

M.Tech.

IN

Materials Science and Engineering

CURRICULUM AND SYLLABI

(Applicable from 2026 admission onwards)



Department of Materials Science and Engineering
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT
Kozhikode - 673601, KERALA, INDIA

The Program Educational Objectives (PEOs) of M.Tech.in Materials Science and Engineering

PEO1	Graduates from diverse academic backgrounds in engineering and science shall demonstrate creativity, critical thinking and research aptitude on the fundamental and applied topics in materials science and engineering.
PEO2	Graduates shall do innovative research in the interdisciplinary areas of materials science and engineering.
PEO3	Graduates shall contribute by providing engineering solutions through sustained academic and professional activities.

Programme Outcomes (POs) & Programme Specific Outcomes (PSOs) of M.Tech. in Materials Science and Engineering

PO1	Ability to independently carry out research and innovation to solve practical problems.
PO2	An ability to express and communicate the acquired technical knowledge effectively.
PO3	Ability to demonstrate a degree of mastery in the learned subjects.
PSO 1	Ability to demonstrate a sound technical knowledge of basic scientific and engineering principles in the field of Materials Science.
PSO 2	Ability to do innovations in various areas of Materials science and Engineering and contribute to the industries, R&D and academics.

CURRICULUM

Total credits for completing M.Tech. in Materials Science and Engineering is 75.

COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of M.Tech. programme shall have the following Course Categories:

Sl. No.	Course Category	Minimum Credits
1.	Program Core (PC)	23
2.	Program Electives (PE)	15
3.	Institute Elective (IE)	2
4.	Projects	35

The effort to be put in by the student is indicated in the tables below as follows:

L: Lecture (One unit is of 50 minute duration)

T: Tutorial (One unit is of 50 minute duration)

P: Practical (One unit is of one hour duration)

O: Outside the class effort / self-study (One unit is of one hour duration)

PROGRAMME STRUCTURE

Semester I

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	MT6201E	Experimental Techniques for Materials	3	0	2	8	4	PC
2.	MT6202E	Thermodynamics of Materials	3	0	0	6	3	PC
3.	MT6203E	Structure and Properties of Materials	3	0	0	6	3	PC
4.		Programme Elective-1	3	0	0	6	3	PE
5.		Programme Elective-2	3	0	0	6	3	PE
6.	MT6204E	Materials Synthesis and Fabrication	3	0	2	8	4	PC
7.		Institute Elective	2	0	0	4	2	IE
Total							22	--

Semester II

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	MT6211E	Spectroscopy for Materials	3	0	0	6	3	PC
2.	MT6212E	Foundations of Computational Materials Science	2	0	2	5	3	PC
3.		Programme Elective-3	3	0	0	6	3	PE
4.		Programme Elective-4	3	0	0	6	3	PE
5.		Programme Elective-5	3	0	0	6	3	PE
6.	MT6294E	Advanced Functional Materials Lab	0	0	6	6	3	PC
7.	MT6295E	Project Phase I	0	0	0	8	2	PC
Total							20	--

Semester III

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	MT7297E	Project Phase II (To be completed during Summer)	0	0	0	12	3	PC
2.	MT7298E	Project Phase III	0	0	0	36	15	PC
Total							18	--

Semester IV

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	MT7299E	Project Phase IV	0	0	0	36	15	PC
Total							15	--

List of Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1.	MT6221E	Nano Materials for Energy and Environment	3	0	0	6	3
2.	MT6222E	Computational Nanotechnology	3	0	0	6	3
3.	MT6223E	Carbon Nanomaterials	3	0	0	6	3
4.	MT6224E	Combustion and Nanoparticle Fuel-Additives	3	0	0	6	3

5.	MT6225E	Polymer Technology	3	0	0	6	3
6.	MT6226E	Chemistry of Materials	3	0	0	6	3
7.	MT6227E	Nano Fabrication	2	0	2	6	3
8.	MT6228E	Elements of X-Ray Diffraction	3	0	0	6	3
9.	MT6229E	Surface Science with Nanomaterials	3	0	0	6	3
10.	MT6230E	Micro Electro Mechanical Systems and applications	3	0	0	6	3
11.	MT6231E	Materials for Thermal Management and Energy Conversion	3	0	0	6	3
12.	MT6232E	Applied Transmission Electron Microscopy	3	0	0	6	3
13.	MT6234E	Advanced Electron Microscopy	3	0	0	6	3
14.	MT6235E	Microscale and Nanoscale Heat Transfer	3	0	0	6	3
15.	MT6236E	Nanosized Structures	3	0	0	6	3
16.	MT6237E	Corrosion Science and Engineering	3	0	0	6	3

MT6201E EXPERIMENTAL TECHNIQUES FOR MATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	2	8	4

Total Sessions:52 (39L+26P)

Course Outcomes:

- CO1: Examine various techniques for particle size measurement.
CO2: Distinguish the microscopic measurement techniques for the material characterization.
CO3: Apply different experimental techniques for the surface analysis of the materials
CO4: Analyse the underlying concepts and instruments for thermal analysis and film thickness measurement.

Design of experiments and Particle size analysis

Design of Experiments - Best guess approach, One factor at time approach, Factorial approach. Elementary ideas of blocking, randomization, replication. Errors, Uncertainty analysis. Particle size distribution – Dynamic image analysis (DIA), Static laser light scattering (SLS), Dynamic light scattering (DLS), Attenuation spectroscopy, Zeta potential, Surface streaming potential.

Optical and electron microscopy

Optical microscope - Basic principles and components, Resolution and Magnification, Different modes of operation (Bright field illumination, Oblique illumination, Dark field illumination), Stereomicroscopy, Scanning Electron Microscopy - instrumentation and application, different imaging modes sample preparation techniques - Transmission electron microscopy- different modes of operation, contrast mechanisms, HRTEM, SAED, EELS, Electron back scattering (EBSD) - X-ray micro analysis (EDS, WDS).

Surface analysis

Surface Analysis: Scanning probe microscopy, tapping mode, contact mode, MFM, EFM, I-AFM, DC-AFM, PFM, FMM, LFM, SCM, SThM, SKM, F-d spectroscopy, Nanoindentation, Nano scratching, scanning tunnelling microscopy, Scanning near field microscopy (SNOM), X-ray photoelectron spectroscopy, XRD. Surface area - Gas Sorption Technique - Brunauer–Emmett–Teller (BET) theory, Mercury Intrusion Porosimetry (MIP). Surface roughness: Direct measurement methods, Non-contact methods.

Temperature and thickness measurements

Temperature measurement: Infrared thermography, Thermo reflectance thermography, Liquid crystal thermography. Interferometry. Thermal Analysis: Differential Scanning Calorimeter (DSC), Differential Thermal Analyzer (DTA), Thermogravimetric Analysis (TGA) - Dynamic mechanical analysis (DMA)- Temperature programme reduction (TPR). Coating thickness measurement: Ultrasonic measurement, Magnetic Induction method, Eddy current method, Ultrasonic thickness gauges.

List of experiments

1. Particle size distribution and zeta potential measurement using DLS
2. Optical microscopy, bright field, dark field, and oblique illumination techniques
3. XRD analysis of multiphase materials
4. SEM sample preparation and imaging modes, elemental analysis using EDS
5. TEM - Data analysis, Indexing of diffraction patterns
6. AFM in contact and tapping modes, surface roughness analysis, nanoindentation, and nanoscratch testing
7. BET surface area determination of porous materials
8. DSC, DTA, TGA, DMA
9. Thermal Characterization using Interferometry and Infrared Thermography
10. Coating thickness measurements

References:

1. Robert K., Ian H., Mark G., Nanoscale Science and Technology, John Wiley & Sons Ltd., 2005.
2. Weillie Zhou and Zhong Lin Wang, Scanning Microscopy for Nanotechnology, Springer 2006.
3. David B. Williams, C. Barry Carter, Transmission Electron Microscopy, Springer 2009.
4. Nan Yaho and Zhong, Hand book of Microscopy for Nanotechnology, Kluwer Academic press, Boston, 2005.
5. K.S. Birdi, Scanning Probe Microscopy, CRC Press, 2003.
6. Ernest O. Doebelin, Measurement Systems: Application and Design, McGraw Hill (Int. Edition) 1990.
7. Micheal E. Brown, Introduction to Thermal Analysis, Techniques and applications, Kluwer Academic Publishers 2001.
8. Peter Eaton, Paul West, Atomic Force Microscopy, Oxford University Press, 2010

MT6202E THERMODYNAMICS OF MATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Examine thermodynamics and physical properties of materials and systems.
CO2: Distinguish thermodynamic functions and laws of thermodynamics applicable to nanoscale systems
CO3: Analyze thermodynamic equilibrium and phase stability
CO4: CO4: Assess the application of thermodynamics in the development of small scale systems.

Fundamentals of Thermodynamics and Entropy

First Law of Thermodynamics, heat, work, heat capacity, enthalpy and internal energy, Second Law of Thermodynamics – Entropy and Criterion for Equilibrium – Statistical interpretation of entropy – Boltzmann equation.

