ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

43000623 - Laboratorio De NnanoelectrÓnica

DEGREE PROGRAMME

04AN - Master Universitario En Ingenieria De Materiales

ACADEMIC YEAR & SEMESTER

2023/24 - Semester 2

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	43000623 - Laboratorio de Nnanoelectrónica
No of credits	3 ECTS
Type	Optional
Academic year ot the programme	First year
Semester of tuition	Semester 2
Tuition period	February-June
Tuition languages	English
Degree programme	04AN - Master Universitario en Ingenieria de Materiales
Centre	04 - Escuela Tecnica Superior De Ingenieros De Caminos, Canales Y Puertos
Academic year	2023-24

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Jorge Pedros Ayala (Subject coordinator)	ETSIT, B-308	j.pedros@upm.es	Th - 16:00 - 18:00

* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

3. Prior knowledge recommended to take the subject

3.1. Recommended (passed) subjects

The subject - recommended (passed), are not defined.

3.2. Other recommended learning outcomes

- Semiconductor physics

- Materials properties

- Electromagnetism

4. Skills and learning outcomes *

4.1. Skills to be learned

CE1 - Capacidad para aplicar los fundamentos científicos del comportamiento físico y químico de los materiales para relacionar causalmente sus propiedades fundamentales físicas y químicas con su comportamiento macroscópico y el de los productos con ellos realizados / Ability to apply the scientific foundations of the physical and chemical behavior of materials to correlate their fundamental physical and chemical properties with their macroscopic behavior and that of the products made with them.

CE3 - Capacidad de diseñar, modelizar, evaluar, seleccionar, fabricar y utilizar materiales con propiedades específicas (estructurales y funcionales) para satisfa

CE4 - Autonomía para adquirir, analizar, actualizar y aplicar nuevos conocimientos, modelos y técnicas experimentales y numéricas en relación con la composición y estructura de los materiales, su caracterización física y química, sus procesos de fabricación, su utilización y aplicación científica y tecnológica, y su reciclado, reutilización y eliminación / Autonomy to acquire, analyze, update and apply new knowledge, models and experimental and numerical techniques related to the composition and structure of materials, their physical and chemical characterization, their manufacturing processes, their use and scientific and technological application, and their recycling, reuse and disposal

CE7 - Manejo de herramientas de simulación numérica para diseño y análisis de materiales, desde la escala microscópica a la macroscópica / Management of numerical simulation tools for design and analysis of materials,

from the microscopic to the macroscopic scale

CG1 - Uso de la lengua inglesa: Los alumnos son capaces de transmitir conocimientos y expresar ideas y argumentos de manera clara, rigurosa y convincente, tanto de forma oral como escrita, adaptándose a las características de la situación y de la audiencia / Use of the English Language: Students are able to transmit knowledge and express ideas and arguments in a clear, rigorous and convincing manner, both orally and in writing, adapting to the characteristics of the situation and the audience .

CG4 - Creatividad: Los alumnos son capaces de resolver de forma nueva, original y aportando valor, situaciones o problemas en el ámbito de la ingeniería de materiales / Creativity: Students are able to solve situations or problems in the field of materials engineering in a new, original way and adding value.

CG5 - Organización y planificación: Los estudiantes son capaces de fijar objetivos, con la planificación y programación de actividades (tiempo y fases) y con la organización y gestión de los recursos necesarios para alcanzarlos / Organization and Planning: Students are capable of setting objectives, with the planning and programming of activities (time and phases) and with the organization and management of the necessary resources to achieve them..

CG7 - Uso de las TIC: Los alumnos son capaces de aplicar conocimientos tecnológicos necesarios de manera que les permitan desenvolverse cómodamente y afrontar los retos que la sociedad les va a imponer en su quehacer profesional empleando la informática / Use of ICT: Students are able to apply the necessary technological knowledge in a way that allows them to function comfortably and face the challenges that society is going to impose on them in their professional work using computers.

CG8 - Resolución de problemas: Los estudiantes son capaces de reconocer, describir, organizar y analizar los elementos constitutivos de un problema para idear estrategias que permitan obtener, de forma razonada, una solución contrastada y acorde a ciertos criterios preestablecidos / Problem solving: Students are able to recognize, describe, organize and analyze the constitutive elements of a problem to devise strategies that allow obtaining, in a reasoned way, a contrasting solution and according to certain pre-established criteria.

CG9 - Análisis y Síntesis: Los alumnos son capaces de reconocer y describir los elementos constitutivos de una realidad, y de proceder a organizar la información significativa según criterios preestablecidos adecuados a un propósito / Analysis and Synthesis: Students are able to recognize and describe the constituent elements of a reality, and to proceed to organize significant information according to pre-established criteria suitable for a purpose.

