https://jmi.ac.in

Centre for Nanoscience and Nanotechnology
Jamia Millia Islamia, New Delhi-110025

M. Tech. (Materials Science and Technology)

Specializations: (A) Semiconductor Technology, (B) Energy Materials

Duration of course: 2 Years (4 Semesters)
No of Credits: 80
Total Intake= 20
Mode= Regular Course
Eligibility for admission in M. Tech. Material Science

(i) **B.Tech.** in Electrical, Electronics and Communication, Mechanical, Computer Science and allied Engineering subjects
(ii) **B.Sc. Four-year** degree in Physics, Chemistry, Material Science and allied subjects
(iii) **M.Sc.** in Physics, Chemistry, Material Science and allied subjects

SEMESTER I — COMMON CORE

COURSE CODE	COURSE TITLE	L	P	T	CREDITS
MS1-01	Fundamentals of Material Science	4	0	0	4
MS1-02	Thermodynamics and Phase Transitions	4	0	0	4
MS1-03	Materials Processing	4	0	0	4
MS1-04	Advanced Materials Characterization Techniques	4	0	0	4
MSL-01	Lab I	0	3	0	3
MSE1	Elective-1: Nanofabrication and Cleanroom Processes	2	1	0	3
TOTAL CREDITS					**22**

SEMESTER II

COURSE CODE	COURSE TITLE	L	P	T	CREDITS
MS2-01	Quantum Theory of Matter	3	0	0	3
MS2-02	Computational Material Science	3	0	0	3

All students must choose ONE specialization (A or B) which includes:

(I) 2 Core Courses of that specialization

(II) 1 Elective course

A. SEMICONDUCTOR TECHNOLOGY (Core Courses + Elective)

COURSE CODE	COURSE TITLE	L	P	T	CREDITS
MS2-01	Micro and Nano Fabrication Technology	4	0	0	4
MS2-02	Semiconductor Materials and Technology	4	0	0	4
MSLS-02	Lab II	0	3	0	3
MSE2	Elective 3: Advanced Semiconductor Devices	3	0	0	3

B. ENERGY MATERIALS (Core Courses + Elective)

COURSE CODE	COURSE TITLE	L	P	T	CREDITS
MS2-03	Materials for Electrochemical Energy Storage	4	0	0	4
MS2-04	Solar Energy Materials	4	0	0	4
MSLE-02	Lab II	0	3	0	3
MSE2	Elective 3: Hydrogen and Sustainable Energy Materials	3	0	0	3
TOTAL CREDITS					**22**

SEMESTER III

COURSE CODE	COURSE TITLE	L	P	T	Credits
MS3-01	Research Methodology	3	0	0	3
MS3-02	Indian Knowledge System (IKS)	3	0	0	3
P-01	Minor Project	0	12	0	12
Total Credits					**18**

SEMESTER IV

COURSE CODE	COURSE TITLE	Credits
P-02	M. Tech. Dissertation / Thesis (Major Project)	18
	Total Credits	**18**

SEMSETERS	CREDITS
SEMESTER I	22
SEMESTER II	22
SEMESTER III	18
SEMSTER IV	18
TOTAL CREDITS	**80**

Detailed Course Structure

M.Tech. (Materials Science and Technology)

Centre for Nanoscience and Nanotechnology
Jamia Millia Islamia
New Delhi

SEMESTER I

Fundamentals of Materials Science

Credits: 4, **Lectures:** 40, **Units:** 4

Unit 1: Structure of Materials and Defects
Classification of materials; structure of atoms; bonding in solids; unit cells; crystal systems; crystallographic directions and planes; polycrystalline materials; FCC, BCC, and HCP crystal structures; polymorphism and allotropy; point defects; line defects; grain boundaries; importance of defects and their influence on material properties.

Unit 2: Electrical Properties of Materials
Ohm's law; electrical conductivity; energy band structures in solids; electron mobility; electrical resistivity of metals; classification of semiconductors; carrier concentration; Hall effect; basic semiconductor devices; dielectric materials; ferroelectricity; piezoelectricity electrical properties of polymers.

Unit 3: Magnetic and Superconducting Materials
Classification of magnetism; magnetic domains and hysteresis; magnetic anisotropy; hard and soft magnetic materials; temperature dependence of magnetism; superparamagnetic materials; superconductors and Meissner effect; magneto-optic materials.

