Department of Metallurgical and Materials Engineering

Functional Materials

Table 2: List of Specialization Core and Electives as per Senate approved document

	List of core courses [8 Credits]		List of Elective courses [12 Credits]
1	MTL 4XXX: Nanomaterials for Hydrogen Production and Storage [3-0-0]	1	MTL 4XXX: Fundamentals of Transmission Electron Microscopy [3-0-0]
2	MTL7XXX: Functional Materials [3-0-0]	2	MTL 4XXX: Smart Ceramics and Composites [3-0-0]
3	MTP7XXX Functional Materials Laboratory [0-0-2]	3	MTL7XXX: Symmetry, Structure and Tensor Properties [3-0-0]
4	MTL7XXX: Metamaterials [1-0-0]	4	MTL/EEL 7XXX: Advanced Semiconductors Materials and Device Applications [2-0-2]
		5	MTL 7XXX: Functional 2D Materials [2-0-2]
		6	MTL 7XXX: Functional Materials for Sensors and Actuators [2-0-2]
		7	MTL/PHL 7XXX: Materials for Electrochemical Energy Conversion and Storage [2-0-0]
		8	CHL 4XXX: Organic Molecules, Complexes and Polymers for Electronics and Optoelectronics [3-0-0]
		9	PHL 7XXX: Solar Energy Technologies [3-0-2]
		10	MEL 7XXX: MEMS & Microsystems Technology [3-0-2]
		11	CHL7XX0: Structure & Property for Polymers [3-0-0]
		12	CYL6XXX: Advanced Electrochemistry and Applications
		13	BBL7XX0: Tissue Engineering & Medical devices and Implants [3-0-0]
		14	MTD 7XXX: Project [0-0-6]/[0-0-8]/[0-0-12]

Table 3: Proposed Semester-wise Structure of **20 Graded Credits** and positioning of core courses for Functional Materials Specialization

	Courses	GC		Courses	GC
	V Semester			VI Semester	
	One 400 level 3 credit course may be placed in this semester for overloading		SC	Metamaterials	1
			SC	Nanomaterials for Hydrogen Production and Storage	3

			Overload this semester 3-4 credits		
				Total	**4**
	VII Semester			VIII Semester	
SC	Functional Materials	3	SC	Functional Materials Laboratory	1
SE	Specialization Elective	3	SE	Specialization Elective	3
SE	Specialization Elective	3	SE	Specialization Elective	3
Overload this semester 4-3 credits			**Overload this semester 3 credits**		
	Total	**9**		Total	**7**

Note: Students will also be required to complete any non-graded credits associated with a minor programme.

Dual Degree in Functional Materials

Table 4: Credit requirements for dual degree

	Specialization Core	Programme Core Credits	Specialization Elective	Programme Elective Credits	Open Electives Credits	M.Tech Project	Non-Graded Credits
Semester VI and VII during Specialization	7	0	6	0	0	0	0
Semester VIII - X	1	2	**15**	**0**	3	20	2
Total (As per Dual Degree requirement)	**8**	**2**	**21**	**0**	**3**	**20**	**2**
	31 (Compulsory + Elective)				**3**	**20**	**2**

Table 5: List of Dual Degree Programme Core (Excluding courses of Preparatory nature)

	List of core courses [Credits]
1	Industry 4.0: Applications in Metallurgical and Materials Engineering [2-0-0] **(MC)**

Note: List of Specialization Core up to VIII Semester will be as per B.Tech. (Specialization) curriculum
List of Specialization Electives up to VIII Semester will be as per B.Tech. (Specialization) curriculum
List of Specialization Electives in IX th Semester will be as per M.Tech. Functional Materials Course Bouquet

Table 6a: Proposed Semester-wise Structure of **54-56 Graded and 4 Non-Graded Credits** and positioning of core courses for the specialization leading to dual degree **[**B.Tech.+M.Tech.]

