MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST801

Course Name : Biomaterials

Credits : 3 L - 3 T - 0 P - 0
Course Type : Program elective
Prerequisites : None

Course Contents

Unit I: Introduction to biological and bio inspired materials, biomimetic and bioinspired engineering, inspiration from nature, bio-inspired designs, biological engineering principles, basic building blocks found in biological materials.

Unit II: Concept of Biocompatibility and host response, cell-material interaction, tissue-material interaction, protein adsorption on biomaterials, Introduction to nanotechnology, surface engineering, bio-inspired nanostructures.

Unit III: Bio-inspired nanoparticles, polymer-reinforced and ceramic-toughened composites, lightweight biological and bio-inspired materials, bio-functional interfaces, components of a bio-functional interface and fabrication, biocompatibility vs. bio-functionality, bio-inspired functional interfaces, characterization of bio-functional interfaces.

Unit IV: Introduction to tissue engineering, bio-inspired scaffolds for tissue engineering, self-healing and adaptive materials, bio-sensing, nature-inspired sensing, smart targeted drug delivery, examples of bio-inspired lab on chip devices and organs on chips.

Recommended Readings

1. Text book-
   (i) Biomaterials Science and Tissue Engineering: Principles and Methods; Bikramjit Basu.
   (ii) Bioinspired approaches for human-centric technologies; Roberto Cingolani.
   (iii) Biological materials science; M. A. Meyers and P-Y. Chen.

2. Reference book-
   (i) Biomimetics, biologically inspired technologies; Yoseph Bar-Cohen.
   (ii) Materials design inspired by nature; P. Fratzl, J. W. C. Dunlop and R. Weinkamer

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST802

Course Name : Ceramic Materials and Properties

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Basic knowledge of thermodynamics, Elementary crystallography and crystal structure, Mechanical behavior of materials

Course Contents

Unit I: Review of bonding types in ceramics – calculation of percentage ionic character. Types of ceramics, Ceramic crystal structures: Sodium chloride, cesium chloride, alumina, spinel and fluorite structures - examples. Co-ordination number and ionic radius ratio - Pauling"s Rules, Packing Fraction, critical radius ratio and density. Atomic defects including intrinsic and extrinsic point defects, Kroger-Vink notation.

Unit II: Microstructure development in equilibrium and nonequilibrium phases, Solid- state sintering, densification vs. coarsening processes, Grain boundary mobility, Porosity evolution (stability/entrapment), Liquid phase sintering, constrained sintering, Ceramic coatings and their deposition.

Unit III: Preparation of Alumina, Zirconia, Silicon carbide, Silicon Nitrides, Boron Nitride, Brief description of slip and slurry casting - applications. Powder processing equipment and process details of hot pressing, Hot Isostatic Pressing and Cold Isostatic Pressing., Shock wave compaction, reaction sintering, cermets.

Unit IV: Types of glasses - structure, properties and applications of various types of glasses. Silicate Glass ceramics- heat flow and precipitation from glasses – growth controlled by diffusion of solutes – crystalline glasses – enamels – photosensitive and photochromic glasses; Blowing, pressing, drawing, rolling and casting - Pilkington process for float glass. Property Evaluation: Rupture strength; fracture Toughness, Elastic Constants, Hardness, Creep, Thermal Property Coefficient of thermal expansion, Electronic Property, Measurement of electro-optic properties Weibull Statistics of Strength Data for Fine Ceramics.

Recommended Readings

1. Text book-
   (i) Introduction to Ceramics; W.D. Kingery, H.K. Bowen, D.R. Ulhmann.
   (ii) Introduction to Ceramics; M. N. Rahman.
   (iii) Advanced Structural Ceramics; B. Basu, K. Balani.

2. Reference book-
   (i) Introduction to Ceramics; W. D. Kingry (John-Wiley).

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST803

Course Name : Colloids and Surfaces

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program Elective

Prerequisites : Basic knowledge of Chemistry and Physics

Course Contents

Unit I: Introduction to Colloids and surfaces, Types of Colloids, Source, Synthesis and Characterization of colloids, Importance of surfaces.

Unit II: Interaction between colloidal particles, Brownian force and its application in measurement of diffusivity and size, Van der Waal's force and its molecular origin, Effect of medium on Van der Waal's interactions, Electrostatic forces and electric double layer; DLVO theory, Hamaker constant, Boltzmann distribution, Debye length, specific ion adsorption, Stern layer, Electrostatic, steric and electrosteric stabilization, zeta potential, surface tension, wetting and spreading, Young's equation, contact angle.

Unit III: Introduction to Surfactants, Types and uses of surfactants, Adsorption of surfactants at interfaces, Micelles and Micellization, Critical Micellar concentration (CMC) and factors affecting CMC, Structure of micelles, Catalysis by Micelles, Emulsions and Microemulsions, Emulsion stability, Phase inversion temperature of emulsions, Applications of Microemulsions. Preparation, Characterization and Applications of Foams. Stability of foams, Mechanisms of Foaming and Antifoaming.

Unit IV: Sedimentation and Creaming, Ultracentrifugation, Rheology of colloidal dispersions, Optical, Electron and Atomic force microscopy of colloids, Light scattering and spectroscopy of colloids.

Unit V: Solid surfaces - surface mobility, characteristics, formation; Adsorption, energy consideration of physical adsorption vs. chemisorption's, Gibbs surface excess, Gibbs adsorption equation, Langmuir isotherm, BET isotherm, adsorption at solid-liquid, liquid-liquid and liquid-gas interfaces, Langmuir-Blodgett films.
Polymers at Interfaces: Adsorption of polymers, Copolymers, Liquid-liquid interface, polymer brushes, Effect of polymers on colloid stability.