Unit 4: Ceramics, Polymers and Composites
Glasses and glass-ceramics; advanced ceramics and their applications; plastic deformation in ceramics and glasses; heat treatment of glasses and ceramics; hydrocarbon and polymer molecules; structure property relationships in polymers; deformation of semicrystalline polymers; glass transition; polymer-matrix composites; hybrid composites.

Text Books:

1. William D. Callister, "Materials Science and Engineering ", John India Pvt. Ltd, 2013.
2. C. Kittel, "Introduction to Solid State Physics" Wiley Eastern Ltd, 2005.
3. V. Raghavan, "Materials Science and Engineering: A First Course", Prentice Hall, 2006.
4. A.J. Dekker, "Solid State Physics", Macmillan & Co, 2000

Thermodynamics and Phase Transitions

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I **10 Lectures**

Thermodynamic systems and equilibrium, thermodynamic laws, thermodynamic properties, internal energy and enthalpy, entropy and irreversibility, thermodynamic relations, statistical thermodynamics, Boltzmann distribution, configurational entropy, order–disorder phenomena.

Unit II **10 Lectures**

Helmholtz and Gibbs free energies, chemical potential, partial molar properties, Gibbs–Duhem equation, phase equilibrium, phase stability, metastability, supercooling and superheating, surface and interface thermodynamics, thermodynamic driving forces for phase transformations.

Unit III **10 Lectures**

Ideal and non-ideal solutions, activity and activity coefficients, excess free energy, phase rule, binary and ternary phase diagrams, invariant reactions, miscibility gap, spinodal decomposition, thermodynamics of solidification, Introduction to CALPHAD methodology and computational thermodynamics.

Unit IV **10 Lectures**

Diffusion and interdiffusion, Kirkendall effect, first- and second-order phase transitions, nucleation theory, homogeneous and heterogeneous nucleation, growth mechanisms, diffusional and martensitic transformations, JMAK theory, TTT and CCT diagrams, precipitation and coarsening, microstructural evolution, phase transformation kinetics.

Text Books

1. Introduction to the Thermodynamics of Materials, David R. Gaskell and David E. Laughlin, 6th Edition, CRC Press
2. Phase Transformations in Metals and Alloys, David A. Porter, Kenneth E. Easterling and Mohamed Y. Sherif, 4th Edition, CRC Press
3. Materials Thermodynamics, Y. Austin Chang and W. Alan Oates, 1st Edition, Wiley
4.

Reference Books

1. Phase Equilibria, Phase Diagrams and Phase Transformations: Their Thermodynamic Basis, Mats Hillert, 2nd Edition, Cambridge University Press
2. Theory of Transformations in Metals and Alloys, John W. Christian, 3rd Edition, Pergamon (Elsevier)
3. Thermodynamics in Materials Science, Robert DeHoff, 2nd Edition, CRC Press

Materials Processing

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Fundamentals of Material Processing **8 Lectures**

Overview of material processing routes for semiconductors and energy materials, Crystal structures and defects relevant to functional materials (point, line, planar defects; their role in electronic and ionic transport), Diffusion and mass transport mechanisms in solids, thin films, and nanostructures, Nucleation and growth mechanisms in bulk and thin-film processing, Stress, strain, and defect evolution during processing (thermal stress, lattice mismatch, residual stress in thin films)

Unit II: Bulk and Powder Processing Techniques **10 Lectures**

Powder synthesis methods: solid-state reaction, sol–gel, co-precipitation, hydrothermal, Powder compaction: uniaxial pressing, isostatic pressing, Sintering mechanisms: solid-state, liquid-phase, spark plasma sintering, Melt processing: Bridgman, Czochralski crystal growth, Additive manufacturing of functional materials, Case studies: Si wafers, thin film electrolytes, cathode materials/anode

Unit III: Thin Film and Nanomaterial Processing **12 Lectures**

Physical Vapor Deposition (PVD): evaporation, sputtering, Chemical Vapor Deposition (CVD): LPCVD, PECVD, ALD, Molecular Beam Epitaxy (MBE), Solution-based deposition: spin coating, dip coating, spray pyrolysis, Thin films for microelectronics, solar cells, and sensors.