Thermodynamic Relations and Laws of Thermodynamics

Auxiliary Functions – Thermodynamic Relations – Maxwell's Equations – Gibbs - Helmholtz Equation – Examples – Heat capacity, enthalpy, entropy and the third law of Thermodynamics- First, second, and third laws of thermodynamics as applied to nanoscale systems.

Phase Equilibria and Phase Transformations

Phase equilibrium in a one – component system – Composition and Phase diagrams of binary Systems – Criteria for Phase stability – Thermodynamics and kinetics of phase transformations- Homogeneous nucleation- Heterogeneous nucleation.

Physical phenomena of small scale systems

Nano-crystals, macromolecules, thermodynamics and physical properties of long chain molecules and molecular structures.

References:

1. David V. Ragone, Thermodynamics of Materials, Volume I, J. W. Wiley 1995.
2. Robert T. De Hoff, Thermodynamics in Materials Science, McGraw-Hill, 1993
3. Y.K. Rao, Stoichiometry and Thermodynamic Computations in Metallurgical Processes, Cambridge University Press, 1985.
4. Robert K, Ian H, Mark G, Nanoscale Science and Technology, John Wiley & sons Ltd., 2005.
5. Daniel V. Schroeder: An Introduction to Thermal Physics, Addison-Wesley, 2000t.

MT6203E STRUCTURE AND PROPERTIES OF MATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Analyze crystal structures and crystallographic defects and their influence on material properties in engineering materials.

CO2: Evaluate the effectiveness of materials processing routes in tailoring the performance of materials for specific engineering applications.

CO3: Apply structure - property relationships to select and design materials for specific applications.

Crystalline Structures, Crystallography, and Crystal Defects

Introduction of Materials, classification, properties, and applications of Metals, Ceramics, and Polymers. Common Crystalline and amorphous structures in all class of materials Geometry of crystals, Bravais lattices, and unit cells. Crystallographic directions and planes. Interplanar spacings and angles. Defects in Crystals Point defects, dislocations, Burgers vector, and its representation. Line defects : Dislocations, slip. Planar defects: stacking faults, twins, grain boundaries.

Microstructural Evolution, Phase Diagrams, and Functional Materials

Microstructure evolution: equilibrium phase diagrams, cooling curves, phase rule, lever rule, and invariant reactions. Introduction to important binary phase diagrams. Scope of metals, ceramics, polymers and composites as functional materials. Advanced materials- 2D materials, Metamaterials, Nanomaterials, Biomaterials.

Mechanical, Electrical, Optical, and Magnetic Properties of Materials

Properties of materials: Mechanical behaviour, Stress- strain curve for metals, ceramics and polymers, Mechanical properties of Metals, Ceramics and Polymers: hardness, toughness, fatigue, creep, fracture. Applicable strengthening mechanisms. Defect engineering for tailoring properties. Electrical, Optical and Magnetic properties of functional materials

References:

1. W. D. Callister Jr. & D. Rethwisch, Materials Science and Engineering: An Introduction
2. V. Raghavan, Materials Science and Engineering
3. Shackelford, Introduction to Materials Science for Engineers
4. Fred W. Billmeyer, Jr, Text Book of Polymer Science, third edition, Wiley Interscience.

MT6204E MATERIALS SYNTHESIS AND FABRICATION

Pre-requisites: Nil

Total Sessions:52 (39L+26P)

L	T	P	O	C
3	0	2	8	4

Course Outcomes:

CO1: Evaluate the strengths and limitations of various synthesis methods of materials

CO2: Analyse the influence of the synthetic pathway on the nature of the chemical bonding and the material properties

CO3: Apply the concepts and principles of different nanofabrication techniques.

CO4: Design and build nanofabricated surfaces for devices.

Design Principles of Functional Materials

Classes of materials- inorganic and organic materials, nanomaterials, functional materials, thin films, porous materials, aerogels, covalent organic frameworks, porous organic polymers, soft materials- effects of synthesis on the structure and properties of various materials, surfaces, interfaces, stabilisation mechanisms, concepts of thermodynamics and kinetics in material formation, nucleation and growth mechanisms.

Methodologies and Mechanisms of Advanced Material Synthesis

Solid state synthesis, solution-based synthesis, co-precipitation, solvothermal, sol-gel, microwave synthesis, electrodeposition, synthesis from the melt, combustion synthesis, gas phase synthesis, Vapour–Liquid-Solid (VLS) and Solution–Liquid–Solid (SLS) growth, Template-based growth, Electrospinning, self-assembly and self-organization

Deposition and Lithography

Fabrication of Nanomaterials by Physical method: Nanofabrication by bottom up and top down approach, Chemical and Physical vapor deposition method, LPCVD, Nanofabrication by photons and charged beams, Optical Lithography, Photoresist, Deep UV, Extreme UV and X ray Lithography, optical E-beam lithography mask making. Mask less optical lithography, contact proximity and projection lithography, Different etching techniques, reactive Ion Etching. ICPRIE, Thermal oxidation of silicon.

Device Fabrication

Focused ion beam, Dual Beam and electron beam for nanolithography, Limitations of Lithography. Nanofabrication by scanning probe, Nanoscratching and oxidation, soft lithography, nanoimprint lithograph, Dip pen lithography.

List of experiments

1. Synthesis of oxide nanoparticle by co-precipitation method
2. Synthesis of nano fibres by Solvo thermal method
3. Electrochemical deposition of Nanoparticle on a support material
4. Synthesis of silica nanoparticles using Stober method
5. Thermal evaporation for metallic thin film depositions.
6. Reactive sputtering of metals or ceramics by DC/ RF magnetron sputtering.
7. Polymer thin film deposition by spin coating and dip coating.
8. Smart surface preparation by Soft lithographic process.
9. Polymer fibre preparation by electro spinning process.
10. Single level photolithographic fabrication of devices.
11. Fabrication of TFT for sensors

References:

1. Kazuaki Suzuki. Bruce W Smith, Microlithography: science and technology, CRC press,2007.

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2. Mark J Jackson, Microfabrication and nanomanufacturing, CRC Press, Taylor & Francis, 2006.
3. John A. Rogers, Hong H Lee, Unconventional nanopatterning techniques and applications, John Wiley & Sons, Inc., 2009.
4. Syed Rizvi, Handbook of photomask manufacturing technology, CRC Press Taylor & Francis, 2005.
5. Ulrich S. Schubert, Nicola Hüsing. Synthesis of inorganic materials, John Wiley & Sons, 2019
6. Johnpierre Paglione, Nicholas P Butch, Efrain E Rodriguez, Fundamentals of quantum materials: A practical guide to synthesis and exploration, World Scientific, 2021

MT6211E SPECTROSCOPY FOR MATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Apply the concepts and principles of spectroscopic methods for the characterization of Nanomaterials.

CO2: Interpret the analytical information for the comprehensive characterization of nanomaterials.

CO3: Assess the suitable technique for the apt evaluation of nanomaterials.

CO4: Appraise the electrochemical methods to comprehend the nanomaterial.

Molecular Spectroscopic Analysis of Advanced Materials

Surface analytical techniques, Surface sensitivity, Basic elements of practical spectroscopy, Infrared spectroscopy (IR), Functional groups, Attenuated total internal reflection IR, Diffuse reflectance and specular reflectance, AFM-IR, Raman Spectroscopy, resonance Raman, surface enhanced Raman and Tip enhanced Raman spectroscopy, Confocal Raman microscopy, analysis of carbon nanomaterials by Raman spectroscopy, Analysis of nanomaterials using IR, Raman spectroscopy.

Principles and Applications of Electronic Spectroscopy

UV-Visible absorption spectroscopy, Principle and application in nanomaterials, Metal nanoparticles and semiconductor nanoparticles, Diffuse reflectance, Calculation of band gaps, Fluorescence spectroscopy, Photoluminescence of nanomaterials, Photoelectron spectroscopy, Ultraviolet photoelectron spectroscopy and X-ray photoelectron spectroscopy, detailed analysis of spectra, X-ray Fluorescence, Auger electron spectroscopy, Electron energy loss spectroscopy.

Mass Spectrometry of Nanostructures and Quantum Clusters: Principles and Practice

Mass spectrometry techniques -Basics and application in nanomaterials, Tandem Mass, Matrix Assisted Laser Desorption/Ionisation, Secondary ion mass spectrometry, Electron spray ionization, Analysis of quantum clusters using mass spectrometry.

Interfacial Electrochemistry and Spectroelectrochemical Techniques

An overview of electrochemistry, Electrochemistry in materials science, Processes at electrodes, Electrochemical instrumentation and techniques, Cyclic voltammetry, Differential pulse voltammetry, Impedance spectroscopy, Electro chemiluminescence, spectroelectrochemistry, scanning electrochemical microscopy, Electrochromic and photoelectrochromic aspects of nanostructured metal oxide films.

