

**Malaviya National Institute of Technology Jaipur
Materials Research Centre**

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

Physical Processes in Microfabrication			
Prerequisite: Basic Thermodynamics and materials science	L	T	P
Type: Program core	3	0	0
Credit: 03			
Course Description: The course will provide basic understanding of diffusion and oxidation in materials.			
Course Content			
Unit 1 (7L)	Diffusion and mechanism: Thermodynamic basis of diffusion, chemical potential gradients, Theory of diffusion, diffusion in various geometries, mechanisms for diffusion: Vacancy diffusion, Interstitial diffusion, concept of random walk; substitutional diffusion, Activation energy for diffusion, orientation dependence, diffusion in ordered phases.		
Unit 2 (5L)	Laws of diffusion: Fick's first law, Fick's second law, methods for analysing diffusion		
Unit 3 (8L)	Diffusion in metals and semiconductors: self-diffusion, interstitial solutes, dilute substitutional alloys, binary intermetallics, quasi-crystalline alloys, foreign atom diffusion and its impact, interstitial-substitutional diffusion.		
Unit 4 (4L)	Temperature Dependence and Diffusion Kinetics: Arrhenius equation for diffusion, Activation energy and pre-exponential factor, Diffusion-controlled phase transformations, Role of microstructure and defects.		
Unit 5 (6L)	Role of diffusion and case studies: grain growth, high temperature corrosion and creep, Ion implantation: physics and damage, diffusion doping, annealing and activation, junction formation.		
Unit 6 (9L)	Thermodynamics and Kinetics of Oxidation: Oxidation reactions in metals and ceramics, Ellingham diagram, Gibbs free energy, oxidation states and phase stability, Growth kinetics of oxide layers, Wagner's theory of oxidation and ionic transport, Pilling-Bedworth ratio and protective vs. non-protective oxides, Internal oxidation, selective oxidation		
References	<ol style="list-style-type: none"> 1. Shewmon, P. G., <i>Diffusion in Solids</i>, 2nd Edition, Wiley-TMS, 1991. 2. Helmut, M., <i>Diffusion in Solids: Fundamentals, Methods, Materials, Diffusion-Controlled Processes</i>, Springer, 2007. 3. Paul, A., Laurila, T., Vuorinen, V., Divinski, S. V., <i>Thermodynamics, Diffusion and the Kirkendall effect in Solids</i>, Springer, 2014. 		

	<p>4. Birks, N., Meier, G. H., Pettit, F. S., <i>Introduction to the High Temperature Oxidation of Metals</i>, Cambridge University Press, 2006.</p>
Course Outcome	<p>CO1. Understand and apply the fundamental principles of atomic diffusion in various types of solid materials.</p> <p>CO2: Analyze diffusion data using Fick's laws, and understand the significance of diffusion coefficients in material design and processing.</p> <p>CO3: Apply the theory of diffusion to understand different material properties in various types of solids.</p> <p>CO4: Predict oxidation behavior of different materials using thermodynamic and kinetic tools.</p>

Electronic Oxide Materials			
Prerequisite: Basic knowledge of physical chemistry, physics, and material characterization	L	T	P
Type: Program elective	3	0	0
Credit: 03			
Course Description: This course deals with the science and engineering of oxide materials, their properties and applications.			
Course Content			
Unit 1 (4L)	Introduction: Overview of functional oxides, Classes of oxides: perovskites, spinels, pyrochlores, fluorites, Key electronic functions: insulating, semiconducting, superconducting, ferroelectric, magnetic.		
Unit 2 (10L)	Bonding, crystal structures and electronic structures in oxides: Coordination, crystal field theory, and ionic radii, Common oxide structures: perovskite (ABO_3), rutile, corundum, Structure-property correlations. Band theory in oxides, Mott insulators and charge transfer insulators, Role of d- and f-electrons, Oxide semiconductors and wide-bandgap materials, Density of states and band gap engineering.		
Unit 3 (6L)	Defects and doping in oxide materials: Point defects: vacancies, interstitials, anti-sites, Defect chemistry using Kröger-Vink notation, Oxygen vacancies and redox reactions, n-type and p-type doping in oxides		
Unit 4 (8L)	Dielectric, ferroelectric, magnetic oxide and multiferroics: Polarization mechanisms: electronic, ionic, orientation, Ferroelectricity, piezoelectricity, pyroelectricity, Soft vs. hard ferroelectrics, Hysteresis behavior and fatigue, Key materials: $BaTiO_3$, PZT, HfO_2 -based ferroelectrics. Magnetism in solids: paramagnetism, ferromagnetism, antiferromagnetism, Double exchange and super exchange interactions, Spinel ferrites and manganites, Multiferroic materials and magnetoelectric coupling.		
Unit 5 (4L)	Oxide semiconductors and conductors: Transparent conducting oxides (TCOs): ITO, ZnO, SnO_2 , Oxide thin-film transistors (TFTs), Amorphous vs. crystalline oxides, Mobility mechanisms in disordered oxides.		
Unit 6 (7L)	Energy applications of electronic oxides: Oxides in fuel cells and batteries, Oxides in photocatalysis and solar cells (e.g., TiO_2 , $BiVO_4$), Thermoelectric		