Unit IV: Surface Engineering **10 Lectures**

Surface structure, surface energy, and interface phenomena, Surface treatment methods: Ion implantation, Plasma treatment, Laser surface processing, Chemical and electrochemical etching, Surface coatings: hard coatings, functional and protective coatings, Diffusion-based surface science: carbonization nitriding, oxidation, role of surface engineering in reliability and durability

 Recommended References

- Callister, W. D., & Rethwisch, D. G. (2018). Materials Science and Engineering: An Introduction. John Wiley & Sons.
- German, R. M. (2014). Sintering: From Empirical Observations to Scientific Principles. Butterworth-Heinemann.
- Smith, D. L. (1995). Thin-Film Deposition: Principles and Practice. McGraw-Hil

Advanced Materials Characterization Techniques

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Structural Characterization

Understanding the crystalline arrangement and phase composition of materials, X-Ray Diffraction (XRD): Principles of Bragg's Law, phase identification, crystallite size determination (Scherrer equation), and lattice parameter calculations, Selected Area Electron Diffraction (SAED): Interpretation of diffraction spots vs. rings, indexing patterns to determine crystal systems and zone axes, Raman Spectroscopy: Inelastic scattering to identify vibrational modes, Structural fingerprinting for carbon allotropes (G and D bands) and phase transitions, X-ray Photoelectron Spectroscopy (XPS): Analyzing elemental composition and chemical bonding states (oxidation states) at the surface.

Unit II: Optical Characterization

Probing interactions of materials with light to determine electronic band structures, UV-Visible Spectroscopy (UV-Vis): Absorption and reflectance measurements, Tauc plot bandgap analysis, Photoluminescence (PL): Radiative recombination processes, defects, impurities and exciton 7ehaviour in semiconductors, Ellipsometry: Measuring thin-film thickness and refractive index by analyzing changes in light polarization.

Unit III: Morphological & Topographical Characterization

Visualizing the physical shape, size, and surface roughness at the micro and nano scales, FE-SEM: High-resolution surface imaging using a cold-cathode field emission source, Energy Dispersive X-ray Analysis (EDX) for elemental mapping, Transmission Electron Microscopy (TEM): Internal structure imaging at sub-nanometer resolution. High-Resolution TEM (HRTEM) for visualizing individual atomic planes, Atomic Force Microscopy (AFM): Contact, non-contact, and tapping modes, 3D surface mapping, roughness measurement, and nanomechanical properties.

It IV: Thermal & Magnetic Characterization

Thermogravimetric Analysis (TGA): Measuring mass change vs temperature to study thermal stability, Vibrating Sample Magnetometry (VSM): Analyzing hysteresis loops to determine coercivity and saturation magnetization.

Reference Books:

1. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Author: Yang Leng, Publisher: Wiley-VCH.
2. Characterization of Materials, Editor: Elton N. Kaufmann, Publisher: John Wiley & Sons.
3. Elements of X-Ray Diffraction, Authors: B.D. Cullity and S.R. Stock.
4. Scanning Electron Microscopy and X-Ray Microanalysis, Authors: Joseph I. Goldstein et al.
5. Transmission Electron Microscopy: A Textbook for Materials Science, Authors: David B. Williams and C. Barry Carter.
6. Principles of Thermal Analysis and Calorimetry, Author: Peter J. Haine

MSL1-01 Material Science Laboratory

List of Experiments

1. To deposit a uniform thin film on glass and investigate how withdrawal speed affects film thickness by Dip Coating Technique.

2. To synthesize nanoparticles using a ball milling technique and analyze their crystal structure and crystallite size using X-ray diffraction (XRD).

3. To deposit a thin film of a selected material on a suitable substrate using a thermal evaporation technique and determine its bandgap using UV spectroscopy.

4. To deposit a PVA or PMMA or PANI thin film on a glass substrate using the spin-coating technique and determine its current–voltage (I–V) characteristics.

5. To determine the capacitance–voltage (C–V) characteristics of a semiconductor device using a C-V analyser.

6. To study photoconductivity of thin films using laser driven I-V measurement setup.

Credit Course (Elective)
MSE-01: Nanofabrication and Cleanroom Processes

Credits: 3: L-01, P-02

Module 1: Cleanroom Infrastructure, Vacuum Systems, and Patterning

- **Cleanroom Protocols & Safety Engineering**

  Theory: Classification of cleanrooms (ISO 1 to ISO 9, Federal Standard 209E), laminar airflow, HVAC systems, particle dynamics, and contamination control.

  Operational Rules: Gowning protocols, personal protective equipment (PPE), chemical handling safety (MSDS), and emergency shutdown procedures.

- **Vacuum Science & Thin Film Deposition**

  Theory: Fundamentals of vacuum (rough, high, and ultra-high vacuum), gas laws, pumps (rotary, diffusion, turbomolecular, and cryo-pumps), and vacuum gauges.

