



AMRUTVAHINI COLLEGE OF ENGINEERING, SANGAMNER
Department of Electronics and Computer Engineering
Honours in Semiconductor Manufacturing and Chip Technology (18 Credits)

Year	Semester	Course Code	Course Name	Credits
Second Year	Sem III	R25-ECE-HOC-201	Fundamentals of Semiconductor Technology	3
	Sem IV	R25-ECE-HOC-202	Advanced Semiconductor Devices	3
Third Year	Sem V	R25-ECE-HOC-301	Fundamentals of IC Fabrication	3
	Sem VI	R25-ECE-HOC-302	Digital IC Design and Functional Verification	3
Final Year	Sem VII	R25-ECE-HOC-401	Advanced Chip Design: RTL to GDS	3
	Sem VIII	R25-ECE-HOC-402	IC Packaging, Testing and Reliability	3

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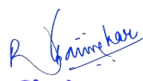
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Program:		S. Y. B. Tech (E&CE)		Semester:		III	
Course:		Fundamentals of Semiconductor Devices		Course Code:		R25-EC-HOC-201	
Teaching Scheme				Examination Scheme			
Lecture	Practical	Tutorial	Credit	CCE	ESE	TW	PR
03	-	-	03	40	60	-	-
Course Description: This course seeks to cover the basics of semiconductor devices including the physics of energy bands, doping and carrier statistics and transport leading up to the understanding of common semiconductor devices including p-n junctions and their applications, BJTs and MOSFETs. The course will also give a flavour of the basics of compound semiconductors and their devices, and also touch base with opto-electronic devices such as solar cells, photodetectors and LEDs. The course will ensure that undergraduates, college teachers and other interested audience with no background in semiconductors are able to grasp the content. In parallel, the course will consistently seek to engage the audience by giving real-life examples pertaining to the content, and also seek to calibrate the content with respect to practical and commercial technologies which are all around us and which use semiconductor devices.							
Course Relevance: The Fundamentals of Semiconductor Devices course develops a basic understanding of semiconductor physics, energy bands, carrier transport, p-n junctions, BJTs, MOS devices, MOSFETs, compound semiconductors and optoelectronic devices. The course is highly relevant to Electronics and Computer Engineering, as semiconductor devices form the foundation of modern electronic systems, including analog and digital circuits, power electronics, RF systems, sensors, communication systems, solar-energy systems, LEDs, photodetectors, memory and integrated circuits.							
Prerequisite: 10+2 Physics & Math, Basic Electronics Engineering							
Bridge Content: - Basic concepts of electric field, voltage and current, Basic atomic structure and valence electrons, Conductors, insulators and semiconductors.							
Course Objectives: 1. Understand the fundamental concepts of semiconductor physics, energy-band theory, carrier statistics, doping and carrier transport phenomena. 2. Analyze the operation and characteristics of p-n junctions and Schottky junctions under equilibrium and bias conditions. 3. Explain and analyze the operating principles, characteristics and applications of BJTs, MOS structures and MOSFETs. 4. Understand the operating principles and applications of compound semiconductor and optoelectronic devices such as heterojunction devices, solar cells and photodetectors. 5. Explain the working principles and applications of LEDs and semiconductor transistors used in power electronics, RF electronics and memory systems.							
Course Outcomes: After learning the course, students will be able to							
CO	Course Outcome						Bloom's Level
CO1	Explain semiconductor energy bands, Fermi-Dirac statistics, density of states, doping, carrier concentration and carrier transport mechanisms.						2
CO2	Analyze the characteristics and operation of p-n junctions and Schottky						4


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	junctions under equilibrium and bias conditions, including breakdown and C-V characteristics.	
CO3	Analyze the operating principles and electrical characteristics of BJTs, MOS structures and MOSFETs including threshold voltage, I-V characteristics and short-channel effects.	4
CO4	Explain the principles and applications of compound semiconductor devices, heterojunctions, solar cells and photodetectors.	2
CO5	Apply semiconductor-device concepts to LEDs and transistor applications in power electronics, RF electronics, memory and microelectronic systems.	3

