ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

93001301 - Fundamentals Of Solar Cells

DEGREE PROGRAMME

09BP - Master Universitario En Energia Solar Fotovoltaica

ACADEMIC YEAR & SEMESTER

2023/24 - Semester 1

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	93001301 - Fundamentals Of Solar Cells
No of credits	6 ECTS
Type	Core
Academic year ot the programme	First year
Semester of tuition	Semester 1
Tuition period	September-January
Tuition languages	English
Degree programme	09BP - Master Universitario en Energia Solar Fotovoltaica
Centre	09 - Escuela Tecnica Superior De Ingenieros De Telecomunicacion
Academic year	2023-24

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Ivan Garcia Vara	IES-204	ivan.garciav@upm.es	Sin horario. Get an appointment by email
Antonio Marti Vega	IES-108	antonio.marti@upm.es	Sin horario. Get an appointment by email

Carlos Del Cañizo Nadal	IES-113-1	carlos.canizo@upm.es	Sin horario. Get an appointment by email
Ignacio Rey-Stolle Prado (Subject coordinator)	IES-107	ignacio.reystolle@upm.es	Sin horario. Get an appointment by email

* 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

- Fundamentals of Electronics

- Semiconductors fundamentals

- Measurement theory and uncertainty analysis

- Basic electrical measurements

4. Skills and learning outcomes *

4.1. Skills to be learned

CB10 - Que los estudiantes posean las habilidades de aprendizaje que les permitan continuar estudiando de un modo que habrá de ser en gran medida autodirigido o autónomo.

CB6 - Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación

CB7 - Que los estudiantes sepan aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio

CB8 - Que los estudiantes sean capaces de integrar conocimientos y enfrentarse a la complejidad de formular juicios a partir de una información que, siendo incompleta o limitada, incluya reflexiones sobre las responsabilidades sociales y éticas vinculadas a la aplicación de sus conocimientos y juicios

CE1 - Comprender, analizar y juzgar la relevancia de cualquier contribuciÃ³n en este campo, en relaciÃ³n con su entorno social, energÃ©tico y cientÃfico-tÃ©cnico.

CE2 - Conocimiento, anÃ¡lisis y propuestas de nuevos conceptos, mÃ©todos o dispositivos para la conversiÃ³n fotovoltaica.

CE3 - RealizaciÃ³n, desarrollo e innovaciÃ³n de procesos tecnolÃ³gicos para la fabricaciÃ³n de dispositivos fotovoltaicos.

CG5 - GestiÃ³n de la informaciÃ³n: buscar y gestionar recursos bibliogrÃ¡ficos adecuados con eficiencia, aprender a continuar los estudios de manera ampliamente autÃ³noma como base para la futura actividad de investigaciÃ³n e innovaciÃ³n

CG8 - Aplicar metodologÃas, procedimientos, herramientas y normas del estado del arte para la creaciÃ³n de nuevos componentes tecnolÃ³gicos; Construir nuevas hipÃ³tesis y modelos, evaluarlos y aplicarlos a la resoluciÃ³n de problemas

CG9 - Comunicar juicios, y conocimientos a audiencias especializadas y no especializadas, de una manera razonada, clara y sin ambigÃ¿edades

CT3 - Uso de la lengua inglesa: comprender los contenidos de clases magistrales, conferencias y seminarios en lengua inglesa; redactar en inglÃ©s informes y artÃculos cientÃfico-tÃ©cnicos usando herramientas informÃ¡ticas; realizar exposiciones pÃºblicas en inglÃ©s de trabajos, resultados y conclusiones de investigaciÃ³n, por ejemplo, en las asignaturas del MÃ¡ster o en congresos de carÃ¡cter mayoritariamente internacional o en estancias en centros extranjeros, todo ello con la ayuda de medios informÃ¡ticos audiovisuales

CT4 - Liderazgo de equipos: realizar trabajos en equipo (como los de algunas de las actividades de evaluaciÃ³n de las asignaturas), integrarse en un grupo de investigaciÃ³n participando activamente en sus reuniones, colaborando con iniciativa propia en trabajos o proyectos de I+D+i; interaccionar con efectividad con los miembros del equipo de trabajo multidisciplinar

4.2. Learning outcomes

RA16 - RA27 - Capacidad crítica para analizar los diferentes modelos en términos de principios básicos de la física

RA15 - RA5 - Relacionar los principios básicos con los aspectos prácticos

RA4 - RA2 ? RA24 ? Conocimiento de los fundamentos físicos de las células solares

RA5 - RA5 ? RA36 ? Conocer los efectos físicos que permiten el aprovechamiento de la energía solar

