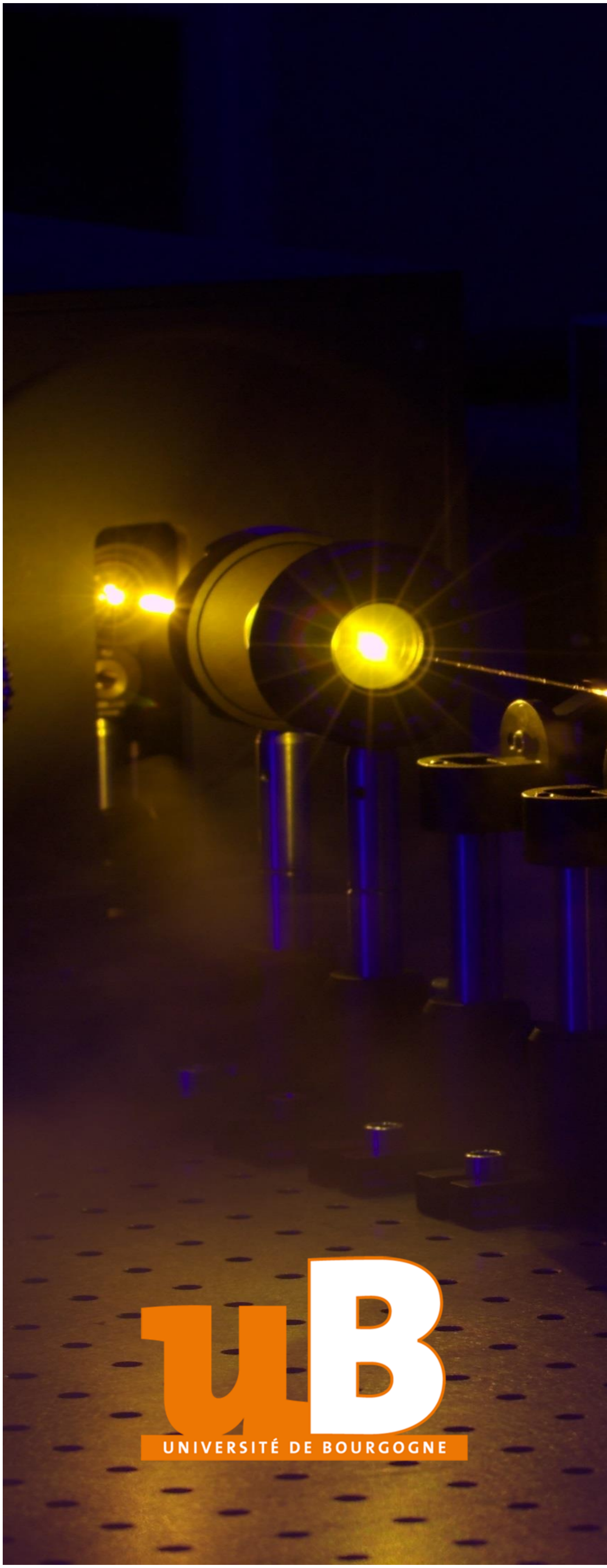

Master

Physics, Photonics & Nanotechnology

Mention

Physique Fondamentale et Applications

Responsables du diplome :

- Prof. Claude LEROY
- Prof. Benoît CLUZEL
- Dr. Aurélien COILLET

Secrétariat Pédagogique :

Mme Marielle COUTAREL

marielle.coutarel@u-bourgogne.fr

UFR sciences & techniques

UNIVERSITÉ DE BOURGOGNE

SYLLABUS

1st year

UE 1	Solid-state physics and soft matter
	A. Dereux, P. Senet
6 ECTS 60 H	The first part of this course (Prof. P. Senet) focusses on the quantum description of electrons in crystals (quasielectrons) in order to master the quantum description of the electrical conductivity which is a ubiquitous concept of technologies at the nanoscale. In a second part, the course presents an introduction to statistical physics of complex molecular systems (as biopolymers) with applications in nanosciences: • partition functions, free-energy, potential of mean force, free-energy landscape; • Brownian motion, Smoluchowski equation, linear response functions, self-avoiding random walks; • statistical properties of simple models of polymers: freely jointed chain model, continuum elastic model, Zimm model, Go model; • flexible chain under an external field, singlebiomolecule experiments, confinement in nanopores; • advanced applications. Unsupervised learning methods for molecular time series data (protein folding). The second part of this course (Prof. A. Dereux) is devoted to the quantum description of electron transport in metals, semiconductors as well as in junctions and heterostructures : • Describe and understand the many-body problem of electrons in crystals using the one-electron approximation and the concept of quasiparticles in reciprocal space using the Sommerfeld and Bloch models. • In-depth understanding of the Bloch electron dynamics (Bloch wave packets, effective mass, etc). • Classification of metals, semiconductors and insulators. • Describe and understand the Boltzmann equation in the 6D phase space to describe the electrical conductivity and thermo-electric effects. • Compute the electron band structure of semiconductors.