Course Content			
Unit 1	Basic of Semiconductor Physics and Carrier transport Phenomenon	Week 1-3	CO1
Introduction to semiconductors, Introduction to energy bands, Fundamentals of band structure, Fermi-Dirac distribution, Density of states. Doping and intrinsic carrier concentration, Equilibrium carrier concentration, Temperature-dependence of carrier concentration, High doping effects and incomplete ionization. Carrier scattering and mobility, Low-field and high-field transport, introduction to diffusion, Drift-diffusion and trap statistics, Current continuity equation, introduction to p-n junction. Exemplars / Practical Applications and usage: • Comparison of silicon, germanium and compound semiconductor materials for electronic devices. • Understanding the effect of scattering mechanisms on semiconductor device performance. Assignments: 1. Derive the relationship between carrier concentration and Fermi level for intrinsic and doped semiconductors. 2. Explain the effect of temperature, doping and carrier mobility on semiconductor conductivity with suitable practical examples.			
Unit 2	P-N junction and its Application	Weeks 4-5	CO2
P-N junction under equilibrium, p-n junction under bias, p-n junction: generation-recombination currents. Application of p-n junctions, Breakdown of junction and C-V profiling, Introduction to Schottky junction, Schottky junction under equilibrium, Schottky junction under bias. Exemplars / Practical Applications and usage: • Use of p-n junction diodes in AC-to-DC conversion. • High-speed switching and low-forward-voltage applications. Assignments: 1. Explain the formation of depletion region and built-in potential in a p-n junction. Analyze the behavior of the junction under forward and reverse bias. 2. Compare p-n junction diode and Schottky diode with respect to construction, barrier formation, forward voltage, switching speed, reverse characteristics and applications.			
Unit 3	BJT, MOS Devices and its characteristics	Weeks 6-8	CO3
Introduction to transistors: BJT, Basics of BJT, Working of BJT, Delays in BJT. MOS: Introduction, MOS: Capacitance-voltage, Ideal MOS system: derivation of threshold voltage, MOS C-V in more details. MOSFET- An introduction, Gradual Channel Approximation: Derivation of I-V characteristics, Substrate bias effect and subthreshold conduction in MOSFET, Short Channel Effects in MOSFET.			

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Exemplars / Practical Applications and usage:

- BJT and MOSFET operation as electronic switches.
- MOS transistor applications in semiconductor memory.
- Understanding scaling issues in modern semiconductor technology.

Assignments:

1. Compare the common-emitter, common-base and common-collector configurations based on their characteristics and applications.
2. Derive the MOSFET drain-current equations for different operating regions and explain threshold voltage, substrate-bias effect, subthreshold conduction and short-channel effects.

Unit 4	Compound Semiconductors and Opto-electronic Devices	Weeks 9-10	CO4
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Introduction to compound semiconductors, Basics of heterojunctions, Band diagram of heterojunctions, Heterojunction transistors, III-nitrides.

Solar cell basics, Solar cell: Shockley Quiesser Limit, Basics of photodetectors, Photodetectors: figures of merit and types of devices, Junction photodetectors.

Exemplars / Practical Applications and usage:

- Applications in high-frequency and high-performance transistor technologies.
- Application of semiconductor physics in photovoltaic energy systems.

Assignments:

1. Explain heterojunction formation and discuss the advantages of compound semiconductor devices in high-frequency and optoelectronic applications.
2. Explain the construction and working of a solar cell and photodetector. Compare their operating principles, important parameters and practical applications.

Unit 5	LED and Applications of transistors	Weeks 11-12	CO5
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Basics of recombination, Basics of LED, LED: light extraction and design issues, Visible LED: photometry and colorimetry.

Transistors for power electronics, Transistors for RF electronics, Transistors for Memory, Basics of microelectronic fabrication, Summary.

Exemplars / Practical Applications and usage:

- LEDs in indicators, displays and large-screen systems.
- High-frequency semiconductor transistors in communication systems.

Assignments:

1. Discuss recombination, light extraction efficiency, visible LED characteristics, photometry and colorimetry.
2. Prepare a comparative study of transistor applications in power electronics, RF electronics and memory systems, highlighting device requirements and practical applications.

Textbooks:

1. B. G. Streetman and S. K. Banerjee, Solid State Electronic Devices, 7th ed. Boston, MA, USA: Pearson, 2016.
2. D. A. Neamen, Semiconductor Physics and Devices: Basic Principles, 4th ed. New York, NY, USA: McGraw-Hill, 2012.
3. R. S. Muller, T. I. Kamins, and M. Chan, Device Electronics for Integrated Circuits, 3rd ed. New York, NY, USA: Wiley, 2003.
4. R. F. Pierret, Semiconductor Device Fundamentals, 2nd ed. Upper Saddle River, NJ, USA: Pearson, 1996.



