Course guide
2301213 - PDS - Power Devices and Systems

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Unit in charge: Barcelona School of Telecommunications Engineering
Teaching unit: 230 - ETSETB - Barcelona School of Telecommunications Engineering.

Degree: MASTER'S DEGREE IN SEMICONDUCTOR ENGINEERING AND MICROELECTRONIC DESIGN (Syllabus 2024). (Optional subject).

Academic year: 2025 **ECTS Credits:** 4.0 **Languages:** English

LECTURER

Coordinating lecturer: MIQUEL VELLVEHI HERNANDEZ

Others: Segon quadrimestre:
XAVIER JORDÀ I SANUY - 11
AMADOR PÉREZ TOMÁS - 11
JOSÉ ANDRÉS REBOLLO PALACIOS - 11
MIQUEL VELLVEHI HERNANDEZ - 11

LEARNING RESULTS

Knowledges:
KT01. Identify semiconductor devices, technological processes, the most appropriate microelectronic design tools, and relationships between these elements in order to integrate a given product or system into microelectronic technologies.
KT03. Describe the physical principles underlying current semiconductor devices in relation to their application, as well as their emerging trends, modelling and characterisation techniques.
KT04. Identify and describe the different manufacturing and characterisation processes in microelectronics and their applicability according to the functional and cost requirements of the final integrated product.
KT05. Describe the main methods and tools used to design integrated circuits and systems in accordance with the required functional specifications and cost of the final integrated product.
KT06. Identify and describe the main verification and test strategies for integrated circuits and systems according to their application.

Skills:
ST01. Design integrated devices, circuits and systems for new products according to their applications, taking into account sustainability and energy efficiency requirements.
ST02. Apply the manufacturing techniques and processes and design, simulation and characterisation tools of semiconductor engineering and microelectronic design to provide a solution to a specific integrated system proposal.
ST04. Select appropriate sources of information from the scientific and technical literature, using appropriate channels, and integrate this information, demonstrating the ability to synthesise information, analyse alternatives and engage in critical debate.
ST06. Plan the different activities involved in successfully carrying out an assigned task within a team, managing time and resources appropriately.

Competences:
CT01. Design new devices and integrated systems that require the use of manufacturing techniques specific to microelectronic technologies or the use of microelectronic design tools.
CT02. Apply sustainability criteria to projects based on integrated microelectronic products.
CT03. Apply the processes of semiconductor engineering and microelectronic design to fields in diverse areas of science or engineering where integrated systems are required.

TEACHING METHODOLOGY

Classroom lectures: 24 h
Practical sessions: 6 h
Practical sessions performed at IMB-CNM.
Used simulation programs: Synopsis-Sentaurus / LT-Spice.

LEARNING OBJECTIVES OF THE SUBJECT

• Acquire basic knowledge on semiconductor physics for describing both the operation and the electrical-thermal characteristics of the main power semiconductor devices currently available in the market (e.g., diodes, MOSFETs, IGBTs, HEMTs), also taking into account the different types of semiconductor materials used: silicon and WBG semiconductors.
• Acquire basic knowledge on manufacturing technological processes used in power semiconductor devices.
• Be able to evaluate and identify the thermal problems associated with power semiconductor devices, their packages, as well as their possible cooling solutions.
• Be able to select the reliability and aging protocols used in power semiconductor devices more adequate for a given final application, as well as interpret their impact on converter design and lifespan.

STUDY LOAD

Type	Hours	Percentage
Self study	70,0	70.00
Hours small group	6,0	6.00
Hours large group	24,0	24.00

Total learning time: 100 h

CONTENTS

Physical Properties of Semiconductorslish

Description:
Introduction. Crystal structure. Energy bandgap and intrinsic carrier concentration. Energy band structure and carrier particle properties. Doped semiconductors. Carrier transport. Recombination-generation and carrier lifetime in non-equilibrium. Impact ionization. Basic equations of semiconductor devices.

Full-or-part-time: 2h
Theory classes: 2h

pn Junctions

Description:
pn junction in thermal equilibrium. Current-voltage characteristics of pn junction. Blocking and breakdown characteristics of pn junction.

Full-or-part-time: 2h
Theory classes: 2h

pin Diodes

Description:
pin diode structure. I-V characteristic of pin diode. Design and breakdown voltage of pin diode. Forward conduction behavior. Relationship between stored charge and forward voltage. Turn-on behavior of power diodes. Reverse recovery of power diodes.