	Courses	NC	GC		Courses	NC	GC
	V Semester				VI Semester		
	One 400 level 3 credit course may be placed in this semester for overloading		-	SC	Metamaterials		1
				SC	Nanomaterials for Hydrogen Production and Storage		3

				Overload this semester 4 credits			
					Total		**4**
	VII Semester				VIII Semester		
SC	Functional Materials		3	SC	Functional Materials Laboratory		1
SE	Specialization Elective		3	SE	Specialization Elective		3
SE	Specialization Elective		3	SE	Specialization Elective		3
Overload this semester 3 credits				**Overload this semester 3 credits**			
	Total		**9**		Total		**7**
	IX Semester				X Semester		
MC	Industry 4.0: Applications in Metallurgical and Materials Engineering		2	MO	Open Elective		3
SE	Specialization Elective		3	MP	M.Tech. Project		15
SE	**Specialization Elective**		3				
SE	**Specialization Elective)**		3				
MP	M.Tech. Project		5				
	Non-graded PG courses	1	-		Non-graded PG courses	1	-
	Total	**1**	**16**		Total	**1**	**18**

Note:
- The total of semester VI+VII+VIII should be 20 graded credits and IX+X would be graded 34 credits
- Graded credit requirements for M.Tech. is 54, whereas 2 Non-graded requirements.
- Courses out of 11-12 Credits of Specialization done in Semester VI and Semester VII if not part of M.Tech. Programme will be counted towards M.Tech. PE.
- Students will be required to complete all MTech. Core courses except for preparatory courses. Students will be required to take additional credit of Programme Elective against preparatory courses.
- Clearly state courses of M.Tech. core/electives UG students cannot take due to significant overlap with Minor/Specialization core/elective

Title	**Nanomaterials for Hydrogen Production and Storage**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Functional Materials Specialization Core
Pre-requisite			

Objectives

1. To develop an understanding of different forms of nanostructured materials.
2. Tuning of intrinsic properties of nanomaterials for hydrogen storage and generation.

Learning Outcomes

The students will be able to understand the role of nanomaterials and nanodevices in hydrogen energy production and storage.

Contents

Introduction: Brief overview of the role of nanomaterials in hydrogen energy conversion and storage, Basics of Hydrogen economy *(4 lectures)*

Thermodynamics of hydrogen storage: Kinetics and Thermodynamics of hydrogen storage, Molecular hydrogen physisorption, Chemisorption of atomic hydrogen. *(8 lectures)*

Production using nanomaterials, transportation, conversion and Development of commercial metal hydride electrodes. *(4 lectures)*

Natural Process: Hydrogen production from biowaste and fossil fuels, Artificial processes: Thermochemical, Electrochemical, and Photo-electrochemical, Emerging nanomaterials for hydrogen production: 2D Materials, nano-catalysts, artificial photosynthesis. *(8 lectures)*

Metal hydride nanomaterials for hydrogen storage: Hydrogen storage in metal hydrides, Microcrystalline hydride materials. *(6 lectures)*

Non-metal hydride nanomaterials for hydrogen storage: carbon hydrides: Fullerenes, Carbon nanotubes, Graphene *(6 lectures)*

Hydrogen and Water in positive electrode materials, Manganese Dioxide electrodes in aqueous systems, The "Nickel" Electrode: Structural aspects of the $Ni(OH)_2$ and NiOOH phases. *(6 lectures)*

Textbook

1. Nalwa, H.S., Nanomaterials for Energy Storage Applications, Journal of Nanoscience and Nanotechnology, USA, 2009.
2. Varin, R. A., Czujko, T., Wronski Z. S., *Nanomaterials for Solid State Hydrogen Storage*, Springer, 2019.
3. Sankir, M., Sankir, N. D.,*Hydrogen Production Technologies*, ISBN 9781119283652, 1119283655, Wiley, 2017.

Reference Books

1. Cheong, K.Y., Impellizzeri, G., Fraga, M. A., *Emerging Materials for Energy Conversion and Storage*, 1st Edition, Elsevier, 2018.
2. Şen, F., Khan, A., Asiri, A.M.A, *Nanomaterials for Hydrogen Storage*, Elsevier, 2020.

Online Course Materials

1. Pal, K., *Selection of Nanomaterials for Energy Harvesting and Storage Application*, NPTEL Course Material, Mechanical Engineering, Indian Institute of Technology Roorkee, https://nptel.ac.in/courses/112/107/112107283/.

Title	**Functional Materials**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech, B.Tech-M.Tech. Dual Degree, M.Tech	Type	Functional Materials Specialization Core
Pre-requisite			

Objectives

1. To provide the students with a detailed understanding (synthesis/growth, structure, and properties) of the functional materials.
2. To develop an understanding of the usage of functional materials as a component of modern devices.

Learning Outcomes

The students will be able to:

1. Compare, correlate and investigate the different synthesis, characterization, and application of exemplar functional materials.
2. Integrate the understanding of functional materials' properties and their applications.