Recommended Readings

1. Text book-

(i) Introduction to Applied Colloid and Surface Chemistry; G. M. Kontogeorgis, S. Kiil.
(ii) Principles of Colloid and Surface Chemistry; P. C. Hiemenz and R. Rajagopalan.

2. Reference book-
   (i) Colloid Science; T. Cosgrove.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST804

Course Name : Computational Materials Engineering

Credits : 3 L - 2 T - 0 P - 2

Course Type : Program elective

Prerequisites : Quantum Mechanics, Basic Material Science

Course Contents

Unit I: Introduction and Fundamentals: Introduction to various regimes, multiscale modeling and simulation of materials, system size versus computation time, parallel processing.

Unit II: Ab-initio Methods: Density functional theory, quantum mechanics, Schrodinger's wave equation, many particle system, Car Parrinello method, Born-Oppenheimer approximation, Hohenberg-Kohn theorem, Kohn-Sham formulation, local density approximation, Bloch's theorem, pseudo potential, energy minimization techniques, examples of crystals and non-crystals.

Unit III: Atomistic Level Modeling: Review of thermodynamic laws, micro and macro state, ergodic system, partition function, statistical mechanics, thermodynamic ensembles.
Monte Carlo Simulation: Markov process, algorithm and application of MC simulation (percolation problem etc.) molecular dynamics – force fields, MD algorithm, accelerating MD, verletalgo, leap from method, velocity varlet method, gear also, particle mesh method, multipole method, fast multipole method. Lattice Mesoscale methods: Lattice gas automata, lattice director model. ABCMCMC algorithm for small sample size simulation.

Unit IV: Lab Exercises:
Experiment 1: Introduces geometry optimization in CASTEP and the use of the volume visualization tools to display isosurfaces.
Modules: Materials Visualizer, CASTEP
Experiment 2: To introduce basic DFTB+ calculations for structural and electronic properties of materials
Modules: Materials Visualizer, DFTB+
Experiment 3: Introduces the use of CASTEP for calculating linear response and thermodynamic properties.
Modules: Materials Visualizer, CASTEP

Recommended Readings

1. Text book-

(i) Computational Materials Science; Dierk Raabe.
(ii) Multiscale Materials Modeling: Fundamental and Applications; Z. Xiao Guo (Ed).
(iii) Modeling Materials: Continuum, Atomistic and Multiscale techniques; Ellad B. Tadmor, Ronald E. Miller.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST805

Course Name : Introduction to Soft Materials

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : None

Course Contents

Unit I: Introduction to Soft Materials and soft matter, Generic aspects of soft materials, Examples of soft systems: polymers, foams, granular media, colloids, and liquid crystals, Micelles, vesicles and biological membranes.

Unit II: Synthesis of hard and soft colloids, hard systems, softer systems and their characterization, Dispersion forces, polymers in solution, gels, emulsions and foams.

Unit III: Complex shape particles, Introduction and applications of Patterning of Thin Films and Surfaces, Soft Lithography: Introduction and techniques,

Unit IV: Block copolymers, Block copolymer nanotemplates, Experimental methods for study of block copolymers, Application of Block copolymers.

Recommended Readings

1. Text book-
   (i) Fundamentals of Soft Matter Science; Linda S. Hirst.
   (ii) Introduction to Soft Matter; Ian W. Hamle.
   (iii) Polymer Surfaces and Interfaces; M Stamm.

2. Reference book-
   (i) Soft Condensed Matter; R.A.L. Jones.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST806

Course Name : Optoelectronic Materials and Devices

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Compound semiconductor devices, Electrical and optical properties of materials.

Course Contents

Unit I: Introduction, Alloys semiconductors, Crystal growth – (bulk crystal growth and epitaxial material growth), Device processing.

Unit II: Light Emitting Diodes (LED), The electroluminescent process, Choice of LED materials, LED structure, Manufacturing Process and Applications, LEDs for display applications, Defects and Device Reliability, Lasers: Operating principles, Quantum Well Lasers, Device fabrication, Heterojunction Lasers-Heterostructure laser materials, Photodetectors: Introduction, Photoconductors - (DC Photoconductors, AC Photoconductors, Gain and Bandwidth), p-i-n (PIN) Photodiodes. Solar Cells: Introduction, Basic principles: current-voltage characteristics, Schottky Barrier Cells, Materials and design consideration- (Materials Requirements, Solar cell design)

Unit III: Introduction, Applications, Materials and processing, Guided wave devices, Fiber Bragg Gratings (FBG): Basic Theory and Sensing Principle, Fabrications techniques, FBG fabrication parameters, Sensing principle: (Strain sensitivity of Bragg gratings, Temperature sensitivity of Bragg gratings), Photonic Crystals: Introduction, Structures and Photonic Bands, Fabrications, Application: (Laser, Waveguides, Optical Fiber, Photonic Integrated Circuit).

Unit IV: Photobiology, Photo-process in Biopolymers, Photosynthesis, Photo-excitation, optical fiber delivery system, Optical coherence Tomography, Fluorescence, resonance energy transfer imaging, Bio-imaging, phase contrast microscopy, Optical Biosensors, Flow Cytometry, Laser activated therapy, Tissue engineering, laser surgery, Laser tweezers and scissors, optical trapping, Photonics and biomaterials.

Recommended Readings

1. Text book-
   (i) Introduction to Biophotonics; P. N. Prasad.

(ii) Fundamentals of Optoelectronics; C. R. Pollack.

2. Reference book-
   (i) Fundamentals of Solid-State Engineering; M. Razeghi.
   (ii) Optoelectronics; Emmanuel Rosencher & Borge Vinter.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST807

Course Name : Organic Electronics

Credits : 3 L - 3 T - 0 P - 0
Course Type : Program elective
Prerequisites : Basic knowledge of polymers and electronics

Course Contents

Unit I: Overview and advantages of electronics based on organic materials, Conjugated organic materials: Electrical conductivity, insulators, semiconductors and conductors; Band theory and molecular orbital theory of solids; Comparison between covalent solids and molecular solids; Low molecular weight molecules and polymers: advantages and disadvantages; Charge carriers and excitons; Organic devices, injection and extraction of charge carriers; Charge carrier mobility and charge transport properties of organic solids.

