M. TECH – MATERIALS SCIENCE AND ENGINEERING
Center for Excellence in Advanced Materials and Green Technologies
Department of Chemical Engineering and Materials Science

The M.Tech. Materials Science and Engineering program is offered at Amrita Vishwa Vidyapeetham through the Department of Chemical Engineering and Materials Science by the Center of Excellence in Advanced Materials and Green Technologies established in May 2013. The Center was established based on a grant awarded by the Ministry of Human Resource Development (MHRD). The Center has numerous ongoing research projects covering materials for fuels/energy, electricity, construction, and water.

The program is designed to develop graduates that can apply fundamental knowledge of mathematics, physics & chemistry of materials, and statistics, to model and solve problems related to design, synthesis, performance enhancement, and optimization of materials. Recognizing the multidisciplinary nature of the field, the teaching and project guidance will be accordingly delivered by highly qualified, world-class faculty from various departments including, chemical engineering, chemistry, physics, & aerospace engineering.

With a view towards developing both science and engineering skills, the program curriculum has been framed so as to incorporate and deliver on experimental, analytical, statistical, and computational tools & educational components of globally accepted standards in the materials discipline. The core courses include: Engineering Materials, Advanced Materials, Electronic Materials Science, Materials Thermodynamics, Physical Metallurgy, Materials Processing, Statistical Design of Experiments, Materials Characterization Techniques, and Materials Design. While the labs cover important aspects of synthesis, testing, and characterization, the electives are structured in such a way as to offer opportunities for acquisition of specialized and advanced knowledge in sub-disciplines such as electronic materials, biomaterials, and materials for energy systems. Students have the opportunity to pursue their projects either in-house (research in the departments of Chemical Engineering, Sciences, Aerospace Engineering, Civil Engineering, and the Center for Excellence in Advanced Materials & Green Technologies), or outside in reputed industrial or R&D institutions.

With a strong focus on developing research skills among the students, in frontier areas, the program includes educational components that would make the graduates suited to, and employable in, industrial, government R&D, and academic settings, spanning diverse areas such as electronics & communications, energy, chemicals, medicine, and transportation.

Program Educational Objectives (PEOs)

The overall educational objectives of the MTech (Materials Science and Engineering) program are:

1. To develop knowledgeable, skilled and trained human resources in the broad domain of materials science and engineering who can effectively contribute towards design, development, processing, and optimization of materials for innovative applications in new products and processes

2. To enable the graduates to gain employment in industries and consultancies or pursue higher studies in research and academic institutions

3. To equip the graduates with good technical communication skills, and promote communication of their ideas and knowledge via scholarly articles, patents, delivery of effective presentations, and/or training of co-workers and associates

4. To inculcate professional ethics & values for responsible individual/team work, leadership, management, self-development and lifelong learning, applied for nation building and global sustainable development.

Program Outcomes (POs)

On completion of the MTech (Materials Science and Engineering) program, the graduate will be able to:

PO1. Independent Research. Independently carry out research /investigation and development work to solve practical problems

PO2. Technical Writing. Write and present a substantial technical report/document/thesis

PO3. Specialization. Demonstrate a degree of mastery over Materials Science and Engineering at a level higher than the requirements in the appropriate bachelor program.

Program Specific Outcomes (PSO)

On completion of the MTech (Materials Science and Engineering) program, the post-graduate will be able to:

PSO1. Understand and predict the *structure, compositions and properties* of different classes of materials (e.g., metals and alloys, ceramics, polymers, composites, nanomaterials, advanced materials), and their *relationships* leading to adequate *performance* in real-world applications

PSO2. Determine the conditions for *synthesizing or manufacturing and modifying* different classes of *materials* and understand the relationships between the process conditions and material structure

PSO3. Use theoretical, computational and experimental tools for *designing materials*, their synthesis and modification into products to meet specific requirements for various applications

Proposed New Curriculum and New Courses
for
MTech Materials Science & Engineering
Amrita Vishwa Vidyapeetham, Coimbatore

CURRICULUM

I Semester

Course Code	Type	Subject	L T P	Credits
22MA601	FC	Mathematical Foundations for Materials Science	2-1-0	3
22MS601	FC	Engineering Materials	3-0-0	3
22MS602	FC	Materials Thermodynamics	3-1-0	4
22MS603	FC	Electronic Materials Science	4-0-0	4
22MS604	SC	Advanced Materials	4-0-0	4
22MS681	SC	Materials Synthesis Lab	0-0-2	1
22AVP103	HU	Mastery Over Mind	1 0 2	2
21HU601	HU	Amrita Values Program*		P/F
21HU602	HU	Career Competency I		P/F
		Credits		**21**

II Semester

Course Code	Type	Subject	L T P	Credits
22MS611	SC	Materials Processing	4-0-0	4
22MS612	FC	Physical & Mechanical Metallurgy	4-0-0	4
	E	Elective I	3-0-0	3
	E	Elective II	3-0-0	3
22MS613	SC	Materials Structural Characterization	3-0-2	4
21HU603	HU	Career Competency II	0-0-2	1
21EN600	HU	Technical Writing*		P/F
		Credits		**19**

III Semester

Course Code	Type	Subject	L T P	Credits
22MS791	P	Materials Design		3
	E	Elective III	3-0-0	3
22MS781	SC	Materials Performance Analysis Lab	0-0-2	1
22MS798	P	Dissertation – Mini Project		10
		Credits		**17**

IV Semester

Course Code	Type	Subject	L T P	Credits
22MS799	P	Dissertation – Major Project		16
		Credits		**16**
		Total Credits		**73**

List of Courses

Foundation Core

Course Code	Subject	L T P	Credits
22MA601	Mathematical Foundations for Materials Science	2-1-0	3
22MS601	Engineering Materials	3-0-0	3
22MS602	Materials Thermodynamics	3-1-0	4
22MS603	Electronic Materials Science	4-0-0	4
22MS612	Physical & Mechanical Metallurgy	4-0-0	4

Subject Core

Course Code	Subject	L T P	Credits
22MS604	Advanced Materials	4-0-0	4
22MS611	Materials Processing	4-0-0	4
22MS681	Materials Synthesis Lab	0-0-2	1
22MS613	Materials Structural Characterization	3-0-2	4
22MS781	Materials Performance Analysis Lab	0-0-2	1

Project

Course Code	Subject	L T P	Credits
22MS791	Materials Design		3
22MS798	Dissertation – Mini Project		10
22MS799	Dissertation – Major Project		16

Electives

Course Code	Subject	L T P	Credits
22MS631	Statistical Design of Experiments	3-0-0	3
22MS632	Processing of Polymeric Materials	3-0-0	3
22MS633	Electrochemistry and Corrosion	3-0-0	3
22MS634	Catalytic Chemistry	3-0-0	3
22MS635	Carbon Nanomaterials	3-0-0	3
22MS636	Interfacial Science and Engineering	3-0-0	3
22MS637	Waste to Energy	3-0-0	3
22MS638	Solar Energy	3-0-0	3
22MS639	Energy Storage Technologies	3-0-0	3
22MS640	Computational Materials Science	3-0-0	3
22MS641	Design for Sustainable Development	3-0-0	3
22MS642	Biomaterials	3-0-0	3
22MS643	Ceramic Materials	3-0-0	3

In addition to the above list, students will be able to take courses from other M. Tech programs subject to their offering and pre-requisites being met.