Contents

Material synthesis and processing of functional materials: Bulk Synthesis: Solid state synthesis, Sol-Gel synthesis, Thin-Film synthesis: Sputtering, Molecular beam epitaxy, CVD, 3D printing, electrospinning. *(8 lectures)*

Defects in solids: Defect types and dimensionality effect on defects, Characterization (morphological and spectroscopic), Control of defects. *(8 lectures)*

Semiconductor materials: Band structure, Doping, Band-Gap engineering. *(2 lectures)*

Applications: Beyond Si semiconductors, GaN, GaAs, SiC, Ga_2O_3, LEDs, and photovoltaic cells (CdS, CIGS, CZTS, Perovskites and Organic solar cell materials). *(6 lectures)*

Materials for energy applications: Thermoelectric materials: ZT value, Band-Gap, Conductivity engineering, Oxide materials, Heusler alloys, Artificial and hierarchical materials, Peltier cooling, Thermoelectric generator, Dielectric, Piezoelectric, Ferroelectric materials and applications. *(8 lectures)*

Magnetic materials & applications: Magnetic exchange energy, anisotropy energy, Magnetic domains, Application of soft and hard magnetic materials, Magnetic data storage, and Superconductors in electronics. *(6 lectures)*

Optical materials: Optical lithography, and applications, Electro-optic materials. *(4 lectures)*

Textbook

1. Askeland, D.R., Phule, P.P., Wright, W.J., *The Science and Engineering of Materials*, 6th edition, Cengage Learning, 2010.
2. Callister, W.D., Rethwisch, D.G., *Materials science and Engineering: An Introduction*, 8th edition, Wiley, 2010.
3. Mitchell, B.S., *An Introduction to Materials Engineering and Science for Chemical and Materials Engineers*, 1st ed., Wiley- Interscience, 2003.
4. Kittel, C., *Introduction to Solid State Physics*, 8th edition, Wiley, 2005.

Reference Books

1. Kasap, S.O., *Principles of Electronic Materials and Devices*, 3rd edition, McGraw-Hill, 2006.
2. Raghavan, V., *Materials Science & Engineering: A first course*, 5th edition, PHI Learning, 2004.

Online Course Material

1. Haridoss, P., *Physics of Materials*, NPTEL Course Material, Department of Metallurgy & Material Science, Indian Institute of Technology Madras,
https://nptel.ac.in/courses/113/106/113106039/.
2. Garg, A., *Electroceramics*, NPTEL Course Material, Department of Material Science & Engineering, Indian Institute of Technology Kanpur,
https://nptel.ac.in/courses/113/104/113104005/.

Title	**Functional Materials Laboratory**	Number	MTP7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	0-0-2 [1]
Offered for	B.Tech, B.Tech-M.Tech. Dual Degree, M.Tech	Type	Functional Materials Specialization Core
Pre-requisite			

Objectives

1. To introduce different kinds of functional material synthesis (thin film and bulk) techniques, as well as an insight into device fabrication.
2. Introduce different functional property measurement techniques and concomitant analysis.

Learning Outcomes

The students will be able to:

1. Get first-hand knowledge of synthesizing functional materials and device fabrication.
2. Understand different types of measurement techniques and analyse the device performance.

Laboratory Experiments

1. Performance evaluation of capacitors by electrochemical impedance spectroscopy.
2. Performance evaluation of secondary batteries by electrochemical impedance spectroscopy.
3. Fabrication and property evaluation of dielectric/ ferroelectric ($BaTiO_3$/PZT) materials.
4. Electrode preparation (Thin-Film deposition) via spin coating.
5. Synthesis of 2D materials and their hybrids (e.g, graphene, MoS2).
6. Magnetic measurements (M-H hysteresis/ M vs T measurement).
7. Semiconductor characterization: Hall/ I-V measurements.
8. Optical Property measurements: Transmittance/ Photoluminescence/ Band-Gap.
9. Performance evaluation of alkaline primary cell/ lead-acid battery/ Li-ion batteries.
10. 3D Printing of electronic material/bio-materials/energy materials.

Textbook

1. Cheong, K.Y., Impellizzeri G., Fraga M. A., *Emerging Materials for Energy Conversion and Storage*, 1st Edition, Elsevier, 2018.
2. Banks, C., E., Browson, D., A., C., *2D Materials, Characterization, Production and Applications*, CRC Press, 2017.
3. Schroder, D.K., *Semiconductor Material and Device Characterization,* 3rd ed., Wiley-Interscience, New York, 2006.
4. Venuvinod, P.K., Ma W., *Rapid prototyping: laser-based and other technologies*. Springer Science & Business Media, 2013.
5. Gibson, I., Rosen, D., Stucker, B., *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing*, Springer, New York, NY, 2015.
6. Kumar, L. J., Pandey, P.M., Wimpenny, D.I., eds. *3D printing and additive manufacturing technologies*. Singapore: Springer, 2019.

