ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

93001307 - Characterization Of Photovoltaic Devices And Materials

DEGREE PROGRAMME

09BP - Master Universitario En Energia Solar Fotovoltaica

ACADEMIC YEAR & SEMESTER

2023/24 - Semester 2

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	93001307 - Characterization Of Photovoltaic Devices And Materials
No of credits	6 ECTS
Type	Optional
Academic year ot the programme	First year
Semester of tuition	Semester 2
Tuition period	February-June
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 (Subject coordinator)	IES-204	ivan.garciav@upm.es	Sin horario. Agreed by email
Ignacio Rey-Stolle Prado	IES-107	ignacio.reystolle@upm.es	Sin horario. Agreed by email
Maria Mercedes Gabas Perez	IES-106	mercedes.gabas@upm.es	Sin horario. Agreed by email

David Fuertes Marron	IES-201	david.fuertes@upm.es	Sin horario. Agreed 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

- Fundamentos De CÉlulas Solares

3.2. Other recommended learning outcomes

- Fundamentals of physics and knowledge about semiconductor physics

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

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

CG4 - OrganizaciÃ³n y planificaciÃ³n: Organizar, planificar y gestionar proyectos complejos y multidisciplinares que involucren varios de los aspectos tratados en el MÃ¡ster

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

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

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

RA8 - RA3 ? RA53 ? Conocer los componentes de los sistemas fotovoltaicos

RA7 - RA6 ? RA25 ? Capacidad para comprender el funcionamiento básico de diferentes tipos de células solares, tanto actuales, como las que surjan en un futuro próximo.

RA10 - RA10 ? RA38 ? Formación aplicada en física de materiales.

RA12 - RA11 ? RA39 ? Capacidad para comprender los fundamentos físicos de las células solares actuales y de nueva generación

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

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

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

* 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

We will first pursue a deep understanding of electrical characterization of solar cells, introduced in previous subject "Fundaments of Solar Cells". Then, we tackle the study of the most important device, material and semiconductor structure characterization techniques in the context of solar cell analysis and development, associating characterization techniques to solar cell fabrication steps.
At the end of this course the student will:

- Understand the operating principles of electronic loads to measure I-V curves.
- Master the measurement of solar cell I-V curves following ASTM standards.
- Know the most relevant characterization techniques used to assess the results of usual solar cell fabrication

steps.

- Be able to assess the performance of semiconductor structures and solar cells by using the appropriate characterization methods

5.2. Syllabus

1. Characterization and data procesing tools
2. Solar cell performance characterization: the I-V curve in depth
   2.1. Accurate I-V curve using electronic loads
   2.2. Solar simulators and spectral effects
   2.3. Measurements under ASTM standards
3. Characterization of semiconductor materials and solar cell structures
   3.1. Spectral response and quantum efficiency
   3.2. Semiconductor surface preparation: surface characterization
   3.3. Optical characterization
   3.4. Characterization of photogeneration and recombination in materials and structures
   3.5. Dopant diffusion: characterization of doping and carrier density profiles
   3.6. Layer deposition: thickness and structural characterization
   3.7. Front grid metal formation: characterization of series resistance components

6. Schedule

6.1. Subject schedule*

Week	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Introduction to the course** Duration: 02:00 Lecture **Characterization and data processing tools** Duration: 02:00 Lecture			
2	**Electronic loads and I-V curve** Duration: 02:00 Lecture	**Lab session 1: I-V curve in depth** Duration: 02:00 Laboratory assignments		**Lab session report (linked to lab session data gathering)** Group work Continuous assessment Not Presential Duration: 00:01 **Lab session data gathering** Individual presentation Continuous assessment Presential Duration: 02:00
3	**Solar simulators and spectral effects** Duration: 02:00 Lecture	**Lab session 2: Solar simulators and spectral effects** Duration: 02:00 Laboratory assignments		**Lab session report. (linked to lab session data gathering)** Group work Continuous assessment Not Presential Duration: 00:01 **Lab session data gathering** Individual presentation Continuous assessment Presential Duration: 02:00
4	**ASTM measurements** Duration: 02:00 Lecture	**Lab session 3: ASTM measurements** Duration: 02:00 Laboratory assignments		**Lab session report (linked to lab session data gathering)** Group work Continuous assessment Not Presential Duration: 00:01 **Lab session data gathering** Individual presentation Continuous assessment Presential Duration: 02:00

5	**Surface characterization** Duration: 02:00 Lecture			
6	**Optical characterization** Duration: 02:00 Lecture	**Lab session 4: Analysis of optical measurements** Duration: 02:00 Laboratory assignments		**Lab session report (linked to lab session data gathering)** Group work Continuous assessment Not Presential Duration: 00:01 **Lab session data gathering** Individual presentation Continuous assessment Presential Duration: 02:00
7	**Photogeneration and recombination characterization** Duration: 02:00 Lecture	**Lab session 5** Duration: 02:00 Laboratory assignments		**Lab session report (linked to lab session data gathering)** Group work Continuous assessment Not Presential Duration: 00:01 **Lab session data gathering** Individual presentation Continuous assessment Presential Duration: 02:00
8	**Layer thickness and structure characterization** Duration: 02:00 Lecture	**Lab session 6: XRD and ECV measurements** Duration: 02:00 Laboratory assignments		
9	**Dopant diffusion characterization** Duration: 02:00 Lecture			
10	**Front grid and series resistance components characterization** Duration: 02:00 Lecture			**Lab session report (linked to lab session data gathering)** Group work Continuous assessment Not Presential Duration: 00:01 **Lab session data gathering** Individual presentation Continuous assessment Presential Duration: 02:00
11				**Lab sessions report (linked to lab session data gathering)** Individual presentation Final examination Not Presential Duration: 00:01
12				
13				