SYLLABUS

22MA601 MATHEMATICAL FOUNDATIONS FOR MATERIALS SCIENCE 2-1-0-3

Prerequisite: Nil

Mathematical representation of problems – Vector & Matrix Algebra: Vector spaces, Linear independence, Basis of a space, Basics of Matrix Algebra, Eigenvalues & Eigenvectors; Basics of Numerical Analysis: Error analysis, Computations of errors of algorithms, Stiffness of algorithms, Interpolation (Lagrange approximation), Polynomial approximation and curve fitting (Newton method), Numerical differentiation and integration (Trapezoidal and Simpson's rules); Linear Algebraic Equations: $Ax = b$ (Gauss-Jordan and Gauss-Siedel), Numerical techniques for ODEs (Euler method, Runge-Kutta method); Partial Differential Equations: Numerical techniques for parabolic and elliptic equations – finite differences, use of MATLAB for solving problems in Materials Science and Engineering

TEXTBOOK/REFERENCE:
1. A. K. Ray and S. K. Gupta, Mathematical Methods in Chemical and Environmental Engineering, Second Edition, Cengage Learning Asia, 2003.
2. E. Kreyszig, Advanced Engineering Mathematics, Ninth Edition, John Wiley & Sons, 2006.
3. V. G. Jenson and G. V. Jeffreys, Mathematical Methods in Chemical Engineering, Second Edition, Academic Press, San Diego, 1978.
4. M. K. Jain, S. R. K. Iyengar and R. K. Jain, Numerical Methods for Scientific and Engineering Computation, Fifth Edition, New Age International, New Delhi, 2008.
5. P. Ahuja, Introduction to Numerical Methods in Chemical Engineering, Prentice Hall India, 2010

CO Code 22MA601	**Course outcome statement**
CO.1	Formulate mathematical problems and identify the correct numerical methods for solving them
CO.2	Represent systems using linear algebraic equations (scalar and vector), ordinary differential equations, and partial differential equations and understand the methodology of solving them, for material and conceptual reconciliation in physical systems
CO.3	Understand and apply techniques of curve-fitting, interpolation, numerical differentiation and integration to aid in mathematical modelling of relationships in coordinate data.

CO Code 22MA601	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	1		3			3
CO.2	1		3			3
CO.3	2		3			3

22MS601 **ENGINEERING MATERIALS** **3-0-0-3**

Prerequisite: Nil

Classification of Engineering Materials: Metals, Ceramics, Polymers, Composites and Their Types; Material Structure, Bonding, Crystals: Lattice, Points, Directions, Planes – Miller Indices, Reciprocal Lattice, Crystal Systems and Bravais Lattices, Primitive and Non-primitive Cells; Crystal Defects: Point Defects, Frenkel and Schottky Defects, Line and Planar Defects, Grain Boundaries; Diffusion in Solids: Fick's 1^{st} and 2^{nd} laws, Ideal solutions, Kirkendall Effect, Darkenn's Analysis, Estimation of Diffusion Coefficient; Solid Solutions, Intermetallics; Cooling Curves and Phase Diagrams: Isomorphous and Eutectic Phase Diagrams; Iron-Carbon Phase Diagram: Cast Iron and Steels; Phase Diagrams of Non-Ferrous Metals & Alloys

TEXTBOOK/REFERENCE:

1. W. D. Callister, Jr., D. G. Rethwisch, "*Materials Science and Engineering: An Introduction*", Tenth Edition, Wiley, 2018.
2. W. F. Smith, J. Hashemi and R. Prakash, "*Materials Science and Engineering*", Fourth Edition, Tata Mc Graw Hill, 2008.
3. D. Askeland, P. Fulay, W. J. Wright and K. Balani, "*The Science and Engineering of Materials*", Sixth Edition, Cengage, 2012.
4. S. H. Avner, "*Introduction to Physical Metallurgy*", Second Edition, McGraw Hill, 1997.
5. V. Raghavan, "*Materials Science and Engineering: A First Course*", Fifth Edition, Prentice Hall India, 2004.

CO Code 22MS601	**Course outcome statement**
CO.1	Understand various types of engineering materials used in the industrial and domestic applications
CO.2	Understand crystal structure, defects, grain boundary and diffusion effects in metals, ceramics and semiconductors; conformations and properties of various polymers and composites
CO.3	Analyze the phase diagrams, heat treatment methods, structure and properties of metals and metal alloys
CO.4	Understand the principles of designing and preparing engineering materials with desirable properties for performance improvements in systems and devices

CO Code 22MS601	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	1	1	3	3		
CO.2	1	1	3	3		
CO.3	1	1	3	2	3	
CO.4	1	1	3	3	3	3

22MS602 MATERIALS THERMODYNAMICS 3-1-0-4

Prerequisite: Nil

Entropy – Statistical Meaning; Combined First and Second Laws; Physical Meaning of Entropy, Pressure, and Chemical Potential; Postulational Approach to Thermodynamics: Criteria for Thermodynamic Equilibrium, Euler and Gibbs-Duhem Equations, Phase Rule, Thermodynamic Potentials, and Criteria for Stability; Liquid and Solid Equilibria; Mixtures and Solutions: Raoult's and Henry's Laws; Gibbs Free Energy of Solution; Activity Coefficients and Models; Ideal, Regular and Sub-Regular Solutions; Phase Diagrams; Reactions involving Pure Condensed Phases - Ellingham Diagrams, Effects of Phase Transformations; Phase Diagrams of Binary Systems - Isomorphous, Eutectic, and Peritectic Systems; Disorder-to-order transformations, ordered alloys, thermodynamics of point defects, surfaces, and interfaces, Glass science; First-order and other transitions; Amorphous and Glassy materials; Thermodynamics of Nucleation; Stability

TEXTBOOK/REFERENCE:

1. D. R. Gaskell, "*Introduction to the Thermodynamics of Materials*", Fifth Edition, Taylor & Francis, New York, 2008
2. A. Ghosh, "*Textbook of Materials and Metallugrical Thermodynamics*", Prentice Hall India, 2002.
3. Y. A. Cengel and M. A. Boles, "*Thermodynamics: An Engineering Approach*", Seventh Edition, Tata McGraw Hill, 2011.
4. Y.V.C. Rao, "*Chemical Engineering Thermodynamics*", Universities Press, New Delhi, 2097.
5. J. P. O'Connell and J. M. Haile, "*Thermodynamics: Fundamentals for Applications*", Cambridge University Press, 2005.

CO Code 22MS602	**Course outcome statement**
CO.1	Understand the fundamentals of thermodynamics, energy & entropy, heat & work, processes, equilibrium and phase change
CO.2	Understand the fundamentals of ideal solutions, real solutions and origin of miscibility gap.
CO.3	Understand the origin of isomorphous and eutectic phase diagrams and apply them in manufacturing processes
CO.4	Understand thermodynamic necessity for existence of defects, predict defect formation and understand disorder-to-order transformations
CO.5	Understand the nucleation process and differentiate homogeneous nucleation & heterogeneous nucleation in terms of free energy and kinetics.

CO Code 22MS602	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO 3**
CO.1	2		3	1		2
CO.2	2		3	1		2

CO.3	2		3	2	3	3
CO.4	2		3	2	3	3
CO.5	2		3		3	3

22MS603 ELECTRONIC MATERIALS SCIENCE 4-0-0-4

Prerequisite: Nil

Electrical Conduction in Solids – Metals, Semiconductors, Ionic Solids; Drude Model, Factors Affecting Resistivity: Temperature and Impurities, Alloys, Mattheissen and Nordheim Rules, Resistivities of Mixed Solid Phases, Hall Effect; Basic Quantum Physics – Atomic Structure, Molecular Orbital Theory, Band Theory and Occupation Statistics in Metals and Non-Metals; Fermi Level; Conductivity of Metals; Metal-Metal Junction: Contact Potential, Seebeck and Peltier Effects; Thermocouples; Intrinsic and Extrinsic Semiconductors; Temperature Dependence of Conductivity; Recombination and Trapping; Drift and Diffusion Currents; Working of Semiconductor Devices using Band Diagrams and their Electrical Characteristics: *pn* junctions, Forward and Reverse Bias, BJT, MOSFET; Dielectric Properties of Materials: Polarization and Permittivity, Mechanisms of Polarization, Dielectric Properties – Dielectric Constant, Dielectric Loss, Dielectric Strength and Breakdown, Piezoelectricity, Ferreoelectricity, and Pyroelectricity; Magnetic properties and Superconductivity: Magnetic moments and Magnetic Permeability, Types of magnetism, Saturation magnetization, Magnetic domains, Soft and Hard Magnetic Materials, Superconductivity and its Origin, Giant Magneto Resistance, Josephson effect, Applications – Magnetic Recording; Optical Properties of Materials: Reflection, Refraction, Dispersion, Refractive Index, Snells Law, Light Absorption and Emission, Light Scattering, Luminescence, Polarization, Anisotropy, Birefringerence; Optoelectronic Properties of Materials and Optoelectronic Devices: LEDs, Solar Cells, Lasers, pin diodes, photodiodes; Thermal Properties of Materials: Heat Capacity, Thermal Expansion, Thermal Conductivity, Thermal Stresses

TEXTBOOK/REFERENCE:

1. S. O. Kasap, “*Principles of Electronic Materials and Devices*”, 2006, Third Edition, Tata McGraw Hill.
2. W. D. Callister, Jr., “*Materials Science and Engineering*”, 2006, Sixth Edition, Wiley India.
3. D. Jiles, “*Introduction to the Electronic Properties of Materials*”, Chapman & Hall. 1994.

