cécile THIRION		
Lecturer (s)	Cécile THIRION		
Workload	TD : 24h	*Homework & self-studies :* 24-48 h	
Objectives	For students to acquire a competency in communication in the French language and an understanding of French society and culture so that they may express themselves, write directly, and express comprehension when communicating with French speakers.		
Content and organisation	I. Four areas of language competency will be covered – oral and written comprehension, oral and written communication – but emphasis will be placed on oral competency, therein integrating pragmatic, socio-cultural and strategic proficiencies according to the Common European Framework of Reference for Languages (CEFR). II. The lesson plans for this class will be communicative and action-oriented. As the approach will be centered on students engaging in communicative tasks, there will be flexibility in the choice and duration of the class activities. The course program will therefore be adapted to best fit the linguistic needs of each level. The topics covered may vary depending on local, national or international news and the time of year. The course is not a lecture and its success depends greatly on student participation. Class attendance is strongly recommended. In the case of an absence, the student is invited to make up the work done in class and any homework given during the student's absence. Documents from class will be available on a digital workspace. III. Resources and training materials : authentic documents, articles, photos, songs, videos, playful material from the publisher or made by the teacher and written or audio documents from manuals, methods or sites.		
Acquired competencies	Varies according to the level of each group.		
Performance Appraisal	Continuous assessment: oral comprehension, written comprehension, exercises relating to grammar and vocabulary lessons, oral presentation.		
Prerequisites	Adapted according to the level of each group.		
Literature	*La Grammaire des premiers temps* (PUG) *Grammaire Progressive du Français* (Clé International)		

Semestre 3

Curriculum

H	S3 - AMU	ECTS
20	Tutorials	2
22	Quantum Optics	3
34	Laser sources and application / matter interaction	3
34	Optical components and optoelectronics	3
24	Photonics for Biomedical Applications	3
24	Advanced Methods for Optical Instrumentation	3
24	Advanced Electromagnetics II (Elective)	3
28	Nanophotonics (Elective)	3
32	Numerical Methods for Elm (Elective)	3
34	Instrumentation for Astronomy (Elective)	3
7w	Apprenticeship	3
20	Technological Intelligence	2
24	FLE ou English	2
320	Total	36

Modules description - AMU

UE00 Tutorials		Semestre : 3	
Module		*Code :* SPHCUH6	*ECTS : 2*
Person in charge	Miguel Alonso		
Lecturer (s)	Miguel Alonso		
Workload	CM : 20 / TD : /		
Objectives			
Content and organisation	**1. Basic elements** Review Maxwell, wave eq., plane waves. Intensity & Poynting vector. Polarization: linear, elliptic, circular. Conventions. **2. Optical elements and Jones calculus** Jones vectors: conventions. Bases (mutually unbiased). Polarizers, retarders, dichroic and active media. Jones matrices. Unitary and projective matrices: conservation of norm and scalar product for unitary operations. Concatenation of elements (e.g. circular polarizers). **3. The Poincaré sphere** Parametrization of Jones vector in terms of angles and phase: Poincaré Sphere in spherical coordinates. Stokes parameters: Poincaré Sphere in Cartesian coordinates. Retarders (unitary transformations) as rotators over the Poincaré sphere. Effect of dichroics and polarizers on Poincaré sphere (exercise?). **4. Geometric phase** Phase of inner product and parallel transport. Geometric phase (Pancharatnam and Berry). Geometric phase elements and some applications. Phase of inner product for retarders (not parallel transport). Redirection geometric phase. **5. Partial polarization** Theory of stochastic processes. Partial polarization: polarization matrix. Degree of polarization: definition as part of light that is fully polarized. Degree of polarization: definition in terms of “purity”. Interpretation as radial coordinate in Poincaré sphere. Stokes parameters as coefficients of Pauli matrices. **6. Mueller calculus** Mueller matrices for retarders, polarizers. General matrices. Rules. Depolarization. Lu-Chipman decomposition. **7. Measurement techniques** Theoretical considerations. Accuracy limits. Polarization measurement techniques (survey). **8. Applications in metrology**		