  Deposition Mechanisms: Physical Vapor Deposition (PVD: Sputtering, E-beam Evaporation) and Chemical Vapor Deposition (CVD/ALD).

- **Lithography & Pattern Transfer**

  Theory: Photolithography fundamentals (photoresists, exposure tools, masks, alignment) alongside wet chemical etching mechanics, selectivity, and isotropy.

  Wet Bench Operations: Acid/base benches, solvent cleaning (RCA cleaning protocols), safety procedures for Hydrofluoric (HF) acid, and chemical waste disposal.

Module 2: Advanced Etching and MEMS/NEMS Virtual Fabrication

- **Advanced Dry & Plasma Etching Systems**

  Theory: Plasma physics fundamentals, Reactive Ion Etching (RIE), Deep Reactive Ion Etching (DRIE), and Inductively Coupled Plasma (ICP) etching.

  Mechanisms: Physical sputtering vs. chemical reaction, anisotropy control, aspect-ratio dependent etching (ARDE), and micro-trenching phenomena.

- **MEMS/NEMS Architectures & Virtual IC Fabrication (VIT)**

  Theory: Introduction to MEMS/NEMS device architectures (cantilevers, sensors) and an overview of the Virtual IC Technology (VIT) framework.

  Design & System Setup: Principles of installing, configuring, and deploying VIT software environments across a networked computer lab for multi-user simulation.

Module 3: Virtual Practical Lab Framework using SEMulator3D

S.No.	Assignment
1.	Install SEMulator3D and run an example
2.	Create a layout of NMOS, PMOS and inverter in SEMulator3D
3.	LOCOS isolation verses Shallow Trench Isolation (STI)

4. Gate-first verses Gate-last
5. Spacer and multiple patterning
6. Replacement metal gate
7. Implantation & Silicidation
8. Damascene Process
9. Dual Damascene Process

Reference Books:

1. Jaeger, R. C., **Introduction to Microelectronic Fabrication**, 2nd Edition, Pearson, 2001.
2. Madou, M. J., **Fundamentals of Microfabrication and Nanotechnology**, 3rd Edition, CRC Press, 2011.
3. Franssila, S., **Introduction to Microfabrication**, 2nd Edition, Wiley, 2010.
4. Williams, K. R., Gupta, K. and Wasilik, M., **Etch Rates for Micromachining Processing**, Journal of Microelectromechanical Systems, 2003. *(Useful technical reference for wet/dry etching processes.)*

SEMESTER II

Quantum Theory of Matter

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Foundations of Quantum Mechanics (10 Lectures)
Wave–particle duality, de Broglie hypothesis, uncertainty principle, wave function and probability interpretation, Schrödinger equation, operators and observables, eigenvalues and eigenfunctions, particle in one- and three-dimensional potential wells, quantum tunneling, harmonic oscillator.

Unit II: Quantum States and Atomic Structure (10 Lectures)
Angular momentum, spin angular momentum, hydrogen atom, quantum numbers, many-electron atoms, Pauli exclusion principle, Hund's rules, atomic spectra, approximation methods, electronic structure of atoms.

Unit III: Quantum Statistics and Many-Particle Systems (10 Lectures)
Identical particles, Bose–Einstein statistics, Fermi–Dirac statistics, Maxwell–Boltzmann distribution, density of states, free electron gas, Fermi energy, phonons, blackbody radiation, quantum statistical description of matter.

Unit IV: Quantum Theory of Solids and Materials (10 Lectures)
Periodic potentials, Bloch theorem, energy bands in solids, metals, semiconductors and insulators, effective mass, holes and charge carriers, quantum confinement, low-dimensional systems, quantum phenomena in nanomaterials, quantum materials and emerging applications.

Reference Books

1. *Introduction to Quantum Mechanics* — David J. Griffiths & Darrell F. Schroeter, 3rd Edition, Cambridge University Press.
2. *Quantum Theory of Materials* — Efthimios Kaxiras & John D. Joannopoulos, 1st Edition, Cambridge University Press.
3. *Principles of Quantum Mechanics* — R. Shankar, 2nd Edition, Springer.
4. *Quantum Theory of Solids*— Charles Kittel, 8th Edition, Wiley.
5. *Modern Quantum Mechanics* — J. J. Sakurai & Jim Napolitano, 3rd Edition, Cambridge University Press.

Computational Material Science

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Foundations of Computational Materials Science **10 Lectures**

Computational materials science paradigm, length and time scales in materials modeling, multiscale modeling, numerical methods for materials simulations, error analysis and convergence, matrix methods and eigenvalue problems, differential equations in materials science, finite difference and finite element methods, high-performance and parallel computing, scientific computing environments.

