COURSE DATA

Data Subject	
Code	36543
Name	Physics and Nanotechnology of Semiconductors
Cycle	Grade
ECTS Credits	6.0
Academic year	2021 - 2022

Study (s)			
Degree	**Center**	**Acad. year**	**Period**
1105 - Degree in Physics	Faculty of Physics	4	Second term

Subject-matter		
Degree	**Subject-matter**	**Character**
1105 - Degree in Physics	16 - Complements of Physics	Optional

Coordination	
Name	**Department**
MARTINEZ PASTOR, JUAN PASCUAL	175 - Applied Physics and Electromagnetism

SUMMARY

The «Physics and Nanotechnology of Semiconductors» is an optional matter offered for the second semester of the fourth year of the Degree in Physics and consists of 6 ETCS credits, of which 4.5 are theoretical and 1.5 corresponds to laboratory.

The objective of this matter is to provide to students an introduction to the basic properties of semiconductors (electronic structure, electron and hole statistics, scattering mechanisms, generation and recombination of carriers out-of-equilibrium, optical properties) and to show how these properties are modified in the case of low-dimensional semiconductor structures (quantum wells, wires and dots). Semiconductor junctions and heterojunctions will be studied, as the basis of current electronic and optoelectronic devices, whose basic operation will also be studied in this matter.

PREVIOUS KNOWLEDGE

Relationship to other subjects of the same degree

There are no specified enrollment restrictions with other subjects of the curriculum.

Other requirements

Mechanics and Waves, Electromagnetism, Optics, Quantum Physics, Quantum Mechanics, Solid State Physics, Statistical Physics.

OUTCOMES

1105 - Degree in Physics

- Knowledge and understanding of the fundamentals of physics in theoretical and experimental aspects, and the mathematical background needed for its formulation.
- To know how to apply the knowledge acquired to professional activity, to know how to solve problems and develop and defend arguments, relying on this knowledge.
- Ability to collect and interpret relevant data in order to make judgements.
- Problem solving: be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems .
- Modelling & Problem solving skills: be able to identify the essentials of a process / situation and to set up a working model of the same; be able to perform the required approximations so as to reduce a problem to an approachable one. Critical thinking to construct physical models.
- Physics general culture: Be familiar with the most important areas of physics and with those approaches which span many areas in physics, or connections of physics with other sciences.
- Basic & applied Research: acquire an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, e.g. engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results.
- Foreign Language skills: Have improved command of English (or other foreign languages of interest) through: use of the basic literature, written and oral communication (scientific and technical English), participation in courses, study abroad via exchange programmes, and recognition of credits at foreign universities or research centres.
- Literature Search: be able to search for and use physical and other technical literature, as well as any other sources of information relevant to research work and technical project development.
- Learning ability: be able to enter new fields through independent study, in physics and science and technology in general.

- Communication Skills (written and oral): Being able to communicate information, ideas, problems and solutions through argumentation and reasoning which are characteristic of the scientific activity, using basic concepts and tools of physics.
- Students must have acquired knowledge and understanding in a specific field of study, on the basis of general secondary education and at a level that includes mainly knowledge drawn from advanced textbooks, but also some cutting-edge knowledge in their field of study.
- Students must be able to apply their knowledge to their work or vocation in a professional manner and have acquired the competences required for the preparation and defence of arguments and for problem solving in their field of study.
- Students must have the ability to gather and interpret relevant data (usually in their field of study) to make judgements that take relevant social, scientific or ethical issues into consideration.
- Students must be able to communicate information, ideas, problems and solutions to both expert and lay audiences.
- Students must have developed the learning skills needed to undertake further study with a high degree of autonomy.

LEARNING OUTCOMES

- Knowledge of the basic parameters of the electronic structure of a semiconductor.
- Knowledge of the statistics of electrons and voids and the role of acceptor and donor impurities.
- Knowledge of the basic transport phenomena in intrinsic and extrinsic semiconductors.
- Understanding of the behavior of non-equilibrium carriers the role they play in electronic devices.
- Understanding of the relationship between the electronic structure and the optical properties of a semiconductor.
- Understanding of the modification of the electronic structure in systems of low dimensionality with respect to that of the bulkmaterial.
- Understanding of the basic physics of the p-n junction and the relationship between its electronic structure and its characteristics and applications.
- Understanding of the band schemes of the different types of heterojunctions and the use of these schemes to determine its characteristics and applications.
- Basic understanding of the physical foundations of light detection by semiconductor devices.
- Basic understanding of the light emission by LEDs and semiconductor lasers.

DESCRIPTION OF CONTENTS

1. Crystal structures and electronic structure of semiconductors

Crystal structure of some semiconductors. Band structures of semiconductors IV, III-V and II-VI. Basic parameters of the electronic structure: forbidden band and effective masses. Direct and indirect semiconductors.

2. Electron and hole statistics and transport properties

The concept of density of states will be introduced and, starting from the Fermi-Dirac statistics in an intrinsic semiconductor, it will be seen how the concentration of electrons and holes is determined by the temperature, the gap energy and the effective masses. The modifications introduced in the semiconductor doped with donor and acceptor impurities will be studied: control of the Fermi level. Starting first from the simple Drude model, the transport parameters will be introduced to, in a second step, give a simple version of the Boltzmann equation and show how it allows to tackle more complex transport problems, such as the electrical conductivity or the thermoelectric power.

