Malaviya National Institute of Technology Jaipur
Materials Research Centre

Syllabus of core courses for M. Tech Program in Semiconductor Materials and Devices

Fundamentals of Semiconductor materials			
Prerequisite: 1.) Introductory Physics (Electricity and Magnetism 2.) Basic Chemistry 3.) Introduction to Materials Science (recommended but not required)	L	T	P
Type: Program core	3	0	0
Credit: 03			

Course Description: Course Description: This course provides a comprehensive introduction to semiconductor materials, focusing on their properties, processing, and applications. It covers the fundamental physics and chemistry underlying semiconductor behavior, types of semiconductor materials, crystal structures, electronic properties, and the basics of device fabrication.

Course Content

Unit 1 (7L)	**Electronic Properties and Band Structure of Semiconductors** Energy Bands in Solids: Valence and Conduction Bands, Band Gap: Direct vs. Indirect Semiconductors, Effective Mass of Electrons and Holes, Carrier Concentration in Intrinsic and Extrinsic Semiconductors, Effects of Temperature on Carrier Concentration, Doping and the Creation of n-type and p-type Semiconductors
Unit 2 (7L)	**Carrier Dynamics, Defects, and Impurity Effects** Carrier Mobility and Conductivity, Drift and Diffusion of Carriers, Recombination and Generation Processes, Einstein Relation and Continuity Equation, Types of Defects: Point, Line, and Planar, Role of Impurities in Semiconductor Properties, Impact of Defects on Electrical and Optical Properties
Unit 3 (7L)	**Semiconductor Junctions and Devices** pn Junctions, Formation and Equilibrium Conditions, Built-in Potential and Depletion Region, Diode I-V Characteristics and Capacitance, Diode Applications: Rectifiers, Photodiodes, Zener Diodes, **Semiconductor Junctions and Devices:** Metal-Semiconductor Junctions, Schottky Barrier Formation, Schottky Diode Characteristics and Uses.
Unit 4 (10L)	**Bipolar Junction Transistors (BJTs)** Structure and Operation (npn, pnp)**,** Modes of Operation and Current Gain**,** Applications in Switching and Amplification **Field-Effect Transistors (FETs):** MOSFET: Structure, Working Principles, Threshold Voltage**,** Types: nMOS, pMOS, CMOS Technology**, s**caling and Short-Channel Effects **Advanced Devices and**

	Applications: Power Devices: IGBT, SiC/GaN MOSFETs**,** Optoelectronic Devices: LEDs, Laser Diodes, Solar Cells**,** Sensors and High-Frequency Devices**,** Device Integration and CMOS Scaling Trends, Semiconductor Hetrostructures.
Unit 5 (8L)	**Optical Properties of Semiconductors, Fabrication and Processing of Semiconductors:** Absorption, Emission, and Photoluminescence, Photovoltaic Effect and Solar Cells, LEDs and Lasers, Crystal Growth Techniques: Czochralski Process, Bridgman Method, Wafer Preparation and Doping Techniques.
References	1. Semiconductor Physics and Devices by Donald A. Neamen 2. Fundamentals of Semiconductor Fabrication by Gary S. May and Simon M. Sze 3. Physics of Semiconductor Devices by Simon M. Sze and Kwok K. Ng
Course Outcome	1. Understand the basic properties of semiconductors and the physical principles that govern their behavior. 2. Describe different types of semiconductor materials and their crystal structures. 3. Explain intrinsic and extrinsic semiconductor behavior, charge carrier dynamics, and doping. 4. Recognize the role of defects and impurities in semiconductor materials. 5. Comprehend the basics of semiconductor devices such as diodes, transistors, and photovoltaic cells. 6. Acquire knowledge about the fabrication processes for semiconductor materials and devices.

Structural and Functional Characterization of Materials			
Prerequisite: 1. Introduction to Materials Science or Chemistry 2. Basic Physics (particularly atomic and molecular physics) 3. Understanding of crystallography is recommended but not required	L	T	P
Type: Program core	3	0	0

Course Description: This course offers an in-depth exploration of techniques used to characterize the structure and functionality of materials. It covers methods to determine the atomic, molecular, and crystalline structure of materials, as well as techniques for evaluating their physical, chemical, and functional properties.