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**Reference Books:**

1. C. T. Sah, Fundamentals of Solid-State Electronics. Singapore: World Scientific, 1991.
2. S. M. Sze, Y. Li, and K. K. Ng, Physics of Semiconductor Devices, 4th ed. Hoboken, NJ, USA: Wiley, 2021.
3. P. Bhattacharya, Semiconductor Optoelectronic Devices, 2nd ed. Upper Saddle River, NJ, USA: Pearson, 1997.
4. J. Singh, Semiconductor Devices: Basic Principles. New York, NY, USA: Wiley, 2000.
5. B. L. Anderson and R. L. Anderson, Fundamentals of Semiconductor Devices, 2nd ed. New York, NY, USA: McGraw-Hill, 2018.

MOOCs Links and additional reading material:

1. NPTEL Course on —Fundamentals of semiconductor devices (IISc, Bangalore)
<https://nptel.ac.in/courses/108108122>

Strength of CO-PO-PSO Mapping

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PSO1	PSO2	PSO3
CO1	3	2	1	2	1	1	1	1	1	1	1	3	2	2
CO2	3	3	2	3	2	1	1	1	1	1	1	3	3	3
CO3	3	3	3	3	3	1	1	1	1	1	1	3	3	3
CO4	3	2	2	3	2	2	2	1	1	1	1	3	2	2
CO5	3	3	3	3	3	2	2	1	1	2	2	3	3	3
Avg.	3	2.8	2.2	2.8	2.2	1.4	1.4	1	1	1.2	1.2	3	2.6	2.6

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

Assessment Pattern**a) Continuous Comprehensive Evaluation (CCE) – 40 Marks**

The Continuous Comprehensive Evaluation shall be carried out by the Department based on the student's performance throughout the duration of the SWAYAM-NPTEL course.

- Performance in NPTEL Weekly Assignments: 30 Marks
- Course Progress and Participation (completion of video lectures, timely submission of weekly assignments, and periodic progress monitored by the Faculty Mentor): 10 Marks

b) End Semester Evaluation (ESE) – 60 Marks

1. Students shall register for and appear in the SWAYAM-NPTEL Proctored Certification Examination.
2. The marks obtained in the NPTEL Proctored Examination shall be converted proportionally to 60 marks using the following formula:

$$\text{ESE Marks} = \left(\frac{\text{NPTEL Proctored Examination Score}}{100} \right) \times 60$$

3. Students who successfully obtain the NPTEL certificate shall have the converted score considered as the End Semester Evaluation (ESE) marks.
4. Students who fail to obtain the NPTEL certificate, fail to appear for the NPTEL certification examination, or fail the certification examination shall appear for the Institute End Semester Examination conducted by the College.
5. If a student appears for both the SWAYAM-NPTEL Certification Examination and the Institute

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End Semester Examination, the higher of the two ESE scores shall be considered for the award of the final grade.

6. The decision of the Department regarding verification of NPTEL scores and award of marks shall be final and binding.

BT Level	CCE						ESE
	CT1	CT2	Assignments	Course Project	Field Activity / Case Study	Quiz / presentation etc.	
K1	-	-	✓	-	-	-	✓
K2	-	-	✓	-	-	-	✓
K3	-	-	✓	-	-	-	✓
K4	-	-	✓	-	-	-	✓
K5	-	-	-	-	-	-	-
K6	-	-	-	-	-	-	-

This course serves as a prerequisite for / maps with the following future courses:

1. Electronic Devices and Circuits
2. Microelectronics / IC Design

Job Mapping:

Job opportunities that one can get after learning this course:

1. Semiconductor Device Engineer
2. VLSI Design Engineer

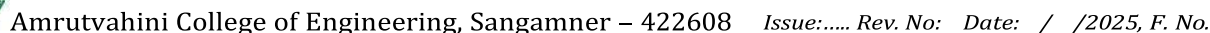
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CO	Course Outcome	Bloom's Level
CO1	Analyze MOS capacitor and MOSFET energy-band diagrams, C-V characteristics, I-V characteristics and high-/low-frequency capacitance models.	4
CO2	Apply SPICE models and simulation techniques to model and analyze MOSFET and semiconductor-device characteristics.	3