	Ellipsometry and scatterometry. Medical imaging. Remote sensing. Microscopy: e.g. DIC. Weak measurements. **9. Applications in quantum optics and communications** Polarization multiplexing. Beamsplitters. QKD protocols. **10. Polarization distributions** Fields with non-uniform polarization. Vector beams. Polarization singularities: c-points (Lemons, Stars, Monstars) and L-lines. Examples. **11. Nonparaxial polarization** High NA focusing: Richards and Wolf method. Focusing of radial and azimuthal light. Spin-orbit coupling. Evanescent waves and surface plasmons. Generalized Stokes parameters. Two-point spheres. Polarization textures: Möbius strips, Skyrmions, etc. Applications.
Acquired competencies	The students • know how to …
Performance Appraisal	Final examination Type of Examination: written exam
Prerequisites	Elecromagnetism
Literature	

UE01 Quantum Optics and Quantum Information		*Semestre :* M2 – S3	
Module		*Code :* SPHCUH7	*ECTS : 2 (ou 3 ?)*
Person in charge	*Thomas Durt*		
Lecturer (s)	*Thomas Durt*		
Workload	CM : 18 h / TD : 4 h	*Homework & self-studies :* 8 h	
Objectives	The goal of our lessons is to familiarize the student with a quantum description of light; in particular it is aimed at introducing fundamentals in quantum optics and quantum information. Concepts such entanglement, vacuum fluctuations, second quantization and so on are indeed necessary in order to go beyond the classical Maxwell description. In our teachings, we aim at providing a survey of the progresses realized between Planck's derivation of the black body distribution in 1900, and quantum teleportation one century later, not fogetting precise predictions regarding spontaneous emission (Fermi golden rule-30's), the machinery of coherent states produced by a laser source (60's) and the so-called second quantum revolution initiated in the 90's. The tools that we introduce aim at giving to the student the ability to understand the most recent achievements in quantum information and quantum optics (entanglement, quantum cryptography, single photon sources, quantum tomography…).		
Content and organisation	I. Introduction (history: Planck-Einstein-Bohr-de Broglie-Schroedinger-basic rules of quantum mechanics) II. Rayleigh-Jeans, Planck, quantization of a one-d harmonic oscillator and application to Maxwell fields; . III. Application: Fermi golden rule and spontaneous emission. IV. Coherent states V. Non-locality and entanglement: Bell's inequalities VI. Second quantum revolution, Quantum Information, basic tools, protocols and applications		
Acquired competencies	The students • get familiar with a quantum description of light • get acquainted with the most recent developments of quantum optics and quantum information • are able to solve elementary exercises similar to those solved during the course.		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites	Solid mathematical background, basic knowledge in physics Fundamentals in Atomic Physics/Quantum Mechanics		
Literature	Griffith: Introduction to Quantum Mechanics		