Unit II: Electronic Structure Methods **10 Lectures**

Quantum mechanical foundations, many-electron problem, Born–Oppenheimer approximation, Hartree and Hartree–Fock methods, density functional theory, Hohenberg–Kohn theorems, Kohn–Sham formalism, exchange–correlation functionals, pseudopotentials, basis sets, Brillouin zone sampling, total energy calculations, geometry optimization, electronic structure and bonding analysis.

Unit III: Atomistic Simulations and Statistical Mechanics **10 Lectures**

Interatomic potentials, molecular dynamics, numerical integration algorithms, statistical ensembles, temperature and pressure control methods, structural, thermodynamic and transport properties, Monte Carlo methods, statistical mechanics, diffusion, defects, interfaces, phase stability, nanostructures and atomistic modeling of materials.

Unit IV: Mesoscale Modeling and Materials Design **10 Lectures**

Phase-field methods, free-energy functionals, microstructure evolution, phase transformations, nucleation and growth, spinodal decomposition, coarsening phenomena, kinetic Monte Carlo methods, dislocation dynamics, grain growth, CALPHAD methodology, thermodynamic database integration, multiscale modeling, computational materials design, applications in structural, electronic, functional and energy materials.

Text Books

1. Computational Materials Science: An Introduction, Author: Richard LeSar Edition: 2nd Edition, Publisher: Cambridge University Press
2. Computer Simulation of Liquids, Authors: Michael P. Allen and Dominic J. Tildesley Edition: 2nd Edition, Publisher: Oxford University Press
3. Electronic Structure: Basic Theory and Practical Methods, Author: Richard M. Martin Edition: 1st Edition, Publisher: Cambridge University Press

Reference Books

1. Density Functional Theory: A Practical Introduction, Author: David S. Sholl and Janice A. Steckel, Edition: 2nd Edition, Publisher: Wiley
2. Understanding Molecular Simulation: From Algorithms to Applications, Author: Daan Frenkel and Berend Smit, Edition: 2nd Edition, Publisher: Academic Press (Elsevier)
3. Computational Thermodynamics: The CALPHAD Method, Authors: Hans Lukas, Suzana

All students must choose ONE specialization (A or B) which includes:

(I) 2 Core Courses of that specialization (1I) 1 Elective course

Specialization A

Micro and Nano Fabrication Technology

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Fundamentals of Microfabrication

Cleanroom fundamentals, contamination control, Crystal growth and wafering, Semiconductor materials and wafer preparation, Oxidation, Thin film deposition techniques, Physical vapor deposition, Chemical vapor deposition, atomic layer deposition, Epitaxy.

Unit II: Etching and Pattern Transfer Techniques

Wet chemical etching, plasma etching, reactive ion etching, deep reactive ion etching (DRIE), Ion beam etching and milling, Lift-off process, Pattern transfer, Surface and bulk micromachining, lithography fundamentals, Electron beam lithography (EBL), Focused ion beam (FIB), Nanoimprint lithography (NIL).

Unit III: Doping, Metallization and Process Integration

Diffusion and ion implantation, Annealing processes and defect engineering, Metallization, Ohmic and Schottky contacts, Interconnects and barrier layers, Dielectrics and passivation layers, Process integration for CMOS and advanced devices, Yield, Process control and reliability issues.

Unit IV: Advanced Fabrication Technologies

Nanofabrication for MEMS and NEMS, 2D materials fabrication and transfer techniques, Flexible and wearable device fabrication, 3D micro/nano printing, quantum device fabrication, Heterogeneous integration and packaging, Lab-on-chip and microfluidic fabrication, AI-assisted fabrication,

Reference Books:

- S. M. Sze and Kwok K. Ng, *Physics of Semiconductor Devices*, (Wiley)
- Marc Madou, *Fundamentals of Microfabrication and Nanotechnology*, (CRC Press)

Semiconductor Materials and Technology

Credits: 4, **Lectures:** 40, **Units:** 4

UNIT I: Semiconductor Materials and Crystal Growth
Classification and properties of semiconductor materials, elemental and compound semiconductors, crystal structure and defects, silicon and germanium, III–V semiconductors, Czochralski process, Float-zone method, Bridgman technique, Epitaxial growth, Wafer Processing.