Unit II: Field-effect transistors based on organic materials; Basics of MOSFET-type field-effect transistors, output characteristics and transfer characteristics; Configurations of field-effect transistors based on organic materials (OFETs); Requirements for organic materials to be used in n-channel, p-channel and ambipolar OFETs; The role of the dielectric and of the molecular organization of the organic layer.

Unit III: Solar cells based on organic materials; Basics of solar cells, current-voltage characteristics, definition of photovoltaic parameters; Photogeneration of excitons and formation of free charge carriers in organic materials; Electron-donors and electron-acceptor materials, bulk-heterojunction structure for the active layer of organic solar cells; Requirements for electron-donor and electron-acceptor materials and role of morphology of the active layer; Some basics of dye-sensitized solar cells (DSSCs).

Unit IV: Light-emitting diodes based on organic materials (OLEDs); Basics of organic light-emitting diodes, luminance-voltage and efficiency-voltage characteristics; Device structures, hole-transporting layer, electron-transporting layer, emitting layer; Formation of emitting states, fluorescent and phosphorescent emitters; Requirements for emitting materials; Some basics of organic light-emitting transistors (OLETs).

Recommended Readings

1. Text book-
   (i) Molecular Electronics: from principles to practice; M.C. Petty.
   (ii) Electronic processes in organic crystals and polymers; M. Pope & C. E. Swenberg.

(iii) Handbook of Conducting Polymers; Terje A. Skotheim and John Reynolds.

2. Reference book-
(i) Organic Photovoltaics Mechanisms, Materials, & Devices; S.-S Sun, N. S. Sariciftci.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST808

Course Name : Polymer Science and Processing Technology

Credits : 3 L - 3 T - 0 P - 0
Course Type : Program elective
Prerequisites : Basic knowledge of physics and chemistry

Course Contents

Unit I: Historical developments in polymeric materials, Basic concepts & definitions: monomer & functionality, oligomer, polymer, repeating unites, degree of polymerization, molecular weight & molecular weight distribution, Molecular forces, chemical bonding, Transitions in polymers, visco-elasticity, types of macromolecules, classification of polymers. Crystalline nature of polymers, factors affecting crystallization, crystallization and melting, melting: factors affecting. The glassy state and glass transition.

Unit II: General characteristics of chain growth polymerisation, initiators, generation of initiators, free radical, anionic and cationic polymerization, ring opening polymerization, General characteristics of step growth polymerization, mechanism of step growth polymerization, coordination polymerization. Kinetics of addition, condensation and coordination polymerization. Copolymerization mechanism. Homogeneous polymerization techniques- Bulk, Solution, Heterogeneous polymerization techniques- Emulsion, Suspension, solid phase polymerization.

Unit III: Thermodynamics of polymer solutions, Solution properties of polymers, Solubility parameter, Conformation of polymer chains in polymer solutions, Flory-Huggins theory, Flory-Krigbaum theory, Solution viscosity, Osmotic pressure, Molecular size and molecular weight. End group analysis, colligative property measurement, ultra-centrifugation, light scattering, gel permeation chromatography, Viscosity methods, IR, NMR etc. Thermal characterization, Rheology and mechanical properties of materials.

Unit IV: Tensile, flexural, compressive, abrasion, endurance, fatigue, hardness, tear, resilience, impact, toughness. Types of degradation: Thermal, mechanical, ultrasonic and photodegradation, oxidative and hydrolytic degradation, Introduction to polymer processing technologies.

Recommended Readings

1. Text book-

(i) Introduction to Polymers; R. J Young and P. A. Lovell.
(ii) Principles of Polymerization; G. Odian.
(iii) Polymer Science and Technology; P. Ghosh

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST809

Course Name : Smart & Intelligent Materials

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Basic knowledge of materials and their properties

Course Contents

Unit I: Smart materials and structures: System intelligence- components and classification of smart structures, common smart materials and associated stimulus-response, Application areas of smart systems.

Unit II: Ferroelectric materials: Piezoelectric materials- piezoelectric effect, Direct and converse, parameter definitions, Piezoceramics, Piezopolymers, Piezoelectric materials as sensors, Actuators and bimorphs. Shape memory materials: Shape memory alloys (SMAs), Shape memory effect, Martensitic transformation, One way and two-way SME, training of SMAs, binary and ternary alloy systems, Functional properties of SMAs.

Unit III: Chromogenic materials: Thermochromism, Photochromism, lectrochromism, Halochromism, Solvatochromism- principle and design strategies. Smart polymers: Thermally responsive polymers, Electroactive polymers microgels, Synthesis, Properties and Applications, Protein-based smart polymers, pH-responsive and photo-responsive polymers, Self-assembly, Molecular imprinting using smart polymers, Approaches to molecular imprinting, Drug delivery using smart polymers.

Unit IV: Smart hydrogels: Synthesis, Fast responsive hydrogels, Molecular recognition, Smart hydrogels as actuators, Controlled drug release, Artificial muscles, 3D- Bioprinting, Hydrogels in microfluidics.

Unit V: Smart systems for device applications: Elastic memory composites, Smart corrosion protection coatings, Self-healing materials, Sensors, Actuators, Transducers, MEMS, Deployment devices, Molecular machines.

Recommended Readings

1. Text book-
   (i) Engineering Analysis of Smart Material Systems; D. J. Leo.
   (ii) New Materials, Processes, and Methods Technology; M. Schwartz.
   (iii) Made to Measure: Materials for the 21st Century; P. Ball.
   (iv) Smart Polymers: Applications in Biotechnology & Biomedicine; I. Galaev, B. Mattiasson.