<table>
<tr><th colspan="2">UE03 Laser sources and application / matter interaction</th><th colspan="2">Semestre : M2 – S3</th></tr>
<tr><th>Module</th><th></th><th>Code :</th><th>ECTS : 3</th></tr>
<tr><td>Person in charge</td><td colspan="3">Nicolas Sanner</td></tr>
<tr><td>Lecturer (s)</td><td colspan="3">Nicolas Sanner, Frank Wagner, Jean-Yves Natoli, Kostas Iliopoulos, Amélie Ferré,</td></tr>
<tr><td>Workload</td><td>CM : 34 h (with exercises and lab work)</td><td colspan="2"></td></tr>
<tr><td>Objectives</td><td colspan="3">The students from different backgrounds elaborate their knowledge on the physical principles of optoelectronic devices. Applications in sensing, lightning, nanotechnology, energy harvesting.</td></tr>
<tr><td>Content and organisation</td><td colspan="3">The teaching unit is composed of <u>3 completely independent parts</u>: Optoelectronics, crystal based components, optical thin film based components
<u>Optoelectronics part</u>
I – Introduction
- Electronic band theory of semi-conductors
- A mono-dimensional toy model: the Kronig-Penney model
- Effective mass: origin of holes
- Extension in 3D and application to common semi-conductors
- Optical transitions in direct and indirect bandgap semi-conductors
II – Light emission
- Light Emitting Diodes: Principles
- From the Electronic band structure to the space band diagram
- Classical homojunction
- Heterojunction
III – Devices
- Structure of a LED
- A word about fabrication
- Extraction and light management
- Efficiencies
- Emission spectrum
- Applications and comparison with sensing devices
<u>Crystal based optical components</u>
I – Introduction: EM waves in isotropic media, polarization, Jones formalism
II – Anisotropic optics: susceptibility tensor, principal axes, index ellipsoid, optical axes, classification, normal modes, Fresnel equation, Eigen-polarizations, walk off angle, propagation in biaxial crystal, propagation in uniaxial crystals, application to phase matching in nonlinear optics, birefringence
III – Crystal based components: specifying optical components, polarizers (polymer, thin-film, crystal-based), waveplates, EOM, LCD-modulators, AOM, phase-matching in NLO
<u>optical thin film based components</u></td></tr>
<tr><td>Acquired competencies</td><td colspan="3">The students
• know how what represents an bandstructure and how it can be obtained
• know what is a direct / indirect bandgap materials
• understand the applications of each
• know what an LED and a CMOS sensor are and how they are build
• know what the efficiency of a LED and a sensor is
> Know how to determine the refractive index and the polarization of the linearly polarized eigenmodes propagating in a crystal
> Know the different types of polarizers
> Know how waveplates, electro-optic modulators (pockels cells), liquid-crystal light modulators, acousto-optic modulators work.
▪</td></tr>
<tr><td>Performance Appraisal</td><td colspan="3">Final examination
Type of Examination: written exam</td></tr>
<tr><td>Prerequisites</td><td colspan="3">Semiconductor class, electromagnetic wave basics, programming basics (matlab or python),</td></tr>
<tr><td>Literature</td><td colspan="3">R. Pierret, Advanced Semiconductor Fundamentals</td></tr>
</table>

UE04 Optical components and optoelectronics		*Semestre : M2 – S3*	
Module		*Code :* SPHCUK1	*ECTS : 3*
Person in charge			
Lecturer (s)	Guillaume Demésy, Frank Wagner, Frédéric Lemarquis, Fabien Lemarchand, Julien Lumeau		
Workload	CM : 34 h (with exercises and lab work)		
Objectives	The students from different backgrounds elaborate their knowledge on the physical principles of optoelectronic devices. Applications in sensing, lightning, nanotechnology, energy harvesting.		
Content and organisation	The teaching unit is composed of 3 completely independent parts: Optoelectronics, crystal based components, thin film optical coatings. **Optoelectronics part** I – Introduction: Electronic band theory of semi-conductors, a mono-dimensional toy model: the *Kronig-Penney* model, effective mass: origin of holes, extension in 3D and application to common semi-conductors, optical transitions in direct and indirect bandgap semi-conductors II – Light emission: Light Emitting Diodes: Principles, from the electronic band structure to the space band diagram, classical homojunction, heterojunction III – Devices: structure of a LED, a word about fabrication, extraction and light management, efficiencies, emission spectrum, applications and comparison with sensing devices **Crystal based optical components** I – Introduction: EM waves in isotropic media, polarization, Jones formalism II – Anisotropic optics: susceptibility tensor, principal axes, index ellipsoid, optical axes, classification, normal modes, Fresnel equation, Eigen-polarizations, walk off angle, propagation in biaxial crystal, propagation in uniaxial crystals, application to phase matching in nonlinear optics, birefringence III – Crystal based components: specifying optical components, polarizers (polymer, thin-film, crystal-based), waveplates, EOM, LCD-modulators, AOM, phase-matching in NLO **Thin film optical coatings** I – Thin film theory: understanding of propagation and interferences inside a multilayer structure; Calculation techniques for the reflectance and transmittance factors of a coating. II – Thin film design: description of the multilayer structures used for classical thin film filters: dielectric mirrors, antireflection coatings, edge filters, bandpass filters. III – Manufacturing and characterization of thin film filters: theoretical elements and experimental demonstration.		
Acquired competencies	The students • know how what represents an bandstructure and how it can be obtained • know what is a direct / indirect bandgap materials • understand the applications of each • know what an LED and a CMOS sensor are and how they are build • know what the efficiency of a LED and a sensor is > Know how to determine the refractive index and the polarization of the linearly polarized eigenmodes propagating in a crystal > Know the different types of polarizers > Know how waveplates, electro-optic modulators (pockels cells), liquid-crystal light modulators, acousto-optic modulators work. ▪ know what happens inside a multilayer structure. ▪ know how to design a thin film stack to obtain a given reflectance or transmittance spectral profile.		