RA6 - RA4 ? RA32 ? Capacidad para analizar y medir las curvas i?v de células solares

RA9 - RA7 ? RA33 ? Formación en los aspectos prácticos de la caracterización de células solares

RA22 - RA70 - Conocer los procesos de fabricación de células solares

RA14 - RA4 - Capacidad para analizar los resultados

RA11 - RA12 ? RA37 ? Comprender los principios físicos relevantes que afectan al funcionamiento de las células solares

RA19 - RA45 - Capacitar al alumno a hacer presentaciones en público

RA1 - Diseño de la estructura de una célula solar en función de sus parámetros internos (dopajes, espesores...) y propiedades de material

RA21 - RA47 - Aprender a argumentar convincentemente

* 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

The subject aims to present the physical principles of operation and the description models of photovoltaic converters (solar cells). First, the current-voltage characteristic of a solar cell and its main parameters such as the open-circuit voltage, the short-circuit current, and the form factor are described. Next, the ambipolar semiconductor equation is proposed, solved, and applied to the pn junction that constitutes the solar cell. This is how you learn to describe the quantum efficiency of a cell and the reverse current of saturation of a cell according to its internal design parameters such as thicknesses and doping. We continue with a global physical description of the functioning of a solar cell supported by some numerical simulation that allows validating the value of the analytical approaches. Finally, there is a global vision of the different types and technologies of solar cells in the market today.

The theoretical vision just presented is complemented by a series of practical sessions and experiments in the lab. The general cognitive goal of such sessions in this course is to get a real feeling of the basic characterization methods and tools for solar cell devices. In particular, this general goal will be achieved by reaching the following set of specific goals:

- To master the basic techniques for solar cell characterization
- To understand the main factors influencing solar cell electrical characteristics
- To operate electrical instrumentation needed for solar cell characterization
- To know how to accurately present experimental data

5.2. Syllabus

1. Solar cell characteristivcs: The I-V curve
2. The solar cell equivalent circuit
3. Quantum effiicieny and spectral response
4. Series and shunt resistance
5. Effects of irradiance and temperature
6. Types of solar cells
    6.1. Silicon
    6.2. Thin film
    6.3. Multijunction
    6.4. Other solar cells
7. Lab session 1: Preliminary work and lab etiquette
8. Lab session 2 : Morphological characterization of a solar cell
9. Lab session 3: I-V curve measurement in dark and lighted conditions
10. Lab session 4: Effect of irradiance and spectrum on I-V curves
11. Lab session 5: Resistive and temperature effects on I-V curves
12. Lab session 6: Fitting I-V curves

6. Schedule

6.1. Subject schedule*

Week	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Course Presentation** Duration: 01:00 Lecture **Lab session 1: Lab etiquette and management of experimental uncertainty** Duration: 03:00 Laboratory assignments			
2	**Solar cell basics: description and operation** Duration: 02:00 Lecture **Semiconductor fundamentals** Duration: 02:00 Lecture			**Report for Lab Session #1** Individual work Continuous assessment Not Presential Duration: 03:00
3		**Lab session 2: Morphological characterization of a solar cell** Duration: 04:00 Laboratory assignments		
4	**The solar cell equivalent circuit** Duration: 01:00 Lecture **Dark and lighted I-V** Duration: 01:00 Lecture **Quantum efficiency, spectral response and thermal effects** Duration: 01:00 Lecture **Series resistance** Duration: 01:00 Lecture			**Report for Lab Session #2** Individual work Continuous assessment Not Presential Duration: 03:00
5		**Lab session 3: I-V curve measurement in dark and lighted conditions** Duration: 04:00 Laboratory assignments		
6	**Photovoltaic efficiency limits** Duration: 01:00 Lecture **Modelling a solar cell from its structure** Duration: 02:00 Lecture **Introduction to the different types of solar cells**			**Report for Lab Session #3** Individual work Continuous assessment Not Presential Duration: 03:00

	Duration: 01:00 Lecture			
7		**Lab session 4: Effect of irradiance and spectrum on I-V curves** Duration: 04:00 Laboratory assignments		
8	**Silicon solar cells** Duration: 03:00 Lecture **Thin-film solar cells** Duration: 01:00 Lecture			**Report for Lab Session #4** Individual work Continuous assessment Not Presential Duration: 03:00
9		**Lab session 5: Resistive and temperature effects on I-V curves** Duration: 04:00 Laboratory assignments		
10	**Multijunction solar cells** Duration: 01:00 Lecture **Emerging solar cell technologies** Duration: 01:00 Lecture **Solar cell fabrication** Duration: 02:00 Lecture			**Report for Lab Session #5** Individual work Continuous assessment Not Presential Duration: 03:00
11		**Lab session 6: Fitting I-V curves** Duration: 04:00 Laboratory assignments		**Report for Lab Session #6** Individual work Continuous assessment Not Presential Duration: 03:00
12	**Review and Q&A** Duration: 04:00 Problem-solving class			
13				
14				**Final Exam** Written test Continuous assessment and final examination Presential Duration: 01:00
15				
16				
17				