2. Reference book-
   (i) Smart Materials and New Technologies in Architecture; M. Addington, D. L. Schodek.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST810

Course Name : Technology Transfer and Intellectual Property (IP) Commercialisation

Credits : 3 L - 3 T - 0 P - 0
Course Type : Program elective
Prerequisites : None

Course Contents

Unit I: Concept of technology transfer, Characterizing features of technology transfer, Technology transfer mechanisms, Motivations for technology transfer, Benefits and legal framework for technology transfer, Overview of the technology transfer process.

Unit II: The technology identification and assessment, Results of R&D activity, Factors to make the right decisions, Value proposition of the technology, Market analysis, time of market entry and market validation, Protection strength, Pathways to transfer technology, Technology transfer strategic plan.

Unit III: Bridging the gap towards the market, Development and proof of concept, Process for locating technology partners, The engagement process with technology partners, The deal-making and negotiation phase, Overview of the negotiation process.

Unit IV: The contracting phase, Overview of technology transfer contracts, License agreement, Structure of a patent license agreement, Spin-offs (startup creation), Technology transfer implementation, technology package to transfer, Monitoring actions, Disputes in technology transfer.

Recommended Readings

1. Text book-
   (i) Innovate Like Edison: The Five-Step System for Breakthrough Business Success; M. J. Gelb, S. M. Caldicott.
   (ii) Technology Transfer: From the Research Bench to Commercialization: Part 1: Intellectual Property Rights—Basics of Patents and Copyrights; G. A. Van Norman, R. Eisenkot.
   (iii) Intellectual Property: From Creation to Commercialisation - A Practical Guide for Innovators & Researchers; J. P. Mc Manus.
   (iv) Nanotechnology Intellectual Property Rights: Research, Design, and Commercialization, Perspectives in Nanotechnology; P. Ganguli, S. Jabade.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST811

Course Name : Advanced Ceramics

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Basic knowledge of thermodynamics, Elementary crystallography and crystal structure.

Course Contents

Unit I: Engineering Ceramics: Carbides: Boron carbide, Silicon carbide, Titanium carbide, Zirconium carbide, Hafnium carbide & Uranium carbide. Nitrides: Boron, Silicon & Aluminium nitrides. Silicides: Molybdenum disilicide. Borides. Sialon. Graphites. Cermets & Composites.

Unit II: Electronic Ceramics: Ceramic substrates, Processing of Thick Film, Thin Film, Multilayer Packages. Properties of Ceramic Insulators. Ceramic Capacitor Dielectrics, Titanate based dielectrics, Composition with high Pb content, Processing of thick & thin film capacitors, Integrated capacitors. Relax or Dielectrics. Piezoelectric & electrostrictive Ceramics, Ferroelectric and Pyroelectric Ceramic, Piezoelectric ceramic applications.

Unit III: Exotic ceramics: functionally graded, smart/ Intelligent, bio-mimetic and nano-ceramics - basic principles, preparation and applications. Ceramic based Sensors: Oxygen Sensors, Principles of operation, Solid electrolyte sensors, Semiconductor sensors, Thermistors and related sensors. Magnetic Ceramics: Spinel Ferrites, Hexagonal Ferrites, Garnet, Processing, Single crystal ferrite, Applications. Critical parameters and Powder synthesis, Ceramic Superconductors: High Tc Superconductors, Structure of Y-Ba-Cu oxide system, Powder synthesis, Theory of Superconductivity, Applications.

Unit IV: Uses of ceramics in advanced applications; Ceramics for Medical and Scientific products: Tissue attachment mechanism, Bio- active materials, nearly inert crystalline ceramics, porous ceramics, bioactive glass and glass ceramics, calcium phosphate ceramics, carbon base implant materials, ceramics for dental applications. Ceramics for optical applications: CRT and TV picture tubes, Telecommunication and related uses, Information display, Laser, Fibre optics, Electromagnetic windows. Ceramics in Electrochemical cells: Sodium sulphate cell (with β – alumina), Electrical ceramics for fuel cell and high energy batteries.

Recommended Readings

3. Text book-

(i) Advanced Structural Ceramics; B. Basu and K. Balani.
(ii) Friction and Wear of Engineering Ceramics: Principles and Case Studies; B. Basu et al.
(iii) Fundamental of Ceramics; Michel W. Barsoum.
(iv) Modern Ceramic Engineering; David. W. Richerson.

4. Reference book-
   (i) Handbook of Advanced Ceramics; S. Somiya
   (ii) Ceramic Processing and Sintering; M. N. Rahman, Mercel Dekker

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST812

Course Name : Advanced Polymer Physics

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Basic knowledge of Polymers and their properties

Course Contents

Unit I: Molecular flexibility, Classification of polymers, Principles and types of Polymerization, Average molecular weights and polydispersity, Polymer Morphology: Crystalline and semi-crystalline polymers; Liquid crystalline polymers, Self-assembly by microphase separation of block copolymers, Morphology of polymer thin films vs. bulk - surface influence.

Unit II: Random walk models in polymer physics: 1-D random walk (drunkard walk), 2-D random walk on a lattice, freely jointed chain, modified freely jointed chain, freely rotating chain; Elastic energy of polymer chain, bead-spring model, ideal polymer chain and finite extension models, radius of gyration, pair correlation function, scattering experiments.

Unit III: Concentrated polymer solutions, Review of Solution thermodynamics: Mixing and phase separation, osmotic pressure, chemical potential, thermodynamic origin of diffusion. Lattice model of solutions, Flory-Huggins theory of polymer solutions, Definition of partition function and free energy, binodal and spinodal curve, critical point, extension to polymer blends and melt.