CO Code 22MS603	**Course outcome statement**
CO.1	Understand the mechanisms and models of electrical and thermal conduction in metals semiconductors and dielectrics based on classical and quantum models
CO.2	Apply the classical and quantum models to junctions involving metals, insulators and semiconductors
CO.3	Understand the origin of polarization in dielectric materials, piezoelectricity, ferroelectricity and pyroelectricity, and apply the classical and quantum models to

	predict polarization
CO.4	Understand the origin of magnetism and magnetic properties of materials, and analyse their behaviour in different applications
CO.5	Understand optical properties of materials and analyse their application in optoelectronic devices; Understand thermal properties and their origins

CO Code 22MS603	PO1	PO2	PO3	PSO1	PSO2	PSO3
CO.1	2		2	3	2	3
CO.2	2		2	3	2	3
CO.3	2		2	3	2	3
CO.4	2		2	3	2	3
CO.5	2		2	3	2	3

22MS611 MATERIALS PROCESSING 4-0-0-4

Prerequisite: 21MS601

Metals and Alloys
Metal casting; forming and shaping processes: rolling, forging, extrusion, drawing, sheet and metal forming; joining processes: welding, machining; Powder metallurgy: pressing and sintering; Drilling, milling, cutting; grinding
Ceramics
Glass working; Processing of traditional, new ceramics and cermets; powder pressing, tape casting
Polymers
Polymerisation: Condensation, Addition, Bulk, Solution, Suspension, Emulsion; Polymer Processing: Mixing, extrusion, moulding, spinning, casting, calendaring, joining, foam processing, rubber processing, and machining of plastics, processing of polymer matrix composites, solvent cementing, adhesive bonding
Nanomaterials
Top-down and bottom-up approach; optical and E-beam lithography, MBE, etching, vacuum processing/PVD and CVD; molecular self-assembly; nanoparticle synthesis – sol gel, solid phase, solvothermal and co-precipitation processes

TEXTBOOK/REFERENCE:

1. S. Kalpakjian and S. R. Schmid, "*Manufacturing Engineering and Technology*", Fourth Edition, Pearson Education India, 2002.
2. M. P. Groover, "*Principles of Modern Manufacturing*", Fifth Edition, SI Version, Wiley India, 2014.
3. M. D. Ventra, S. Evoy and J. R. Heflin, "*Introduction to Nanoscale Science and Technology*",

Kluwer Academic Publishers, 2004.
4. Chanda and S. K. Roy, "*Plastics Technology Handbook*", CRC Press, Atlanta, 2007.
5. A. Ghosh and A.K. Mallik, "*Manufacturing Science*", Affiliated East-West Press Pvt. Ltd., 2010.

CO Code 22MS611	**Course outcome statement**
CO.1	Understand the forming, shaping, and joining processes employed for metallic materials
CO.2	Understand the various processes for the manufacture of ceramic products
CO.3	Classify and explain different polymerization processes; Comprehend various plastics conversion techniques
CO.4	Understand the various approaches for nanomaterials synthesis

CO Code 22MS611	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	3	2	3	3	2	2
CO.2	3	2	3	3	2	2
CO.3	3	2	3	3	3	3
CO.4	2	2	3	3	2	3

22MS612 PHYSICAL AND MECHANICAL METALLURGY 4-0-0-4

Prerequisite: 21MS601

Review of Crystal Structure and Defects; Mechanical Properties of Metals and Alloys: Tensile, Impact, Hardness, Creep; Elastic Deformation: Characteristics of Elastic Deformation, Atomic Mechanisms of Elastic Deformation; Inelastic Deformation: Strain–Time Curves; Plastic Deformation: Mechanism of Plastic Deformation, Slip and Twinning; Strengthening Mechanisms: Work Hardening, Grain Boundary Hardening, Dispersion Hardening; Creep: Primary, Secondary and Tertiary Creep; Fracture: Ideal Fracture Stress, Brittle Fracture, Griffith's Theory, Cup and Cone-type Fracture, Schmidt's Law, Critical Resolved Shear Stress; Fatigue: S-N curves, Endurance Limit; Materials Damage: Wear, Corrosion, Failure

Phase Diagrams of Non-Ferrous Systems: Brass, Bronze, Aluminum, Magnesium, Nickel, Lead, Tin, Titanium, Zinc Alloys; Steel: Heat Treatment, Alloy Steels: Influence of Alloying Elements on Iron-Iron Carbide Phase Diagram, Effects on Properties of Steel, Stainless Steels: Austenitic, Martensitic, Ferritic, Heat-Resistant Steels, Maraging Steels, Tool Steels

TEXTBOOK/REFERENCE:

1. W.D. Callister, "*Materials Science and Engineering*", Sixth Edition, John Wiley & Sons, 2003.
2. S. H. Avner, "*Introduction to Physical Metallurgy*", Second Edition McGraw Hill, 1997.
3. R. E. Reed-Hill, "*Physical Metallurgy Principles*", Affiliated East-West Press, 2008.
4. G. E. Deiter, "*Mechanical Metallurgy*", McGraw Hill Education, 2017.

5. V. Raghavan, “*Materials Science and Engineering: A First Course*”, Fifth Edition, Prentice Hall India, 2004.

CO Code 22MS612	**Course outcome statement**
CO.1	Recall and understand the structure of solids and the various crystal imperfections.
CO.2	Understand the types of deformations in solids and the failure patterns.
CO.3	Suggest and explain testing methodologies for the characterization of different categories of materials
CO.4	Interpret phase diagrams of alloys with special reference to Iron-Carbon and non-ferrous systems
CO.5	Understand the concept of heat treatment of steels & strengthening mechanisms

CO Code 22MS612	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO 3**
CO.1	2		3	3		
CO.2	2		3	3	2	3
CO.3	2		3	3	2	3
CO.4	2		3	3	2	3
CO.5	2		3	3	3	3

22MS604 ADVANCED MATERIALS 4-0-0-4

Prerequisite: Nil

Nanomaterials Fundamentals: Atomic Structure, molecules and phase, 0-D, 1-D, 2-D and 3-D nanomaterials, nanostructured metals, MO_x, MS_x, and nanocarbon; structure-property relationships – optical, catalytic, mechanical, thermal, electrical properties; MEMS and NEMS nanoscale Optoelectronics

Polymers: Types, Commodity Plastics: PE, PP, PVC, PS; Engineering Plastics: PA, Fluoropolymers, Polyesters; Thermosets – Phenolics and Epoxy Resins; Rubbers: Natural and Synthetic, Additives; High-Performance Polymers: PEEK; Structure-Property Relationships: Chemical Properties, Solubility, Mechanical Properties, Calorimetric Properties, Electrical Properties, Optical Properties, Acoustic Properties, Processability; Smart Materials: Shape Memory Alloys, Super Alloys, High Entropy Alloys, Magnetorheological and Electrorheological Fluids, Gels

TEXTBOOK/REFERENCE:

1. M. A. Ratner and D. Ratner, "*Nanotechnology: A Gentle Introduction to the Next Big Idea*", Prentice Hall, 2002.
2. M. Wilson, K. Kannangara, G. Smith, M. Simmons and B. Raguse, "*Nanotechnology: Basic Science and Emerging Technologies*", Chapman and Hall, 2002.
3. A. Nouailhat, "*An Introduction to Nanosciences and Nanotechnology*", Wiley-ISTE, 2008.
4. J. A. Brydson,"*Plastics Materials*", Butterworth-Heinemann, Seventh Edition, Oxford, 1999.
5. M. Morton, "*Rubber Technology*", Third Edition, Kluwer Academic Publishers, Dordrecht, Netherlands, 1999.