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
2	Report for Lab Session #1	Individual work	No Presential	03:00	5%	5 / 10	CB8 CE2 CG3 CG9 CB10 CB7 CT3 CE1 CE3 CG5 CG8 CB6
4	Report for Lab Session #2	Individual work	No Presential	03:00	9%	5 / 10	CE2 CG3 CG9 CB10 CB7 CT3 CE1 CB8 CE3 CG5 CG8 CB6
6	Report for Lab Session #3	Individual work	No Presential	03:00	9%	5 / 10	CB8 CE2 CG3 CG9 CB10 CB7 CT3 CE1 CE3 CG5 CG8 CB6

8	Report for Lab Session #4	Individual work	No Presential	03:00	9%	5 / 10	CB8 CT4 CE2 CG3 CG9 CB7 CT3 CE1 CE3 CG5 CG8 CB6
10	Report for Lab Session #5	Individual work	No Presential	03:00	9%	5 / 10	CE2 CG3 CG9 CB10 CB7 CT3 CE1 CE3 CG5 CG8 CB6 CB8 CT4
11	Report for Lab Session #6	Individual work	No Presential	03:00	5%	5 / 10	CB8 CT4 CE2 CG3 CG9 CB10 CB7 CT3 CE1 CE3 CG5 CG8 CB6
14	Final Exam	Written test	Face-to-face	01:00	54%	5 / 10	CE2 CG3 CG9 CB10 CB7 CB8 CT4 CT3 CE1 CE3 CG5 CG8 CB6

7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
14	Final Exam	Written test	Face-to-face	01:00	54%	5 / 10	CE2 CG3 CG9 CB10 CB7 CB8 CT4 CT3 CE1 CE3 CG5 CG8 CB6

7.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Theory exam	Written test	Face-to-face	01:00	54%	5 / 10	CT4 CE2 CG3 CG9 CB10 CB7 CT3 CE1 CE3 CG5 CB8 CG8 CB6
Laboratory Practical Exam	Problem-solving test	Face-to-face	01:00	46%	5 / 10	CB8 CT4 CE2 CG3 CG9 CB10 CB7 CT3

						CE1 CE3 CG5 CG8 CB6

7.2. Assessment criteria

Progressive evaluation

- The subject is evaluated on 10 points

- Up to 4.6 points are obtained from the average of the grades from the lab session reports.
- The remaining 5.4 points are obtained from the theory exam (multiple choice) that will be held in the exam period after the school period
- It is necessary to reach at least 5.0 points to pass the course.

Global evaluation

The course can be successfully passed with the final theory exam (multiple choice) that will be held in the exam period after the school period. This is the same exam as the final theory exam in *Progressive evaluation*. As this exam counts 56% of the evaluation, to pass the course using this exam only a score of 8,9/10 or higher needs to be achieved.

Extra evaluation

In the case of failure to pass the progressive and global evaluations, the course can be passed in an extra (final) evaluation, typically taking place at the end of the second semester.

Such evaluation consists of two parts: a theory exam (multiple choice) and a practical exam that takes place in the lab and revises the experimental parts of the course. If during the regular course period, the lab sessions have been passed (globally) there is no need to take this practical exam.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
Course web page	Web resource	The course web page at UPM's Moodle server contains all material needed to follow the course. This includes: * Presentations for all sessions * Lab session guides * Additional material (readings, videos, Matlab programs, Excel sheets, data ...)
Solar cell characterization lab	Equipment	The Solar Cell Characterization Facility at the Solar Energy Institute of the Technical University of Madrid will be the lab used for this course.
Handbook of photovoltaic Science and Engineering	Bibliography	Varios autores, Handbook of photovoltaic Science and Engineering 2 ed. Chichester: John Wiley & Sons, 2004.
Course notes	Bibliography	Teacher notes and texts on some dificult topics in the course

9. Other information

9.1. Other information about the subject

This course is related to SUSTAINABLE DEVELOPMENT GOAL 7, "Ensure access to affordable, reliable, sustainable and modern energy for all". In particular, to its specific target "7.1 By 2030, increase substantially the share of renewable energy in the global energy mix". This course aims at understanding the operation and measurement of basic photovoltaic devices and thus constitutes fundamental knowledge for the impulse and penetration of Photovoltaic Solar Energy.