References:

1. J. O'Connor, B. Sexton, R. Smart, Surface analysis methods in materials science, Springer, 2003.
2. Helmut Gunzler and Alex Williams, Handbook of analytical techniques, Wiley-VCH, 2002.
3. C. Banwell and E. Mccash, Fundamentals of molecular spectroscopy, Mc Graw Hill, 1994.
4. James M. Thompson, Infrared spectroscopy, Taylor and Francis, 2018
5. G. Hodes, Electrochemistry of nanomaterials, Wiley-VCH, 2001.
6. D.P. Woodruff, Modern techniques of surface science, Cambridge University Press, 2016.

MT6212E FOUNDATIONS OF COMPUTATIONAL MATERIALS SCIENCE

Pre-requisites: Nil

L	T	P	O	C
2	0	2	5	3

Total Sessions: 39 (26L + 26P)

Course Outcomes:

CO1: Apply basic knowledge of computational skills required for describing various physical systems.
CO2: Validate understanding of the fundamentals of density functional theory (DFT) simulation
CO3: Validate understanding of the fundamentals of molecular dynamics (MD) simulation
CO4: Able to write code that correctly represents a physical system and to draw conclusions from the simulation results

Introduction to modelling and simulation

Computer simulations as a tool for materials science: Need and prospects, continuum breakdown, length and time scales, particle methods, multiscale simulations.

Density functional theory

Schrodinger equation, Electronic states of many particle systems. Introduction to first principles energy methods: The Hartree-Fock approximation, Density functional theory
DFT calculations: reciprocal space, energy cutoffs, geometry optimisation, periodic structures, supercells, crystal structure prediction, phase transformations, slab models, surface relaxation, adsorbates on surfaces, vibrational frequencies, transition states.

Molecular dynamics simulations

Empirical methods and coarse graining; Reduction to classical potentials
Molecular Dynamics (MD): Introduction, inter-atomic potential function, Lennard-Jones potential, MD simulation – equilibration and property evaluation, various types of potential functions, computational aspects, introduction to advanced topics.

References:

1. David S. Scholl, and Janice A. Steckel, *Density functional theory: A practical introduction*. John Wiley and Sons, 2009.
2. Ohno, Kaoru, Keivan Esfarjani, and Yoshiyuki Kawazoe. *Computational materials science: from ab initio to Monte Carlo methods*. Springer, 2018.
3. Donald A. McQuarrie, *Statistical mechanics*. University Science Books, 2000.
4. Frenkel, Daan, and Berend Smit. *Understanding molecular simulation: from algorithms to applications*. Elsevier, 2023.
5. Tuckerman, Mark E. *Statistical mechanics: theory and molecular simulation*. Oxford university press, 2023.
6. Atkins, Peter W., and Ronald S. Friedman. *Molecular quantum mechanics*. Oxford University Press, USA, 2011.

MT6294E ADVANCED FUNCTIONAL MATERIALS LAB

Course Outcomes:

L	T	P	O	C
	0	6	6	3

CO1: Acquire knowledge about functional materials.

CO2: Design and built fabricated surfaces for devices using functional materials.

CO3: Assess the suitable technique for the deposition materials.

CO4: Attain practical knowledge about biomaterials.

Selected experiments from a list relevant in the field of functional materials fabrication and property analysis. The experiments include device fabrication experiments, smart material property analysis and biomaterial properties.

List of Experiments

1. Single level photolithographic fabrication of devices.
2. Contact angle measurements- surface energy effect on wetting of surface.
3. Optical behaviour of Liquid Crystals
4. Determination of carrier type, mobility and concentration of semiconductors.
5. Solar cell fabrication and I-V Characterization.
6. Hysteresis loop measurement of ferroelectric materials
7. Piezoelectric coefficient measurements of piezoelectric materials.
8. Frequency response analysis of solid and liquid dielectric materials
9. Cytotoxicity evaluation of bio materials
10. Antibacterial studies on bio materials
11. Development of implantable biomaterials.
12. Synthesis of biocompatible materials.
13. 3D printing of materials
14. Photocatalytic dye degradation in water

References:

1. Cabrini, Stefano, and Satoshi Kawata, Nanofabrication handbook. CRC Press, 2012
2. Sarangan, Andrew, Nanofabrication: Principles to laboratory practice. CRC Press, 2016.
3. Mattox, Donald M, Handbook of physical vapor deposition (PVD) processing. William Andrew, 2010.
4. Mack, Chris, Fundamental principles of optical lithography: the science of microfabrication. John Wiley & Sons, 2008.
5. Jones P, and Stan Wertheimer, Gel electrophoresis, nucleic acids, essential techniques. Analytical Biochemistry 245.2, John Wiley& Sons, 1997.
6. Xian, Wujing. A laboratory course in biomaterials. CRC Press, 2009.

MT6295E PROJECT PHASE I

Pre-requisites: Nil

L	T	P	O	C
	0	0	8	2

Project Phase I is normally an initiation into the project.

Course Outcomes:

- CO1: Understand the process of reviewing and recording the literature.
- CO2: Analyze the literature and identify a project problem.
- CO3: Apply the learning to define the objective and work plan for the project.
- CO4: Develop and improve skills on focused research learning, presentation and communication.

Each student shall identify a topic of interest related to the core/elective courses undergone in the first semester of the M. Tech. programme. He/she shall get the topic approved by the project guide in the concerned area of specialization. The student is expected to conduct a literature survey. A mid semester evaluation shall be done by the guide. At the end of the semester the student shall present the project problem and the related literature in the presence of the duly constituted evaluation committee. Grade will be awarded on the basis of the student's work and presentation.

MT7297E PROJECT PHASE II

Pre-requisites: Nil

L	T	P	O	C
0	0	0	12	3

Course Outcomes for MT6195E, MT6196E and MT6197E Project Phase II, III and IV

Course Outcomes:

- CO1: Develop a systematic procedure to solve the identified research/industrial problem (This primarily pertains to the objective of Phase 2)
- CO2: Analyze and Identify a suitable research methodology for solving the problem identified.
- CO3: Apply the methods/tools learned to develop new methodologies and solve the problem.
- CO4: Apply the techniques of academic writing, critical analysis for consolidating the results to make a report and defend the thesis.
- CO5: Create valuable academic/research outcomes such as high impact publications and intellectual property rights.

Project Phase II can be an extension of Phase I or internship outside during the summer semester break. Students shall continue to work on the problem identified in the project phase I or undergo internship outside. Students shall identify the methodology, apply for a preliminary work. The work should be suitable for communicating to a conference. The student shall submit a report. All the projects will be evaluated by a duly constituted committee.

MT7298E PROJECT PHASE III

Pre-requisites: Nil

L	T	P	O	C
0	0	0	36	15

The project work can be carried out at the institute or in an industry/research organization. Students desirous of carrying out project work in an industry or in other organizations have to fulfill the requirements as specified in the “Ordinances and Regulations for M. Tech.” The student is expected to complete the pilot study, redefine the project based on pilot study, decide on the appropriate research design, develop methodology, generate data/collect data, and obtain preliminary results in the third semester. There shall be evaluations of the project work during and at the end of the third semester by a committee constituted by the department.

MT7299E PROJECT PHASE IV

Pre-requisites: Nil

L	T	P	O	C
0	0	0	36	15

The project work will be extended to the end of the fourth semester. There shall be evaluations of the project work by a committee constituted by the department during the fourth semester. The student shall submit the thesis based on the recommendation of the departmental evaluation committee. There shall be viva-voce examination conducted by an evaluation committee with an external examiner.

“The project work/thesis will be considered for awarding Grade ‘S’ only if a paper, based on the project work is published/accepted for presentation at least in a Scopus indexed conference or a software copyright is granted. However, in exceptional cases, where the student and the guide want to submit a journal/conference publication at a later stage and if the student is able to submit the draft version of the journal/conference paper to the evaluation committee at the time of final presentation of the project work, the student may be considered for awarding ‘S’ grade if the committee finds the work to be excellent and guide ensures the submission of the work for journal/conference publication.

List of Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1.	MT6221E	Nano Materials for Energy and Environment	3	0	0	6	3
2.	MT6222E	Computational Nanotechnology	3	0	0	6	3
3.	MT6223E	Carbon Nanomaterials	3	0	0	6	3
4.	MT6224E	Combustion and Nanoparticle Fuel-Additives	3	0	0	6	3
5.	MT6225E	Polymer Technology	3	0	0	6	3
6.	MT6226E	Chemistry of Materials	3	0	0	6	3
7.	MT6227E	Nanofabrication	2	0	2	6	3
8.	MT6228E	Elements of X-Ray Diffraction	3	0	0	6	3
9.	MT6229E	Surface Science with Nanomaterials	3	0	0	6	3
10.	MT6230E	Micro Electro Mechanical Systems and applications	3	0	0	6	3
11.	MT6231E	Materials for Thermal Management and Energy Conversion	3	0	0	6	3
12.	MT6232E	Applied Transmission Electron Microscopy	3	0	0	6	3
13.	MT6134E	Advanced Electron Microscopy	3	0	0	6	3
14.	MT6235E	Microscale and Nanoscale Heat Transfer	3	0	0	6	3
15.	MT6236E	Nanosized Structures	3	0	0	6	3
16.	MT6237E	Corrosion Science and Engineering	3	0	0	6	3

MT6221E NANOMATERIALS FOR ENERGY AND ENVIRONMENT

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

Students will be able to:

CO1: Apply the concepts and principles of conversion and storage of renewable energy sources.