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CO3	Analyze carrier transport, second-order effects and advanced MOSFET structures including SOI, Double-Gate, Junctionless Transistors and FinFETs.	4
CO4	Analyze the structure, modelling and performance of GAA, Nanosheet and Forksheet FETs considering device-design and process-variation aspects.	4
CO5	Analyze emerging CFET, III-V HEMT and 2D-material-based transistor technologies for next-generation semiconductor applications.	3

Course Content			
Unit 1	MOS Capacitor and MOSFET Fundamentals	Week 1-3	CO1
Introduction of Metal-Oxide-Semiconductor, Energy Band Diagram of MOS Capacitors, Three terminal MOS structure, Second Order Effects in MOS Capacitors. C–V of MOS capacitor, Introduction of MOSFET, I-V and C-V Characteristics of MOSFETs. Capacitance Modeling for High Frequency & Low Frequency, High and Low Frequency Modeling in Bulk MOSFET, Application of MOSFET.			
Exemplars / Practical Applications and usage: - Analysis of high-frequency and low-frequency device behaviour. - Application of MOSFETs in VLSI integrated circuits.			
Assignments: - Draw and explain the energy-band diagrams of a MOS capacitor under accumulation, depletion and inversion conditions. - Derive and analyze the I-V characteristics of a MOSFET for different operating regions. Explain the influence of device parameters on MOSFET performance.			
Unit 2	MOSFET Modelling, SPICE and Semiconductor Heterostructures	Weeks 4-5	CO2
MOSFET as Switch and Amplifier, Introduction to SPICE, SPICE sub-circuit Models, Spice Installation Setup, Discuss Various SPICE Models equations, The SPICE Diode Models. SPICE Models for the MOS Transistor (First, Second and Third Generation models), Practical Aspects and Simulation Techniques, Carriers and Transportation, Introduction to Semiconductor Heterostructures.			
Exemplars / Practical Applications and usage: - Simulation of MOSFET I-V characteristics using SPICE. - Comparison of different MOS transistor models.			
Assignments: - Develop a SPICE simulation of a MOSFET used as a switch and plot its input-output characteristics. Explain the effect of important device parameters. - Compare first-, second- and third-generation MOSFET SPICE models and discuss their significance in semiconductor-device simulation.			
Unit 3	Advanced MOSFETs, Scaling Effects and FinFET	Weeks 6-8	CO3
Carriers and Transport, Band Diagram of Heterostructure, PN Heterojunction Diode, Properties and Application, Leakage in MOSFET. Introduction to 2nd Order Effects at Lower Technology Node, Drain Induced Barrier Lowering (DIBL), Gate Induced Drain Leakage (GIDL), Channel Length Modulation, Source/Drain Series Resistance, Velocity Saturation, Velocity Overshoot, and Ballistic Transport, Mobility and Scattering Effects, Hot Carrier Effect, Self-heating Effect, Introduction to Double Gate MOSFET. SOI MOSFET, Partially and Fully Depleted MOSFET, Subthreshold Swing and Transconductance, Small and Large Signal Modeling, Introduction of Junctionless Transistors, Introduction to FinFETs			