Unit IV: Brownian motion, Correlation functions, Time translational invariance and time reversal symmetry, Brownian motion of a free particle, Einstein relation, Brownian motion in a potential field, Introduction to Molecular Dynamics and Brownian Dynamics, Experimental rheology: rheometers, linear viscoelasticity, superposition principle, relaxation modulus, storage modulus, loss modulus.

Recommended Readings

2. Text book-
   (i) Polymer Physics; M. Rubinstein and R. H. Colby.
   (ii) The Structure and Rheology of Complex Fluids; R. G. Larson.
   Principles of Polymerization; G. Odian.
   4. Soft matter physics; M. Doi

3. Reference book-
   (i) Principles of Polymerization; G. Odian.

(ii) Soft matter physics; M. Doi

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST813

Course Name : Degradation of Materials

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Basic understanding of corrosion and oxidation

Course Contents

Unit I: Environmental degradation of materials. Technological importance of corrosion study, corrosion as non-equilibrium process, corrosion rate expressions, electrochemical principles of corrosion-cell analogy, concept of single electrode potential, reference electrodes, e.m.f. and galvanic series-their uses in corrosion studies, polarization, passivity.

Unit II: Different forms of corrosion-uniform attack, galvanic, crevice, pitting, intergranular, selective leaching, erosion, stress corrosion cracking-their characteristic features, causes and remedial measures.

Unit III: Principles of corrosion prevention-material selection control of environment including inhibitors, cathodic and anodic protection, coatings and design considerations. Corrosion testing methods.

Unit IV: Introduction to high temperature corrosion, Pilling-Bedworth ratio, oxidation kinetics, oxide defect structures, Wagner-Hauffe valence approach in alloy oxidation, catastrophic oxidation, internal oxidation.

Unit V: Considerations in high temperature alloy design, prevention of high temperature corrosion -use of coatings. Liquid metal attack - liquid metal embrittlement, preventive measures, Chemical degradation of non-metallic materials like rubbers, plastics, ceramics etc. Hydrogen damage-types, characteristics, mechanism and preventive measures

Recommended Readings

3. Text book-
   (i) Corrosion Engineering; M.G. Fontana & N.D Greens.
   (ii) Corrosion & Corrosion control; H.H. Uhlig.
   (iii) An Introduction to Metallic Corrosion & its Prevention; Raj Narayan.

4. Reference book-
   (i) Corrosion of Metals: Physicochemical Principles and Current Problems; Helmut Kaesche

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST817

Course Name : Energy Materials

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Basic understanding of physics and electrochemistry

<u>Course Contents</u>

Unit I: 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 II: Thermoelectric Materials: Physics of thermoelectricity, Peltier, Seebeck and Thomson effects, Types of thermoelectric materials, Thermoelectric generators, Peltier cooler.

Unit III: Electrochemical Energy Materials: Fundamentals of electrochemical energy conversions, Primary batteries - Zn-MnO2 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, lithium polymer, Introduction to super capacitors, types of super capacitors, Introduction to fuel cells, Types of fuel cells and technology development.

Unit IV: 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.

<u>Recommended Readings</u>

3. Text book-
   (i) Solar Cells-Materials, Manufacture and Operation; T. Markvart and L. Castaner.
   (ii) Thermoelectric: Basic Principles and New Materials Developments; G. S. Nolas, J. Sharp, J. Goldsmid, M.M. Schwartz.

4. Reference book-
   (i) Renewable resources and renewable energy- A global Challenge; M. Graziani and P. Fornasiero.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST818

Course Name : Material Processing & Microstructure Development

Credits : 3 L - 3 T - 0 P - 0
Course Type : Program elective
Prerequisites : Basic knowledge of thermodynamics and phase diagram

Course Contents

Unit I: What is materials processing, Heat conduction equation, Comparing heat transfer processes, Biot number, Newtonian heating / cooling, Transient solutions and dimensionless variables, Glass fibers & thermal spray industrial processes, Analyzing thermal spray coatings, Hot rolling steel, 2D analysis, superposition & friction welding setup, Friction welding, Introduction to radiation, Black bodies, emissivity & radiation M number.

Unit II: Introduction to solidification, Stefan condition, simplifying thermal profile, Solidification in a thick mold, Sand casting, lost foam, & cooled molds, Interface resistance-limited solidification, Single crystal production, Introduction to binary solidification, Binary solidification, no diffusion in the solid, Solute balance, partition coefficient, Zone refining, Solidification with finite diffusion in liquid, Unstable solidification fronts.

Unit III: Introduction to glass production, Pilkington glass process–fluid flow, Pilkington glass process–heat transfer, Drag force, Navier-Stokes equation, Reynolds number, Newtonian flow, Introduction to non-Newtonian, Solid state shape forming, More on Newtonian and non-Newtonian flow, Blow molding, compressive forming.

Unit IV: Introduction to powder processing, Sintering, slurry processing, Colloid processing, Slurry settling / casting, Introduction to steel making, Steel fluid flow analysis, Steel solidification analysis, Steel solidification (cont.), Steel factory design, A bit about electronics manufacturing.

Recommended Readings

2. Text book-
   (i) Introduction to Heat Transfer; T. L. Bergman et al.
   (ii) Transport Phenomena and Materials Processing; K. Sindo.
   (iii) Solidification Processing; M. C. Flemings.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST819

Course Name : Membrane Technology

Credits	**: 3**	**L -**	**3**	**T -**	**0**	**P -**	**0**

Course Type : Program elective

Prerequisites : Basic knowledge of membrane science

Course Contents

Unit I: Historical Development of Membranes, Types of Membranes, Membrane processes, Membrane Transport Theory; The Solution-Diffusion Model, Structure-Permeability Relationships in Solution-Diffusion Membranes, Pore-Flow Membranes.