CO2: Evaluate the efficiency of nanocatalysts for electrochemical energy generation and storage.

CO3: Design the suitable nanomaterials for environmental remediation.

Fundamentals of Nanoscale Science

The transition from bulk to quantum scale, high surface-area-to-volume ratio, and quantum confinement effects, Energy and Environment, sustainable energy production based on renewable energy sources, Nanomaterials used in energy and environmental applications and their properties

Solar Energy Conversion and Storage

Solar energy, solar cells, Dye sensitized solar cell (DSSC), Quantum Dot-Sensitized Solar Cell (QDSSC), organic solar cells, perovskite solar cells, artificial photosynthesis, Hydrogen energy, hydrogen production by solar water splitting, hydrogen storage.

Electrochemical energy conversion and storage systems

Electrochemical energy conversion and storage systems, water splitting by electrolysis. Electrocatalytic/photoelectrocatalytic water splitting. Fuel cells, thermodynamics of fuel cells, electrocatalysts for anode and cathode reactions, membranes, MEA, Batteries, Li-ion battery, Na-ion battery, Mg batteries, Zn-Air battery, Electrochemical capacitors, Supercapacitor, Electrical double layer capacitor, pseudocapacitor, hybrid supercapacitors, supercapattery, Applications.

Nanomaterials for Environment

Green nanotechnology and its principles, Nanomaterials for environmental Remediation, Photocatalysis, Water purification using nanomaterials, desalination of water, Solid waste conversion, waste-to wealth, Porous materials for gas storage, Carbon capture and utilisation (CCU)

References:

1. Angèle Reinders, Pierre J. Verlinden, Wilfried van Sark, Alexandre Freundlich, Photovoltaic solar energy: From fundamentals to applications, John Wiley, 2017.
2. Viswanathan S Saji; Vijayamohanan K Pillai, Multi-functional electrocatalysts – fundamentals and applications, RSC, 2024.
3. Andreas Hauer, Advances in energy storage: Latest developments from R&D to the Market, John Wiley, 2022.
4. J. Larmine and A. Dicks, Fuel cell system explained, John Wiley, 2000.
5. Dunwei Wang, Guozhong Cao, Nanomaterials for energy conversion and storage, World Scientific Europe Ltd, 2018.
6. Suresh C. Pillai, Vignesh Kumaravel, Photocatalysis, De Gruyter, 2021

MT6222E COMPUTATIONAL NANOTECHNOLOGY

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

Students will be able to:

CO1: Develop computational simulation methodologies and discuss their applications.

CO2: Assess the application statistical mechanics and theorems involved.

CO3: Analyze physical problems with the help of atomistic simulation techniques.

CO2: Analyze problems using mesoscopic simulation techniques.

Foundations of classical mechanics

Introduction- Computational simulation, need for discrete computation. Classical Mechanics: Mechanics of Particles, D' Alembert's principle and Lagrange's equation, variational principles, Hamilton's principle, conservation theorems and symmetry properties, central force problems, virial theorem.

Foundations of statistical mechanics

Statistical Mechanics: Review of probability and statistics, quantum states of a system, equations of state, canonical and microcanonical ensemble, partition function, energy levels for molecules, equipartition theorem, minimizing the free energy, partition function for identical particles, Maxwell distribution of molecular speeds.

Atomistic simulation techniques

Molecular Dynamics (MD): Introduction, inter-atomic potential function, Lennard-Jones potential, MD simulation – equilibration and property evaluation, various types of potential functions, computational aspects, introduction to advanced topics. Monte Carlo (MC) Method: Introduction, Metropolis algorithm, advanced algorithms for Monte Carlo simulations, comparison with Molecular Dynamics.

Mesoscopic simulation techniques

Lattice Boltzmann Method (LBM): Boltzmann equation, derivation of the hydrodynamic equation from Boltzmann equation, Lattice Boltzmann equation and LBM, applications of LBM. Dissipative Particle Dynamics (DPD): Fundamentals of DPD simulations, time step size and noise, repulsion parameter, approximate expressions for transport coefficients. Introduction to Multiscale methods and applications.

References:

1. Bird, G.A., Molecular gas dynamics and the direct simulation of gas flows, Oxford Science Publications, 1994
2. Goldstein, H., Poole, C., and Safko, J., Classical mechanics, 3rd Edn., Pearson Education, 2006.
3. Bowley, R., and Sanches, M., Introductory statistical mechanics, 2nd Edn., Oxford Science Publications, 2007.
4. Ercolessi, F., A molecular dynamics primer, Notes of Spring College in Computational Physics, ICTP, Trieste, June 1997.

MT6223E CARBON NANOMATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

Students will be able to:

- CO1: Appraise the concepts of carbon-based nanostructures.
- CO2: Analyze the synthesis and characterization techniques of carbon-based nanostructures.
- CO3: Appraise the applications and challenges of carbon nanostructures.
- CO4: Develop skill to design devices based on carbon nanoscience.

Synthesis of carbon materials

Different carbon-based nanostructures, Historical developments: Fullerenes, Graphene, Carbon nanotubes, carbon dots, pyrolyzed nanocarbons, hard carbons and its derivatives, Common synthesis technique for carbon nanostructures: arc evaporation, laser ablation and chemical vapor deposition, purification by dry and wet method, Pyrolysis- structural evolution during pyrolysis, glassy carbon, different structural models. Techniques for alignment of CNTs: horizontal alignment and vertical alignment, organization on surfaces: organized assembly, field and flow directed growth, surface directed growth(epitaxy), patterned growth on surfaces. Other synthesis methods. Large area graphene synthesis. Defect free transfer methods for large area graphene.

Properties and characterisation of carbon materials

Mechanical properties of graphene, carbon nanotubes, pyrolyzed nanocarbons and other carbon nanomaterials, Thermal properties of graphene, carbon nanotubes, pyrolyzed nanocarbons and other carbon nanomaterials. Thermal stability, Thermal conductance, Influence of defects on thermal conductivity, Electronic and Optoelectronic properties of graphene, Carbon nanotubes and Pyrolyzed nanocarbons. Characterisation of carbon nanomaterials, Raman Spectroscopy, Electron microscopy, SPM, Photoluminescence spectroscopy, Defect engineering in carbon nanomaterials and its effect on properties. Doping and effect of doping on properties.

Application of carbon materials

Carbon nanomaterials for Micro-Electro-Mechanical Systems (MEMS) and Nano-Electro-Mechanical Systems NEMS applications, Sensors and actuators based on carbon nanomaterials, Carbon nanomaterials for energy storage, graphene, CNT, reduced graphene oxide and its derivatives as electrodes for batteries and supercapacitors, Hard carbon electrodes-structure, properties and microstructural engineering, Metal ion storage mechanism in carbon-based electrodes, Environmental and health effects of carbon nanomaterials, application of graphene, CNT, carbon dots and other carbon nanomaterials in biomedical application, nano carbon-based biosensors and implantable biosensors.

References:

1. Jorio, A., Dresselhaus, G., and Dresselhaus, M.S, Carbon Nanotubes – advanced topics in the synthesis, structure, properties and applications, Springer Verlag, New York, 2008.
2. Michael J. O'Connell, Carbon nanotubes: properties and applications, CRC,2006.
3. Jorio, A.; Dresselhaus, M. S.; Saito, R. & Dresselhaus, G. Raman spectroscopy in graphene related systems, Wiley, 2011.
4. Krueger, A. Carbon materials and nanotechnology, Wiley-VCH, 2010.

MT6224E COMBUSTION AND NANOPARTICLE FUEL-ADDITIVES

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Appraise the thermodynamic aspects of combustion.
CO2: Analyze combustion kinetics in fuel burning systems.
CO3: Compare the combustion phenomena in SI and CI engines.
CO4: Assess the influence of nanoparticles in engine exhaust emission reduction.

Fundamentals of Combustion Thermodynamics

Review of basic thermodynamics and gaseous mixtures, Combustion Thermodynamics, Stoichiometry, First and Second Laws of Thermodynamics applied to combustion, Composition products in equilibrium.

Combustion Kinetics and Flame Characteristics

Fundamentals of combustion kinetics, General characteristics of combustion flame, detonation, deflagration, Factors affecting flame velocity and thickness, Quenching, Flammability, Flame stabilization, Laminar premixed flames, diffusion flames, Turbulent premixed flames.

Combustion Characteristics in Internal Combustion Engines

Combustion in I.C. engines, A/F ratio requirements, Ignition temperature- Ignition delay, Normal combustion in SI engines, Knocking, Effect of variable on knocking tendency, Octane number, Normal combustion in CI Engines- Theories of detonation - Cetane number

Fuels, Nanomaterials, and Emission Control in I.C. Engines

Fuels for I.C. Engines, Properties of fuels, Measurement methods, Fuel additives, Nano catalysts, synthesis and characterization of Ceria based oxide nanoparticles, Oxygen storage capacity, Nano fluids, Diesel engine emissions, Effect of nano particles on fuel properties and emissions, Emission control devices.