14				
15				
16				
17				**Exam** Written test Continuous assessment Presential Duration: 03:00 **Exam** Written test Final examination Not 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
2	Lab session report (linked to lab session data gathering)	Group work	No Presential	00:01	7%	/ 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2
2	Lab session data gathering	Individual presentation	Face-to-face	02:00	%	/ 10	CB7 CG8 CT4
3	Lab session report. (linked to lab session data gathering)	Group work	No Presential	00:01	7%	/ 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2
3	Lab session data gathering	Individual presentation	Face-to-face	02:00	%	/ 10	CB7 CG8 CT4
4	Lab session report (linked to lab session data gathering)	Group work	No Presential	00:01	7%	/ 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9

							CT3 CT4 CE2
4	Lab session data gathering	Individual presentation	Face-to-face	02:00	%	/ 10	CB7 CG8 CT4
6	Lab session report (linked to lab session data gathering)	Group work	No Presential	00:01	6%	/ 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2
6	Lab session data gathering	Individual presentation	Face-to-face	02:00	%	/ 10	CB7 CG8 CT4
7	Lab session report (linked to lab session data gathering)	Group work	No Presential	00:01	7%	/ 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2
7	Lab session data gathering	Individual presentation	Face-to-face	02:00	%	/ 10	CB7 CG8 CT4
10	Lab session report (linked to lab session data gathering)	Group work	No Presential	00:01	6%	/ 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2

10	Lab session data gathering	Individual presentation	Face-to-face	02:00	%	/ 10	CB7 CG8 CT4
17	Exam	Written test	Face-to-face	03:00	60%	5 / 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2

7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
11	Lab sessions report (linked to lab session data gathering)	Individual presentation	No Presential	00:01	40%	/ 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2
17	Exam	Written test	No Presential	03:00	60%	5 / 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2

7.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Exam	Written test	Face-to-face	03:00	60%	5 / 10	CB6 CB7 CB8 CB10 CG3 CG4 CG5 CG8 CG9 CT3 CT4 CE2
Lab reports (lab reports without lab data uploaded during lab sessions will not be considered)	Individual work	Face-to-face	00:02	40%	5 / 10	CB7 CG8 CT4

7.2. Assessment criteria

To pass successfully this course, the final grade should be equal or above 5/10, when considering each of the evaluation activities and their weight.
The lab session data and report elaboration for the progressive evaluation are liberating blocks with regards to the extraordinary evaluation.

PROGRESSIVE ASSESSMENT

Lab Session Work and Reports

Lab sessions are presential. During lab sessions, the characterization techniques learned in theory classes are practiced using instrumentation in a research laboratory. At the end of the class, the data obtained by each alumn has to be uploaded to Moodle. It is compulsory to updload this data and this activity cannot be recovered.

After the lab session, a report must be written. The complete 6 session reports will account for 40% of the grade. The assessment criteria for each of these reports will be as follows:

- Structure and scientific format (30%). How is the text structured and the information displayed; quality of graphs and figures; treatment of uncertainties; delay in delivering the report, etc.
- Data quality (30%). Completeness of data set, quality of measurements, observation errors, etc.
- Discussions (40%). Clarity, conciseness, and accuracy of the discussions included to interpret the results or answer the questions in the report.

Each report must be presented during the next week after the corresponding lab session.

The lab report and the data obtained in the laboratory session are linked. Failure to obtain and upload the measurement data in a lab session will cause a 0 mark in the corresponding session report.

Given the nature of these laboratory sessions, this activity cannot be recovered.

Exam

The written exam will account for 6/10 of the final score. It will consist of a set of 20 multiple-choice questions. No ancillary material or documentation will be allowed in the exam.

The minimum score of the exam to pass the course is 5/10.

ASSESSMENT WITH GLOBAL EVALUATION ONLY

The global evaluation will consist in a written exam, accounting for 6/10 of the final score. This is the same exam as for the rest of students following the continuous assessment.

Laboratory reports can also be presented for the global evaluation, for a maximum total score of 4/10 of the final score. Those reports with no associated laboratory data uploaded during the course will get a 0 score.

EXTRAORDINARY EVALUATION

Lab Session Reports

Laboratory reports can also be presented for the extraordinary evaluation, for a maximum total score of 4/10 of the final score. Those reports with no laboratory data uploaded during the course will get a 0 score.

Exam

For all students: written exam, accounting for 6/10% of the final score.

REQUIREMENTS FOR ADVANCED EXTRAORDINARY EXAM

Students coursing this subject for a second year can exceptionally advance the extraordinary exam to January examination period. The scores obtained in the preceding year for the laboratory part will be used.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
Characterization labs	Equipment	Characterization labs available at IES-UPM
Modeling software	Others	Custom software for modeling
Moodle	Web resource	Repository for documentation, student forum and marks
References	Bibliography	Recommended books and scientific papers

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 mastering the tools and methods to accurately measure the solar cell performance under standar conditions, and to know the main characterization methods used during the development and manufacturing of solar cell. Thus, this course constitutes a fundamental knowledge for the impulse and penetration of Photovoltaic Solar Energy.