UNIT II: Semiconductor Processing and Characterization
Thermal oxidation, diffusion, ion implantation, rapid thermal processing and annealing techniques, resistivity measurement, Four probe method, Hall effect measurement, carrier concentration, Electrical characterization using I-V and C-V measurements, defect characterisation using Deep Level Transient Spectroscopy (DLTS).

UNIT III: Advanced Semiconductor Materials
Wide Bandgap Semiconductors: Silicon Carbide (SiC), Gallium Nitride (GaN), gallium oxide (Ga_2O_3) and Diamond, Two-Dimensional Semiconductor materials: Graphene, Transition Metal Dichalcogenides (MoS_2, WS_2), Nanostructured materials: Carbon nanotubes, Quantum dots and Nanowires.

UNIT IV: Semiconductor Packaging and Reliability
Wafer bonding, Chip packaging, Thermal management, Failure mechanisms, Reliability testing, process monitoring and quality control, semiconductor manufacturing flow, semiconductor supply chain and ecosystem, semiconductor industry in India and India Semiconductor Mission.

Reference Books:

1. S. M. Sze and Kwok K. Ng, Physics of Semiconductor Devices, Wiley.
2. Ben G. Streetman and Sanjay Banerjee, Solid State Electronic Devices, Pearson.
3. S. O. Kasap, Principles of Electronic Materials and Devices, McGraw-Hill.

Elective

Advanced Semiconductor Devices

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Semiconductor Device Physics (10 Lectures)

Energy band theory, intrinsic and extrinsic semiconductors, Charge carriers: electrons and holes, Carrier transport: drift, diffusion, mobility and conductivity, Generation and recombination of charge carriers, PN junction, heterojunction, Metal-semiconductor contacts and MOS structure.

Unit II: Advance Transistor Technologies (10 Lectures)

MOSFET operation and scaling, short channel effects, high-k gate technology, FinFETs and gate-all-around FETs, silicon-on-insulator (SOI) devices, tunnel FETs, heterojunction bipolar transistors (HBTs), high-electron-mobility transistors (HEMTs).

Unit III: Emerging Semiconductor Devices (10 Lectures)

Nanoscale semiconductor devices, quantum confinement and transport, semiconductor nanowire devices, quantum-dot devices, 2D semiconductor devices and FETs, spintronic devices, memristive and resistive-switching devices, neuromorphic applications and emerging device concepts.

Unit IV: Semiconductor Devices for Advanced Applications (10 Lectures)

Light Emitting Diodes (LEDs), Photodiodes and solar cells, Semiconductor sensors (gas and biosensors), Power semiconductor devices (SiC and GaN), Flexible electronics, Quantum devices and recent trends in semiconductor device technology.

Reference Books:

1. Ben G. Streetman and Sanjay Banerjee, Solid State Electronic Devices, 7th Edition, Pearson.
2. Donald A. Neamen, Semiconductor Physics and Devices, McGraw-Hill.
3. S. M. Sze and Kwok K. Ng, Physics of Semiconductor Devices, Wiley.
4. S. O. Kasap, Principles of Electronic Materials and Devices, McGraw-Hill.

SPECIALIZATION B

SEMESTER II

Materials for Electrochemical Energy Storage

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Fundamentals of Electrochemical Energy Storage (10 Hours)

Basic Electrochemistry: Thermodynamics of electrochemical cells and electrode reactions, Electrode kinetics, Mass transport: diffusion, migration, convection in electrolytes, Cyclic voltammetry and electrochemical impedance spectroscopy principles

Energy Storage Fundamentals: Energy density vs. power density: Ragone plots, Capacity, voltage, efficiency, and cycle life metrics, Overview of battery types: primary, secondary, Supercapacitors: EDLC vs. pseudocapacitors, Fuel cells: principles and classification

Unit II: Battery Materials and Technologies (10 Hours)

Lithium-Ion Batteries: Cathode materials & Anode materials, Electrolytes: liquid, gel, solid polymer electrolytes, Beyond Lithium-Ion Systems: Sodium-ion batteries: materials challenges and opportunities, Aqueous Batteries: Zinc-based batteries, Sodium-ion batteries: materials science perspective

Unit III: Supercapacitor Materials and Design (10 Hours)

Electric Double Layer Capacitors (EDLCs) and pseudocapacitors, Carbon materials: graphene, carbon nanotubes, Transition metal oxides, Conducting polymers, Hybrid and asymmetric supercapacitors, Solid-state and flexible supercapacitors, Electrode design and performance parameters.