References:

1. Stephen R Turns, An Introduction to Combustion, McGraw- Hill International Edition, 2000.
2. Kuo, K. K., Principles of combustion, John Willey & Sons, 1986.
3. Mukunda, H. S., Understanding combustion, Macmillan India Ltd., 1992.
4. Smith, M. L. and Stinson, K. W., Fuels and combustion, McGraw-Hill, 1952.
5. Heywood, J. B., Internal combustion engine fundamentals, McGraw-Hill, 1989.
6. Fristrom. R. M. and Westenberg, A. A., Flame Structure, McGraw – Hill Book Co. New York, 1965.
7. Maleev, M. L., Internal combustion engines, Second edition, McGraw-Hill, 1989.
8. Mathur, M. L. and Sharma, R. P., Internal combustion engines, Dhanpath Rai & Sons, 2005.
9. G. R. Pryling, Combustion engineering, Revised Edn., Combustion Engg. Inc., New York 1967.
10. C. Eckbreth, "Laser diagnostics for combustion temperature and species", Cambridge, Abacus Press, 1988.
11. Sajith V. and Shijo Thomas, Internal combustion engines", Oxford University Press, 2017.

MT6225E POLYMER TECHNOLOGY

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Apply the concepts and principles of polymer technology.
 CO2: Interpret the analytical information for the characterization of polymers.
 CO3: Assess the suitable technique for the apt evaluation of polymers.
 CO4: Perceive the viscoelastic behavior of polymers.

Structure Property Relationship

Introduction to Polymers, Basic concepts, characteristic features, texture of polymers, molecular forces and chemical bonding, secondary bond forces, tacticity in polymers, stereo isomerism in polymers, basic determinants of polymer properties, polymer chain flexibility, factors affecting chain flexibility, glass transition temperature and crystalline melting points, variation and structure, molecular interpretation of glassy state of polymers.

Polymer Processing

Compounding and processing of polymers, Additives for compounding plastics, additives for compounding of rubbers, two roll mill, banbury mixer, pigments, processing aids, processing methods for the manufacture of products, blending and mastication, masterbatching, mixing and compounding, calendaring, extrusion and moulding. Different elastomer curing systems-efficient, semi efficient, conventional and sulphurless cure mechanism of vulcanization, sulphur vulcanization, non-sulphur vulcanizing systems for olefin rubbers, batch vulcanization-autoclave, gas curing, oven curing, water curing, cold curing, continuous vulcanisation-high performance steam, hot air tunnel, molten salt bath, fluidized bed, continuous drum cure, microwave curing.

Polymer Characterisation

Testing of Rubbers. Importance of standards and standards organizations, processability and performance, testing of plastics and rubbers, material characterization tests such as hardness, tensile stress/strain, compression stress/strain, shear stress/strain, flexural stress/strain, tear tests, rebound resilience, friction, creep, fatigue, melt flow index, capillary rheometer test, viscosity test, gel permeation chromatography, thermal analysis such as TGA, TMA, and DSC.

Polymer Rheology

Introduction to polymer melt rheology, viscosity, types of fluid flow, time dependent fluids, time independent fluids, viscoelastic fluids, complex rheological fluids, Newtonian fluids, non-Newtonian fluids, Bingham plastics, pseudo plastics, rheopectic and thixotropic behaviour, rheological measurements-the capillary rheometer, cone and plate viscometer, melt flow index apparatus, elastic effects in polymer melt flow-die swell, elastic turbulence, melt fracture, sharkskin.

References:

1. Fred W. Billmeyer, Jr, Textbook of polymer science, third edition, Wiley Interscience Publication, 1994.
2. Joel R. Fried, Polymer science and technology, Prentice- Hall, Inc. Englewood Cliffs, N. J., USA, 2000.
3. A. K. Bhowmik and H. C. Stephense, Hand book of elastomers: New developments and technology, Marcel- Dekker Inc., New York, 1995.
4. D. R. Paul and S. Newman, Polymer blends, Academic Press, New York, 1978.
5. M. J. Folkes, Short fibre reinforced thermoplastics, John Wiley, New York, 1982.
6. Jacob Kline, Handbook of biomedical engineering, Academic Press, NY, 1988.
7. Joseph D. bronzino, The biomedical engineering Handbook, CRC press, London, 2003.

MT6226E CHEMISTRY OF MATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Recognize major classes of materials.

CO2: Describe relationships among structure & composition, physical & chemical properties.

CO3: Analyze the sustainability of materials processing and applications.

CO4: Apply appropriate laboratory techniques to process materials, determine their properties.

Structure and properties of materials

Crystal structures, introduction to lattices, bonding in solids, diffraction and reciprocal lattice, order and disorder in solids, electrical, optical and magnetic properties, unique bonding in nanoparticles and powders, novel properties of nanomaterials, classification of nanomaterials, interparticle interactions, superlattices.

Classes of Advanced Materials

Classes of materials, Semiconductors, metals and alloys, ceramics, polymers, dielectric and ferroelectric materials, magnetic materials, optical materials, super conductors, high T_c Materials, Perovskites, micro and mesoporous materials, nanoporous materials, aerogels, host-guest systems based on nanoporous crystals, fullerenes, carbon nanotubes, graphene, carbon dots, M-Xene, effect of synthesis on the structure and properties of various materials.

Interfacial and Soft Matter Chemistry

Physical chemistry of surfaces, interfaces, thin films, preparation, characterization and application, Langmuir-Blodgett films: growth techniques, self-assembled monolayers, nanocrystalline phases, preparation, nanocomposites, Supramolecular chemistry, rotaxanes as ligands for molecular machines and metal-organic frameworks, synthetic nanotubes from calixarenes, molecular gels-nanostructured soft materials, periodic nanostructures based on metal-organic frameworks (MOFs).

References:

1. K. J. Klabunde, Richards. Ryan, Nanoscale materials in chemistry, 2nd ed, Ed. by John-Wiley and Sons, 2009.
2. A.R. West, Solid state chemistry, Wiley, 1999.
3. G. Gao, Nanostructures and nanomaterials, Imperial College Press, 2006.
4. Jerry L. Attwood, Jonathan W. Steed, Organic nanostructures, Wiley-VCH, 2008.
5. F. Schuth, Kenneth, S.W. Sing, Jens Weitkamp, Handbook of porous solids, Wiley Interscience, 2002.
6. F. Laeri, Ferdi Schuth, Ulrich Simon, Michael Wark, Host-guest-systems based on nanoporous crystals, Wiley Interscience, 2003.

MT6227E NANOFABRICATION

Pre-requisites: Nil

L	T	P	O	C
2	0	2	6	3

Total Sessions: 3 (26L+26P)

Course Outcomes:

CO1: Apply the concepts and principles of different nanofabrication techniques.

CO2: Design and built nanofabricated surfaces for devices.

CO3: Assess the suitable technique for the deposition of nanomaterials.

Introduction to Nanofabrication

Fabrication of Nanomaterials by Physical method: Nanofabrication by bottom up and top down approach, Inert gas condensation, ARC Discharge, RF Plasma. Plasma arc technique, Ion sputtering, Laser ablation, Laser pyrolysis, Ball Milling, Molecular beam epitaxy, Chemical and Physical vapor deposition method, Electro deposition, Nanogrinding, LPCVD.

Lithography process

Nanofabrication by photons and charged beams, Optical Lithography, Photoresist, Deep UV, Extreme UV and X ray Lithography, optical E-beam lithography mask making. Mask less optical lithography, contact proximity and projection lithography, Different etching techniques, reactive Ion Etching. ICPRIE, Thermal oxidation of silicon. Focused ion beam, Dual Beam and electron beam for nanolithography, Limitations of Lithography.

Tip based lithographic process

Nanofabrication by scanning probe, Nanoscratching and oxidation, soft lithography, nanoimprint lithography, Immersion lithography, Deep pen lithography.

Device fabrication

Nanofabrication by replication, Nanofabrication by self-assembly and scanning tunneling techniques, nanopatterning, Nanomanipulation. MEMS fabrication, Lab on Chip.

Experiments:

1. Synthesis of nanoparticles by bottom-up approach
2. RF deposition of different oxide materials
3. DC sputtering of metals
4. Soft lithographic process
5. Single level photolithographic process
6. Fabrication of gas sensors using RF sputtering
7. Isotropic and anisotropic etching of silicon
8. Thermal oxidation of silicon
9. Reactive DC sputtering
10. Graphene CVD process

References:

1. Kazuaki Suzuki. Bruce W Smith, Microlithography: science and technology, CRC press 2007.
2. Mark J Jackson, " Microfabrication and nanomanufacturing," CRC Press, 2006.
3. John A. Rogers, Hong H Lee, Unconventional nanopatterning techniques and applications, John Wiley & Sons, 2009.
4. Syed Rizvi, Handbook of Photomask Manufacturing Technology, CRC Press Group, 2005.