4.2. Learning outcomes

RA29 - C1 - Knowledge of the scientific method applied to structural and functional materials

RA38 - C6 - Advanced knowledge of the operating principles of devices based on structural and functional materials for the main technological applications: solar cells, LEDs, lasers, optical amplifiers, waveguides, transistors (FETs and MOSFETs), permanent magnets, spintronic devices, metalenses, electrochemical cells, batteries, supercapacitors, piezoelectric actuators

RA41 - HRP1 - Ability to solve problems that require the design of novel structural or functional materials or devices based on them

RA40 - HCC2 - Ability to operate with the fundamentals of the chemical, mechanical, optoelectronic and magnetic behavior of materials and determine the necessary model or approximation in each case

RA43 - HC1 - Ability to communicate in technical English reports, projects, problems, methodologies, results, etc. related to research and innovation and development in materials engineering in a clear and fluid way

RA31 - C3 - Knowledge of the main advanced models of materials design through simulation: finite elements, atomistic modeling, homogenization theory, topological optimization, Classical Laminate Theory, IA and machine learning

RA39 - HCC1 - Ability to logically and critically apply the bases of the scientific method in materials science and engineering

RA30 - C2 - Knowledge of the physical-chemical, structural, optical, electrical and magnetic properties of advanced structural and functional materials

RA42 - HTP1 - Ability to use various computer languages and models related to design and properties of materials

* The Learning Guides should reflect the Skills and Learning Outcomes in the same way as indicated in the Degree Verification Memory. For this reason, they have not been translated into English and appear in Spanish.

5. Brief description of the subject and syllabus

5.1. Brief description of the subject

Electronics has become ubiquitous nowadays due to the continuous reduction in size of transistors, the basic building blocks of integrated circuits, over the last five decades. This technological trend, known as Moore's law, has permitted to drastically reduce their cost and boost their performance, shaping the world we live in. However, this trend is currently slowing down as reducing further the transistor size is not only technologically demanding but also conceptually challenging, since the latter requires to understand the quantum mechanics governing the device behavior at the nanoscale. This Laboratory of Nanoelectronics is aimed at reviewing the technological evolution of the transistor using simplified and user-friendly computer-based simulation tools to model and understand the transistor behavior. The course starts with a brief description of the transistor fundamentals and scaling laws, before tackling with its current evolution towards one-dimensional structures (silicon nanowires and carbon nanotubes) and presenting their ultimate scaling limit using zero-dimensional structures (such as quantum dots) for single-electron transport.

5.2. Syllabus

1. Presentation. Introduction to Modelling and the Simulation Environment
2. The Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET)
    2.1. Fundamentals
    2.2. Scaling
3. Evolution towards 1D Structures: the Ballistic MOSFET
    3.1. Silicon Nanowire MOSFET
    3.2. Carbon Nanotube MOS- and Schottky Barrier-FETs
4. The Ultimate Scaling: Coulomb Blockade in 0D Structures and the Single-Electron Transistor (SET)
    4.1. Coulomb Blockade
    4.2. Quantum Dot SET

6. Schedule

6.1. Subject schedule*

Week	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Presentation** Duration: 01:00 Lecture	**Introduction to Modelling and the Simulation Environment** Duration: 01:00 Laboratory assignments		
2		**Exercise 1: MOSFET Fundamentals and Scaling** Duration: 02:00 Laboratory assignments		
3		**Exercise 1: MOSFET Fundamentals and Scaling** Duration: 02:00 Laboratory assignments		
4		**Exercise 1: MOSFET Fundamentals and Scaling** Duration: 02:00 Laboratory assignments		
5	**Evolution towards 1D Structures: the Ballistic MOSFET** Duration: 02:00 Lecture			**Laboratory report 1** Individual work Continuous assessment Not Presential Duration: 00:00
6	**Evolution towards 1D Structures: the Ballistic MOSFET** Duration: 02:00 Lecture			
7		**Exercise 2: Silicon Nanowire MOSFET** Duration: 02:00 Laboratory assignments		
8		**Exercise 2: Silicon Nanowire MOSFET** Duration: 02:00 Laboratory assignments		
9		**Exercise 2: Silicon Nanowire MOSFET** Duration: 02:00 Laboratory assignments		
10	**Carbon Nanotube MOS- and Schottky Barrier-FETs** Duration: 02:00 Lecture			**Laboratory report 2** Individual work Continuous assessment Not Presential Duration: 00:00
11		**Exercise 3: Carbon Nanotube FETs** Duration: 02:00 Laboratory assignments		

12		**Exercise 3: Carbon Nanotube FETs** Duration: 02:00 Laboratory assignments		
13	**The Ultimate Scaling: Coulomb Blockade in 0D Structures and the Single-Electron Transistor (SET)** Duration: 02:00 Lecture			**Laboratory report 3** Individual work Continuous assessment Not Presential Duration: 00:00
14		**Exercise 4: Quantum Dot SET** Duration: 02:00 Laboratory assignments		
15		**Exercise 4: Quantum Dot SET** Duration: 02:00 Laboratory assignments		
16		**Exercise 4: Quantum Dot SET** Duration: 02:00 Laboratory assignments		
17				**Laboratory report 4** Individual work Continuous assessment Not Presential Duration: 00:00 **Laboratory report 4** Individual work Final examination Not Presential Duration: 00:00 **Laboratory exam** Problem-solving test Final examination Presential Duration: 03:00

Depending on the programme study plan, total values will be calculated according to the ECTS credit unit as 26/27 hours of student face-to-face contact and independent study time.