CO Code **22MS604**	**Course outcome statement**
CO.1	Outline the structure, properties and applications of nanomaterials
CO.2	Outline the structure, properties, processing and applications of common thermoplastics, thermosets and elastomers.
CO.3	Summarize the properties and applications of some smart materials and systems

CO Code 22MS604	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1		1	3	3	1	3
CO.2		1	3	3	3	3
CO.3		1	3	2	2	3

22MS791 MATERIALS DESIGN 3 credits

Prerequisite: 21MS601, 21MS603, 21MS605, 21MS612, 21MS613

This is a project-based course. The student will be assigned *three to six* case studies in designing materials for specific applications wherein properties such as Density, Mechanical, Thermal, Electrical, Magnetic, Optical, Reactivity, and Catalytic Properties will be relevant. Student has to translate an application requirement to (i) product specifications (ii) translate to functions, constraints, design objectives and identify free variables (iii) screen using constraints (use property charts) (iv) rank based on design objectives (v) prepare material documentation. In doing so, the student has to identify and utilize relevant process-structure-property-function relationships in materials to carry out design of (i) material (ii) its processing.

Lectures on materials design, selection and product/process development, preferably by industry experts will be included.

TEXTBOOK/REFERENCE:

1. M. Ashby, H. Shercliff and D. Cebon, "*Materials: Engineering, Science, Processing and Design*", Second Edition, Butterworth-Heinemann, 2010
2. U. Schubert and N. Hüsing, "*Synthesis of Inorganic Materials*", Third Edition, Wiley-VCH, 2012
3. Selected recent papers published in reputed international journals discussing materials design - for case studies

CO Code 22MS791	**Course outcome statement**
CO.1	Understand the material manufacturing process tree and material property charts
CO.2	Understand the materials design and materials selection process
CO.3	Connect the material properties, such as mechanical, electrical, thermal, magnetic and electrochemical properties, with structure and apply them for design problems
CO.4	Analyze how to manipulate the material properties to fit in specific applications

CO Code 22MS791	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	1	1	3	2	3	3
CO.2	1	1	3	3	1	3
CO.3	1	1	3	3	1	1
CO.4	1	1	3	3	3	3

22MS681 MATERIALS SYNTHESIS LAB 0-0-2-1

Prerequisite: Nil

The lab will comprise hands-on materials synthesis experiments. Students shall perform 6-8 experiments from among the following:

1. Bulk polymerization
2. Hydrothermal synthesis
3. Electrodeposition of copper
4. Hummers method for graphene oxide,
5. Ball milling of nanostructured metal powders

6. Sol-gel synthesis
7. Solid-state synthesis
8. Spray pyrolysis
9. Self-assembly of monolayers
10. Chemical and ultrasonication-assisted reduction of graphene oxide
11. Electrodeposition of alloys
12. Injection moulding
13. Spin coating of thin films
14. Doctor blade coating of thin films
15. Annealing of materials
16. Sintering of materials

CO Code 22MS681	**Course outcome statement**
CO.1	Discuss the underlying principles behind materials synthesis/modification methods
CO.2	Develop and standardize experimental protocols and carry out experiments for synthesizing/modifying materials
CO.3	Understand the effects of synthesis/modification process conditions on the structure and properties of the obtained materials
CO.4	Prepare systematic record of experiments carried out and interpret the results obtained

CO Code 22MS681	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	3	1	3	2	3	2
CO.2	3	3	3	2	3	2
CO.3	3	1	3	2	3	2
CO.4	3	3	3	2	3	2

22MS613 MATERIALS STRUCTURAL CHARACTERIZATION 3-0-2-4

Prerequisite: 21MS601

Characterization of Materials Structure – Composition, Bonds/Functional Groups, Electronic Band Structure, Crystallinity, Phases, Morphology; Fundamental Principles, Experimental Protocols and Interpretation of Results for 8 to 10 Techniques (italicized ones must be taught, selections from other techniques by instructor)

Atomic and Molecular Spectroscopy: *UV-Visible Spectroscopy*, *Infrared Spectroscopy*, X-ray

Photoelectron Spectroscopy, Mass Spectrometry, Energy Dispersive X-ray Spectroscopy, Atomic Absorption, Fluorescence and Emission Spectroscopy, Raman Spectroscopy

Imaging Microscopies and Image Analysis: *Optical Microscopy*, *Scanning Electron Microscopy*, Scanning Probe Microscopy, Transmission Electron Microscopy, Image Analysis

X-ray and Electron Diffraction: *X-Ray Diffraction*, Selected Area Electron Diffraction; Properties of X-Rays, Review of Crystal Systems and Miller Indices, Stereographic Projections, The Reciprocal Lattice, Laué Equations, Diffraction Methods, Scattered Intensities, Phase Identification, Small Angle Scattering

Thermal and Thermomechanical Techniques: *Thermogravimetric Analysis*, Differential Scanning Calorimetry and Differential Thermal Analysis, Dynamic Mechanical Analysis and Thermomechanical Analysis

TEXTBOOK/REFERENCE:

1. D. A. Skoog, F. J. Holler and S. R. Crouch, "*Principles of Instrumental Analysis*", Sixth Edition, Cengage Learning, New Delhi, 2007.
2. B. D. Cullity and S. R. Stock, "*Elements of X-ray Diffraction*", Third Edition, Prentice Hall Inc., New Jersey, 2001.
3. K.P. Menard, "*Dynamic Mechanical Analysis; A Practical Introduction*", CRC Press, Boca Raton, 1999.
4. S. Zhang, L. Li and A. Kumar, "*Materials Characterization Techniques*", CRC Press, Boca Raton, 2008.
5. Y. Leng, "*Materials Characterization*: *Introduction to Microscopic and Spectroscopic Methods*", Second Edition, Wiely-VCH, 2013.

CO Code 22MS613	**Course outcome statement**
CO.1	Understand the fundamental principles behind the individual characterization methods which are included in the course.
CO.2	Analyze, interpret and present observations from the different characterization methods.
CO.3	Assess which methods of characterization are appropriate for different material / requirement/ condition/ problems.
CO.4	Evaluate the uncertainty of observations and results from the different characterization methods.

CO Code 22MS613	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	3	1	3	3	3	3
CO.2	3	3	3	3	3	3
CO.3	3	1	3	3	3	3
CO.4	3	3	3	3	3	3

22MS781 MATERIALS PERFORMANCE ANALYSIS LAB 0-0-2-1

Prerequisite: 21MS601, 21MS611

Hardness Test, Impact Test, Tensile/Compression Test, Three-Point Bending Analysis, Uv-visible Spectroscopy - Transparency of a Thin Film, Photocatalytic Degradation of a Volatile Organic Compound, Electrical Conductivity - AC and DC, Magnetoresistance, Charge-Discharge of Batteries, Charge-Discharge Behavior of Capacitor, Hall Effect Measurement, I-V Characteristics of a Solar Cell, Energy Storage in a Phase Change Material

CO Code 22MS781	**Course outcome statement**
CO.1	Conduct experiments to validate thermal and electrical behaviour of materials
CO.2	Evaluate the mechanical behaviour of materials under different loading conditions.
CO.3	Suggest materials testing techniques based upon desired results, perform analysis on data, and present test results in a written format

CO Code 22MS781	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	3	1	3	3	3	3
CO.2	3	1	3	3	3	3
CO.3	3	3	3	2	3	3

ELECTIVES

22MS631 STATISTICAL DESIGN OF EXPERIMENTS 3 0 0-3

Prerequisite: Nil

Introduction to the role of experimental design; basic statistical concepts; sampling and sampling distribution; Testing of hypotheses about differences in means - randomized designs and paired comparison designs; testing of hypotheses about variances; Analysis of variance (ANOVA) – one-way classification ANOVA; analysis of fixed effects model; comparison of individual treatment means; the random effects model; the randomized complete block design; Principle of Least Squares and Linear Regression; Model assumptions and residual analysis; 2^k Factorial and Fractional Factorial Designs (Plackett-Burman); concepts of coded & un-coded variables, repetition, replication, and randomization; graphical and numerical analysis; concepts of confounding and orthogonal contrasts; model interpretation, checking of model assumptions, predictions, and simultaneous optimization; Split-plot designs; Response Surface Methodology – central composite designs (structure, rotatability, orthogonality, types of CCD, analysis); Box-Behnken designs; Mixture designs - structure, analysis, and applications; Basics of Taguchi designs

TEXTBOOK/REFERENCE:

1. D. C. Montgomery, "*Design and Analysis of Experiments*", Sixth edition. New York, New York: John Wiley & Sons, 2005.
2. Box, Hunter, and Hunter, "*Statistics for Experiments*", Second edition. Wiley-Interscience, 2005.
3. J. Antony, "*Design of Experiments for Engineers & Scientists*", Butterworth-Heinemann, 2003.
4. Z. Lazic, "*Design of Experiments in Chemical Engineering*". Wiley-VCH, Weinheim, 2004.