3. Carrier scattering and non-equilibrium carriers

After introducing the concepts of scattering probability and relaxation time the carrier scattering mechanisms by ionized impurities and lattice vibrations are studied. The temperature dependence of carrier mobility is discussed. The concepts of carrier generation and recombination introduced as well as the difference between carrier diffusion and drift. Using these ideas, the Einstein relation and the diffusion equation are deduced and discussed.

4. Optical properties of semiconductors

The optical parameters and their relationship with the dielectric function are introduced from a simple resonant absorption model. The fundamental absorption around the energy gap of the semiconductor is studied, distinguishing between the absorption thresholds for direct and indirect semiconductors. The concept of exciton and Einstein's relationships for spontaneous and stimulated emission are introduced.

5. Low dimensionality systems

Quantum wells wires and dots. Electronic states in a 2D system. Density of states in low dimensionality systems. Fermi level in a 2D system. Triangular and square potential wells. Coupled quantum wells superlattices. Quantum wires. Quantum dots.

6. Technology of semiconductors, devices and nanostructures

Synthesis and crystal growth of semiconductors. Epitaxial growth by molecular and metalorganic beam. Manufacture of devices: epitaxy and photolithography. Thin layer techniques Growth of semiconductor nanostructures.

7. P-N junctions, heterojunctions, Schottky diodes and MOS devices

Band Schemes and characteristics I(V) and C(V) of the p-n junction. Junction between degenerate semiconductors: the tunnel diode. Heterojunctions: band schemes. Semiconductor-metal junction (Schottky diode). Structure of the MOS diode: inversion and accumulation, C(V) characteristics.

8. Low-dimensional electronic systems: optical and transport properties

Optical properties of low dimensional systems: excitons in quantum wells, wires and dots. Transport in low dimensional systems. Resonant tunneling devices.

9. Photodetectors and solar cells: from the first to the third generation

The p-n junction under illumination. Photodetectors. Photovoltaic spectrum. Solar cells: efficiency parameters. maximum efficiency and optimal value of the gap. Efficiency limitations: reflection losses, surface recombination, series and parallel resistance effect. High performance and nanostructured solar cells.

10. Emitting devices based on semiconductors of different dimensionality

Emission of light in semiconductors of different dimensionality. Light-emitting diode (LED). Physical bases of the semiconductor laser. Population inversion, gain and modes. Junction lasers: threshold current. Lasers and quantum light emitters based on semiconductor nanostructures.

WORKLOAD

ACTIVITY	Hours	% To be attended
Theory classes	45,00	100
Laboratory practices	15,00	100
Readings supplementary material	5,00	0
Preparation of evaluation activities	15,00	0
Preparing lectures	30,00	0
Preparation of practical classes and problem	25,00	0
Resolution of case studies	15,00	0
TOTAL	**150,00**	

TEACHING METHODOLOGY

Lectures:
Laying down the foundations of Semiconductor Physics, introducing the fundamental aspects and deriving the electrical and optical properties of semiconductors with a view to understand how they determine the electronic device behavior.

Classes of problems:
Complementary exercises are aimed primarily to understand the orders of magnitude of different physical parameters of a semiconductor and the various figures of merit of electronic devices.

Laboratory sessions:

The labs will be conducted in small groups. Students work together on data collection and discussion of results, in a preliminary analysis.

EVALUATION

Theoretical-practical part (75% of the final grade):

— Written exams: the understanding of the physical properties and processes in semiconductors and devices will be mainly evaluated through theoretical-practical questions.

— Continuous evaluation: the realization of exercises proposed during the course will be evaluated. This evaluation will suppose at least 30 % of the note of the theoretical-practical part.

Experimental part (laboratory, 25% of the final mark):

— Individual control of the work in the laboratory and elaboration of data, results and conclusions of each practice by means of a questionnaire.

REFERENCES

Basic

- «Física del estado sólido y de semiconductores», J.P. McKelvey, Ed. Limusa, Méjico, 1976.
- «Fundamentals of semiconductors», P.Y. Yu y M. Cardona, Springer-Verlag, 1996.
- «Basic semiconductor Physics», C. Hamaguchi, Springer-Verlag, 2001.
- «The Physics of Low-dimensional Semiconductors: An Introduction», J. H. Davies, Cambridge U. Press,1997.
- «Physics of Semiconductor devices», 3rd Edition, S. M. Sze and K. K. Ng, John Wiley & Sons, 2007.

Additional

- «Semiconductor physics», K. Seeger, Ed. Springer-Verlag, Berlín, 1982.
- «Optoélectronique», E. Rosencher, B. Vinter, Ed. Masson, Paris, 1998.
- «The Physics of Semiconductors: An Introduction Including Devices and Nanophysics», M. Grundmann, Springer, 2006.

ADDENDUM COVID-19

This addendum will only be activated if the health situation requires so and with the prior agreement of the Governing Council

TEACHING METHODOLOGY:

In case that health situation requires blended teaching, the teaching model approved by the Academic Degree Committee on July 23, 2020 will be adopted.

— Compulsory subjects: 50% student attendance in the classroom, while the rest of students attend the class in streaming broadcast. Two groups will be set with alternate days attendance to the classroom in order to guarantee 50% of teaching hours attendance for all students. Laboratory sessions will have a 100% attendance.

— Optional subjects: 100% attendance in all activities.

If a total reduction in attendance is necessary, classes will be broadcast by synchronous videoconference at their regular schedule, along the period determined by the Health Authority.