MT6228E ELEMENTS OF X-RAY DIFFRACTION

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Apply the principles of X-ray generation and diffraction to analyze the structure and scattering behaviour of materials.

CO2: Interpret diffraction patterns and analyze the structural characteristics of crystalline materials.

CO3: Index diffraction peaks, and analyze material characteristics phase composition.

CO4: Determine precise lattice parameter and construct phase diagrams

X-ray Generation and Material Interactions - Introduction- Electromagnetic radiation, continuous spectrum, characteristic spectrum, absorption, filters, Production of x-rays, Absorption of X-rays, Detection of x-rays. Diffraction - Bragg law, X-ray spectroscopy, Diffraction directions, Diffraction methods. Diffraction under nonideal conditions. Scattering by an electron, Scattering by an atom.

Crystal Structure and X-ray Diffraction - Lattices and crystal structures, Types of solid and order, Point lattices and unit cells, Crystal systems and Bravais lattices, Crystal structures, atoms per lattice points, Miller indices, Diffraction from crystalline materials. Scattering by a unit cell, Structure-factor calculations, Multiplicity factor, Lorentz factor, Absorption factor, Temperature factor. Intensities of powder pattern lines, Measurement of x-ray intensity. Structure factor.

X-ray Diffractometer and Structure Analysis - Geometry of an X-Ray diffractometer, Components of an X-Ray diffractometer, X-Ray sources, Optics, detectors, X-ray safety, Crystal structure data, ICDD, JCPDS etc., Crystal structure determination Cubic, Hexagonal structures, Methods for indexing of XRD peaks, peak shift, residual stress.

X-ray Diffraction Applications - Precise Parameter Measurements- Debye-Scherrer cameras, Method of least squares, Cohen's method, Calibration method, Phase diagram determination- General principles, Solid solutions, Determination of solvus curves- disappearing-phase method and parametric method, Ternary systems. Order – Disorder Transformations, Long-range order, Detection of superlattice lines, Short-range order and clustering.

References:

1. B.D.Cullity and S.R.Stock, Elements of X-Ray diffraction, Third edition, Prentice Hall, 2001.
2. Aaron.D. Krwitz, Introduction to diffraction in material science and engineering, Wiley-Interscience, 2001.
3. C. Suryanarayana and M. Grant Norton, X-Ray Diffraction - A practical approach, Springer, 1998.
4. K. Ramakanth Hebbar, Basics of X-Ray diffraction and its applications", I.K. International Publishing House, 2011.
5. Yoshio Waseda, Eiichiro Matsubara and Kozo Shinoda, X-Ray diffraction crystallography: Introduction, examples and solved problems, Springer, 2011.

MT6229E SURFACE SCIENCE WITH NANOMATERIALS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total hours: 39

Course Outcomes:

- CO1: Appraise the concepts of surfaces and interfaces.
- CO2: Analyze the processes and characterization of surfaces.
- CO3: Develop skill in constructing and designing smart surfaces.
- CO4: Design and fabricate functional and smart materials.

Interfacial Physical Chemistry: Surface Forces and Colloidal Systems

The nature of surfaces and interfaces, Surface free energy, Molecular nature of Interfacial regions, surface activity and Surfactant structures, Classification of physical forces, van der Waals forces, Interaction between surfaces and particles, Electrostatic forces and electrical double layer, Surface force measurements, Colloid structure, mechanism of colloid formation, Sources of colloidal stability, Steric and Enthalpic stabilization, Coagulation kinetics, The complete interaction curve.

Principles of Adsorption and Colloidal Self-Assembly

Surfactants and self-assembly, Micelles and critical micelle concentration, Adsorption in colloid and surface science, Adsorption theories, Adsorption from solution, Characterization methods of colloids- Kinetic properties and rheology, Optical properties, Scattering spectroscopy and Microscopy.

Interfacial Transport: From Capillarity to Electrokinetics

Capillarity-physical origin and measurement techniques, Introduction to wetting, Cassie and Wenzel models, Experimental studies of wetting phenomena, wetting in porous substrates, wetting at soft surfaces, Dewetting, smart surfaces. Capillary driven transport and assembly, Chemical-gradient driven transport, Temperature-gradient driven transport, Capillary flows in an evaporating drop-Coffee ring effect, Reactive wetting, Electrokinetic transport phenomena, Electro-osmosis, Electrophoresis: Electrophoresis in solution, Electrophoresis of non-interacting solutes in gels.

References:

1. Morton, Rosoff, Nanosurface chemistry, Marcel Dekker Inc., 2002.
2. Georgios M. Kontogeorgis, Soren Kiil, Introduction to applied colloid and surface chemistry, Wiley, 2016.
3. Arthur W. Adamson, Alice P. Gast, Physical chemistry of surfaces, John-Wiley & Sons, 1997.
4. de-Gennes, P-G; Brochard-Wyart, F; Quéré, D, Capillarity and wetting phenomena: Drops, bubbles, pearls and waves, Springer, 2004.
5. H. Watarai, N. Teramae, T. Sawada, Interfacial nanochemistry, Springer, 2003.
6. Mayers, Drew, Surfaces, interfaces and colloids-principles and applications, 2nd edition, Wiley-VCH 1999.

MT6230E MICRO ELECTRO MECHANICAL SYSTEMS AND APPLICATIONS

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total hours: 39

Course Outcomes:

CO1: Analyze MEMS devices.

CO2: Appraise MEMS & NEMS fabrication techniques.

CO3: Assess the design and fabrication steps of MEMS devices.

CO4: Apply the MEMS for various applications.

Overview of micro electro mechanical devices and technologies.

Overview of micro electro mechanical devices and technologies. Introduction to architecture design, process flow, fabrication, packaging and testing. MEMS Fabrication, Deposition, lithography, and etching, Surface micromachining, Bulk micromachining, bonding technologies, LIGA technology and related fabrication methods

MEMS device concepts

MEMS device concepts (micro sensors/actuators), Use of capacitive, inductive, optical, piezoresistive, piezoelectric methods for sensing. MEMS Applications, Accelerometers and gyroscope, Pressure sensors, Micro optics, Microsystems Packaging.

Applications of MEMS and NEMS Systems

Introduction to existing and next-generation metrology tools for MEMS and NEMS inspection and qualification. Theoretical principles of metrology and experimental work on characterization of prototype MEMS and NEMS devices. Cross-disciplinary application of MEMS and NEMS to the biological sciences. Interaction of living cells/tissues with nanofabricated structures, microfluidics for the movement and control of solutions - the development of I/O architectures for efficient readout of bioreactions.

References

1. Mohamed Gad – el – Hak, The MEMS handbook, Second Edition, CRC Press, 2005.
2. James J. Allen, Micro Electro Mechanical System design, CRC, 2005.
3. K. Subramanian, Micro Electro Mechanical Systems: A design approach, Springer, 2008.

MT6231E NANOMATERIALS FOR THERMAL MANAGEMENT AND ENERGY CONVERSION

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Describe the characterisation and improvement of colloidal stability of nanofluids
CO2: Distinguish nanomaterials suitable for thermal management and energy conversion
CO3: Develop methods for designing engineering systems employing nanomaterials for solar thermal, refrigeration, phase change materials, desalination, etc.
CO4: Assess the application of nanomaterials for nanofuel, solar fuel, nanolubricants, etc.

Nanofluids: Synthesis, Properties, Heat Transfer, and Applications

Nanofluids- Synthesis of nano fluids- factors affecting stability- Zeta potential – Methods of stability measurement - Dynamic light scattering system – Acoustic Attenuation spectroscopy- Properties of nanofluids- thermal conductivity –viscosity – specific heat – wetting characteristics;
Convective heat transfer in nanofluids -Surface modified channels – Non-intrusive flow measurements in nanofluids – Ferrofluids - Influence of electric and magnetic field in nanofluid - Evaporation of nanofluids - boiling and condensation enhancement using modified surfaces and acoustic waves
Application of nanofluids in refrigeration and air conditioning, CO₂ absorption

Nanomaterials for Solar Thermal and Photocatalytic Applications

Nanomaterials for solar energy utilization: Solar thermal collectors – direct and surface absorption - Optical properties of nanofluids – extinction coefficient; Nanomaterials for solar thermal desalination - solar stills – floating absorber – RO desalination – Solar distillation – Atmospheric water harvesting
Solar fuels – photocatalytic CO₂ conversion – photocatalytic materials – high entropy materials – photocatalytic hydrogen synthesis.

Phase Change Materials and Thermal Energy Applications

Phase change materials (PCM) – Classification of PCM, Composite PCM, properties, Mini emulsion polymerization - Nano encapsulated phase change material, PCM based nanofluids; Applications of PCM - Electronics cooling, Battery cooling, Fuel cell cooling, solar panels, building materials, air conditioning, cold storage. Phase change thermal pads.

Nanomaterials for Fuels, Lubricants, and Emission Control

Fuels and fuel additives - catalytic nanoparticles – synthesis and characterization - cerium based mixed oxide nanoparticles - oxygen storage capacity – Temperature programme reduction –stability of nanofuel - diesel engine exhaust emissions – HC, CO, NO_x, CO₂, smoke reduction, Catalyst coated diesel particulate filter- regeneration.
Lubricants and lubricant additives - solid lubricant additives – MoS₂/WS₂/graphene nanoparticles - synthesis and characterization - Friction and wear measurements- corrosion and wear resistant coatings.