CO Code 22MS631	**Course Outcome Statement**
CO.1	Understand the role of statistics in experimental research, and apply numerical methods for descriptive and graphical representation of data
CO.2	Understand and apply concepts of probability distributions for modeling variation in sampling statistics
CO.3	Formulate and test statistical hypothesis on population mean, variance, and proportion to aid in answering research questions
CO.4	Understand the theory of statistical design of experiments, and create designs for real-world research questions
CO.5	Apply concepts of hypothesis testing and linear regression to analyze experimental data from different types of designs (factorial, response surface, and mixture)

COCode 22MS631	PO1	PO2	PO3	PSO1	PSO2	PSO3
CO.1	3	2	1		1	2
CO.2	2	1	1		1	2
CO.3	2	1	1		2	2
CO.4	3	2	3		3	3
CO.5	3	2	3		3	3

22MS632 PROCESSING OF POLYMERIC MATERIALS 3-0-0-3

Prerequisite: Nil

Physical Basis of Polymer Processing- Mixing- Types of mixing processes. Extrusion-Features of a Single Screw Extruder, Analysis of Flow, Wire and Cable coating, Fibre, Film and sheet extrusion, Co Extrusion-Melt Fracture-Sharkskin-Die swell. Injection Moulding-Principles-Moulding Cycle-Reciprocating Screw Injection Moulding Machine-Types of Clamping Units-PVT diagram- -Hot Runner Moulding-Gas Assisted Injection Moulding. Blow Moulding-P-Injection Blow Moulding-Extrusion Blow Moulding-Stretch Blow Moulding.

Thermoforming-Vacuum Forming-Pressure Forming-Material Stress and Orientation- Compression and Transfer Moulding-Thermosetting Compounds-Flash, Semi Positive, Positive Type Moulds- -Comparison. Fibre Reinforced Plastics-Materials-Lay-up processes-SMC, DMC-Resin Transfer Moulding- Pultrusion, Bag Moulding Processes-Filament Winding-Process Variants-Newer developments using thermosets. Polymers in Rubbery State- Calendaring Process-Types of Calendars, Roll Deflection, Roll Cambering-Rotational Moulding-Types of Machines, Joining and Machining of Plastics-Welding of Plastics- Solvent Cementing-Adhesive Bonding.

Rheology –Newtonian and Non-Newtonian fluids – time dependent fluids – isothermal viscous flow in tubes – Entrance and exit effects - elastic effects in polymer melt flow - die- swell and melt fracture – Weissenberg effect - Extensional Viscosity. Measurement of rheological properties – capillary rheometers – melt flow indexer – cone and plate viscometer – torque rheometers

References

1. Michael L Berins (ed), “Plastics Engineering Handbook Society of Plastics Industry”, Kluwer Academic Publishers, 2000
2. B. R. Gupta, “Applied Rheology in Polymer Processing”, Asian Books Pvt Ltd, New Delhi, 2005
3. R. J. Crawford, “Plastics Engineering”, Butterworth-Heinemann, Oxford, 1998
4. D.V. Rosato and Rosato, “Injection Moulding Handbook Complete Molding Operatio, Technology, Performance and Economics”, CBS Publishers New Delhi, 1987.
5. John M. Dealy and Kurt F. Wissburn, “Melt Rheology and its Role in Plastics Processing”, Chapman, London, 1995.

CO Code 22MS632	Course outcome statement

CO.1	Gain an overview of different type of polymer processing techniques: Injection, extrusion, blow, thermoforming, compression and transfer moulding, composites processing
CO.2	Understand the processing parameters and troubleshooting techniques specific to various polymer processing operations
CO.3	Understand the rheological properties of the polymers and their influence in polymer processing

CO Code 22MS632	PO1	PO2	PO3	PSO1	PSO2	PSO3
CO.1	3	2	3	3	2	2
CO.2	3	2	2	3	2	2
CO.3	3	2	2	3	3	3

22MS633 ELECTROCHEMISTRY & CORROSION 3-0-0-3

Prerequisite: Nil

Fundamentals of Electrochemistry: Arrhenius theory of dissociation, Solvation, Mobility, Transport Number; Ionics: Guoy-Chapman and Debye-Huckel theories of ion-ion interaction; Electrified Interface: Structure of electrode-electrolyte interface – Non-Faradaic processes, Thermodynamic activity, Electrochemical potential and Nernst Equation; Mass Transfer in Electrolytes – Convection, Diffusion, and Migration; Electrode Kinetics – Butler-Volmer Equation, Tafel Equation, Polarization of Electrodes – Activation and Concentration polarization, Reaction Mechanisms in Electrochemistry – Rate Laws; Electroanalytical Techniques: Conductometric and Potentiometric Titrations, Potential Step Methods – Chronoamperometry, Potential Sweep Methods – Linear Sweep Voltammetry and Cyclic Voltammetry: Reversible, Quasireversible, and Irreversible Systems; Pulse Voltammetry – Normal Pulse, Differential Pulse, and Square Wave Voltammetry; Electrochemical Impedance Analysis;

Corrosion: Forms of Corrosion, Determining Rates of Corrosion, Corrosion Prevention: Materials Selection, Coatings, Cathodic Protection, Passivation, Corrosion Inhibitors; Selected Applications such as Electrodeposition of Alloys, Batteries, Fuel Cells, and Electrochemical Sensors

TEXTBOOK/REFERENCE:

1. J. O'M. Bockris and A. K. N. Reddy, "*Modern Electrochemistry*" Volumes 1, 2A, and 2B, Second Edition, Kluwer Academic Publishers, NY, 2000
2. A. J. Bard and L. R. Faulkner, "*Electrochemical Methods: Fundamentals and Applications*", Second Edition, John Wiley and Sons, NY, 2001
3. V. S. Bagotsky, "*Fundamentals of Electrochemistry*", Second Edition, Wiley-Interscience, 2006
4. M. Fontana, "*Corrosion Engineering*", Third Edition, McGraw Hill Indian Edition, 2017

CO Code 22MS633	**Course outcome statement**
CO.1	Understand how ions behave in solution by way of ion-solvent and ion-ion interactions. Understand and explain the theories that capture this behaviour and analyse how they affect ion mobility and transport number in an electrolyte.
CO.2	Understand and describe the structure of an electrified double layer. Analyse the non-Faradaic processes that take place in electrochemical systems. Develop and apply thermodynamic principles for electrochemical systems.
CO.3	Understand how mass transport occurs in electrochemical systems. Develop and apply relations to interpret the behaviour of electrochemical systems under diffusion-controlled conditions.
CO.4	Understand how an electrochemical reaction takes place at an electrode-electrolyte interface. Derive and apply the relevant equations for electrode kinetics in different electrochemical systems. Understand polarization and how the different polarizations affect the Faradaic response of an electrochemical system.
CO.5	Understand how different electroanalytical techniques may be constructed to analyse an electrochemical system. Develop and apply the basic principles and equations of techniques such as chronoampero/coulometry, linear/cyclic voltammetry, pulse voltammetry and electrochemical impedance spectroscopy to analyse electrochemical processes.
CO.6	Understand the principles and forms of corrosion. Analyse how various factors influence the rate of corrosion. Apply electroanalytical techniques to understand corrosion behaviour. Describe the different methods to control corrosion and evaluate their applicability under different conditions.