Self-Learning Materials

1. Lab manuals and study materials will be provided for Hall, I-V measurements, M-H hysteresis, M vs T measurement, spin coater, electrochemical impedance spectroscopy and 3D printing.

Online Course Material

1. Ramanathan, S., Chemistry and Biochemistry, IIT Madras, https://nptel.ac.in/courses/104/106/104106105/.
2. Maiti, H.S., Department of Metallurgy and Material Science, IIT Kharagpur, https://nptel.ac.in/courses/113/105/113105015/.
3. Bhat, K.N., Anathasuresh, G.K., Gopalakrishnan, S., Vinoy, K.J., Department of Mechanical Engineering, IISc Bangalore, https://nptel.ac.in/content/storage2/courses/115103039/module16/lec38/2.html.

4. Ganguli, A.K., Department of Nanotechnology, IIT Delhi,
https://nptel.ac.in/courses/118/102/118102003/.
5. Banerji, P., Department of Metallurgy and Material Science, IIT Kharagpur.
https://nptel.ac.in/courses/113/105/113105025/.
6. Majumder, S.B., Material science Centre, IIT Kharagpur,
https://nptel.ac.in/courses/113/105/113105102/.
7. Kapil, S., Department of Mechanical Engineering, IIT Guwahati,
https://onlinecourses.nptel.ac.in/noc21_me115/preview.

Title	**Metamaterials**	Number	MTL7XXX
Department	Metallurgical and Materials Engineering	L–T–P [C]	1–0–0 [1]
Offered for	B.Tech. Specialization, B.Tech.-M.Tech. Dual Degree	Type	Functional Materials Specialisation Core
Pre-requisite			

Objectives

1. This course introduces the student to the field of metamaterials.

Learning Outcomes

1. The students will learn fundamental concepts underlying physical properties and fabrication techniques of metamaterials.
2. The students will be exposed to the various application of metamaterials.

Contents

Introduction to metamaterials and Meta surfaces. *(2 lectures)*

Optical and mechanical metamaterials, Micro-/Nano-fabrication methodologies, and Prospective applications. *(3 lectures)*

Sub-wavelength waveguiding and focusing, Super-resolution imaging and nano-lithography beyond the diffraction limit of the light, Negative refraction and permeability and Invisibility cloaking. *(5 lectures)*

Plasmonic metamaterials, Enhanced Raman scattering, Extraordinary transmission, Light-trapping for solar cell. *(4 lectures)*

Textbook

1. Choudhury, P.K., *Metamaterials: Technology and Applications*, CRC Press, Taylor & Francis Group, 2021.

Reference Books

1. Simovski, C., Tretyakov, S., *An Introduction to Metamaterials and Nanophotonics*, Cambridge University Press, 2020.
2. Cui, T.J., Smith, D., Liu, R., *Metamaterials: Theory, Design, and Applications*, Springer Publications, 2009.

Title	**Fundamental of Transmission Electron Microscopy**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L–T–P [C]	3–0–0 [3]
Offered for	B.Tech. (MT)	Type	Functional Materials Specialization Elective (SE)
Pre-requisite			

Objectives

1. To introduce the fundamentals of Transmission Electron Microscopy (TEM).
2. Introduce computational techniques of TEM image analysis.

Learning Outcomes

The students will be able to:

1. Simulate the electron diffraction and TEM micrographs.
2. Understand digital micrograph scripting for post-processing the electron micrograph.
3.

Contents

Introduction of basics of TEM: Basics of TEM from instrumental and theoretical perspective, Overview of electron matter interaction in TEM, Wave interference in TEM. (*7 lectures*)

Introduction of various imaging method in TEM: Basics of image formation in TEM, Contrast transfer function, High-resolution TEM imaging (HRTEM) (*7 lectures*)

Scanning transmission electron microscopy imaging (STEM), Bright field imaging, Dark field imaging, spectrum imaging (*7 lectures*)

Introduction of electron diffraction in TEM: Reciprocal lattice, Basics theory of electron diffraction formation in TEM, selected area electron diffraction (SAEDP), Convergent beam electron diffraction (CBED), Electron diffraction analysis methods for material science. (*7 lectures*)

Introduction of spectroscopic method in TEM: Basics of electron energy loss spectroscopy (EELS), Basics EELS analysis for material science (*7 lectures*)

Energy dispersive x-ray in TEM, basics of quantitative chemical analysis by EDS. (*5 lectures*)

TEM alignment: Basics HRTEM alignment, TEM sample preparation methods. (*2 lectures*)

Textbook

1. Kirkland, E. J., *Advanced computing in electron microscopy*, Springer, 2020.
2. Landup, D., *Data visualization in python with pandas and matplotlib*, 2020.
3. Pennycook S.J., Nellist, P.D., Scanning Transmission Electron Microscopy: Imaging and Analysis, Springer, New York, 2011.