	oxides, Electrochemical stability and conductivity.
References	<ol style="list-style-type: none"> 1. Sze, S. M. and Ng, K., <i>Physics of Semiconductor Devices</i>. John Wiley & Sons, 2007. 2. Coey, J.M.D., <i>Magnetism and Magnetic Materials</i>, Cambridge University Press, 2012. 3. Various research and review papers.
Course Outcomes	<p>CO1: Analyze the structure-property relationships in electronic oxide materials.</p> <p>CO2: Explain the role of defects and dopants in controlling electronic behavior in oxides.</p> <p>CO3: Evaluate the dielectric, ferroelectric, and magnetic properties of various oxide classes.</p> <p>CO4: Propose material selection and design strategies for specific oxide-based applications.</p>

Materials for Flexible Electronics

Prerequisite: 1. Introductory courses in Polymer Science or Materials Science 2. Basic Chemistry and Physics	L	T	P
Type: Program elective	3	0	0
Credit: 03			
<p>Course Description: This course explores the synthesis, properties, and applications of functional polymers and composite materials, emphasizing their use in semiconductor devices and electronic applications. Students will learn the key relationships between the structure and properties of polymers, and how these materials are engineered for specific functionalities, such as thermal management, dielectric applications, and flexible electronics.</p>			
Course Content			
Unit 1 (3L)	<p>Introduction to Functional Polymers and Composites: Overview of polymer and composite materials, Types of functional polymers: conductive, dielectric, structural, and biodegradable, Applications and importance across industries, particularly in electronics and semiconductors</p>		
Unit 2 (6L)	<p>Polymer Synthesis and Processing Techniques: Polymerization techniques: addition, condensation, and controlled polymerization, Chemical modification for functionality enhancement, Processing methods: extrusion, solution casting, and spin coating, relevant to electronic devices</p>		
Unit 3 (8L)	<p>Structure and Mechanical Properties of Polymers: Understanding polymer morphology: crystalline, semi-crystalline, and amorphous structures, Mechanical properties: tensile strength, flexibility, toughness, Effects of fillers and reinforcements in polymer composites</p>		
Unit 4 (7L)	<p>Electrical, Dielectric, Thermal Properties and Thermal Management Applications: Conductive polymers and applications in electronics (e.g., polyaniline, PEDOT), Dielectric polymers for insulators and capacitors in semiconductor devices, Low-K and high-K dielectric materials for energy-efficient devices. Thermal properties: glass transition temperature, melting point, and decomposition,</p>		

	Thermally conductive composites for electronic and semiconductor applications, Role of polymers in managing heat dissipation in devices.
Unit 5 (10L)	Emerging Applications and Trends in Functional Polymers, Relevance of Functional Polymers in the Semiconductor Industry: Encapsulation, packaging, and insulation materials for semiconductor devices, Polymers for flexible electronics and wearable devices, Advantages over traditional materials: weight reduction, flexibility, and cost-effectiveness, Advances in nanocomposites, smart polymers, and self-healing materials, Applications in 3D printing and additive manufacturing for microelectronics, Case studies on polymer applications in semiconductor devices and consumer electronics
References	<ol style="list-style-type: none"> 1. "Polymer Science and Technology" by Joel R. Fried 2. "Functional Materials: Preparation, Processing, and Applications" by S. Banerjee 3. "Handbook of Polymer Composites for Engineers" by L.C. Hollaway
Course Outcomes	<ol style="list-style-type: none"> 1. Describe the properties and synthesis of functional polymers and composites. 2. Relate polymer structure to its thermal, mechanical, and electrical properties. 3. Understand the use of polymers and composites in semiconductor and electronic devices. 4. Identify the latest advancements in polymer composites for flexible and wearable electronics.