References:

1. Sarit K. Das, Stephen U. Choi, Wenhua Yu, T. Pradeep, Nanofluids: Science and technology, Wiley, 2007.
2. Vincenzo Bianco, Oronzio Manca, Sergio Nardini, Kambiz Vafai, Heat transfer enhancement with nanofluids, CRC Press, 2017.
3. Amy S. Fleischer, Thermal energy storage using phase change materials: Fundamentals and applications, Springer, 2015.
4. Mohsen Sheikholeslami and Davood Domairry Ganji, Applications of nanofluid for heat transfer enhancement, Elsevier, 2017.
5. S M Sohel Murshed, Carlos Nieto de Castro, Nanofluids: Synthesis, properties and applications, Nova Science Publishers, 2014.
6. Drew Myers, Surfaces Interfaces and colloids, John Wiley & Sons, 1999.

MT6232E APPLIED TRANSMISSION ELECTRON MICROSCOPY

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Evaluate Transmission electron microscope as a tool for the characterization and spectroscopy of various kinds of nanomaterials.

CO2: Analyse different parameters for the examination and interpretation of transmission electron microscopy data

CO3: Evaluate the state of art techniques in in situ TEM and their application

Introduction to TEM

Interaction of electrons with matter; Introduction to TEM, brief history of TEM, basic construction of TEM, electron source, illumination system-lenses and apertures, projection system-lenses and apertures, beam specimen interaction, elastic and inelastic scattering, image formation in TEM, operating modes in TEM, bright field and dark field imaging, diffraction, scanning transmission electron microscopy (STEM), Sample preparation techniques, scattering and diffraction, scattering from a plane of atoms, reciprocal lattice, Ewald's sphere.

Imaging and diffraction in TEM

Indexing of diffraction patterns, computation of intensity of diffraction patterns, different types of diffraction (Selected area, Kikuchi, Convergent Beam and nano-diffraction), contrast theory (kinematical and dynamical theory), imaging of different types of defects (zero, one, two- and three-dimensional defects), weak beam diffraction, phase contrast imaging, point resolution, envelop functions, lens aberrations and aberration correction; lattice imaging with atomic resolution.

Analytical techniques in TEM

Analytical techniques in TEM, Energy Dispersive Spectroscopy (EDS), Electron Energy Loss Spectroscopy (EELS), zero loss and low loss spectra, Energy Loss Near Edge Spectra (ELNES), Extended Energy Loss Fine Structure (EXEFLS), *In situ* techniques in TEM, state of the art, challenges and future, different types of *in situ* holders, *In situ* heating, *In situ* electrical biasing, *In situ* gas system, *In situ* liquid system, *In situ* straining, Sample preparation for *in situ* studies, special sample preparation for biological systems, beam damage and beam induced transformations.

References:

1. Williams, D. B. & Carter, C. B. Transmission Electron Microscopy, Springer US, 2009.
2. Von Heimendahl, M. Wolff, U. Electron microscopy of materials: An introduction, Academic Press, 1980.
3. J.W. Edington, Practical Electron Microscopy in Materials Science, Van Nostrand Reinhold Company, 1976.
4. Xiaodong, Z. Hovmöller, H. and Oleynikov, P. Electron crystallography: Electron microscopy and electron diffraction, Oxford, 2011.
5. Fan, Zheng, et al. In Situ transmission electron microscopy for energy materials and devices, Advanced Materials, vol. 31, no. 33, p. 1900608, Aug. 2019.

MT6134E ADVANCED ELECTRON MICROSCOPY

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Apply electron microscopy techniques for structural and spectroscopic characterization of various materials.

CO2: Analyze different parameters for the examination and interpretation of electron microscopy data

CO3: Evaluate the state of art techniques in electron microscopy and their application

Scanning Electron Microscopy-Principles and Applications: Brief history of the microscope and electron microscope, scanning electron microscopy-basic construction, imaging modes in SEM, resolution in SEM, and the factors affecting resolution, environmental SEM, 3D surface reconstruction and tomography in SEM, spectroscopy in SEM: EDS and WDS, sample preparation in SEM, EBSD – theory and application, brief introduction to Scanning Probe Microscopes (SPM)- AFM, STM, MFM etc., case studies in materials and biological imaging, fractography of composites, nanostructured coatings and thin films, semiconductor and perovskite photovoltaics, lithium ion and post lithium ion batteries, microorganisms and biofilms, tissue–biomaterial interactions, biomaterials.

Transmission Electron Microscopy-Principles and Applications: Introduction to TEM, brief history of TEM, basic construction of TEM, image formation in TEM, operating modes in TEM, scanning transmission electron microscopy (STEM), diffraction, Indexing of diffraction patterns, analysis of selected area electron diffraction (SAED), HRTEM and lattice imaging. Cryo-electron microscopy, analytical techniques in TEM, Energy Dispersive Spectroscopy (EDS), Electron Energy Loss Spectroscopy (EELS), case studies in materials and biological imaging, metal, alloy and nanomaterials, microstructural changes in battery materials, photovoltaic materials-performance and stability, microorganisms and biofilms, automated (S)TEM, analysis for industrial applications.

Modern Techniques in Electron Microscopy: *In situ* and correlative electron microscopy, *in situ* techniques, state of the art, challenges and future, *in situ* measurements in SEM, different types of *in situ* TEM holders, correlative microscopy, sample preparation for SEM and TEM: Conventional sample preparation and Focused Ion Beam (FIB) preparation. Use of a Microtome and Precautions for Biological Sample Preparation and Slicing. Beam damage and beam-induced transformations, data analysis techniques and tools for SEM and TEM.

References:

1. Joseph I. Goldstein , Dale E. Newbury , Joseph R. Michael , Nicholas W.M. Ritchie , John Henry J. Scott , David C. Joy, Scanning electron microscopy and X-ray microanalysis, Third Edition, Springer US 2007.
2. Carter CB and Williams DB, Transmission electron microscopy: Diffraction, imaging, and spectrometry, Springer, 2016.
3. J.W. Edington, Practical electron microscopy in materials science, Van Nostrand Reinhold Company, 1976.
4. Goodhew, P. J., Humphreys, J. & Beanland, R, Electron microscopy and analysis, 3rd ed, Taylor & Francis, 2000.
5. Xiaodong, Z. Hovmöller, H. and Oleynikov, P. Electron crystallography: Electron microscopy and electron diffraction, Oxford, 2011.
6. Egerton, R. F. Electron Energy-Loss Spectroscopy in the electron microscope, 3rd ed, Springer, 2011
7. Sharma, R. In-Situ transmission electron microscopy experiments: Design and practice, Wiley-VCH, 2023.
8. Dehm, G., Howe, J. M. & Zweck, J, In-Situ electron microscopy: Applications in physics, chemistry and materials science, Wiley-VCH, 2012.

MT6235E MICROSCALE AND NANOSCALE HEAT TRANSFER

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Contrast microscale and nanoscale heat transfer analysis and conventional heat transfer.
CO2: Develop fundamentals, measurements and applications of microscale heat conduction.
CO3: Examine microscale convective heat transfer, its measurement and applications.
CO4: Discuss fundamentals of nanoscale heat transfer and its important applications.

Introduction to microscale heat transfer

Introduction to microscale heat transfer - Observations on deviations from conventional theory – experimental and theoretical findings – Overview of studies and comparison of results – Introductory ideas about single phase, multiphase and gas flow in small channels – Contradictory observations and viewpoints in microchannel heat transfer- Applications of microscale heat transfer – basic ideas on micro heat exchangers and microscale heat sinks – applications.

Microscale heat conduction

Conduction in integrated circuits and their constituent films – current trends and future challenges – Microscale thermometry techniques – electrical and optical methods – thermo-reflectance thermometry – Thermal properties of amorphous dielectric films – Thermal characterization and heat transport in dielectric films – Heat conduction in crystalline silicon films – Phonon dispersion - heat conduction in semi-conductors at high temperatures

Microscale convective heat transfer

Fundamentals of convective heat transfer in microtubes and channels – Thermodynamic concepts, general laws and particular laws - Governing equations and size effects. Single phase forced convection in microchannels – Flow structure – entrance length – experimental observations on flow and heat transfer characteristics – Theoretical investigations – Forced convection in mixtures - Gas flow in microchannels. Boiling and two- phase flow heat transfer in small channels – Boiling curve and critical heat flux - flow patterns – Applications of microchannel heat transfer – micro heat pipes and micro heat spreaders

Nanoscale heat transfer

Fundamentals of heat transport in the nanoscale – characteristic lengths and heat transfer regimes – Nanoscale heat transfer phenomena.
Applications of nanoscale heat transfer in microelectronics and energy – Challenges and Future applications

References:

1. C B Sobhan, G P Peterson, Microscale and nanoscale heat transfer-fundamentals and engineering applications,CRC, 2008.
2. Ju, Y.S., and Goodson, K, Microscale heat conduction in integrated circuits and their constituent films, Kluwer Academic Publishers,1999.
3. Chen, G., Nanoscale energy transport and conversion, Oxford University Press, 2005.
4. Mohamed Gad – el – Hak, The MEMS handbook, Second Edition, CRC Press, 2005.