Online Course Material

1. nanoHUB.org - Courses: Transmission Electron Microscopy

Reference Books

1. Beazley, D., Jones, B.K., *Python Cookbook: Recipes for Mastering Python 3 (English Edition)*, O'Reilly media, 2013.
2. Williams, D.B., Carter, C.B, *Transmission Electron Microscopy: A Textbook for Materials Science, Springer,* 2016.

Title	**Smart Ceramics and Composites**	Number	MTL4XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3-0-0 [3]
Offered for	B.Tech. (MT)	Type	Functional Materials Specialization Elective
Pre-requisite			

Objectives

1. Introduce the importance of smart ceramics and composites along with their structures and mechanisms.
2. Enable to understand the design and manufacturing concepts of these materials for specific purposes.

Learning Outcomes

The students are expected to:

1. Realize and appreciate the role of functionalities and functional material-based smart ceramics and composites.
2. Knowledge to extend the compositional and processing variables to enhance the properties of smart ceramics and their composites.

Contents

Introduction: Definition and classification of smart ceramics and composites, Structures and their effect on properties, Multifunctional materials. *(5 lectures)*

Ceramic smart Materials: Introduction, Synthesis of smart ceramic materials, Intelligent control of phase assemblage. *(4 lectures)*

Ceramic based multifunctional nanomaterials: Overview of ceramic based nanomaterials, Strategies of synthesis, Other ceramic systems, Porous nanoceramic materials, Doping of nanoparticles for enhanced functionality. *(5 lectures)*

Bioceramics for clinical applications: Definition, Classification, Biocompatibility and biomedical applications, Mesoporous ceramics as drug delivery system, Bone tissue regeneration. *(5 lectures)*

Smart composites: Laminated composites, Mechanical response to impact and electromagnetic loads. *(4 lectures)*

Design and characterization of magnetostrictive composites: Introduction, Behaviour of high magnetostriction materials, Coupling between magnetic and mechanical properties, Micromechanical analysis, Terfenol D-composite. *(5 lectures)*

Multifunctional nanocomposites: Carbon nano materials-based nanocomposites, Sensing capability, Structural health monitoring and Self-healing, Solid state ceramic fuel cells (solid oxide fuel cells) and silicon manufacturing for solar cells. *(5 lectures)*

Active fibre composites: Micromechanics modelling, Fabrication, Characterization. *(5 lectures)*

Mechanics and Design of smart composites: Analytical model with and without piezoelectric additions, Manufacturing, characterization and applications. *(4 lectures)*

Textbook

1. Schwartz, M., *Smart Materials*, CRC Press, Taylor and Francis Group, 2009.
2. Mishra, A.K., *Smart Ceramics-Preparation, Properties and Applications*, *Pan Stanford Publication*, 2018.

Reference Books

1. Vallet-Regi, M., et al., *Biomedical Applications of Mesoporous Ceramics*, CRC Press, Taylor and Francis Group, 2013.
2. Elhajjar et al., *Smart Composites Mechanics and Design*, LLC, Taylor and Francis Group, 2014.

Online Course Material

1. Bhattacharya, B., Smart Materials and Intelligent System Design, IIT Kanpur, 2018, https://nptel.ac.in/courses/112104251/#.
2. Bhat K. N. et al., Micro and Smart Systems, IISc Bangalore. NPTEL 2012, https://nptel.ac.in/courses/112108092/.

Title	**Symmetry, Structure and Tensor Properties**	**Number**	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	3–0–0 [3]
Offered for	B.Tech, B.Tech-M.Tech. Dual Degree, M.Tech	Type	Functionak Materials Specialization Elective
Pre-requisite	Linear Algebra and Matrix Mathematics, MATLAB/Mathematica		

Objectives

1. Introduce the concept of symmetry in crystal lattices, point groups, and space groups.
2. Use of symmetry in the tensor representation of crystal properties, including anisotropy, representation surfaces, elasticity, and applications to piezoelectricity.

Learning Outcomes

The students will be able to:

1. Learn how to calculate different thermodynamic properties of different materials.
2. Understand how crystalline anisotropy affects/governs the property anisotropy.