	▪ know how thin film filters are manufactured.
Performance Appraisal	Final examination Type of Examination: written exam
Prerequisites	Semiconductor class, electromagnetic wave basics, programming basics (matlab or python),
Literature	R. Pierret, Advanced Semiconductor Fundamentals

UE05 Photonics for biomedical applications		*Semestre :* M2 – S3	
Module		*Code :* SPHCUK2	*ECTS : 3*
Person in charge	*Guillaume Baffou*		
Lecturer (s)	*Guillaume Baffou, Anabela Da Silva*		
Workload	CM : 24 h	*Homework & self-studies :* 8 h	
Objectives	The students build and consolidate their knowledge on the field of imaging biological systems. A first part of the Module will be dedicated to *optical* microscopies with a special focus on cells cultured in vitro. This first series of lecture is aimed to span the wide variety of optical microscopy techniques that have been developed until very recently to image living systems, from standard technique to more advanced approaches enabling ultra-high spatial resolution, high velocity and 3D imaging. A second part of the course is oriented toward imaging of biological tissues, for biomedical applications.		
Content and organisation	I. Cell imaging (G. Baffou, 15h) a. The optical Microscope (spatial resolution, Köhler illumination, bright/dark field imaging, phase contrast, DIC, QLSI) b. Fluorescence microscopy (physics/chemistry of fluorescence, fluorophores families, experimental implementation of fluorescence microscopy, confocal microscopy, fluorescence labelling of cells, two-photon fluorescence, upconversion fluorescence, light sheet microscopy, TIRF microscopy, spinning disc fluorescence microscopy) c. Vibrational microscopies (Rayleigh scattering, Raman scattering and microscopy, stimulated Raman microscopy, CARS) d. Superresolution techniques: Above the diffraction limit (4pi-microscopy, STED, SIM, PALM, SOTRM) e. Advanced optical microscopy techniques (Fluorescence correlation spectroscopy, fluorescence life time imaging, FRAP, nanoparticles for imaging) f. Applications (optogenetics, brain/neuron imaging in vivo and in vitro, embryogenesis, brain/tissue clearance) g. Introduction to the use of deep learning for bioimaging analysis II. Tissue imaging and biomedical applications (A. Da Silva, 10h) a. Introduction to biological tissue optics b. Main contrasts: Absorption, fluorescence, Scattering c. Model of light propagation through biological tissues and inverse problems resolution d. Instrumentation and imaging/diagnostic setups examples		
Acquired competencies	The students • become aware of the importance of the research community working on optical imaging in biology, and of the most active research activities that are animating the fields of bioimaging and biophotonics • possess a solid knowledge on all the techniques capable of imaging living matter, from the scale of single cells in culture, to the scale of animals and patients. • learn/consolidate fundamental knowledge in physics related to main physical contrasts, to light propagation in biological tissues, to molecular fluorescence, Raman spectroscopy. • know basics in biology, such as in cell biology and fluorescence labelling techniques.		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites	Nothing specific.		
Literature	G. Cox, Optical Imaging Techniques in Cell Biology B. Valeur, Molecular Fluorescence Principles and Applications M. Born and E. Wolf, Principles of Optics, Cambridge University Press Ed. Tuan Vo-Dinh, Biomedical Photonics Handbook, CRC Press, 2003 V. Tuchin, Tissue optics, Light scattering methods and instruments for medical diagnosis, SPIE Press, 2000		