Computational Methods for Material Science			
Prerequisite: 1. Basic knowledge of material science principles 2. Familiarity with linear algebra, calculus, and differential equations 3. Programming skills (preferably Python or MATLAB)	L	T	P
Type: Program elective	3	0	0
Credit: 03			
Course Description: This course introduces fundamental computational methods used in material science. It provides information about computational tools and software. The course will enable students to model, simulate, and analyze materials at various scales, from atomic to macroscopic.			
Course Content			
Unit 1 (5L)	Introduction to Computational Material Science: Overview of Computational Material Science, Introduction to the field, scope, and importance of computational methods in material research. Basic Concepts in Material Modeling Brief overview of atomic structures, crystallography, and material properties. Computational Techniques and Approaches, Overview of atomistic, mesoscale, and macroscale modeling; multiscale modeling concepts.		
Unit 2 (5L)	Quantum Mechanics and Electronic Structure Methods: Fundamentals of Quantum Mechanics, Review of quantum mechanical principles relevant to material science.		
Unit 3 (10L)	Density Functional Theory (DFT) - Introduction to DFT and its applications in material science. Basics DFT calculation using different software. Calculation of Band Structure and Density of States Practical session focused on electronic properties determination using DFT.		
Unit 4 (10L)	Molecular Dynamics (MD): Molecular Dynamics - Introduction and Basics of MD simulations, force fields, and algorithms. Setting up and running an MD simulation. Analyzing MD data: calculating radial distribution functions, diffusion coefficients, and thermal properties.		
Unit 5 (10L)	Monte Carlo Methods in Material Science: Introduction to Monte Carlo		

	<p>simulations and their application in material science. Applications of MD and MC Simulations, Case studies: phase transitions, defect studies, and nanomaterials. Kinetic Monte Carlo (KMC) Methods: Introduction to KMC and its application in studying diffusion and reaction kinetics.</p>
References	<ol style="list-style-type: none"> 1. Computational Materials Science: An Introduction by June Gunn Lee 1st Edition, CRC press, October 2011. 2. Introduction to Computational Materials and Sciences: Fundamentals to Applications by Richard LeSar, 1st Edition, Cambridge University Press, March 2023. 3. Molecular Dynamics Simulation: Elementary Methods by J. M. Haile SBN: 978-0-471-18439-3, March 1997
Course Outcome	<ol style="list-style-type: none"> 1. Students develop an understanding of materials behavior across scales—atomic, mesoscale, and macroscale—using computational models like DFT, molecular dynamics, and finite element methods. 2. Ability to predict properties such as mechanical strength, thermal conductivity, and electronic behavior, aiding in material selection and design. 3. Ability to predict properties such as mechanical strength, thermal conductivity, and electronic behavior, aiding in material selection and design.

Energy Materials and their applications			
Prerequisite: Basic understanding of physics and electrochemistry	L	T	P
Type: Program Elective	3	0	0
Credit: 03			
Course Description: The main objective of this course is to give students an overview of energy materials and their utility in various sectors.			
Course Content			
Unit 1 (10L)	Photovoltaic Solar Energy Materials: Solar cell principles and its characterization. Absorption and minority carrier life time, Single crystalline and polycrystalline silicon solar cells, Amorphous silicon solar cells, Cadmium Telluride thin film solar cells, Transparent conductive oxide materials, Chalcopyrite based solar cells, Organic and dye sensitized solar cells.		
Unit 2 (8L)	Thermoelectric Materials: Physics of thermoelectricity, Peltier, Seebeck and Thomson effects, Types of thermoelectric materials, Thermoelectric generators, Peltier cooler.		
Unit 3 (10L)	Electrochemical Energy Materials: Fundamentals of electrochemical energy conversions, Primary batteries - Zn-MnO ₂ system, carbon-zinc and carbon-zinc chlorides performance characteristics and zinc-silver oxide. Secondary batteries – lead acid, nickel cadmium, nickel metal hydride, silver oxide zinc system, lithium ion battery, Batteries beyond Lithium Ion, Introduction to super capacitors, types of super capacitors, Introduction to fuel cells, Types of fuel cells and technology development.		
Unit 4 (8L)	Hydrogen Energy: Hydrogen; its merit as a fuel; Applications, Hydrogen production methods, Production of hydrogen from fossil fuels, Electrolysis, Thermal decomposition, Photochemical and photo-catalytic methods, Hydrogen storage methods, Metal hydrides, Metallic alloy hydrides, Carbon nano-tubes, Sea as source of Deuterium.		
References	(i) Markvart ,T., Castaner L., <i>Solar Cells-Materials, Manufacture and Operation</i> , 2 nd ed., Elsevier Ltd. 2012 (ii) Nolas, G. S., Sharp, J., Goldsmid ,J., . Schwartz, M.M., <i>Thermoelectric: Basic Principles and New Materials Developments</i> , Springer series 2001 (iii) Bard, J., Allen. and Larry Faulkner,R., <i>Electrochemical methods: Fundamentals</i>		