Unit II: Polymer basics, polymers used in membrane preparation and their properties, Material properties and preparation of phase-inversion membranes: Inorganic Materials for Membrane Preparation, Membrane Modules and Selection, Flow Types, Preparation of Synthetic Membrane, Phase Inversion Membranes.

Unit III: Membrane Processes: Theory, System Design, Applications and Economics; Reverse Osmosis, Pressure-Retarded Osmosis and Nanofiltration, Ultrafiltration, Microfiltration, Gas Separation, Pervaporation, Ion Separation

Unit IV: Membrane Contactors, Membrane Distillation, Membrane Reactors and Membrane Bioreactors, Carrier Facilitated Transport, Submerged Membranes, Medical Applications of Membranes.

Recommended Readings

2. Text book-
(i) Membrane Technology and Applications; Richard W. Baker.
(ii) Basic Principles of Membrane Technology; Marcel Mulder.
(iii) Advanced Membrane Technology; Norman N. Li, Anthony G. Fane, W.S. Winston Ho and Takeshi Matsuura, (Ed).

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST821

Course Name : Nanomanufacturing

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Basic knowledge of nanotechnology, electrical and electronic properties of materials, semiconducting devices

<u>Course Contents</u>

Unit I: Moore's Laws and technology' Roadmap–clean rooms Processing Methods: Cleaning, Oxidation Lithography, Etching, CVD, Diffusion. Ion implantation, metallization, state of the art CMOS architectures Photolithography Overview – Critical Dimension – Overall Resolution – Line-Width – Lithographic Sensitivity and Intrinsic Resist Sensitivity (Photochemical Quantum Efficiency) – Resist Profiles – Contrast and Experimental Determination of Lithographic Sensitivity –Photolithography Resolution Enhancement Technology.

Unit II: Next-Generation Technologies: – State of the Art (including principles, capabilities, limits, applications) EUV lithography – Phase-shifting photolithography – X-ray lithography – Electron Beam Direct Writing System – Focused ion beam (FIB) lithography – Neutral atomic beam lithography – Plasma-Aided Nanofabrication – Soft Lithography – Nanosphere Lithography – Nanoimprint – Dip-pen nanolithography – Electrospinning.

Unit III: Conventional techniques: Scanning tunnelling microscopy – Atomic force microscopy – Near-field scanning optical microscopy – Advanced Techniques: Embossing and surface passivation, Dimensional Subtraction and Addition, Multistep Processing, of Microcontact printing– Molding – implications and applications of the conventional & advanced techniques.

Unit IV: Material Wave Nanotechnology: Nanofabrication Using a de Broglie Wave-Electron Beam Holography – Atomic Beam Holography- Nanometer Lithography Using Organic Positive/Negative Resists – Sub-10 nm Lithography Using Inorganic Resist – 40 nm-Gate-Length Metal-Oxide-Semiconductor Field-Emitter-Transistors-14 nm GateLength Electrically Variable Shallow Junction MOSFETs-Operation of Aluminum-Based Single-Electron Transistors at 100 Kelvins- Room Temperature Operation of a Silicon Single-Electron Transistor.

Unit V: Fundamental scaling limits to the transistors – Beyond CMOS: Self-Assembled structures – Gravitational field assisted assembly – Template-assisted assembly- Shear force assisted assembly - Electroforming and Molding– Fundamentals of Quantum Computing – Quantum Algorithms - Realizing quantum computers – Physical Implementations.

Recommended Readings

3. Text book-
   (i) Nanotechnology & Nanoelectronics: Materials, Devices, Measurement Techniques; W. R.Fahrner,
   (ii) Nanofabrication, Principles, Capabilities and Limits; Z. Cui.
   (iii) Fundamentals of Microfabrication: The Science of Miniaturization; M. J. Madou.

4. Reference book-
   (i) Nanostructures & Nanomaterials Synthesis, Properties and Applications; G. Cao.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST822

Course Name : Nanomaterials Technology

Credits : 3 L - 3 T - 0 P - 0
Course Type : Program Elective
Prerequisites : Basic knowledge of chemistry, physics and biology

Course Contents

Unit I: Introduction to nanomaterials, Surface area to volume ratio, stabilizers, Synthesis of nanomaterials, General properties of nanomaterials. History of nanomaterials.

Unit II: Metallic nanoparticles: Surface plasmon resonance, Synthesis of metal nanoparticles by wet chemical methods, Ostwald ripening and sintering, Anisotropic nanoparticles. Metal nanoclusters, Bimetallic nanoparticles. Quantum Dots: Quantum confinement, Band gap tuning and properties of quantum dots. Surface defects and Doping in Quantum dots. Carbon nanomaterials: Preparation and properties of graphene oxide, graphene, fullerenes, carbon nanotubes and carbon dots. Composites of carbon nanomaterials.

Unit III: Nanomaterials for catalysis, optical sensing and as artificial enzymes; Catalysis: Types of catalysis, Metallic nanoparticles and nanoclusters as catalyst, metal oxide and carbon nanostructures for photocatalysis; Optical Sensing: Principles of optical sensing, Fluorescence and Quenching mechanisms, Metal nanoparticles and fluorescent nanostructures as optical sensors for heavy metal ions, important biomolecules and explosives with examples of paper and film based sensing devices; Artificial enzymes: Enzymes, Importance of nanozymes; Metallic, oxide, carbon and hybrid nanoscale materials as artificial enzymes.

Unit IV: Nanomaterials for Energy and Environmental Protection; Nanomaterials for solar cells, Dye and QD-sensitized solar cells, Organic-inorganic hybrid solar cells, Current status and future prospects. Nano technology processes – Nano Engineering materials for Pollution Prevention, Green Chemistry, Energy efficient resources and materials, Nanomaterials for clean water & air.