UE06 Advanced Methods for Optical Instrumentation		*Semestre :* M2 – S3	
Module		*Code :* SPHCUK8	*ECTS : 3*
Person in charge	*Elodie Choquet*		
Lecturer (s)	*Elodie Choquet*		
Workload	CM : 24 h / TD : 0 h / TP : 0 h	*Homework & self-studies :* 8 h	
Objectives	The students with a basic knowledge of ray optics and optical systems develop a strong understanding of the optical systems. They know the key characteristics that drive their performance and specifications. The learn to recognise the main aberrations that limit their perfomance, and what the levers are to minimize or cancel them, with a mathematical and analytical method. They learn how to diagnose the performance of an existing optical system, and how to desing new systems given specifications.		
Content and organisation	I. Geometrical Optics (General principles, Gauss approximation, Aperture, Field of view, depth of field) II. Chromatic aberrations (Axial and Transverse chromatic aberration, achromatic doublet) III. Geometrical aberrations (3rd order transverse aberration, Wavefront aberration: Nijboer equations, Seidel aberrations, Zernike polynomials; 3rd order aberrations of the spherical dioptre and of the thin lens.) IV. Fourier optics and aberrations (Diffraction, point spread function, Strehl ratio, Rayleigh and Marechal criteria, Seidel aberration and wave optics) V. Radiometry (Definition of radiometric quantities, radiation spectrum, radiation emission, metrology)		
Acquired competencies	The students •can compute the aperture and field of view of a given optical system and conversely they can compute the dimensions of an optical system given specifications. •can compute the chromatic aberation of a system and design optical elements that make a system achromatic. •can recognize the main aberrations from their transverse and longitudinal behaviors. •can estimate the size of the transverse aberation (spherical, coma, astigmatism, field curvature, distorsio) of a given optical system •can compute the expression of the transverse aberration of a system knowing its wavefront aberration •know about geometric aberrations varies with the position of the pupil in an optical system •can quantify the quality of an optical system with wave optics using Strehl ratio, Rayleigh and Marechal criterio •can quantify the radiometric properties of a source and of an optical system.		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites	Solid mathematical background (Taylor expansion, polynomial developments) Fundamentals in ray optics (ray tracing, conjugation formulae, definition of an optical system). Basic knowledge in Fourier optics (diffraction, Fresnel approximation, Fourier transforms)		
Literature	E. Hecht: Optics, Addison-Wesley 2nd ed. 1987 M. Born & E. Wolf: Principles of optics, Pergammon Press, 6th ed. 1980 W.T. Welford: Aberrations of optical systems, Adam Hilger, 1991		

UE02 Advanced Electromagnetism 2		*Semestre : 3*	
Module		*Code :* SPHCUK6	*ECTS : 3*
Person in charge	Miguel Alonso – Frédéric Zolla		
Lecturer (s)	Miguel Alonso – Frédéric Zolla		
Workload	CM : 24 / TD : /		
Objectives			

Content and organisation

1. Rays and Waves

An overview is given of the many ways to understand the connection between the ray and wave models, and the corresponding ways to construct models for propagating waves based exclusively on rays. Analogies with other areas of physics are stressed, particularly that with the connection between the classical and quantum models for particles.