Contents

Introduction: Spherical trigonometry and Applications in crystallography. *(5 lectures)*

Crystal lattices: Direct lattice, Crystal systems, Bravais lattice. *(2 lectures)*

Point groups: Stereographic projection, Proper cubic point groups, Improper point groups (dihedral angle, inversion symmetry), Types of point groups: 2D and 3D lattices. *(7 lectures)*

Space groups: Enumeration of the operations, Different space groups with specific materials examples. *(7 lectures)*

Group theory: Basic Concepts, Character Tables, Examples, Symmetry and Lattice Vibrations: Mode of Vibrations, Jahn-Teller Effect. *(7 lectures)*

Tensor properties of materials: Basic tensorial operations, Transformation of axis, Eulerian angles, Orthogonality Neumann principle, Pseudo tensors, Symmetry and Mathematical properties of tensors. *(7 lectures)*

Different ordered tensors: 2nd order (Stress-Strain, Permittivity, Permeability, Thermal Expansion), 3rd order (Piezoelectricity), 4th order (Elasticity Tensor). *(7 lectures)*

Textbook

1.Newnham, R.E., *Structure-property relations* (Vol. 2). Springer Science & Business Media, 2012.
2. Nye, J.F., *Physical properties of crystals: their representation by tensors and matrices*. Oxford university press, 1985.

Reference Books

1. Buerger, M.J., *Elementary crystallography*, John Wiley & Sons, 1956.
2. International Tables for Crystallography Volume A: Space-group symmetry, ISBN: 978-0-470-68575-4.

Online Course Material

1. Wuensch, B., *Symmetry, Structure, and Tensor Properties of Materials*, DMSE MIT, MIT OCW, https://ocw.mit.edu/courses/materials-science-and-engineering/3-60-symmetry-structure-and-tensor-properties-of-materials-fall-2005/syllabus/.

Title	**Advanced Semiconductors Materials and Device Applications**	Number	7XXX
Department	Metallurgical and Materials Engineering and Electrical Engineering	L-T-P [C]	2-0-2 [3]
Offered for	B.Tech, B.Tech-M.Tech. Dual Degree, M.Tech	Type	Functional Materials Specialization Elective
Pre-requisite			

Objectives

1. To develop an understanding of the layered and non-layered semiconductor materials synthesis/growth and characterization techniques used in the semiconductor industry.

Learning Outcomes

The students will be able to:

1. Understand the basics of advanced semiconductor materials properties, failure analysis methods, reliability, and characterization.
2. Fabricate semiconductor layered material devices and analyse their properties.

Contents

Fractal-1: Material Synthesis and Characterization

Introduction, Basics of semiconductor, Crystallographic properties of the semiconductors. *(7 lectures)*

Growth and synthesis of semiconductor materials (2D and 3D), Defects and its characterization and Advantages of 2D materials. *(7 lectures)*

Fractal-2: Device Characterization

Electrical characterization of semiconductors: Material influenced test structure based electrical characterization methods like: two-probe/four-probe, Van der Pauw method, Hall-effect measurements etc. *(5 lectures)*

Characterization of junctions and diodes: C-V measurements, Life-time measurement, Metal-semiconductor: Schottky contacts, Barrier-height measurement, I-t techniques. *(5 lectures)*

Reliability and failure analysis: Gate oxide reliability measurement, Time-to-breakdown and charge to breakdown and Failure analysis, Noise measurements and analysis. *(4 lectures)*

Lab:

1) Synthesis of semiconductor materials atomic sheets of Graphene Oxide (MT).
2) Synthesis of semiconductor elemental sheets of Xenes and Transition metal dichalcogenides (TMDCs) (MT).
3) Fabrication of p-n junction (Graphene/Si/SiO_2, G/MoS_2, etc.) (MT).
4) Characterization of p-n junction (Graphene/Si/SiO_2, G/MoS_2, etc.) (MT).
5) Electrical characterization of the fabricated devices (EE).
6) Reliability and Failure analysis (EE).
7) Material process (spectroscopic) and Quality control (MT).
8) Tailoring the electrical, optical and Youngs' modulus of the semiconducting materials (MT).
9) Application of semiconductor in sensing (SERS/gas/strain) (MT/EE).
10) Application of semiconductor in opto-electronics (MT/EE).

Textbook

1. Schroder, D.K., *Semiconductor Material and Device Characterization,* 3rd edition, Wiley-Interscience, New York, 2006.