	<i>and Applications</i> , 2nd Edition John Wiley & Sons. Inc 2004 (iv). Linden, D., <i>Handbook of Batteries</i> , 2nd edition, McGraw-Hill, New York 1995
Course Outcome	CO1: Grasp the basics of Energy materials and their properties. CO2: Understanding the working principle of devices made of energy materials. CO3: Synthesis routes for energy materials for different targeted applications.

2D Materials: Synthesis, Properties, and Applications

Prerequisite: 1. Basics of Solid State Physics (crystal structures, band theory) 2. Introduction to Materials Science and Engineering 3. Fundamentals of Semiconductor Physics (charge carriers, p–n junctions)	L	T	P
Type: Program Elective	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 (4L)	Introduction to 2D Materials: Overview of 2D materials: Graphene, MXenes, Transition Metal Dichalcogenides (MoS ₂ , WS ₂), h-BN, Phosphorene. Importance and uniqueness of 2D materials in electronics and energy devices.		
Unit 2 (5L)	Structural and Electronic Properties: Crystal structure and lattice dynamics of 2D materials, Electronic band structure and surface states, Mechanical and thermal properties, Role of surface terminations and defects.		
Unit 3 (10L)	Synthesis Techniques: Top-down methods: Mechanical exfoliation, liquid-phase exfoliation, Bottom-up methods: CVD, ALD, MBE for 2D semiconductors, Etching and delamination techniques for MXenes and MAX phases, Growth of van der Waals heterostructures.		
Unit 4 (10L)	Surface Engineering and Doping Strategies: Surface functionalization and defect engineering, Substitutional doping, molecular doping, and electrostatic gating, Environmental stability, passivation, and surface protection.		
Unit 4 (10L)	Devices Based on 2D Materials: Field-effect transistors and logic devices, Photodetectors, LEDs, and optical modulators, Supercapacitors, lithium-ion and sodium-ion batteries, and catalysis, Sensors: gas, strain, biomedical, and environmental, Flexible, wearable, and printable electron.		
References	1. 2D Materials: Properties and Devices, Phaedon Avouris and Tony F. Heinz, Cambridge University Press (2017). 2. 2D Materials for Electronics, Sensors and Devices: Synthesis,		

	<p>Characterization, Fabrication and Applications, S. Balendhran, S. Walia and M. Bhaskaran, Elsevier (2019)</p> <p>3. 2D Materials: Sensing Applications, Edited by A. K. Mishra, CRC Press (2023)</p>
Course Outcome	<ol style="list-style-type: none"> 1) To understand the structural, electronic, optical, and mechanical properties of 2D materials. 2) To learn the fabrication and processing techniques for 2D materials. 3) To gain insight into their applications in electronics, optoelectronics, energy storage/conversion, and sensors. 4) To explore the state-of-the-art advances and future directions in 2D material research.

Quantum Heterostructures and Their Applications			
Prerequisite: Basic knowledge of Chemistry, Physics and Biology	L	T	P
Type: Program elective	3	0	0
Credit: 03			
Course Description: The course will cover the principles, synthesis, and diverse applications of quantum dots (QDs), which are semiconductor nanocrystals with unique optical and electronic properties due to quantum confinement effects.			
Course Content			
Unit 1 (3L)	Introduction to Quantum Heterostructures: Overview of heterostructures, Dimensionality and quantum confinement, Types of quantum heterostructures: wells, wires, dots, superlattices.		
Unit 2 (4L)	Quantum Wells: Potential well models (finite and infinite), Bound states and energy quantization, Tunneling and resonant states, Density of states in 2D systems.		
Unit 3 (5L)	Quantum Well Lasers: Principles of operation, threshold current, gain, and confinement factor. Strained-layer and multiple quantum well designs, Performance comparison with bulk lasers		
Unit 4 (6L)	Quantum dots: What are quantum dots? Definition, size, and quantum confinement. Understanding quantum mechanical principles in nanomaterials, Energy quantization in low-dimensional systems, Comparison of bulk materials and nanomaterials. Types of quantum dots: Semiconductor quantum dots (CdSe, CdTe, PbS, etc.), Core-shell quantum dots, carbon quantum dots.		
Unit 5 (7L)	Synthesis of Quantum dots: Solution-phase methods: hot injection, colloidal synthesis, and chemical vapor deposition. Green and environmentally friendly synthesis routes: non-toxic precursors, surfactant-free methods. Surface modification and passivation strategies to improve optical properties and stability. Synthesis parameters affecting quantum dot properties, Methods for tuning optical properties.		
Unit 6 (5L)	Optical and Electronic Properties of Quantum dots: Optical properties: Quantum dot absorption and emission spectra, Photoluminescence, fluorescence,		