	• Physics of electron transport in various junction exploiting quantum effects (metal-metal, metal-semiconductor, semiconductor featuring different doping, semiconductor heterostructures)

UE 2	Quantum Physics
	S. Guérin, D. Sugny, H-R. Jauslin, V. Boudon
6 ECTS 70 H	This course covers the principles and concepts of non-relativistic quantum physics, including: • quantization, • superposition, • wave-particle duality, • tunneling, • entanglement and composite systems, • addition of angular momenta, • spin, • identical particles, • time-dependent problems, • quantum dissipative systems - master equations, Lindblad equation, • numerical tools to solve various problems relevant for quantum technologies applications. and their advanced modern applications relevant to QT, focusing on: • atomic & molecular physics & spectroscopy, • introduction to quantum optics, • introduction to open quantum systems & quantum dissipation, • introduction to quantum control & optimal control. We will use numerical tools to solve various problems relevant for QT applications such as quantum control and spectroscopy.

UE 3	Signal Processing
	A. Coillet, B. Sinardet
6 ECTS 50 H	The aim of this course is to give the students the basic and advanced tools needed for an efficient data acquisition, interpretation, and transformation, all relevant for quantum information processing. Control process and data acquisition automation are realised through LabVIEW software and specific practical exercises. The content summarises as: • analysis of a signal using the tool of Fourier transform, • solving differential equation by Fourier transform, • convolution filters and correlation operations, • discrete Fourier transform & fast Fourier transform algorithm for signal processing, • heterodyne detection and frequency mixing, • advanced processing techniques with Laplace and wavelet transforms, • LabVIEW: The development environment (programming tools, creating application by example), • data acquisition (interfaces, drivers, measurement automation eXplorer, data acquisition by integrated ports, by GPIB link, by input/output cards and NIDAQ).

UE 4	Minor External speakers
40 ECTS 40 H	From focusing on technical project management to mastering the innovation process and beyond, there is a large body of competencies, soft-skills and knowledge one has to learn in order to understand, take part in and manage modern businesses. This course is an open window on those subjects, focusing on innovation management, project management and high-tech companies and research labs interaction and inner workings, with a specific focus on the ethics and understanding of the quantum technologies' impact on our society: • innovation and innovation management, • intellectual property, • transfer of technology, • creativity for innovation, • project management, • oral communication: credibility, conviction, clarity, • business models, • start-up and spin-off creation and financing, • ethics and impact of quantum technologies on our society.

UE 5	Numerical methods for physics
	A. Dereux, M. Sala
3 ECTS 40 H	The module provides the students with a suite of numerical tools for solving problems relevant to QT, including the modelling of quantum systems, data analysis such as linear and nonlinear fits to data sets, applications of high-performance computing, visualisation techniques, and methods of machine learning: • numerical linear algebra for QT, • numerical integration, • modelling: interpolation, curve fitting, optimisation, • differential equations, • introduction to machine learning, including deep learning techniques, • symbolic computation. The programming languages used are Matlab or Python. The examples of applications will be overlapping the topics of the other courses with emphasis on the applications of the course on quantum condensed matter and statistical physics.

UE 6	French Language & Culture
	External speakers
4 ECTS 55 H	The aim of this module is to equip students from a scientific background with the necessary competencies in order to confidently enter into the competitive job market. The course covers several subjects concerning self-confidence, presentation and communication skills, using techniques from transactional analysis, neuro-linguistic programming and non-violent communication. French Language and Culture course is organised to improve the individual skill of French as a foreign language, providing different levels from A1 (beginners) to C1 (expert), depending on the initial level of the students. The course will address all aspects: oral and written comprehension, oral and written expression (EO) with particular emphasis on phonetic and phonological aspects especially for beginners. For native French speakers, an alternative language course will be proposed (such as advanced English or German). Discussions targeting science & technology and global challenges related to environment and health will be organised. Cultural outings & activities, such as visit to museums and excursions in Dijon and Beaune will be offered.

UE 7	Guided Optics and laser technologies
	P. Tchofo-Dinda, External speakers
4 ECTS 40 H	Guided optics is the set of concepts and principles for confining light and guiding its propagation from its source to its destination. It has been a rapidly developing topic since the invention of lasers and fiber optics. Currently, guided optics abundantly irrigates the field of telecoms and laser sources, with a host of innovative components (passive and active optical fibers, Bragg gratings, couplers, multiplexers, splitters, attenuators, isolators, etc.) which make up the physical layer of Telecoms networks such as MAN, WAN, and the Internet. Content: • Introduction to waveguides. • Planar dielectric waveguides. • Step-index optical fiber. • Functional properties of optical fibers (Numerical aperture, Attenuation, Dispersion, kerr effect). • Mode coupling in optical waveguides. • Mode coupling based devices (directional coupler, grating coupler, multiplexers). • Fibered and/or integrated optical components. • Microstructured waveguides.