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Structure, Fabrication steps of FinFETs and HF Modeling.			
Exemplars / Practical Applications and usage: - Analysis of short-channel effects in nanoscale MOSFETs. - FinFET applications in advanced processors and digital ICs.			
Assignments: - Explain DIBL, GIDL, channel-length modulation, velocity saturation and hot-carrier effects in scaled MOSFETs. Discuss their impact on device performance. - Compare Planar MOSFET, Double-Gate MOSFET, SOI MOSFET and FinFET with respect to structure, electrostatic control, leakage, scalability and applications.			
Unit 4	GAA, Nanosheet and Forksheet FETs	Weeks 9-10	CO4
High-Frequency Small Signal Modeling, RLC FinFET modeling, Introduction of Different Types of Gate All Around (GAA) FETs, Device-Design Perspective, Current Trends in GAA Devices, Nanosheet FET. Process Variation in Nanosheet FET, Analog Perspective of Nanosheet FET- Negative Capacitance: Improved Subthreshold Swing, Introduction to Forksheet FET, Discuss the challenges of Forksheet.			
Exemplars / Practical Applications and usage: - GAA FETs for advanced semiconductor scaling. - Comparison of FinFET and GAA device architectures.			
Assignments: - Compare FinFET and GAA FET structures with respect to gate control, scalability, leakage, drive current and suitability for advanced technology nodes. - Prepare a technical report on Nanosheet FET, Negative-Capacitance FET and Forksheet FET, highlighting their structures, advantages, challenges and potential applications.			
Unit 5	CFET, III-V HEMT and 2D-Material-Based Transistors	Weeks 11-12	CO5
CFET Advancements and Industry Adoption, Discuss the Circuit Design Challenges with CFET, CFET Optimization for Semiconductor Scaling, Introduction to Compound Semiconductor Materials, III-V Materials and their role in High-Speed Devices, High Electron Mobility Transistors (HEMT) and its Modeling.			
III-V HEMT: Modeling and Simulation, Vertical High Electron Mobility Transistor, Introduction to 2D Semiconductor Materials, 2D Materials-based Transistor and its Properties and Future Scope.			
Exemplars / Practical Applications and usage: - III-V materials for high-speed electronic devices. - Emerging transistor architectures for beyond-CMOS technologies.			
Assignments: - Explain the working principle and advantages of III-V HEMTs. Discuss their modelling requirements and applications in high-speed electronic systems. - Prepare a comparative study of CFET, III-V HEMT and 2D-material-based FETs with respect to structure, materials, operating principle, advantages, limitations and potential applications.			
Textbooks:			
Y. Tsividis and C. McAndrew, Operation and Modeling of the MOS Transistor, 3rd ed. New York, NY, USA: Oxford University Press, 2011. B. Razavi, Design of Analog CMOS Integrated Circuits, 2nd ed. New York, NY, USA: McGraw-Hill, 2017. S. M. Sze and K. K. Ng, Physics of Semiconductor Devices, 3rd ed. Hoboken, NJ, USA: Wiley, 2006. C. Hu, Modern Semiconductor Devices for Integrated Circuits. Upper Saddle River, NJ, USA:			


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Pearson, 2010.

Reference Books:

1. J. M. Rabaey, A. Chandrakasan, and B. Nikolic, Digital Integrated Circuits: A Design Perspective, 2nd ed. Upper Saddle River, NJ, USA: Pearson, 2003.
2. W. M. C. Sansen, Analog Design Essentials. Dordrecht, Netherlands: Springer, 2006.
3. J.-P. Colinge, Silicon-on-Insulator Technology: Materials to VLSI, 3rd ed. Boston, MA, USA: Springer, 2004.
4. J.-P. Colinge and C. A. Colinge, Physics of Semiconductor Devices. Boston, MA, USA: Springer, 2002.
5. Y. Taur and T. H. Ning, Fundamentals of Modern VLSI Devices, 3rd ed. Cambridge, UK: Cambridge University Press, 2021.

MOOCs Links and additional reading material:

1. NPTEL Course on — Semiconductor Devices for Next Generation Field Effect Transistors (More than Moore): A Physics Perspective (IIT, Roorkee)
<https://nptel.ac.in/courses/108107586>

Strength of CO-PO-PSO Mapping

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PSO1	PSO2	PSO3
CO1	3	3	2	2	2	1	1	1	1	1	1	3	2	3
CO2	3	3	3	3	3	1	1	1	1	2	2	3	3	3
CO3	3	3	3	3	3	2	1	1	1	2	2	3	2	3
CO4	3	3	3	3	3	2	1	1	1	2	2	3	2	2
CO5	3	3	3	3	3	2	2	1	1	2	3	3	2	2
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Assessment Pattern

a) Continuous Comprehensive Evaluation (CCE) – 40 Marks

The Continuous Comprehensive Evaluation shall be carried out by the Department based on the student's performance throughout the duration of the SWAYAM-NPTEL course.

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considered as the End Semester Evaluation (ESE) marks.

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K1	-	-	✓	-	-	-	✓
K2	-	-	✓	-	-	-	✓
K3	-	-	✓	-	-	-	✓
K4	-	-	✓	-	-	-	✓
K5	-	-	-	-	-	-	-
K6	-	-	-	-	-	-	-

This course serves as a prerequisite for / maps with the following future courses:

1. Semiconductor and Chip Design
2. Low-Power VLSI Design

Job Mapping:

Job opportunities that one can get after learning this course:

1. Analog IC Design Engineer
2. Digital IC Design Engineer
3. Device Modelling Engineer

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