	and quantum yield, Excited-state dynamics and carrier relaxation. Electronic properties: Energy band structure and density of states, Carrier transport and trapping.
Unit 7 (9L)	<p>Applications of Quantum Dots: Quantum dots for photovoltaic applications: Quantum dot solar cells (QDSCs), Carrier dynamics in QDs: Charge transport, recombination, and exciton dissociation, Types of quantum dot solar cells: Sensitized, all-solution-processed, and hybrid systems.</p> <p>Quantum dots in light-emitting diodes (LEDs): Mechanisms of electroluminescence, Color-tunable emission in QD-LEDs and quantum dot displays, Quantum dots for lasing applications: Thresholds, stimulated emission, and QD lasers.</p>
References	<ol style="list-style-type: none"> 1. Bimberg, D., Grundmann, M., Ledentsov, N. N., <i>Quantum Dot Heterostructure</i>, Wiley, 1999. 2. Rogach, A. L., <i>Semiconductor Nanocrystal Quantum Dots</i>, Springer, New York, 2008. 3. Harrison, P., <i>Quantum Wells, Wires and Dots: Theoretical and Computational Physics of Semiconductor Nanostructures</i>, John Wiley & Sons, Ltd. 2005. 4. Meng, H., <i>Colloidal Quantum Dot Light Emitting Diodes: Materials and Devices</i>, Wiley-VCH, 2023. 5. Various research and review papers.
Course Outcomes	<p>CO1: Understand the principles of quantum confinement and how they give rise to unique properties in quantum heterostructures.</p> <p>CO2: Understand the concept of Quantum wells and quantum well lasers.</p> <p>CO3: Be proficient in various synthesis methods for quantum dots and their surface modifications.</p> <p>CO4: Explore the diverse applications of quantum heterostructures in areas such as photovoltaics and optoelectronics.</p>

Electronic Materials and Devices

Prerequisite: 1. Introductory Physics or Materials Science 2. Basic knowledge of Solid-State Physics or Chemistry	L	T	P
Type: Program elective	3	0	0
Credit: 03			
<p>Course Description: This course explores the synthesis, properties, and applications of functional polymers and composite materials, emphasizing their use in semiconductor devices and electronic applications. Students will learn the key relationships between the structure and properties of polymers, and how these materials are engineered for specific functionalities, such as thermal management, dielectric applications, and flexible electronics.</p>			
Course Content			
Unit 1 (3L)	<p>Fundamentals of Electronic Materials: Classification of electronic materials: conductors, semiconductors, and insulators, Band theory and energy bands in solids, Charge carriers: electrons and holes, Electrical conductivity, resistivity, and mobility, Temperature dependence of electrical properties, Thermal conductivity and heat management in electronic devices</p>		
Unit 2 (9L)	<p>Dielectric and Ferroelectric Materials: Understanding dielectric constant and different polarization mechanisms (electronic, ionic, dipolar). Key applications include capacitors and memory devices that rely on dielectric behavior. Study of spontaneous polarization, hysteresis loops, and phase transitions. Important applications in non-volatile ferroelectric memories (FeRAM), sensors, and actuators.</p>		
Unit 3 (8L)	<p>Optical Materials and Optoelectronic Devices: Interaction with light: Fundamentals of absorption, emission, and transmission of light through materials, along with key optical properties like refractive index and absorption coefficient. Optoelectronic devices: Basics and working principles of LEDs, semiconductor lasers, and photodetectors, highlighting their roles in communication and sensing. Transparent conductive materials: Characteristics and use of materials like Indium Tin Oxide (ITO) in displays, touchscreens, and solar cells.</p>		