Course Content

Unit 1 (2L)	**Introduction to Material Characterization:** Overview of Material Properties and Characterization Techniques, Importance of Structural and Functional Characterization, Brief Overview of Analytical Techniques in Materials Science
Unit 2 (6L)	**Structure characterization techniques:** Fundamental crystallography, Generation and detection of X-rays, X-ray diffraction techniques, Phase identification, indexing and lattice parameter determination, Secondary Ion Mass Spectrometry (SIMS)
Unit 3 (7L)	**Thermal, electrical and magnetic characterization techniques:** Differential thermal analysis (DTA), Differential Scanning Calorimetry (DSC), Thermo-gravimetric analysis (TGA), Electrical resistivity in bulk and thin films, Hall effect, Dielectirc Measurements, Ferroelectric and Piezoelectric properties, Magnetic Property Characterization: Vibrating Sample Magnetometer (VSM), SQUID
Unit 4 (10L)	**Microscopy characterization techniques:** Scanning Electron Microscopy (SEM): Imaging, Elemental Analysis, and Applications, Transmission Electron Microscopy (TEM): High-Resolution Imaging, SAED, Sample Preparation Techniques for SEM and TEM, Atomic Force Microscopy (AFM): Imaging Modes and Applications, Scanning Tunneling Microscopy (STM): Basics and Applications in Surface Analysis
Unit 5 (12L)	**Spectroscopic Characterization Techniques:** X-ray Photoelectron

	Spectroscopy (XPS) for Surface Chemistry, Auger Electron Spectroscopy (AES) for Surface Composition, Energy Dispersive X-ray Spectroscopy (EDS) in Conjunction with SEM, Fourier-Transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy, UV-Visible Spectroscopy for Bandgap and Optical Properties, Applications of Spectroscopic Techniques in Material Analysis.
References	1. Characterization of Materials (Materials Science and Technology:A Comprehensive Treatment,Vol 2A & 2B, VCH (1992). 2. Semiconductor Material and Device Characterization, 3rd Edition, D.K. Schroder, Wiley-IEEE Press (2006). 3. Materials Characterization Techniques,S Zhang, L. Li and Ashok Kumar, CRC Press (2008). 4. Physical methods for Materials Characterization,P.E. J. Flewitt and R K Wild, IOP Publishing (2003). 5. Characterization of Nanophase materials,Ed. Z LWang, Willet-VCH (2000).
Course Outcome	1. Understand the principles and applications of various structural and functional characterization techniques. 2. Be able to select appropriate methods to characterize materials based on their structural, chemical, and physical properties. 3. Gain hands-on experience (if applicable) in using different characterization tools. 4. Develop skills to analyze and interpret data from characterization techniques. 5. Apply characterization methods to solve real-world materials science and engineering problems.

Semiconductor Material Characterization Lab			
Prerequisite: Basic material characterization techniques	L	T	P
Type: Program core	0	0	6
Credit: 03			

Course Description: The course will provide hands on exposure to various characterization techniques used for semiconductor materials.

Course Content

Experiment 1: X-ray diffraction studies of basic semiconductor materials like Si, TiNiSn etc.

Experiment 2: Optical Band gap determination of semiconductor materials like Si, TiNiSn etc using UV-visible spectroscopy.

Experiment 3: Electrical Band gap determination of semiconductor materials like Si, TiNiSn etc. using SDA.

Experiment 4: Determination of surface roughness of semiconductor materials through AFM.

Experiment 5: Surface morphological studies of semiconductor materials using SEM

Experiment 6: Growth of SiO_2 on Si and determination of its thickness with time

Experiment 7: Determination of chemical composition and trap charges in SiO_2 grown over Si.

Experiment 8: Mechanical properties determination of SiO_2 grown over Si.

Experiment 9: Study of residual stress in a sample using X-ray diffraction.

Thin Film Technology			
Prerequisite: Basic physics and materials science	L	T	P
Type: Program core	3	0	0
Credit: 03			

Course Description: The course will provide basic understanding of various thin film deposition techniques.

Course Content

Unit 1 (5L)	**Vacuum components and systems**: Need for vacuum, ways to achieve vacuum, determination of vacuum, dry and vapour pumps, pressure measurement gauges, conductance and other system design considerations.
Unit 2 (13L)	**Thin film deposition techniques**: Physical and chemical vapour deposition techniques, including molecular beam epitaxy, laser ablation and hot wire and microwave CVD techniques. Film contamination, cosine law of deposition, conformal coverage and line of sight deposition
Unit 3 (7L)	**Growth of thin films**: Thermodynamic and kinetic considerations of deposition of thin films by both CVD and PVD, including magnetron sputtering. In situ characterization of thin film deposition process.
Unit 4 (4L)	**Epitaxy and Epitaxial growth and characterization:** Types of epitaxy, Vapour phase epitaxy, Metal-organic CVD, Molecular beam epitaxy, *In situ* monitoring techniques (RHEED, STM, AFM).
Unit 5 (6L)	**Characterization of thin films**: Different methods of thickness measurements, electrical, optical, chemical and structural property determination.
Unit 6 (4L)	**Applications of thin films:** Hard and decorative coatings, semiconductor thin films, organic thin films. Applications in optical windows, integrated circuits, micro-electro-opto-mechanical systems and photovoltaics.
References	1. Ohring, M., *The Materials Science of Thin Films*, 2nd Edition, Academic press, 2002. 2. Smith, D.L., *Thin-Film Deposition: Principles and Practice*, McGraw-Hill, 1995. 3. Soriaga, M.P., Stickney, J., Bottomley, L.A., and Kim Y.G, *Thin Films: Preparation, Characterization, Applications,* Springer Science, 2011. 4. Chopra, K. L., *Thin Film Phenomena*, McGraw Hill, 1969.