2. Nicollian, E.H., Brews, J., *MOS Physics and Technology,* ISBN: 978-0-471-43079-7, 1982.

Online Course Material

1. Haridoss, P., *Physics of Materials*, NPTEL Course Material, Department of Metallurgy & Material Science, Indian Institute of Technology Madras, https://nptel.ac.in/courses/113/106/113106039/.
2. Parasuraman, S., *Fundamentals of electronic materials and devices*, NPTEL Course Material, Department of Metallurgy & Material Science, Indian Institute of Technology Madras, https://nptel.ac.in/courses/113/106/113106039/.

Title	**Functional 2D Materials**	Number	MTL7XXX
Department	Metallurgical and Materials Engineering	L–T–P [C]	2–0–2 [3]
Offered for	B.Tech, B.Tech-M.Tech. Dual Degree, M.Tech	Type	Functional Materials Specialisation Elective
Pre-requisite			

Objectives

1. To introduce the emergent field of functional 2D materials.
2. Provides a comprehensive overview of 2D materials their hybrids and heterostructures systems that are relevant to different scientific applications.

Learning Outcomes

Upon completion, students are expected to

1. To know the basics of 2D materials.
2. Van der Waal and Non- van der Waal materials hybrids and heterostructures.
3. Design and fabricate 2D Advanced Materials based devices.

Contents

Fractal-1: Fundamentals of 2D Materials

Introduction of functional quantum materials, 2D family, Electronic, Magnetic, Optical properties of functional quantum materials, Dirac metals, Weyl fermions. *(5 lectures)*

2D functional quantum materials at atomic scale, Topological insulators, Computation of electronic properties of functional quantum materials, Investigation of defect and Ohmic/Schottky contacts. *(5 lectures)*

Fundamental and properties of two-dimensional materials in sensing: Introduction, Band Alignment, Parameters of sensor performance. *(4 lectures)*

Fractal-2: Fabrication of Devices, Application and Challenges

Synthesis (top-down and bottom-up approach and challenges), Characterization, and transfer of Van der Waals (graphene, boron nitride, Molybdenum disulphide, Tungsten Disulphide, Black Phosphorus, etc.) atomic sheets, Microscopic characterization by TEM. *(3 lectures)*

Non-Van der Waals Materials (Borophene, Hematene, Plumbene, MXene, etc.) their Hybrids (2D/1D, 2D/2D, 2D/3D), composites and heterostructures, Fabrication of 2D Material devices and challenges. *(3 lectures)*

Application of 2D Materials and their hybrids as well as heterostructures: Introduction (Graphene, Xenes, MXene, and Complex 2D Materials) Opto-Electronics (LEDs), Gas Sensor, Bio-Sensor, Drug-Delivery, Filtration/Desalination, Photovoltaics, Energy Storage and Generation, Lubricants, Environmental Remediation. *(6 lectures)*

Challenges with 2D Materials hybrids/heterostructures and device fabrications. *(2 lectures)*

Lab:

1) Synthesis of Van der Waals 2D material (e.g. Graphene, TMDCs) atomic sheets.
2) Characterization (morphological and spectroscopic) of the atomic sheets.
3) Fabrication of nano-devices (bio sensors, gas sensors, etc.).
4) Failure analysis and Quality control.
5) Synthesis of non-Van der Waals 2D material (e.g. Hematene, borophene, etc.) atomic sheets.
6) Characterization (morphological and spectroscopic) of the atomic sheets.
7) Fabrication of nano-devices (bio sensors, gas sensors, etc.).
8) Failure analysis and Quality control.

9) Synthesis of 2D hybrids and heterostructres (e.g. graphene/graphene oxide/reduced graphene oxide/borophene/hematene/TMDCs, etc.) atomic sheets.
10) Characterization (morphological and spectroscopic) of the atomic sheets.
11) Failure analysis and Quality control.

Textbook

1. Zettilli, N., Gubernatis, J.E., Lookman, T., *Quantum Mechanics: Concepts and Applications, Wiley*, 2009.
2. Griffiths, D.J., *Introduction to quantum mechanics*, Prentice Hall International, 2004.
3. Banks, C., E., Browson, D.A.C., *2D Materials, Characterization, Production and Applications*, CRC Press, 2017.

Reference Books

1. Ng, L.W.T., Hu, G., Howe, R.C.T., Zhu, X., Yang, Z., Jones, C., Hasan, T., *Printing of Graphene and Related 2D Materials: Technology, Formulation and Applications*, Springer, 2019.
2. Errana, G., *Metal Oxide Nanostructures as Gas Sensing Devices,* CRC Press, 2012.
3. Avouris, P., Heinz, T.F., Low, T*., 2D Materials Properties and Devices*, Cambridge University Press, 2017.