Unit 4 (7L)	Magnetic Materials and Their Applications: Magnetic properties: paramagnetism, diamagnetism, ferromagnetism, Magnetic domains, hysteresis, and magnetic permeability, Applications in data storage, sensors, and inductors
Unit 5 (7L)	Emerging Trends and Advanced Applications in Electronic Materials: Overview of emerging materials: 2D materials, organic semiconductors, and topological insulators, Nanoelectronics and quantum materials, Advanced applications in flexible electronics, sensors, and wearable devices
References	<ol style="list-style-type: none"> 1. "Solid State Electronic Devices" by Ben G. Streetman and Sanjay Kumar Banerjee 2. "Electronic Properties of Materials" by Rolf E. Hummel 3. "Physics of Semiconductor Devices" by Simon M. Sze and Kwok K. Ng
Course Outcomes	<ol style="list-style-type: none"> 1. Understand the fundamental properties of electronic materials. 2. Analyze the behavior of materials in electronic devices. 3. Gain knowledge on the specific role of semiconductors in electronics. 4. Apply principles of electronic materials to understand device functionality and applications. 5. Stay informed on emerging trends in electronic materials for next-generation devices.

Machine Learning For Materials Science

Prerequisite: 1. Introduction to Materials Science or Chemistry 2. Basic Physics (particularly atomic and molecular physics) 3. Programming knowledge (Python recommended)	L	T	P
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Type: Program Elective	3	0	0
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Course Description: This course offers an exploration to introduce machine learning concepts and algorithms relevant to material science. Equip students with skills to handle material-related datasets and apply ML techniques. Demonstrate ML applications in material discovery, property prediction, and process optimization. Foster understanding of how to integrate ML with existing computational material science tools.

Course Content

Unit 1 (7L)	Introduction to Machine Learning (ML) and Material Science: Introduction to ML and Its Importance in Material Science. Overview of ML methods and their relevance in solving material science challenges. Basics of material science data, types of material data: structural, compositional, mechanical, electronic, and thermal properties. Data Preparation for ML, Data cleaning, normalization, and handling missing data in material datasets.
Unit 2 (10L)	Machine Learning Fundamentals: Supervised Learning Overview, Concepts of regression and classification with material science examples. Regression Models in Material Science, Linear regression, polynomial regression, and regularization methods. Classification Models and Applications, Logistic regression, support vector machines, and their applications in materials categorization. Unsupervised Learning Basics Clustering (e.g., K-means, hierarchical clustering) and dimensionality reduction (e.g., PCA) techniques.
Unit 3 (11L)	Advanced ML Algorithms: Decision Trees and Ensemble Methods Random Forest, Gradient Boosting, and their applications in property prediction. Neural Networks (NN) Basics, Introduction to NN architectures and their relevance in complex materials data. Deep Learning for Material Science CNNs and RNNs for imaging and sequence data in material science. Bayesian Methods and Gaussian Processes, Probabilistic modeling for uncertainty quantification in material predictions.

Unit 4 (11L)	<p>Material-Specific Applications: Property Prediction with ML, Predicting properties like bandgap, elasticity, and thermal conductivity. Material Classification and Discovery ML for finding novel alloys, polymers, and composites. ML for Process Optimization Applications in manufacturing, crystal growth, and additive manufacturing. Case Study: Predicting catalytic activity Hands-on example for materials discovery.</p>
References	<ol style="list-style-type: none"> 1. Machine Learning in Materials Informatics: Theory and Applications" edited by Tingyu Zhu, Zi-Kui Liu, and Mo Li 2. Materials Data Science: Introduction to Data Mining, Machine Learning, and Data-Driven Predictions for Materials Science and Engineering (The Materials Research Society Series) by Stefan Sandfeld, 1st edition, Springer, May 2024
Course Outcome	<p>Students will:</p> <ol style="list-style-type: none"> 1) Acquire hands-on skills in applying ML to materials challenges. 2) Develop ML models for property prediction, process optimization, and materials discovery. 3) Gain proficiency in modern ML tools and computational techniques, enabling impactful research and industry contributions. 4) Demonstrate ML applications in material discovery, property prediction, and process optimization. 5) Foster understanding of how to integrate ML with existing computational material science tools.