Full-or-part-time: 1h
Theory classes: 1h

Schottky Diodes

Description:
Energy band diagram of metal-semiconductor junction. Current-voltage characteristics of Schottky junction. Structure of Schottky diodes. Ohmic voltage drop of a unipolar device.

Full-or-part-time: 1h
Theory classes: 1h

Bipolar Transistors

Description:
Function of bipolar transistor. Structure of power bipolar transistor. I-V characteristic of power transistor. Blocking behavior of power bipolar transistor. Current gain of bipolar transistor. Base widening, field redistribution, and second breakdown. Limits of silicon bipolar transistor. SiC bipolar transistor. Thyristor-like structures.

Full-or-part-time: 1h
Theory classes: 1h

MOS Transistors

Description:
Operating principle of MOSFET. Structure of power MOSFETs. Current-Voltage characteristics of MOSFETs. Characteristics of MOSFET channel. Ohmic region. Compensation structures in modern MOSFETs (Superjunction). Temperature dependency of MOSFET characteristics. Switching properties of MOSFET. MOSFET switching losses. Safe operating area of MOSFET. Reverse diode of MOSFET. SiC field-effect devices: JFET and MOSFET.

Full-or-part-time: 3h
Theory classes: 3h

IGBTs

Description:
Operating mode. I-V characteristic of an IGBT. Switching behavior of an IGBT. Plasma distribution in IGBTs. IGBTs with higher carrier charge density modules. Bidirectional blocking capability IGBTs. Reverse Conducting IGBTs (RC-IGBTs). Potential of IGBT

Full-or-part-time: 3h
Theory classes: 3h

WBG / UWBG Materials and Related Power Devices

Description:
Related materials: SiC and GaN. SiC-based power devices: Schottky and pin diodes, JFET and MOSFET. GaN lateral power transistors. GaN vertical power transistors. Power devices based on UWBG materials.

Full-or-part-time: 4h
Theory classes: 4h

Introduction to Power Device Manufacturing Technology

Description:
Complete conception process of a power device. Review of basic manufacturing technology processes. Example of a power device manufacturing process: Vertical double-diffused MOSFETs and IGBTs.

Full-or-part-time: 2h
Theory classes: 2h

Packaging Technologies for Power Devices

Description:
Challenges faced by packaging technologies. Types of packaging. Physical properties of materials. Thermal simulation and thermal equivalent circuits. Parasitic electrical elements in power modules. Advanced packaging technologies.

Full-or-part-time: 3h
Theory classes: 3h

Reliability and Testing for Verification

Description:
Higher reliability needs required in power devices. Different tests for reliability verification: high-temperature reverse bias, High-Temperature Gate Stress, temperature and humidity bias, high and low-temperature
storage, temperature cycling and thermal shock, power cycling. Failures due to cosmic rays. Statistical evaluation of reliability test results. Other reliability tests.

Full-or-part-time: 2h
Theory classes: 2h

Practical sessions

Description:
Practical sessions will be devoted to simulation for design, manufacturing, and electrical behaviour analysis of power devices, covering the following topics (6h):
1. Review of technological, physical, and electrical simulators.
2. Simulation of a technological process.
3. Physical analysis of electrical behaviour through simulation.
4. Correlation with models used in behavioural electrical simulators.

Full-or-part-time: 6h
Practical classes: 6h

GRADING SYSTEM

Examination: course work (50%) plus exam (50%)

BIBLIOGRAPHY

Basic:
- Lutz, J.; Schlangenotto, H.; Scheuermann, U.; De Doncker, R. Semiconductor power devices: physics, characteristics, reliability [on line]. 2nd ed. Cham: Springer International Publishing, 2018 [Consultation: 14/06/2024]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-3-319-70917-8. ISBN 9783319709178.
- Baliga, B.J. Fundamentals of power semiconductor devices [on line]. 2nd ed. Cham: Springer, 2019 [Consultation: 14/06/2024]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-3-319-93988-9. ISBN 9783319939889.
- Baliga, B.J. Modern power devices. New York: John Wiley & Sons, 1987. ISBN 0471637815.
- Iannuzzo, F. Modern power electronic devices: physics, applications, and reliability [on line]. London, England: Institution of Engineering and Technology, 2020 [Consultation: 10/07/2024]. Available on: https://ebookcentral-proquest-com.recursos.biblioteca.upc.edu/lib/upcatalunya-ebooks/detail.action?pq-origsite=primo&docID=6467737. ISBN 9781785619182.