Unit V: Nanotechnology for Medical Diagnostics and Therapy: Disease diagnostics: Quantum dot conjugation strategies with DNA-aptamer, Protein and Antibody and FRET based assays for disease diagnostics. Drug delivery: Lipid and polymeric nanoparticles as drug delivery vehicles; Polymeric, peptide and metal-organic gels for drug delivery, nanoparticle induced Gene delivery for gene therapy. Nanotechnology for therapy: Metallic nanostructures and nanoscale metal-organic frameworks for Phototherapy of cancer; Magnetic nanoparticles as MRI contrast agents.

Recommended Readings

3. Text book-
   (i) Nanoscience & Nanotechnology: Fundamentals of Frontiers; M. S. Ramachandra Rao, S. Singh.
   (ii) Nanoparticles: From Theory to Application; G. Schmid.
   (iii) Nanomaterials for Medical Diagnostics and Therapy; Challa Kumar.

4. Reference book-
   (i) Nanostructures and Nanomaterials: Synthesis, Properties, and Application; G. Cao, Y. Wang.

5. Online Resources-
   (i) Updated research and review articles

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST823

Course Name : Nanomechanics

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Differential equations, mechanics of materials

Course Contents

Unit I: Introduction: Nanomaterials and their properties, Size effect on nanomaterials properties. Two - atom chain mechanics, interaction potentials, external forces, dynamics motion, Three atom chain. Lattice mechanics, Stress and strain. Introduction to nanomechanics, High resolution force spectroscopy (HRFS): The force transducer, Additional nanomechanics instrumentation components.

Unit II: Linear elasticity relations and Molecular dynamics: Orthotropic and isotropic materials, crystallines materials. Molecular dynamics: verlet algorithms, Nordsieck/gear predictor-corrector methods, molecular dynamics applications, nanomachines, wear at the nanometer level.

Unit III: Force versus distance curves, Atomic force microscope (AFM) imaging, AFM imaging II: Artifacts and applications, Structure and mechanical properties of carbon nanotubes: Structure of carbon nanotubes, mechanical properties of carbon nanotubes. Nanomechanical measurement techniques and application: AFM measurements: mechanical properties of CNTs, Nano-indentation.

Unit IV: Nano- Microelectromechanical System: MEMS fabrication techniques, NEMS fabrication techniques, MEMS/NEMS Motion Dynamics, MEMS Devices and applications, NEMS Devices and applications.

Unit V: Single cell mechanics, Qualitative introduction to intra - and intermolecular forces, Quantitative description of intra - and intermolecular forces, Molecule - surface interactions, Colloids and interparticle potential, Van der Waals forces at work: Gecko feet adhesion.

Unit VI: Nanomechanics of cartilage, Protein - surface interactions, Nanomechanics and biocompatibility, Theoretical aspects of nanoindentation, Nanoindentation: Oliver-Pharr method and one literature example: Nacre.

Recommended Readings

3. Text book-
   (i) Foundations of Nanomechanics: Andrew N Cleland, Springer International, 2003.
   (ii) Nanomechanics: an extension of Continuum Mechanics to the nanoscale, by Kaibin Fu, VDM verlag, 2009.
   (iii) Nanoscience and Nanotechnology: Fundamentals of Frontiers; M. S. Ramachandra Rao, S. Singh, Wiley India., 2016.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MST826

Course Name : Thin Films and Surface Engineering

Credits : 3 L - 3 T - 0 P - 0

Course Type : Program elective

Prerequisites : Solid State Physics, Thermodynamics

Course Contents

Unit I: Thin films and Surfaces, thermodynamics and reactivity of Surfaces, Surface crystallography and reconstruction, atomic models for crystalline surfaces, Nucleation and Growth in thin films: Capillarity theory, atomistic and kinetic models of nucleation, basic modes of thin film growth (Volmer- Weber, Frank van der Merwe, Stranski-Krastanov), Microstructural development in epitaxial, polycrystalline, and amorphous films.

Unit II: Thin film deposition (Vapour based), Hertz Knudsen equation; mass evaporation rate; Directional distribution of evaporating species Evaporation of elements, compounds, alloys. Raoult's Law: E-beam, pulsed laser and ion beam evaporation, Sputtering, ion beam assisted deposition. Chemical Vapor Deposition (CVD) Methods, sputtering, epitaxial films, Laser ablation, lattice misfit and imperfections.

Unit III: Characterization of coatings and surfaces: Measurement of coatings thickness; porosity & adhesion of surface coatings; Measurement of residual stress & stability; Surface microscopy & topography by scanning probe microscopy; Spectroscopic analysis of modified surfaces, elemental analysis.

Unit IV: Thin Film Applications for electrical and optical devices -Transistors (TFT), Sensors and Solar cells, thin film Coatings like Diamond-like carbon (DLC) coating & Bio-Medical coatings (TiN, DLC), Hard Transparent Protective Coatings etc.

Recommended Readings

3. Text book-
   (i) The Materials Science of Thin Films; M. Ohring.
   (ii). Thin Film Phenomenon by K.L. Chopra.

4. Reference book-
   (i) Electronic Thin Film Science for Electrical Engineers and Materials Scientists; K-N Tu, J. W. Mayer and L. C. Feldman.

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MSP820

Course Name : Microscopy Lab

Credits : 3 L - 0 T - 0 P - 6
Course Type : Program elective
Prerequisites : Basic course on microscopy

Course Contents

Experiment 1: Surface roughness characterisation of thin films using atomic force microscopy.

Experiment 2: Study of morphology and size of nanoparticles using scanning electron microscope.

Experiment 3: Thin film thickness calculation using scanning electron microscope.

Experiment 4: Characterising crystalline (micro and nano grain) and amorphous materials using transmission electron microscope.

Experiment 5: Using EDS elemental mapping to distinguish alloy and core-shell nanoparticles.

Experiment 6: Identifying and locating different phases in multiphase alloy using dark field (DF) imaging in TEM.