1.1 Mathematical elements

- Asymptotic methods: stationary phase and saddle points
- Fourier uncertainty
- Phase-space representations: Wigner, Husimi/Q/Spectrogram, Kirk-wood/Rihaczek/Dirac

1.2 Ray-wave connection in the paraxial limit

- Review of wave optics in the paraxial regime
- Review of ray optics in the paraxial regime: phase space representation
- Collins formula and LCT for connecting rays and waves
- Complex ray bundles and Gaussian beams

1.3 Ray-wave connection in the short-wave limit

- Nonparaxial scalar wave optics in terms of amplitude and phase: super- and sub-oscillations (Gouy phase)
- Use of stationary phase and Feynman integral picture.
- Flux lines and Bohmian paths
- Debye asymptotic series
- The many faces of ray optics: Eikonal equation, Fermat's principle and the Ibn Sahl-Decartes-Snell law
- Ray-based wave estimates in the position representation: connection with WKB
- Caustics
- Angular spectrum/Fourier regime
- Ray-based wave estimates in the direction/momentum representation: con-nection with Debye-Wolf (& Richards-Wolf)
- Direction/momentum caustics
- Connections through stationary phase
- Diffraction: Keller's diffracted rays
- Uniform asymptotics
- Gaussian summation methods

1.4 Ray-wave connection in the low coherence limit

- Basic elements of spatial coherence: the cross-spectral density and the Wolf equations
- Radiative transfer equation: the radiance or specific intensity
- Wave-based definitions of the radiance and conservation along rays
- Analogies in other areas of optics and physics.

2. Structured light

This course presents the basic elements of structured light beams, including properties and applications. General aspects of optical fields are also discussed such as polarization, geometric phase, energy flow, and gradient and scattering forces on particles.

	<u>2.1 Scalar solutions</u> • Types of self-similarity • Plane-wave superposition • Talbot effect • Closed-form solutions of wave equations through separation of variables • Propagation-invariant beams: Bessel, Mathieu, others • “Accelerating” beams: Airy and its variants • “Self-healing”, “acceleration” and other apparently strange behavior • Structured Gaussian beams: Hermite-Gauss, Laguerre-Gauss, Ince-Gauss, others • Ray pictures • Applications in imaging, machining, manipulation, and information transfer <u>2.2 Polarization</u> • Review: Jones vectors, Stokes parameters, Poincaré sphere • Polarizers, birefringent elements, and geometric phase • Vector beams and non-uniform polarization • Orbital and Spin angular momentum in the paraxial regimes; interaction with particles. <u>2.3 Nonparaxial generalizations</u> • Modeling strongly focused light: angular spectrum, Debye-Wolf and Richard-Wolf integrals • Multipolar expansions • Scalar structured nonparaxial fields • Montgomery effect • Orbital and spin angular momenta in the nonparaxial regime, and spin-orbit coupling • Nonparaxial descriptions of polarization • Trapping forces and torques • Principles of Mie theory: forces and torques.
Acquired competencies	The students • know how to …
Performance Appraisal	Final examination Type of Examination: written exam
Prerequisites	Elecromagnetism
Literature	