Compound Semiconductor Devices			
Prerequisite: Basic solid state and quantum physics	L	T	P
Type: Program elective	3	0	0
Credit: 03			
Course Description: This course is designed to familiarize post graduate students to key concepts in compound semiconducting devices			
Course Content			
Unit 1 (12L)	Semiconductor crystal structures- diamond, zinc-blende & wurtzite structure, reciprocal lattice, diffraction condition & brillioun zone, band structures of common semiconductors, structural & electrical properties of compound semiconductor crystals, III-V compound semiconductors – lattice constant & band gap engineering, group III nitrides.		
Unit 2 (10L)	Heterostructure fundamentals – energy band alignment, Anderson’s electron affinity model, strained layer structures, heterostructure band diagrams, current confinement in double heterostructures, density of states.		
Unit 3(6L)	Crystal growth techniques, epitaxy- liquid phase epitaxy, vapor phase epitaxy, molecular beam epitaxy.		
Unit 4 (7L)	Electrical properties of compound semiconductor heterostructures, abrupt heterojunction under equilibrium, p-N heterojunction under bias, quantum well heterostructures, superlattices & mini bands, resonant tunnelling.		
Unit 5 (7L)	Heterostructure electronic devices – MESFETs, basic operation principles, current voltage characteristics, high electron mobility transistor basics, HEMT operation, heterojunction bipolar transistors (HBTs), basic theory, band discontinuity, high frequency operation.		
References	<ol style="list-style-type: none"> 1. T. Steiner, Semiconductor Nanostructures for Optoelectronic Applications 2. U. W. Pohl, Epitaxy of Semiconductors: Introduction to Physical Principles 3. S.M. Sze and K.K. Ng, Physics of Semiconductor Devices 4. M. Shur, Physics of Semiconductor Devices, 5. J. H. Davies, The Physics of Low Dimensional Semiconductors. 		

	6. K. Y. Cheng, III–V Compound Semiconductors and Devices - An Introduction to Fundamentals, Springer.
Course Outcome	<p>CO1: The student will be equipped with the ability to model and apply compound semiconductors in electronic, optoelectronic, and photonic devices and integrated circuits.</p> <p>CO2: The student will acquire comprehension of the properties, preparation, and processing of compound semiconductors.</p> <p>CO3: The student will be able apply the knowledge of heterojunctions and quantum structures for practical work.</p> <p>CO4: The student will have ability to independently carry out research/investigation, design and development in the area of compound semiconductors.</p>

Photonics Technology			
Prerequisite: 1. Basics of electromagnetic theory 2. Wave optics 3. Basic quantum mechanics and semiconductor physics	L	T	P
Type: Program Elective	3	0	0
Course Description: This course introduces the fundamentals of photonics, including light-matter interaction and photonic devices. This will explore the principles and applications of lasers, optical fibers, and photonic integrated circuits. Discuss advanced photonic technologies and their applications in communications, sensing, and quantum systems.			
Course Content			
Unit 1 (5L)	Fundamentals of Photonics: Introduction to Photonics, Overview of photonics and its importance in modern technology. Nature of Light, Wave-particle duality, electromagnetic spectrum, and photon energy. Basics of Wave Optics Reflection, refraction, interference, and diffraction. Polarization of Light Types of polarization, birefringence, and applications. Light-Matter Interaction Absorption, emission, scattering, and nonlinear optical effects.		
Unit 2 (5L)	Optical Waveguides and Fibers: Introduction to Optical Waveguides, Slab waveguides, modes, and confinement of light. Optical Fibers: Types and Properties, Single-mode, multi-mode, graded-index, and step-index fibers. Signal Propagation in Optical Fibers, Attenuation, dispersion, and polarization effects. Fiber Fabrication and Testing, Techniques for manufacturing and characterizing optical fibers.		
Unit 3 (5L)	Lasers and Light Sources: Basics of Laser Operation: Stimulated emission, population inversion, and optical cavities. Types of Lasers: Gas, solid-state, semiconductor, and fiber lasers. Laser Characteristics and Applications: Coherence, monochromaticity, power, and uses in various domains. Nonlinear Optical Effects in Lasers: Harmonic generation, self-focusing, and Raman scattering. LEDs and Other Light Sources: Principles of operation, materials, and applications.		
Unit 4 (4L)	Photonic Devices and Components: Photodetectors and Photodiodes: Principles, types, and performance metrics. Electro-Optic and Acousto-Optic Modulators: Modulation techniques for controlling light properties. Optical Amplifiers: Erbium-doped fiber amplifiers (EDFAs) and semiconductor		