MT6236E NANOSIZED STRUCTURES

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Analyze different nanosystems and their properties.

CO2: Appraise the concepts and principles of various methods for stabilization of the functional nanomaterials.

CO3: Assess the synthesis and fabrication of emerging nanomaterials and hybrid materials.

CO4: Apply the nanoparticles in advanced applications of nanomaterials.

Thermodynamics and Kinetics of Nanomaterial Formation

Introduction to nanomaterials, quantum confinement, properties and applications, band gap engineering and property tuning, surface science for nanomaterials, surface energy, stabilization mechanisms, electrostatic - Nernst Equation, electric double layer, zeta potential, Interaction between nanoparticles - DLVO Theory, steric stabilization and electrosteric stabilization, nucleation and growth of nuclei, critical radius, homogenous and heterogeneous nucleation.

Design and Synthesis of Nanomaterials with Controlled Morphology and Size

Bottom-up approaches for nanostructure fabrication: Metal nanocrystals by reduction, Solvothermal, Photochemical, Template based and Electrochemical synthesis, Nanocrystals of semiconductors and oxides, sol-gel, micelles and microemulsions, top-down approaches for nanostructure fabrication. Quantum clusters of metals, properties, Quantum clusters as catalysts, Anisotropic nanomaterials, properties and applications, One dimensional nanostructures, evaporation condensation growth, Vapor –Liquid-Solid (VLS) growth, electrospinning, Two dimensional nanostructures, thin films, single and multilayered material structure, molecular beam epitaxy, chemical vapour deposition, atomic layer deposition, molecular self-assembly phenomena, Langmuir-Blodgett films and self-assembled monolayers, emerging hybrid materials, nanoporous materials.

Functional Nanomaterials for Emerging Technologies

Nanomaterials for advanced technology- Photonic crystals, molecular electronics and nanoelectronics, Single electron transistors, Nanoparticle-biomaterial hybrid systems for bioelectronic devices, nanostructures in biondiagnostics, tissue engineering and drug delivery, catalysis, size and shape dependent catalysis.

References:

1. G. Cao and Y.Wang, *Nanostructures and nanomaterials*, 2nd Ed., Imperial College Press, 2004.
2. R. Kelsall, I.Hamley and M. Geoghegan, *Nanoscale science and technology*, Wiley, 2005.
3. K. J Klabunde, R. M. Richards, *Nanoscale materials in chemistry*, 2nd Ed., Wiley, 2009.
4. T. Pradeep, *A text book of nano science and technology*, Tata McGraw-Hill Education, 2012.
5. G. Schmidt, *Nanoparticles: from theory to applications*, Wiley-VCH, 2004.

MT6237E CORROSION SCIENCE AND ENGINEERING

Pre-requisites: Nil

L	T	P	O	C
3	0	0	6	3

Course Outcomes:

CO1: Explain the electrochemical thermodynamics and kinetics governing corrosion, including Pourbaix diagrams, mixed potential theory, Butler–Volmer equation, polarisation behavior, and passivity of metals and alloys.

CO2: Analyze the mechanisms of aqueous corrosion forms—uniform, galvanic, pitting, crevice, intergranular, dealloying, erosion-corrosion, and microbial corrosion—and evaluate environmentally assisted cracking phenomena including stress corrosion cracking, hydrogen embrittlement, and corrosion fatigue.

CO3: Interpret high-temperature oxidation kinetics using Wagner's theory and the Pilling–Bedworth ratio, and assess hot corrosion, sulfidation, and other gaseous corrosion mechanisms for alloy selection in elevated-temperature service.

CO4: Design corrosion mitigation strategies—cathodic/anodic protection, coatings, inhibitors, and materials selection—and apply electrochemical monitoring (EIS, LPR), non-destructive inspection, and standards-based methods for corrosion monitoring, failure analysis, and life management.

Electrochemical Thermodynamics, Kinetics, and Passivity of Metals

Significance of corrosion – global economic impact and societal consequences – classification of corrosion: wet (electrochemical) vs. dry (chemical); forms and morphology of corrosion attack. Electrochemical thermodynamics: electrode potential – standard hydrogen electrode (SHE) – EMF series – Nernst equation – effect of concentration, pH, and temperature on equilibrium potential. Pourbaix (potential–pH) diagrams: construction and interpretation – regions of immunity, passivity, and corrosion – limitations and use in corrosion prediction – thermodynamic stability of oxides and hydroxides. Electrochemical kinetics of corrosion: overpotential concept – activation, concentration, and resistance overpotentials – Butler–Volmer equation – exchange current density – Tafel slopes and their significance. Mixed potential theory and corrosion potential (E_{corr}) – Evans diagrams – anodic and cathodic polarisation curves – corrosion current density (i_{corr}). Passivity: active–passive transition – critical and passive current densities – repassivation kinetics.

Forms of Corrosion

Forms of aqueous corrosion: uniform (general) corrosion - Galvanic corrosion – galvanic series in seawater – area ratio and geometric effects – prevention strategies. Crevice corrosion – critical crevice solution chemistry – critical crevice corrosion potential. Pitting corrosion – pit initiation and propagation – pitting potential (E_{pit}) and repassivation potential (E_{rep}) – influence of chlorides and microstructure. Intergranular corrosion – sensitization in austenitic stainless steels – Cr-depletion model – weld decay and knife-line attack. Selective leaching (dealloying) – dezincification and graphitic corrosion – mechanism of selective dissolution. Erosion-corrosion and cavitation corrosion – synergistic effects of mechanical and electrochemical attack – fretting corrosion. Microbiologically influenced corrosion (MIC) – sulfate-reducing bacteria (SRB) – iron-oxidizing bacteria (IOB) – biofilm formation and ennoblement – detection and mitigation. Environmentally assisted cracking (EAC): stress corrosion cracking (SCC). Hydrogen embrittlement (HE) – hydrogen entry. Distinguishing SCC from HE – experimental techniques. SCC behavior in austenitic stainless steels, high-strength steels, Al-alloys, Ti-alloys, and Ni-base superalloys.

High Temperature Oxidation Kinetics and Corrosion Prevention Strategies

High-temperature oxidation kinetics: linear, parabolic, cubic, and logarithmic rate laws – physical meaning and rate-limiting steps. Pilling–Bedworth ratio (PBR) – protective vs. non-protective oxides – oxide scale stress and spallation. Selective oxidation and internal oxidation – transient oxidation – formation of protective Al_2O_3 , Cr_2O_3 , and SiO_2 scales. Alloy design for high-temperature corrosion resistance: FeCrAl, MCrAlY, ODS alloys, thermal barrier coatings (TBCs). Corrosion in specific environments: seawater – acidic solutions (HCl, H_2SO_4 , HF) and alkaline media – CO_2 (sweet) and H_2S (sour). Corrosion prevention

and control: materials selection principles – cathodic protection: impressed current (ICCP) and sacrificial anode (SACP) systems – anodic protection for aggressive acid environments. Metallic coatings: hot-dip galvanizing, electroplating, electroless plating, thermal spray, weld overlay cladding. Organic coatings: paint systems (primer, intermediate, topcoat) – adhesion testing – cathodic disbondment. Corrosion inhibitors: anodic, cathodic, and mixed types; film-forming inhibitors; volatile corrosion inhibitors (VCI); methods for assessing inhibitor efficiency; environmental considerations.

References:

1. Jones, D. A., Principles and prevention of corrosion, 2nd ed., Prentice Hall, 1996.
2. Revie, R. W. and Uhlig, H. H., Corrosion and corrosion control: An introduction to corrosion science and engineering, 4th ed., John Wiley & Sons, 2008.
3. Fontana, M. G., Corrosion engineering, 3rd ed., McGraw-Hill, 1986.
4. Perez, N., Electrochemistry and corrosion science, Kluwer Academic Publishers, Springer, 2004.
5. Bard, A. J. and Faulkner, L. R., Electrochemical methods: Fundamentals and applications, 2nd ed., John Wiley & Sons, 2001.
6. Marcus, P., Corrosion mechanisms in theory and practice, 3rd ed., CRC Press, Taylor & Francis, 2001.
7. Birks, N., Meier, G. H. and Pettit, F. S., Introduction to the high temperature oxidation of metals, 2nd ed., Cambridge University Press, 2006.
8. ASM International, ASM Handbook Vol. 13A: Corrosion: Fundamentals, testing, and protection, ASM International, 2005.
9. ASM International, ASM Handbook Vol. 13B: Corrosion: Materials; Vol. 13C: Corrosion: Environments and industries, ASM International, 2006.
10. Shrier, L. L., Jarman, R. A. and Burstein, G. T., Corrosion, Vols. 1 and 2, 3rd ed., Butterworth-Heinemann, 1994.