UE 8	Non-linear Optics
	F. Chaussard, P. Mathey
4 ECTS 40 H	Nonlinear optical phenomena such as optical frequency conversion or Raman scattering have become commonplace in optical devices and materials thanks to the technological advancements in lasers producing intense fields with ultrashort pulses. This course introduces the concepts underlying nonlinear optics and aims at giving essential ingredients to understand its origins, consequences and applications. It is complemented by a course of materials for nonlinear optics, designed to provide students with developments in crystalline and glassy media involved in linear and nonlinear phenomena and their applications. The course covers: • description of the origin of nonlinearities through a standard model based on the classical anharmonic oscillator and an introduction to nonlinear susceptibility formalism, • derivation of the nonlinear wave propagation equation, • propagation in anisotropic materials and the derivation of solutions regarding phasematching conditions, • study of optical processes: second harmonic generation (SHG) or frequency doubling, sum and difference frequency generation (SFGDFG), optical parametric amplification and oscillation (OPA – OPO), • optical Kerr effect, Stimulated Raman scattering, • Faraday effect, • electro-optic properties of Crystals, • optical Phase Conjugation.

<table>
<tr><td>UE 9</td><td>Opto-electronics and optical communications</td></tr>
<tr><td></td><td>P. Tchofo-Dinda, P. Grelu</td></tr>
<tr><td>4 ECTS
40 H</td><td>The objective of this module is to provide students with a rationale introduction to modern optical communications, explaining their possibilities, current limitations, and some of their prospects. The long-haul high-bit-rate optical communication link is a central figure of this presentation. The optoelectronics technological building blocks are presented and explained: laser diodes, photodiodes, passive and doped optical fibers, fiber integrated components. Modulations formats and methods to measure the quality of optical digital transmissions (eye diagram, Q-factor, Bit Error Rate) are presented, leading to an overview of the design of optical telecom systems.
Content:
• Introduction to optical fiber communications.
• Wave optics mathematical tools survey: Gaussian beams and pulses.
• Semiconductor Light Emitters LED/LD/VCSEL. PIN Photodiodes.
• Fiber integrated devices.
• Fiber amplifiers and lasers.
• Dispersion limitations and dispersion management.
• Modulation formats.
• SNR in optical communications. Eye diagram, Q-factor, Bit Error Rate.
• Multiplexing and Demultiplexing, TDM, FDM, WDM, OFDM,
• Design of optical telecom systems.
• Nonlinearity impairments and other physical limitations in optical communication systems.
Several important aspects of the course are illustrated in lab classes: Fiber amplifier and fiber laser; Optical fiber reflectometry; Fiber integrated components and application to chromatic dispersion measurement; Optical polarisation control and application to optical telecom; Propagation effects in optical telecom (software); Design of an optical transmission line (software).</td></tr>
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UE 10	Micro Nano Fabrication & clean-room
	L. Markey, Technical staff ARCEN CARNOT
4 ECTS 30 H	Micro-Nano-Fabrication covers the experimental techniques used to fabricate integrated circuits or to integrate nano-objects onto a substrate (wafer, chip). These techniques are mainly based on the heritage of the microelectronics semiconductor sector and its fantastic development since the early sixties, but have also evolved in the past two decades towards more diversified techniques developed for an increased amount of applications, including for example on-chip photonics for data communication or biosensing. Micro-Nano-Fabrication techniques are nowadays used for a very large number of applications. This UE proposes laboratory work on thin film deposition, lithography and plasma etching which are the core techniques in this field. Content: • General introduction to nanotechnologies • Micro-nano-fabrication general process flows • Thin film deposition • Optical Lithography (UV) • e-beam lithography • resist processes • recent and non-conventional patterning techniques • plasma etching, (RIE =Reactive ion Etching), wet etching • Clean room

UE 11	Lasers
	O. Faucher, E. Hertz
5 ECTS 50 H	The purpose of this course is to present a semi- classical model providing a good understanding of the laser operating principles and a description of the main features of the coherent light emission as for instance laser power, laser frequency, spectral bandwidth, and spatial modes structure. The first part of the course covers the description of the amplifying medium, the optical pumping system, the optical cavity, the spectral broadening sources, and single-mode or multimode operation. The seconds part is dedicated to the spatial structure of laser waves and their propagation. Two main families of Gaussian propagation modes, associated to rectangular and cylindrical geometries of the laser cavity, are derived as particular solutions of Maxwell's equations. The presented model describes the transverse distribution of energy and the wave front properties as a function of the propagation distance. Finally, ABCD law is introduced in order to describe the modification of the Gaussian mode when a laser beam propagates though diverse optical elements.

UE 12	Research Project
	Members of the ICB lab
9 ECTS 6 sem.	The laboratory project is a research internship supervised by one of the professors of the master at UBFC in the topics of quantum technology, or in the area of the specialisation at UBFC.