CO Code 22MS633	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	1		3	3	1	1
CO.2	1		3	3	1	1
CO.3	1		3	3	2	1
CO.4	1		3	3	2	2
CO.5	1		3	3	1	2
CO.6	1		3	3	2	3

22MS634 **CATALYTIC CHEMISTRY** **3-0-0-3**

Prerequisite: Nil

Catalysis – introduction, Catalyst and catalysis, positive and negative catalysis, Type of catalysis, Characteristics of catalytic reactions, promoters, Catalytic poisoning, Catalysis in gas phase – examples, Catalysis in solution phase – Homogeneous catalysis – acid base catalysis, oxidation reactions, heterogeneous catalysis – introduction, organometallic catalysis, metallocenes, Ziegler Natta catalyst, phase transfer catalysts and various industrially employed reactions
Enzyme catalysis –introduction, classification, mechanism of enzyme catalysis, characteristics of enzyme catalysis, metalloenzymes, solid support, application of catalysis in industries.
Catalysis by zeolites – introduction, classifications, synthesis, examples of various reactions and functional modification on zeolite surface.

TEXTBOOK/REFERENCES:

1. Catalytic Chemistry, Bruce C Gates, John Wiley and sons USA (1992)
2. Concise Coordination Chemistry, Gopalan and Rajalingam
3. Physical Chemistry for Engineering Students, Puri, Sharma and Pathania
4. Principles of Chemical Kinetics, James E house, Academic press (2007)
5. Catalysis, Principles and Applications, Viswanathan, Sivashankar and Ramaswamy, CRC press (2006).

CO Code 22MS634	**Course outcome statement**
CO.1	Understand the fundamentals, types and characteristics of catalysis
CO.2	Understand the catalytic reactions in gas phase and solution phase
CO.3	Understand homogeneous catalysis and heterogeneous catalysis
CO.4	Understand the enzyme catalysis and catalysis by zeolites.

CO Code 22MS634	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	3	2	3	3	2	2
CO.2	3	2	2	3	2	3
CO.3	2	2	3	2	3	3
CO.4	2	2	3	2	2	3

22MS635 CARBON NANOMATERIALS 3-0-0-3

Prerequisite: Nil

Graphene: Synthesis, Properties, and Applications; Fullerene C60 Architectures in Materials Science; Graphite Whiskers, Cones, and Polyhedral Crystals; Epitaxial Graphene and Carbon Nanotubes on Silicon Carbide; Cooperative Interaction - Crystallization, and Properties of Polymer–Carbon Nanotube Nanocomposites; Carbon Nanotube Biosensors; Carbon Nanostructures in Biomedical Applications, Field Emission from Carbon Nanotubes; Nanocrystalline Diamond; Carbon Onions; Carbide-Derived Carbons; Templated and Ordered Mesoporous Carbons; Oxidation and Purification of Carbon Nanostructures; Hydrothermal Synthesis of Nano-Carbons; Carbon Nanomaterials for Water Desalination by Capacitive Deionization; Carbon Nanotubes for Photoinduced Energy Conversion Applications;

TEXTBOOK/REFERENCE:

1. Yury Gogotsi, Volker Presser, "*Carbon Nanomaterials*", *2nd ed., CRC Press, 2013*
2. Francis and Karl M. Kadish, *"Handbook of Carbon Nanomaterils", Vol.1&2, World Scientific, 2011*
3. Relevant journal articles

CO Code 22MS635	**Course outcome statement**
CO.1	Describe the methods of synthesizing and modifying carbon nanomaterials including graphene, fullerenes, CNTs, Graphite whiskers, cones, and polyhedral crystals.
CO.2	Explain the methods of characterizing carbon nanomaterials.
CO.3	Apply carbon nanomaterials in the fields of biosensors, biomedicine, water desalination, and photo-induced energy conversion.

CO Code 22MS635	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1		1	3	3	3	1
CO.2		1	3	2	2	1
CO.3		1	3	2	2	3

22MS636 INTERFACIAL SCIENCE & ENGINEERING 3-0-0-3

Prerequisite: Nil

Introduction to Surfaces, Interfaces, and Colloids; Surface and Interface – Molecular Origin, the work of cohesion and adhesion, Surfactants structure, types Interaction forces and potential, chemical and physical interaction, classification of physical forces. Van der Waals force, interaction between surface and particles - Electrostatic forces and electric double layer; DLVO theory, Hamaker constant, Boltzmann distribution, Debye length, specific ion adsorption, ion adsorption, Stern layer, Electrostatic, steric and electrosteric stabilization, zeta potential, surface tension, wetting and spreading, Young's equation, contact angle - Solid surfaces - surface mobility, characteristics, formation; Adsorption, energy consideration of physical adsorption vs. chemisorptions, Gibbs surface excess, Gibbs adsorption equation, Langmuir isotherm, BET isotherm, adsorption at solid-liquid interfaces - Stability of colloids – Emulsions, formation and stability, HLB number, PIT (phase inversion temperature) Foams, Aerosols, Microemulsions, Vesicles, Micelles and Membranes - Applications of various colloidal systems

TEXTBOOK/REFERENCE:

1. D. Myers, "Surfaces, Interfaces, and Colloids: Principles and Applications", 2nd Edition, Wiley-VCH, 1999.
2. T. Cosgrove, "Colloid Science: Principles, Methods and Applications", 2nd Edition, Wiley-Blackwell, 2010.
3. P.C. Hiemenz and R. Rajagopalan (Editors), "Principles of Colloid and Surface Chemistry", 3rd Edition, Academic Press, New York, 1997.

CO Code 22MS636	**Course outcome statement**
CO.1	Understand the fundamental theories associated with the surface and interface properties
CO.2	Study the surface and interfacial phenomena of thin film coatings and colloids
CO.3	Analyze the role of surface and interface properties in the processings of different industrial products, intermediates and raw materials
CO.4	Design of new product formulations with superior surface and interface properties

CO Code 22MS636	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO 3**
CO.1	2		3	2	2	2
CO.2	2		3	2	2	2
CO.3	2		3	2	3	3
CO.4	2		3	2	3	3

22MS637 WASTE TO ENERGY 3-0-0-3

Prerequisite: Nil

Waste – energy content, waste classification, waste composition, and waste segregation; Emissions from waste-to-energy technologies; Introduction to gasification, pyrolysis and combustion technology(s); Pyrolysis of waste to liquid fuels – Thermal, catalytic / thermal, catalyst and reactor choice for pyrolysis; Gasification to Liquid fuels via synthesis gas route – Petrol and Diesel production, Processes for waste to value-added chemicals via synthesis gas– Hydrogen production, methanol production, ethanol production – Design and catalyst choice for various technologies;

Gasification to Electricity – A Case study; Biomass – Classification and Composition; Biomass pyrolysis and gasification to engine grade fuels – catalyst and equipment design; Carbon dioxide capture and production of Synthetic fuels; Microbial fuel cells; Phycoremediation

TEXTBOOK/REFERENCE:

1. Gary C. Young, *Municipal Solid Waste Conversion Processes,* John Wiley & Sons Inc., 2010
2. Marc J. Rogoff and Francois Screve, *Waste to Energy: Technologies and Project Implementation*, 2nd Edition, Elsevier Inc., 2011.
3. Avraam Karagiannidis, *Waste to Energy*, Springer-Verlag Limited., 2012
4. E. N. Kalogirou, *Waste-to-Energy Technologies and Global Applications*, CRC Press, 2018
5. M. Goel, M. Sudhakar, R. V. Shahi (ed.), *Carbon Capture, Storage and Utilization*, Routledge, 2018
6. K. Scott and E. H. Yu, *Microbial Electrochemical and Fuel Cells*, Elsevier, 2016
7. Relevant journal articles

CO Code 22MS637	**Course outcome statement**
CO.1	Classify waste based on energy content, phase and composition.
CO.2	Establish a relationship between composition and energy content of the waste.
CO.3	Analyze effect of feed variation and process parameters on waste to energy conversion processes and optimize the same for required output.
CO.4	Evaluate the kinetics of waste to energy process / technologies - Combustion, gasification and pyrolysis

CO Code 22MS637	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO 3**
CO.1	2		3	2	2	2
CO.2	2		3	2	2	2
CO.3	2		3	2	3	3
CO.4	2		3	2	3	3

22MS638 SOLAR ENERGY 3-0-0-3

Prerequisite: Nil

Solar energy: Solar radiation, its measurements and analysis. Solar angles, day length, angle of incidence on tilted surface, Sun path diagrams, Shadow determination. Extraterrestrial characteristics, Effect of earth atmosphere, measurement & estimation on horizontal and tilted surfaces. Solar cell physics: p-n junction, homo and hetro junctions, Metal-semiconductor interface, Dark and illumination characteristics, Figure of merits of solar cell, Efficiency limits, Variation of efficiency with band-gap and temperature, efficiency measurements, high efficiency cells, Tandem structure.