	optical amplifiers. Micro-Optomechanical Systems (MOEMS): Integration of photonics with mechanical components. Photonic Integrated Circuits (PICs) Design, fabrication, and applications in communication systems.
Unit 5 (8L)	Photonic Technologies: Silicon Photonics Integration of photonics with CMOS technologies. Plasmonics: Surface plasmon resonance, waveguides, and sensors. Quantum Photonics: Entangled photons, single-photon sources, and quantum cryptography. Photonic Crystals: Bandgap engineering, waveguiding, and filters. Terahertz Photonics Generation, detection, and applications in imaging and spectroscopy.
Unit 6 (8L)	Applications of Photonics: Photonics in Healthcare: Optical coherence tomography, biosensing, and laser surgery. Photonics in Sensing: Environmental, structural, and industrial sensors. Photonics in Renewable Energy: Solar cells, light management, and photovoltaics. Photonics for Security and Defense: LIDAR, laser-guided weapons, and secure communications.
References	1. "Photonics: Optical Electronics in Modern Communications" by Amnon Yariv and Pochi Yeh, Oxford University Press, 2007 2. "Fundamentals of Photonics" by Bahaa E. A. Saleh and Malvin Carl Teich, John Wiley & Sons, Inc. DOI:10.1002/0471213748
Course Outcome	<ol style="list-style-type: none"> 1. Develop a strong foundation in photonic principles and devices. 2. Gain insights into designing and analyzing photonic systems. 3. Understand applications of photonics in industries such as telecommunications, healthcare, and defense. 4. Be equipped to pursue advanced research or careers in photonic technologies.

Electrochemical Processes in Semiconductors

Prerequisite: 1. Basic knowledge in Semiconductor Physics or Materials Science 2. Introductory courses in Electrochemistry are beneficial	L	T	P
Type: Program elective	3	0	0
Credit: 03			
<p>Course Description: This course focuses on the electrochemical processes that play a vital role in the fabrication, modification, and functionality of semiconductor devices. Students will explore the principles of semiconductor electrochemistry, including material processing, interface reactions, and electrochemical techniques essential in device fabrication. Applications in energy storage, sensors, and semiconductor devices are emphasized, providing students with knowledge relevant to both research and industry.</p>			
Course Content			
Unit 1 (3L)	<p>Fundamentals of Electrochemistry in Semiconductors: Basic principles of electrochemistry relevant to semiconductors, Redox reactions, Nernst equation, and electrode potentials, Electrochemical cell setup and potential distributions in semiconductor materials</p>		
Unit 2 (9L)	<p>Semiconductor/Electrolyte Interfaces: Formation and characteristics of the semiconductor/electrolyte interface, Space charge layer, Helmholtz layer, and electric double layer, Charge transfer kinetics and their impact on device performance</p>		
Unit 3 (8L)	<p>Electrochemical Deposition and Etching Techniques: Principles of electrochemical deposition and its applications in microelectronics, Electrochemical etching processes for device fabrication, Control of deposition and etching parameters for thin films and interconnects in semiconductor devices</p>		
Unit 4 (7L)	<p>Photoelectrochemical Processes in Semiconductor Devices: Fundamentals of photoelectrochemistry and photogenerated charge carriers, Semiconductor materials for solar water splitting and photodetectors, Applications in photovoltaic cells, water-splitting, and energy harvesting</p>		

Unit 5 (7L)	Electrochemical Energy Storage in Semiconductor Materials: Role of semiconductors in lithium-ion and other advanced batteries, Electrochemical processes for energy storage in semiconductor-based materials, Key performance metrics: capacity, rate capability, cycling stability
Unit 6 (5L)	Electrochemical Sensing and Semiconductor Sensors: Semiconductor-based electrochemical sensors: principles and applications, Electrochemical sensing mechanisms, sensitivity, and selectivity, Case studies: gas sensors, biosensors, and environmental monitoring applications, Cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS), Mott-Schottky analysis for semiconductor doping profile characterization, Advanced techniques such as scanning electrochemical microscopy (SECM) and in-situ monitoring of device processes, Charge carrier concentration using CV curves and electrochemical etching.
References	<ol style="list-style-type: none"> 1. "Electrochemical Methods: Fundamentals and Applications" by Allen J. Bard and Larry R. Faulkner 2. "Semiconductor Electrochemistry" by Rudolf Memming 3. "Electrochemistry of Silicon and its Oxide" by Xiaoge Gregory Zhang
Course Outcomes	<ol style="list-style-type: none"> 1. Understand the fundamental electrochemical properties of semiconductors. 2. Learn how electrochemical processes are applied in semiconductor fabrication. 3. Analyze the behavior of semiconductor/electrolyte interfaces. 4. Gain knowledge in the application of electrochemical techniques for characterization and device optimization. 5. Investigate real-world applications of electrochemical processes in semiconductor-based devices.