Unit IV: Fuel Cell Materials and Emerging Energy Storage Technologies (10 Hours)

Fuel Cells: Principles and classification of fuel cells, Proton Exchange Membrane Fuel Cells (PEMFC), Solid Oxide Fuel Cells (SOFC): durability and degradation mechanisms.

Emerging Energy Storage Materials, Metal-air batteries (overview), Hydrogen storage materials, Recent advances in nanostructured materials for energy storage, Recycling and sustainability of battery materials

Reference Books

1. Reddy, T. B. (Ed.). (2010). Linden's handbook of batteries. McGraw-Hill Professional.
2. Conway, B. E. (2013). Electrochemical supercapacitors: scientific fundamentals and technological applications. Springer.
3. O'hayre, R., Cha, S. W., Colella, W., & Prinz, F. B. (2016). Fuel cell fundamentals. John Wiley & Sons.

Solar Energy Materials

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Fundamentals of Solar Energy Conversion **(10 Lectures)**
Solar spectrum and solar radiation, light–matter interaction, semiconductor fundamentals, optical absorption, charge carrier generation and recombination, charge transport, photovoltaic effect, efficiency limits, loss mechanisms, structure–property relationships in solar energy materials.

Unit II: Photovoltaic Materials **(10 Lectures)**
Crystalline silicon, thin-film photovoltaic materials, III–V compound semiconductors, organic photovoltaic materials, dye-sensitized solar cells, perovskite solar cells, tandem solar cells, quantum dot photovoltaics, defects, interfaces, degradation and stability.

Unit III: Solar Fuels and Photoelectrochemical Materials **(10 Lectures)**
Photoelectrochemical principles, semiconductor photoelectrodes, photocatalytic materials, water splitting, hydrogen generation, CO_2 photoreduction, band-edge engineering, cocatalysts, heterostructures, stability of photoelectrochemical materials.

Unit IV: Advanced Solar Energy Materials **(10 Lectures)**
Nanostructured solar materials, plasmonic materials, photonic structures, two-dimensional materials, hybrid photovoltaic systems, multifunctional solar materials, flexible solar materials, emerging trends in solar energy materials.

Text Books

1. Physics of Solar Cells: From Basic Principles to Advanced Concepts — Peter Würfel, 2nd Edition, Wiley-VCH.
2. Solar Energy: The Physics and Engineering of Photovoltaic Conversion, Technologies and Systems — Olindo Isabella, Arno Smets, Klaus Jäger and Miro Zeman, 1st Edition, Cambridge University Press.
3. Photoelectrochemical Hydrogen Production — Roel van de Krol and Michael Grätzel (Editors), 1st Edition, Springer.

Reference Books

1. Perovskite Photovoltaics: Basic to Advanced Concepts and Implementation — Aparna Thankappan (Ed.), Springer.
2. Nanostructured Materials for Solar Energy Conversion — Tetsuo Soga (Ed.), Elsevier.
3. Advanced Renewable Energy Systems — Fang Lin Luo and Hong Ye, CRC Press.

Elective
Hydrogen and Sustainable Energy Materials

Credits: 4, **Lectures:** 40, **Units:** 4

Unit I: Hydrogen Energy Materials **(10 Lectures)**

Hydrogen economy, hydrogen production pathways, hydrogen storage materials, hydrogen purification membranes, materials selection, hydrogen embrittlement, safety considerations, structure–property relationships.

Unit II: Electrochemical Energy Conversion Materials **(10 Lectures)**

Fuel cell materials, proton exchange membranes, solid oxide fuel cells, electrolyzer materials, electrocatalysts, oxygen reduction, oxygen evolution and hydrogen evolution reactions, catalyst degradation, interface engineering.

Unit III: Carbon Capture and Carbon Utilization Materials **(10 Lectures)**

Carbon capture technologies, adsorption materials, porous materials, zeolites, activated carbons, metal–organic frameworks, covalent organic frameworks, membranes for carbon separation, CO_2 utilization, CO_2 reduction catalysts.

Unit IV: Waste-to-Energy and Emerging Sustainable Energy Materials **(10 Lectures)**

Biomass conversion materials, thermochemical conversion, waste-to-energy technologies, photocatalytic environmental remediation, circular carbon technologies, artificial photosynthesis, multifunctional catalytic materials, emerging sustainable energy materials.

Text Books

1. Fuel Cell Fundamentals — Ryan P. O'Hayre, Suk-Won Cha, Whitney Colella and Fritz B. Prinz, 4th Edition, Wiley.
2. Photoelectrochemical Hydrogen Production — Roel van de Krol and Michael Grätzel (Editors), 1st Edition, Springer.
3. Hydrogen Storage Materials: The Characterisation of Their Storage Properties — Darren P. Broom, 2nd Edition, Springer.