Solar cell fabrication technology: Preparation of metallurgical, Electronic and Solar grade Silicon, Production of Single Crystal 'Si', Chocharlski (CZ) and Float Zone (FZ) method for preparation of silicon, procedure of masking, photolithography and etching, Design of a complete silicon, GaAs, InP solar cell. High efficiency III-V, II-VI multijunction solar cell, a-Si-H based solar cells, Quantum well solar cell, Thermophotovoltaics. Nanosolar cells. Flexible solar cells: Dye-sensitized solar cells; Solution-processed and Perovskite solar cells; Solar photovoltaic system design: Solar cell arrays, system analysis and performance prediction, shadow analysis, reliability, solar cell array design concepts, PV system design, Design process and optimization, Detailed array design, storage autonomy, Voltage regulation, maximum tracking, Power electronic converters for interfacing with load and grid, use of computers in array design, Quick sizing method, Array protection and troubleshooting; Solar Photovoltaic applications – detailed design and economics; Solar Thermal systems: Solar thermal collectors, flat plate collectors, concentrating collectors, solar heating of buildings, solar still, solar water heaters, solar driers; conversion of heat energy in to mechanical energy, solar thermal power generation systems.

TEXTBOOK/REFERENCE:

1. J. W. Twidell and A.D. Weir, "*Renewable Energy Resources*", Second Edition, Taylor & Francis, New York, 2005.
2. H.P. Garg and J. Prakash, "*Solar Energy: Fundamentals & Applications*", Tata McGraw Hill, New Delhi, 1997.
3. S.P. Sukhatme and J.K. Nayak, "*Solar Energy: Principles of Thermal Collection and Storage*", Third Edition, McGraw Hill, New York, 2009.
4. J.F. Kreider and F. Kreith, "*Solar Energy Handbook*", McGraw Hill, New York, 1981.
5. D.Y. Goswami, F. Kreith and J.F. Kreider, "*Principles of Solar Engineering*", Third Edition, CRC Press, Boca Raton, 2015.
6. G. N. Tiwari, Arvind Tiwari, Shyam, "*Handbook of Solar Energy*: *Theory, Analysis and Applications*", Springer, 2016
7. Recent journal articles

CO Code 22MS638	**Course outcome statement**
CO.1	Calculate the solar radiation at a given location, time and tilt.
CO.2	Compare the methods of synthesis and characterization of different solar cells based on Si, GaAs, InP, III-V, II-VI multijunctions, a-Si-H, quantum wells.
CO.3	Design simple photovoltaic systems
CO.4	Outline the main solar thermal devices and systems

CO Code 22MS638	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1		1	3			2
CO.2		1	3	3	3	1
CO.3		1	3	1	1	3
CO.4		1	3	1	1	2

22MS639 ENERGY STORAGE TECHNOLOGIES 3-0-0-3

Prerequisite: Nil

Introduction to energy storage, need for energy storage and different modes of energy storage. Electrochemical Energy storage - Supercapacitors, Materials for Supercapacitors, Batteries, Lead-Acid Batteries, Nickel-Metal Hydride batteries, Lithium-Ion Batteries, Thin-film Batteries, Metal-Air Batteries, Energy Storage for Fuel Cells; Hydrogen storage- Hydrogen Economy, Different modes of hydrogen storage, compressed gas storage, liquid hydrogen storage, metal hydrides, Advanced Materials for Solid-State hydrogen storage; Role of carbon materials in energy conversion and storage - carbon nanotubes, graphene; Other Types of Energy Storage – Flywheels, Superconducting Magnetic Energy Storage (SMES), Pumped Storage Hydroelectricity (PHS), Compressed Air Energy Storage (CAES); Electrolysis of water and Methanation; Electrical energy storage; Thermal Storage; Hydraulic Hydro Energy Storage (HHS); Energy Storage technologies for wind power integration;

TEXTBOOK/REFERENCE:

1. Tetsuya Osaka, Madhav Datta , "*Energy Storage Systems in Electronics*", 1st ed., CRC Press , 2000.
2. David Michael Rowe, "*Thermoelectrics Handbook: Macro to Nano*", CRC Press, 2006.

CO Code 22MS639	Course outcome statement
CO.1	Understand the concept of kinetic and thermodynamic aspects of electrochemical reactions and able to correlate the electrode kinetics with battery operation.
CO.2	Understand the different battery technologies and differentiate with respect to performance and operating conditions
CO.3	Understand the concept of solid-state hydrogen storage and supercapacitor materials and their advantages and disadvantages.
CO.4	Understand other storage technologies, such as mechanical and thermal energy storage.

CO Code 22MS639	PO1	PO2	PO3	PSO1	PSO2	PSO 3
CO.1	1		3			2
CO.2	2		3	2	2	2
CO.3	2		3	2	2	2
CO.4	2		3	2	2	2

22MS640 COMPUTATIONAL MATERIALS SCIENCE 3-0 -0-3

Prerequisite: Nil

Types of Simulations; Length and Time Scales; Information from Molecular Simulations; Benchmarking and Validation with Experiments

Forces and Energies of Interactions; Intraatomic, Interatomic (Primary) and Intermolecular (Secondary) Interactions; Determining Interaction Energies in Lattice and Continuum Systems; Free Energy and Forces; Statistical Thermodynamic Understanding of Entropy; Ensembles – Microcanonical, Canonical, Grand Canonical and Isothermal-Isobaric; Ensemble Averages and Fluctuations; Ergodic Hypothesis; Correlation Functions; Newton’s Laws of Motion – Force to Velocity to Displacement; Dynamics to Equilibrium

Constructing Intermolecular Potentials in Simulations; Random Walks; Periodic Boundary Conditions; Potential Truncation; Neighbor Lists; Cell Structures and Linked Lists; Ewald Sums; Molecular Dynamics: Equations of Motions; Algorithms – Verlet, Leap Frog, Velocity Verlet; Constraints and Checks on Accuracy; Linear Molecules and Hard Spheres; Monte Carlo Simulations: Integration; Importance Sampling; Metropolis Algorithm; Energy Minimization Techniques; Simulations of Gases, Liquids and Solids

TEXTBOOK/REFERENCE:

1. T. Schlick, “*Molecular Modeling and Simulation: An Interdisciplinary Guide*”, Springer, 2002.
2. D. Frenkel and B. Smit, “*Understanding Molecular Simulations: From Algorithms to Applications*”, Second Edition, Academic Press, 2002.
3. M. P. Allen and D. J. Tildesley, *Computer Simulation of Liquids*, Clarendon Press, 1987.
4. K. I. Ramachandran, D. Gopakumar and K. Namboori, “*Computational Chemistry and Molecular Modeling: Principles and Applications*”, Springer, 2008.
5. Journal articles on molecular simulation of molecules of interest.