Experiment 7: Identifying equilibrium phases in alloys synthesized by melt-quenching.

Experiment 8: Study of microstructure of welded component and HAZ (Heat Affected Zone) macro and micro examination.

Experiment 9: Specimen preparation for microstructural examination- cutting, grinding, polishing, etching.

Experiment 10: Investigation of the effect of heat treatment and quenching on the microstructure of mild steel.

Experiment 11: Study of Microstructure of Composite Material subjected to tensile test.

Recommended Readings

1. Text book-
   (i) Atomic Force Microscopy: Understanding Basic Modes and Advanced Applications; G. Haugstad" John Wiley & Sons, 2006.
   (ii) Transmission Electron Microscopy and Diffractometry of Materials, B. Fultz and J. M. Howe, 2nd Edition, 2001.
   (iii) Scanning Electron Microscopy — Physics of Image Formation and Microanalysis, L. Reimer, Springer verlag, 1985.

2. Online resources-
   (i) http://experimentationlab.berkeley.edu/sites/default/files/writeups/AFM.pdf
   (ii) www.nptel.ac.in
   (iii) http://vlabs.iitb.ac.in/vlabs-dev/approved_labs.php

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MSP824

Course Name : Spectroscopy Lab

Credits : 3 L - 0 T - 0 P - 6
Course Type : Program elective
Prerequisites : Basic knowledge of thin film deposition techniques

Course Contents

Experiment 1: Study of kinetics of reduction of 4-nitrophenol using UV-visible spectroscopy in the presence of metallic nanoparticles as catalyst.

Experiment 2: Probing the conformational changes in protein secondary structure by using fluorescence spectroscopy.

Experiment 3: Studying the coordination of metal ions to organic molecules by use of FTIR spectroscopy.

Experiment 4: Characterization of some carbonaceous material by Raman spectroscopy and study of the effect of metallic nanoparticles on the Raman spectra of the material.

Experiment 5: Study of FRET between Au nanoparticles and Carbon dots using UV-visible and fluorescence spectroscopy.

Experiment 6: Characterization of various oxidation states of Ag in Ag nanoparticles synthesized using biomolecules by means of X-ray photoelectron spectroscopy.

Experiment 7: Construction of Job's plot and study of metal: ligand stoichiometry using UV-visible spectroscopy.

Experiment 8: Characterization of an organic compound using NMR spectroscopy.

Experiment 9: Determination of the concentrations of Hg and Cd ions in a water sample using atomic absorption spectroscopy.

Recommended Readings

1. Text book-
   (i) Fundamentals of Molecular Spectroscopy; C. N. Banwell and E. M. McCash, 4th edition, Tata McGraw- Hill Publishing Company Ltd., New Delhi, 2006.

(ii). Principles of Fluorescence Spectroscopy; J. R. Lackowicz, 3rd edition,Springer, New York, 2006.

2. Reference book-
(i) Introduction to spectroscopy; D. L. Pavia et al. 5th edition, Stamford Cengage Learning, 2015.
(ii) VOGEL'S textbook of quantitative chemical analysis; J. Mendham et al., 6th edition, Pearson education limitedy, 2007.

3. Online resources-
(i) https://pubs.rsc.org/en/content/articlelanding/2015/nr/c4nr05424e
(ii) www.nptel.ac.in

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Materials Research Centre

Course Code : 21MSP825

Course Name : Thin Film fabrication & Characterization Lab

Credits : 3 L - 0 T - 0 P - 6
Course Type : Program elective
Prerequisites : Basic knowledge of thin film deposition techniques

Course Contents

Experiment 1: Preparation of the Metal Oxide thin films by using spin coating technique.

Experiment 2: Preparation of the metal oxide thin films by using Dip coating technique.

Experiment 3: Preparation of the Carbon nanotubes by the CVD process.

Experiment 4: Preparation of the transparent conductive coating via DC magnetron sputtering/e-beam evaporation.

Experiment 5: Determination of average crystalline size and macrostrain by using X-Ray diffraction Analysis.

Experiment 6: Investigation of the surface morphological studies by Atomic force microscope.

Experiment 7: Using AFM and SEM to characterize the thickness of thin films and compare it with thickness calculated theoretically.

Experiment 8: Determination of electrical properties of metal oxide and transparent conductive coatings using Semiconductor Device Analyzer.

Experiment 9: Investigation of the corrosion inhibition properties of dip coated stainless steel using polymeric and organic inhibitors.

Experiment 10: Investigation of the effect of calcination temperature on the Hardness of Metal oxide thin films.

Recommended Readings

1. Text book-
   (i) Modern Surface Technology, Edited by Friedrich-Wilhelm Bach, Andreas Laarmann, and Thomas Wenz, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany, 2006

(ii). M. H. Francombe, S. M. Rossnagel, A. Ulman, Frontiers of Thin Film Technology, Vol. 28, Academic press, 2001.

2. Reference book-
(i) Thin Film Phenomena, K. L. Chopra McGraw Hill, 1979.R.F. Bunshah, Deposition Technologies for Films and Coatings, Noyes Publications, New Jersey, 1982.
(ii). Materials Science of Thin Films ; M. Ohring, 2nd ed., Academic Press, San Diego, 2002.
(iii). Electroplating, F. A. Lowenheim, , McGraw Hill, New York, 1978.
(iv). Surface Engineering ,ASM Metals Handbook, American Society for Metals, Vol.5, 9th ed., 1994.
(v). Nanomaterials and Surface Engineering, Edited by Jamal Takadoum, John Wiley & Sons, Inc., USA.

3. Online resources-
(i) http://ocw.mit.edu/courses/
(ii) www.nptel.ac.in
(iii) http://vlabs.iitb.ac.in/vlabs-dev/approved_labs.php
(iv) https://www.nanomatch.de/virtual-lab/