* The schedule is based on an a priori planning of the subject; it might be modified during the academic year, especially considering the COVID19 evolution.

7. Activities and assessment criteria

7.1. Assessment activities

7.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
5	Laboratory report 1	Individual work	No Presential	00:00	25%	3 / 10	CE3 CG7 CE1 CE7 CG4 CE4 CG9 CG1 CG5 CG8
10	Laboratory report 2	Individual work	No Presential	00:00	25%	3 / 10	CE3 CG7 CE1 CE7 CG4 CE4 CG9 CG1 CG5 CG8
13	Laboratory report 3	Individual work	No Presential	00:00	25%	3 / 10	CE3 CG7 CE1 CE7 CG4 CE4 CG9 CG1 CG5 CG8
17	Laboratory report 4	Individual work	No Presential	00:00	25%	3 / 10	CE1 CE7 CE3 CG7 CG4 CE4 CG9 CG1 CG5

							CG8

7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Laboratory report 4	Individual work	No Presential	00:00	25%	3 / 10	CE1 CE7 CE3 CG7 CG4 CE4 CG9 CG1 CG5 CG8
17	Laboratory exam	Problem-solving test	Face-to-face	03:00	75%	5 / 10	CE1 CE7 CG4 CE4 CE3 CG7 CG9 CG1 CG5 CG8

7.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Laboratory exam	Problem-solving test	Face-to-face	04:00	100%	5 / 10	CE3 CG7 CE1 CE7 CG4 CE4 CG9 CG1 CG5 CG8

7.2. Assessment criteria

Progressive examination

The progressive examination will include four laboratory reports to be submitted through Moodle before the established deadlines along the course. Each report will require a minimum mark of 3/10 and will account for 25% of the total mark of the subject. The minimum total mark to pass will be 5/10.

Global examination

The global examination will include the last (fourth) laboratory report (to be submitted through Moodle before the established deadline) and an exam comprising the content of the first three laboratory exercises. The exam will last 3 hours and will consist of simulation exercises to be solved in the laboratory. The report will require a minimum mark of 3/10 and will account for 25% of the total mark of the subject, whereas the exam will require a minimum mark of 5/10 and will account for 75% of the total mark of the subject. The minimum total mark to pass will be 5/10.

Referred (Re-sit) examination

The referred examination will consist of an exam requiring a minimum mark of 5/10 and accounting for 100% of the total mark of the subject. The exam will last 4 hours and will consist of simulation exercises to be solved in the laboratory. It will comprise the content of the whole course.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
Moodle site of the subject	Web resource	https://moodle.upm.es/titulaciones/oficiales/
Nanohub	Web resource	Simulation software at https://nanohub.org/
SciDAVis	Others	Scientific Data Analysis and Visualization software
PC	Equipment	PC for simulation and data analysis
Physics of Semiconductor Devices (3rd Edition); S. M. Sze and Kwok K. Ng; Wiley 2007.	Bibliography	Reference book
Semiconductor Devices: Physics and Technology (3rd Edition); S. M. Sze and M. K. Klee; Wiley 2010.	Bibliography	Reference book
Physics of Semiconductor Devices; Jean-Pierre Colinge and Cynthia A. Colinge; Kluwer 2002.	Bibliography	Reference book
Fundamentals of Nanotransistors; Mark Lundstrom; World Scientific 2017.	Bibliography	Reference book
Nanoscale Transistors: Device Physics, Modeling and Simulation; Mark Lundstrom and Jing Guo; Springer 2006.	Bibliography	Reference book

9. Other information

9.1. Other information about the subject

This subject is aligned with the *'Agenda 2030 UPM'* for implementing the Sustainable Development Goals (SDGs) ('*Objetivos de Desarrollo Sostenible (ODS)*'). The specific SDGs being promoted within the subject are:

- *4.4 Aumentar el número de personas con las competencias profesionales y técnicas necesarias para acceder al empleo, al trabajo decente y al emprendimiento. Fortaleciendo la formación técnica y profesional del alumnado.*
- *4.7 Asegurar que todos los estudiantes adquieran los conocimientos teóricos y prácticos necesarios para promover el desarrollo sostenible. Incluyendo el desarrollo sostenible como un criterio en las decisiones de diseño de los sistemas.*
- *9.5 Aumentar la investigación científica y mejorar la capacidad tecnológica industrial. Potenciando aspectos de investigación y temas de prospectiva tecnológica.*
- *17.7 Promover el desarrollo de tecnologías ecológicamente racionales y su transferencia, divulgación y difusión a los países en desarrollo en condiciones favorables. Buscando retos que se adecúen a este objetivo.*