CO Code 22MS640	**Course outcome statement**
CO.1	Classify molecular simulation approaches, understand their scope and applicability and determine the suitability of simulation approaches for materials engineering problems.
CO.2	Understand the statistics in estimating macroscopic properties from molecular simulations and employ principles of thermodynamics and transport processes for the same.
CO.3	Understand the quantum mechanical model of atoms, molecules and their interactions. Understand the principles and algorithms of quantum mechanical simulations such as Hartree-Fock, DFT, Ab Initio and Semi-Empirical simulations.
CO.4	Apply models of molecular interactions in molecular dynamics and Monte Carlo simulations, understand different algorithms in these simulations and minimization of energy.

CO.5	Gain hands-on skills in simulation techniques, analyse case studies and simulate model cases.

CO Code 22MS640	PO1	PO2	PO3	PSO1	PSO2	PSO3
CO.1	2	1	3	1	1	3
CO.2	2	1	3	1	1	3
CO.3	2	1	3	1	1	3
CO.4	2	1	3	1	1	3
CO.5	2	1		1	1	3

22MS641 DESIGN FOR SUSTAINABLE DEVELOPMENT 3-0-0-3

Prerequisite: Nil

Introduction: Sustainability, Need for Design, interdisciplinary holistic approach. Fundamental concepts: Physics, Thermodynamics, Flow, Stoichiometry, biological processes.

Philosophy of Sustainability: Fundamental causes of unsustainability, justice and sustainability ethics, societal and personal goals.

Principles of Sustainable Design: The design process, cyclical design, goal-based design, systems thinking, Life Cycle Analysis (LCA), Environmental Impact Assessment (EIA), resource management, supply chains, socio-economic considerations. Case studies: Building, Water, Agriculture, Energy, Transportation, Industrial symbiosis.

TEXTBOOK/REFERENCE:

1. Daniel Vallero and Chris Brasier, *Sustainable Design: The Science of Sustainability and Green Engineering*, John Wiley & Sons, Inc., Hoboken, New Jersey, 2008. ISBN 978-0-470-13062-9.
2. W. McDonough and M. Braungart, *Cradle to Cradle: Remaking the Way We Make Things*, North Point Press, New York, 2002.
3. J. M. Benyus, *Biomimicry*, William Morrow, New York, 1997.
4. B. B. Marriott, *Environmental Impact Assessment: A Practical Guide*, McGraw-Hill, New York, 1997.
5. M. Ashby, *Materials and Sustainable Development*, Elsevier, 2016.
6. M. Ashby, *Materials and The Environment*: *Eco-informed Material Choice*, 3rd Edition, Elsevier, 2020.

CO Code 22MS641	Course outcome statement

CO.1	Identify the need for a holistic design approach to achieving sustainability
CO.2	Identify the ethical roots of unsustainability and identify ethics as a prerequisite for sustainable design
CO.3	Design cyclical and sustainable systems meeting the triple bottom line

CO Code 22MS641	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	1	1	3	1	1	3
CO.2	1	1	3	1	1	2
CO.3	1	1	3	1	1	3

22MS642 BIOMATERIALS 3-0-0-3

Prerequisite: Nil

Introduction to Biomaterials – Overview of the Biomedical Product Development Process and Regulation. Basics of Material Structure, Overviews of Metals, Polymers, Ceramics and Natural Materials used in Biomedical Engineering. Surface Modification Methods. Properties and Characterization of Materials.
Structure, Function and Adhesion of Proteins, Cell-Surface Interactions, Blood-Materials Interactions, Molecular and Cellular Host Responses, Biocompatibility, Degradation of Biomaterials, Testing of Biomaterials.
Biomedical Applications of Materials in the Areas - Cardiovascular, Orthopedic, Ophthalmologic, Dental Implants, Sutures, Burn Dressings, Adhesives & Sealants, Bioelectrodes, Biomedical Sensors & Biosensors, Tissue Engineering and Scaffolds.

TEXTBOOK/REFERENCE:

1. Ratner B D, Hoffman A S, Schoen F J and Lemons J E, *Biomaterials Science: An Introduction to Materials in Medicine*, Third Edition, Academic Press, 2012.
2. Hill D, *Design Engineering of Biomaterials for Medical Devices*, John Wiley, 1998.

CO Code 22MS642	**Course outcome statement**

CO.1	Apply the understanding of materials and biocompatibility in designing materials and devices for some biomedical applications
CO.2	Design materials for biomedical applications including cardiovascular, ophthalmologic, orthopedic, dental and other applications
CO.3	Interpret the results from common materials characterization instruments.

CO Code 22MS642	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	1	1	2	3		3
CO.2	1	1	2	3		3
CO.3			2	2		

22MS643 CERAMIC MATERIALS 3-0-0-3

Bonding and structure of ceramic materials; Crystal structure and defects; Defect structures; Structure of silicates; Polymorphic transformations; Raw materials.

Non crystalline ceramics - Structure, requirement for Glass formation, Zachariasen rules, Ciscosity based transition points, Devitrification; Glass forming methods; One component system- silica; Binary and Ternary systems.

Thermal, optical, electrical, magnetic and mechanical properties of ceramic materials - Effects of composition, crystal structure, processing, temperature and atmosphere on properties - Toughened ceramics

Introduction to specific ceramic materials - phase diagrams, processing, applications – silicate glasses and glass ceramics, cements, castables, superconductors, piezoelectrics, silicon carbide and nitride, sialons, cermets, bioceramics and bio-glass.

TEXTBOOK/REFERENCE:

1. Kingery W. D., Bowen, H. K., Uhlhmen D. R., "*Introduction to Ceramics*", 2nd Edition, John Wiley, 1976
2. Richerson D. W. and Lee, W. E., "*Modern Ceramic Engineering* **-** *Properties Processing and Use in Design*", 4th Edition, CRC Press, 2018
3. Chiang Y.M., Birnie D. P., Kingery W.D., "*Physical Ceramics: Principles for Ceramic Science and Engineering*", John Wiley, 1997

2. Callister, Jr. W. D., Rethwisch, D. G., "*Materials Science and Engineering: An Introduction*", 10th Edition, Wiley, 2018.

3. Askeland, D., Fulay, P., Wright, W. J., and Balani, K., "*The Science and Engineering of Materials*", 6th Edition, Cengage, 2012.

CO Code 22MS643	**Course outcome statement**
CO.1	Define an open and practical research problem in materials science and engineering based on a well-defined literature survey.
CO.2	Identify the gaps in the literature pertaining to that problem, define the scope of the dissertation and frame specific objectives.
CO.3	Develop appropriate theoretical/computational/experimental methodology pertaining to material/product design, materials synthesis/modification/processing, materials characterization and structure-property relationships.
CO.4	Perform guided, independent research employing the developed methodology, estimating and managing the project timelines and costs
CO.5	Analyse, evaluate and interpret the outcomes of the research, draw major conclusions, and develop detailed reports/dissertation in written and presentation formats.

CO Code 22MS643	**PO1**	**PO2**	**PO3**	**PSO1**	**PSO2**	**PSO3**
CO.1	3	1	3	3	3	3
CO.2	3	1	3	3	3	3
CO.3	3	1	3	3	3	3
CO.4	3	2	3	3	3	3
CO.5	3	3	3	3	3	3

22MS798 & 22MS799 DISSERTATION 10 + 16 = 26 Credits

Dissertation 22MS798 – Mini Project – 10 Credits
Dissertation 22MS799– Major Project – 16 Credits

Syllabus

The dissertation will have the following components:

1. Literature Survey and Problem Identification
2. Identification of Gaps, Definition of Scope and Specific Objectives
3. Development of Methodology
4. Guided Independent Research
5. Analysis, Evaluation and Interpretation of Outcomes and Dissertation Writing/Presentation

The dissertation research will be executed in two phases – Mini Project (Phase – I) with 10 credits and Major Project (Phase – II) with 16 credits. Each phase will require the submission of a report/dissertation and a presentation, in addition to intermittent evaluations. Phase – I should complete components 1 and 2 and make significant progress in the remaining components. Further progress in Phase – II should result in a Master's thesis with analysis, evaluation and interpretation of results at a level significantly higher than undergraduate research project reports. A manuscript arising from the Dissertation work shall be communicated to an appropriate peer-reviewed journal/conference.