UE07 Nanophotonics		*Semestre : 3*	
Module		*Code :* SPHCUK9	*ECTS : 3*
Person in charge	Guillaume Demésy		
Lecturer (s)	Nicolas Bonod, Guillaume Demésy, Brian Stout		
Workload	CM : 36 / TD : /		
Objectives	The students from different backgrounds elaborate their knowledge on nanophotonic modeling, concepts and devices.		
Content and organisation	**I – Finite element modeling for nanophotonics** - Electromagnetism prerequisite : Maxwell's equation in matter in harmonic regime, wave equations in 2D and 3D in electromagnetism - Notion of modes, eigenvalue problems - Total/scattered field formulation of a scattering problem - Open boundary conditions (BC) : Perfectly matched layers and Absorbing BC - Finite element variational formulation - A word about other methods (Plane Wave Expansion, FDTD, etc) - Hands on 1: a 1D finite element wave problem from scratch in python - Hands on 2: a 2D finite element scattering problem almost from scratch in python **II – Plasmonics** **Part I: SPP** - Survey of plasmonics (Wood's anomalies, total absorption, near field observation, time dynamics) - Electromagnetism pre-requisite: Rayleigh coefficients, polarization - Brewster incidence - Pole and zero of the reflection coefficient - Conditions on materials to get a pole - Dispersion curves of SPP, asymptotic limits - Excitation of SPP with prims (Kraetschmann, Otto) - Application of SPP to biosensing - Near field excitation of SPPs (defect, tip, emitters) - Diffraction grating's law - Excitation of SPPs with diffraction gratings **Part II: LSPR** - Basics on light scattering - Rayleigh scattering - Metal colloids on solution: history, ultramicroscope, Mie - Mie coefficients, polarizability of sub-wavelength sized particles - Pole of the polarizability - Plasmons on metallic nanospheres (influence of metals, hybrization) - Near, intermediate and far fields scattered by electric dipoles - Mie resonances on high refractive index particles **III – Quantum Aspects of photonics, Green's function - Mie Theory** - Basics of métasurfaces - Basics of Quantum aspects of light - Basics of spontaneous and stimulated emission - Density of States - Introduction to the theory of Green's functions - Overview of Mie theory		
Acquired competencies	The students • know how to formulate a scattering problem using Finite elements • know how to apply proper boundary conditions • know how to compute energy-related quantities from the electromagnetic field • know how to plot dispersion curves of SPP • know how to derive solution of SPPs and LSPRs		

	• know how to plot dispersion curves of SPP • Notion of poles and zeros of optical responses (reflection coefficient, polarizability) • know how to derive solutions of SPPs and LSPRs • know how to formulate resonant light scattering • know how to calculate a EM density of states • Understand some basic concepts of the quantum nature of light • Know how to calculate a Green's function in free space • Understand the role of the Green's function in photonics. • Know the definition of cross sections and their relationship with energy conservation
Performance Appraisal	Final examination Type of Examination: written exam
Prerequisites	Elecromagnetism
Literature	Theory and Computation of Electromagnetic Fields, Jian-Ming Jin, Wiley 2010 The Finite Element Method: Theory, Implementation, and Applications, Mats G. Larson, Springer 2013 S.Enoch, N. Bonod, (Eds.). (2012). Plasmonics: from basics to advanced topics (Vol. 167). Springer. Maier, S. A. (2007). Plasmonics: fundamentals and applications (Vol. 1, p. 245). New York: springer. Novotny, L., & Hecht, B. (2012). Principles of nano-optics. Cambridge university press.

UE09 Instrumentation for Astronomy		Semestre : M2 – S3	
Module		*Code :*	*ECTS : 3*
Person in charge	Philippe Amram		
Lecturer (s)	Philippe Amram		
Workload	CM : 34 H		
Objectives			
Content and organisation	**Chapter 1. Observing the universe. Links with instrumentations** 1.1 Observing the universe at different wavelengths 1.2 Parasitic sources of light emission 1.3 Other sources of light emission 1.4 Neutrinos 1.5 Gravitational waves 1.6 Observatories of the 21st century **Chapter 2. Telescopes** 2.1 Basics on telescopes 2.2 UVOIR (UV-Optical-IR) telescopes 2.3 High angular resolution 2.4 Radio telescopes 2.5 Observing from space 2.6 X and γ-rays astronomy **Chapter 3. Light dispersers** 3.1 Prisms 3.2 Gratings and Grisms 3.3 Fabry-Perot interferometers, tunable filters 3.4 Michelson interferometers, FFT **Chapter 4. Detectors** 4.1 The observer's problem 4.2 Flux Measurements and noises 4.3 Charge Coupled Devices (CCD) 4.4 Alternative detectors	**Chapter 5. Introduction to spectroscopes** 5.1 Introduction to astrophysical instrumentation 5.2 Spectroscopy: basic Layouts 5.3 Introduction to spectroscopes and data cubes 5.4 Quick spectroscope history 5.5 Spectrographs and spectrometers **Chapter 6. Spectrographs** 6.1 Introduction 6.2 Elementary ray optics 6.3 Energy flow 6.4 Study of a spectrograph 6.5 Dispersers 6.6 Study of a spectrograph, the case of gratings 6.7 Application: Example of grating spectrograph 6.8 Instrumental design constraints **Chapter 7. Spectro-Imagers** 7.1 Etendue Conservation 7.2 Multi-object spectrographs (MOS) 7.3 Spectro-imagers (IFU, IFS) 7.4 Spectro-imagers: spectrograph imagers 7.5 Spectro-imagers: spectrometer imagers	
Acquired competencies	▪		
Performance Appraisal	Final examination Type of Examination: written exam		
Prerequisites			
Literature			