References

1. Paglione, J., Butch, N.P., Rodriguez, E. E., *Fundamentals of Quantum Materials: A Practical Guide to Synthesis and Exploration,* World Scientific Pub Co Inc, 2021.
2. Heitmann, D., Quantum Materials*, Lateral Semiconductor Nanostructures, Hybrid Systems and Nanocrystals,* Springer, 2010.
3. Bartolomeo, D., *2D Materials and Van der Waals Heterostructures,* MDPI, ISBN 978-3-03928-769-7, https://doi.org/10.3390/books978-3-03928-769-7.
4. Hywel, M., Rout, C.S., Late, D.J., *Late Fundamentals and Sensing Applications of 2D Materials,* Elsevier, 2021.

Title	**Functional Materials for Sensors and Actuators**	Number	MTL7XX0
Department	Metallurgical and Materials Engineering	L-T-P [C]	2-0-2 [3]
Offered for	B.Tech, B.Tech-M.Tech. Dual Degree, M.Tech	Type	Functional Materials Specialization Elective
Pre-requisite			

Objectives
1. To understand the basics of sensors, actuators materials, and their operating principle.
2. To explain the working of various types of electrochemical sensors and actuators.

Learning Outcomes
The students will be able to:
1. Apply the knowledge for the selection of appropriate materials for sensing, design, and device fabrication.
2. Understand the design and device fabrication challenges.

Contents
Fractal-1: Sensor Materials and its Applications: Introduction of sensors, Basics of energy transformation and differences between transducers, Sensors and Actuators, Principles of micro sensors, basics of semiconducting metal oxide–based gas sensors. *(7 lectures)*

Conducting polymers sensor materials, mechanism of sensing, properties and their applications, magnetic nanoparticles sensors, gas sensing materials: Transition metal oxides, SiC, 2D materials their hybrids and heterostructures, Materials for Biosensing, FET based biosensors and luminescent materials for biosensing. *(7 Lectures)*

Fractal-2: Actuator Materials and its Applications: Introduction of actuators and its working principle, Piezoelectric Actuators: Resonant and Non-Resonant actuation, Bimorphs, Figure of merit, Group III-V nitrides (GaN/AlN), Electrochromic and Electroactive Polymer actuators: Wet and Dry Electroactive polymer actuators (EAP) actuators, material selection, design and fabrication of actuators. *(7 lectures)*

Shape memory alloys (SMAs): Introduction of Shape memory alloy materials, design of SMAs, figure of merit (FOM), Scaling laws, magnetic actuators: Magnetostriction, Magnetostrictive materials: giant magnetostriction, Design and Control of magnetostrictive actuators, Scaling laws *(7 lectures)*

Lab:
1) Synthesis of functional materials (graphene oxide, boron nitride) for application in gas sensing (MT).
2) Fabrication of gas sensor (graphene oxide/ other 2D materials) (MT).
3) Characterization using spectroscopic technique (UV-Visible) and Quality control (MT).
4) Synthesis of metal (gold/silver/glass substrate) nanoparticles for biosensing (MT).
5) Fabrication and characterization (Raman Spectroscopy) of biosensor (MT).
6) Characterization using spectroscopic technique (UV-Visible) and Quality control (MT).
7) Synthesis of PVDF for application in polymeric sensing (MT).
8) Characterization using spectroscopic technique (UV-Visible) and Quality control (MT).
9) Fabrication of polymer sensor (Universal Testing Machine) (MT).
10) Synthesis of carbonaceous material for electrochemical sensing (MT).
11) Fabrication of electrochemical sensor (Three-Electrode System) (MT).
12) Characterization using spectroscopic technique (UV-Visible) and Quality control (MT).

Textbook
1. Kloeck, B., Rooji, N.F., *Mechanical Sensors in semiconductor Sensors*, John Wiley NY 1994.
2. Silva, D., Clarence W., *Sensors and actuators: Engineering system instrumentation*. CRC Press, 2015.

Reference Books

1. Rupitsch, Johann, S., *Piezoelectric Sensors and Actuators*. Springer-Verlag Berlin Heidelberg, Heidelberg, 2018.

Online Course Material

1. Pandya, H.J., Department of Electrical & Electronic Engineering IISc Bangalore NPTEL Course Material, https://www.youtube.com/watch?v=nE1C4ghfvac&list=PLgMDNELGJ1CbufZjqWa8uoSlQWKqVwPN7.