Reference Books

1. Carbon Capture — Jennifer Wilcox, Springer.
2. Advanced Catalytic Materials — Inamuddin, Abdullah M. Asiri and Eric Lichtfouse (Editors), Springer.
3. Hydrogen and Fuel Cells: Emerging Technologies and Applications — Bent Sørensen, 2nd Edition, Academic Press.

SEMESTER III

Research Methodology

Credits: 3, **Lectures:** 30, **Units:** 3

UNIT I: Introduction to Research

The concept of research, characteristics of good research, Application of Research, Meaning and sources of Research problem, characteristics of good Research problem, Research process, outcomes, application of Research, Meaning and types of Research hypothesis, Importance of Review of Literature, Organizing the Review of Literature.

UNIT II: Types of Research

Types of research: pure (basic, fundamental) and applied research, qualitative and quantitative. Research Design : Meaning, need, types of research design – Exploratory, Descriptive, Casual research Design, Components of research design, and Features of good Research design, Experiments, surveys and case study Research design.

UNIT III: Sampling, Data Collection and Research Report:

Types and sources of data – Primary and secondary, Methods of collecting data, Concept of sampling and sampling methods – sampling frame, sample, characteristics of good sample, Research Report : Research report and its structure, journal articles – Components of journal article, Thesis and dissertations, components of thesis and dissertations. Referencing styles and bibliography.

Reference Books:

1. Donald Cooper and PS Schindler (2009) Business Research Methods, 9th edition, Tata McGraw Hill.
2. Kothari, C. R. Research Methodology: Methods and Techniques. 2nd ed., New Age International Publishers, 2004.
3. Kerlinger, F.N. (1986) Foundations of Behavioral Research. 3rd Edition, Holt, Rinehart and Winston, New York.

Indian Knowledge System (IKS)

Credits: 3, **Lectures:** 30, **Units:** 3

Unit I: Introduction to IKS

Caturdaśa Vidyāsthānam, 64 Kalas, Shilpa Śāstra, Four Vedas, Vedāṅga,, Indian Philosophical Systems, Vedic Schools of Philosophy (Sāṃkhya and Yoga, Nyaya and Vaiśeṣika, Pūrva Mīmāṃsā and Vedānta), Non-Vedic schools of Philosophical Systems (Cārvāka, Buddhist, Jain), Puranas (Maha-puranas, Upa-Puranas and Sthala-Puranas), Niti Sastras, Subhasitas.

Unit II: Indian Traditional Knowledge; Science and Practices

Introduction to the Science and way of doing science and research in India, Ancient Science in Intra & Inter Culture Dialogue & coevolution. Traditional agricultural practices, Traditional water-harvesting practices, Traditional Livestock and veterinary Sciences Traditional Houses & villages, Traditional Forecasting, Traditional Ayurveda & plant based medicine, Traditional writing Technology

Unit III: Physics in India

Vaisheshika darshan, atomic theory & law of motion, theory of panchmahabhoota, Brihath Shathaka (divisions of the time, unit of distance), bhaskarachaya (theory of gravity, surya siddhanta & sidhanta shriomani), Lilavati (gurutvakashan Shakti).
Indian S & T Heritage ,sixty-four art forms and occupational skills (64 Kalas) Metals and Metalworking technology (Copper, Gold, Zinc, Mercury, Lead and Silver), Iron & Steel, Dyes and Painting Technology).

Reference Books:

1. Introduction to Indian Knowledge System: Concepts and Applications, Authors: B. Mahadevan, Vinayak Rajat Bhat, Nagendra Pavana R.N., Publisher: PHI Learning Pvt. Ltd.
2. India's Rebellious Technology & Heritage in Metallurgy / Ancient Mining and Metallurgy in India Authors: D. P. Agrawal / A. K. Biswas, Publisher: Munshiram Manoharlal Publishers

<u>P-01: Minor Project</u>

M.Tech students must take a substantial research type project during the study period. Projects are generally based in one of the nanoscience/technology research groups and involve a structured experimental investigation of a research or development nature.

SEMESTER IV

P-02: Project Presentation Examination (Major Project)

M.Tech students must take a substantial research type project during the study period. Projects are generally based in one of the Materials Science/technology research groups and involve a structured experimental investigation of a research or development nature.