UE Apprenticeship		Semestre : M2– S3	
Module		**Code : SPHCUK5**	*3 ECTS*
Person in charge	*A. Litman / F. Wagner*		
Lecturer (s)			
Workload	CM: TD: TP:		
Objectives	To provide the student with experience of working as part of a research team and the opportunity to demonstrate and apply the knowledge in optics and photonics acquired during classes		
Content and organisation	During the whole semester the students will spend one to two weeks/month (6 to 7 weeks in total) in a research laboratory or in a company. They work with researchers/postdocs, PhD students and others. This apprenticeship training is a real immersion in the working life of a French company or in a laboratory of Aix-Marseille Université. The students work on different theoretical and/or experimental projects and participate to the activities (meetings, presentations, scientific discussion) carried out in the institutions where they do their apprenticeship.		
Acquired competencies	The students - understand the connections between theoretical results, simulations, experimental studies and practical solutions in optics and photonics - understand work procedures and methodology in a research institution or a company - are able to systematically approach a practical problem. - gather experience in interdisciplinary team work and are able to express their knowledge in such an environment. - are able to scientifically report and present their work		
Performance Appraisal	The evaluation is made by the Apprenticeship supervisor on the basis of the students assiduity, seriousness, assiduity, results		
Prerequisites	Strong background in optics and photonics		
Literature	Literature is provided by the supervisors of the apprenticeship projects beforehand		

UE12 Français Langue Etrangère – French as a Foreign Language		*Semestre :* M2 – S3	
Module		*Code :* SPHCUO6J	*ECTS : 2*
Person in charge	Cécile THIRION		
Lecturer (s)			
Workload	TD : 24h	*Homework & self-studies :* 24-48 h	
Objectives	For students to acquire a competency in communication in the French language and an understanding of French society and culture so that they may express themselves, write directly, and express comprehension when communicating with French speakers.		
Content and organisation	I. Four areas of language competency will be covered – oral and written comprehension, oral and written communication – but emphasis will be placed on oral competency, therein integrating pragmatic, socio-cultural and strategic proficiencies according to the Common European Framework of Reference for Languages (CEFR). II. The lesson plans for this class will be communicative and action-oriented. As the approach will be centered on students engaging in communicative tasks, there will be flexibility in the choice and duration of the class activities. The course program will therefore be adapted to best fit the linguistic needs of each level. The topics covered may vary depending on local, national or international news and the time of year. The course is not a lecture and its success depends greatly on student participation. Class attendance is strongly recommended. In the case of an absence, the student is invited to make up the work done in class and any homework given during the student's absence. Documents from class will be available on a digital workspace. III. Resources and training materials : authentic documents, articles, photos, songs, videos, playful material from the publisher or made by the teacher and written or audio documents from manuals, methods or sites.		
Acquired competencies	Varies according to the level of each group.		
Performance Appraisal	Continuous assessment: oral comprehension, written comprehension, exercises relating to grammar and vocabulary lessons, oral presentation.		
Prerequisites	Adapted according to the level of each group.		
Literature	*La Grammaire des premiers temps* (PUG) *Grammaire Progressive du Français* (Clé International)		