Course Outcome	CO1. To understand the principle, differences and similarities, advantages, and disadvantages of different thin film deposition techniques. CO2. To understand and evaluate and use models for understanding nucleation and growth of thin films. CO3. To understand about different instrumentation techniques and to analyze thin film properties to apply for various applications. CO4. To improve problems solving skills related to evaluation of different properties of thin films.

Physics of Semiconductor Devices			
Prerequisite: 1. Basic understanding of quantum mechanics and solid-state physics. 2. Fundamentals of electrical circuits and electromagnetism.	L	T	P
Type: Program Core	3	0	0
Course Description: This course introduces the fundamentals of semiconductor physics. Exploration of the working principles of basic semiconductor devices. This will help student to understand device fabrication processes and performance metrics. It will provide analytical and numerical approaches to device behavior.ter understanding of how to integrate ML with existing computational material science tools.			
Course Content			

Unit 1 (3L)	**Fundamentals of Semiconductor Physics:** Introduction to Semiconductors: Semiconductor materials, elemental vs. compound semiconductors, energy bands. Carrier Statistics: Fermi-Dirac distribution, intrinsic and extrinsic semiconductors, doping. Carrier Transport Mechanisms: Drift, diffusion, mobility, and scattering mechanisms. Generation and Recombination: Carrier lifetime, Shockley-Read-Hall (SRH) recombination, Auger recombination.
Unit 2 (10L)	**P-N Junctions:** Formation of the P-N Junction: Band diagram, depletion region, built-in potential. Electrostatics of the P-N Junction: Space charge region, electric field, and potential distribution. P-N Junction Under Forward and Reverse Bias: Current-voltage characteristics, diffusion and drift currents. Breakdown Mechanisms in P-N Junctions: Zener and avalanche breakdown. Small-Signal and High-Frequency Analysis: Capacitance-voltage characteristics, transient behavior. **Bipolar Junction Transistors (BJTs):** Basic Structure and Operation: NPN and PNP transistors, current flow, modes of operation. BJT I-V Characteristics: Input and output characteristics, Early effect. Current Gain and Base Transport Factor: Gain mechanisms, recombination in the base.
Unit 3 (8L)	**Metal-Semiconductor Contacts:** Schottky Contacts: Formation, energy band diagrams, thermionic emission. Ohmic Contacts: Contact resistance, tunneling, and fabrication techniques. Applications of Metal-Semiconductor Junctions Applications in rectifiers, detectors, and Schottky diodes.

Unit 4 (8L)	**Metal-Oxide-Semiconductor (MOS) Structures:** Introduction to MOS Capacitors: Energy band diagrams, accumulation, depletion, and inversion. Capacitance-Voltage Characteristics: High-frequency and low-frequency C-V analysis. Interface States and Their Effects: Trap states, Dit measurement techniques. MOS Fabrication Techniques: Oxidation, photolithography, and thin-film deposition.
Unit 5 (8L)	**Semiconductor Devices:** Charge-Coupled Devices (CCDs): Principles of operation, applications in imaging. Photodetectors and Solar Cells: Principles, characteristics, and performance metrics. Light-Emitting Diodes (LEDs): Radiative recombination, efficiency, and device design. Power Devices: Diodes, BJTs, and MOSFETs for power applications, memory devices.
References	1. "Semiconductor Physics and Devices: Basic Principles" by Donald A. Neamen, Fourth Edition, McGraw-Hill, March 2011. 2. Fundamentals of Semiconductor Devices" by Pierret Robert F., 1st Edition, Pearson, January 2006.
Course Outcome	Students will: 1. Gain a strong foundation in semiconductor physics and device principles. 2. Analyze and model the behavior of basic devices such as diodes, BJTs, and MOSFETs. 3. Understand fabrication processes and device performance metrics. 4. Be prepared for advanced studies or careers in semiconductor device engineering.

Fabrication of semiconductor device and electrical characterization lab			
Prerequisite: Course on semiconductor materials and semiconductor device physics	L	T	P
Type: Program core	0	0	6
Credit: 03			

Course Description: The course will deal with the fabrication of devices using thin film growth method and the electrical characterization of the devices.

Course Content

Experiment 1: Study of I-V characteristics of a diode.

Experiment 2: Study of I-V characteristics of a transistor.

Experiment 3: Cyclic voltammetric characteristics of fuel cells.

Experiment 4: Calculation of capacitance of a supercapacitor using Cyclic voltammetry.

Experiment 5: Growth of graphene on a substrate using CVD technique.

Experiment 6: Electrical characterization of graphene grown using CVD.

Experiment 7: Structural characterization of a metallic thin film grown using magnetron sputtering.

Experiment 8: Fabrication of metallic thin film on semiconductor substrate using magnetron sputtering.