INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

M.Tech. program in

Materials Science and Engineering

Indian Institute of Technology Patna

Course curriculum according to NEP

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

Academic Program:

Program Learning Objectives:	**Program Learning Outcomes:**
Program Goal 1: To equip graduates with a comprehensive understanding of the fundamental principles of materials science and engineering, encompassing the relationships between processing, microstructure, properties, and performance of materials. **Program Goal 2:** To foster the ability to apply scientific and engineering knowledge to design, develop, characterize, and optimize novel materials for diverse applications. **Program Goal 3:** Demonstrate a deep understanding of the structure, properties, and behaviour of various material classes, including metals, ceramics, polymers, and composites. **Program Goal 4:** To gain knowledge of advanced materials concepts, such as nanomaterials, functional materials, and smart materials, and the latest research trends in materials science and engineering.	**Program Learning Outcome 1a:** At the end of M.Tech program students will be able to apply fundamental principles of materials science and engineering to understand the relationships between processing, microstructure, properties, and performance of various materials. **Program Learning Outcome 1b:** Students will be able to analyze the structure, properties, and behaviour of different material classes, including metals, ceramics, polymers and composites. **Program Learning Outcome 2:** Utilize advanced processing techniques to synthesize and manipulate materials at different scales (macro, micro, and nano). Students will be able to characterize and refine innovative materials for a variety of uses. **Program Learning Outcome 3a:** To cultivate critical thinking, problem-solving, and analytical skills to address complex challenges in materials research and development. **Program Learning Outcome 3b:** Apply fundamental scientific and engineering principles to design and develop materials with tailored properties for specific applications. **Program Learning Outcome 4:** Graduates will demonstrate professionalism, adhere to ethical principles in research and development activities, and contribute to sustainable development through responsible material design and utilization. Acquire expertise in cutting-edge materials concepts like nanomaterials, functional materials, and smart materials, and to stay abreast of the latest developments in materials science and engineering research.

Course Number Pattern (revised format for all programs): XXnmPQ

XX: Department/Branch Code
N: Year/Level
M: Semester
PQ: Course number of the Department
Example: MA4101: Mathematics course for first year (level four-core) in first semester with course number 01 for Department (Maths) at that level.
PH5141: Physics course for second year (level five) in fourth semester with course number 41 for the Department (PH) at that level.
A few advanced level dedicated electives (Level-6) in specific area meant for PhD course work may be allowed for MSc second year students subject to compliance of pre-requites.

CSIR-NET / GATE syllabus to be coved on priority in the core courses itself to enable students ready for such examinations.

Course syllabus to be created as a composite structure comprising Lecture/Tutorial/Lab as far as possible to enable students understand concepts taught in the classroom with clarity in the concurrent Lab.

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Sl. No.	Subject Code	SEMESTER I	L	T	P	C
1.	HS5111	Technical Writing and Soft Skill	1	2	2	4
2.	MM5101	Thermodynamics and Phase Transformation	3	1	0	4
3.	MM5102	Concepts in Materials Science	3	0	0	3
4.	MM5103	Mechanical Behavior of Materials	3	0	2	4
5.	MM5104	Nano-structured Materials	3	0	0	3
6.	MM61PQ	DE-1	3	0	0	3
7.	MM61PQ	IDE	3	0	0	3
TOTAL			**19**	**3**	**4**	**24**

IDE (inter Disciplinary electives) in the curriculum aims to create multitasking professionals/ scientists with learning opportunities for students across disciplines/aptitude of their choice by opting level (5 or 6) electives, as appropriate, listed in the approved curriculum.

Sl. No.	Subject Code	SEMESTER II	L	T	P	C
1.	MM5201	Advanced Polymer Technology	3	0	2	4
2.	MM5202	Advanced Engineering Materials	3	0	2	4
3.	MM62XX	DE-II	3	0	0	3
4.	MM62XX	DE-III	3	0	0	3
5.	MM62PQ	DE-IV	3	0	0	3
6.	RM6201	Research Methodology	3	1	0	4
7.	IK6201	IKS	3	0	0	3
TOTAL			**21**	**1**	**4**	**24**

Sl. No.	Subject Code	SEMESTER III	L	T	P	C
1.	MM6198	Summer Internship/ Mini Project*	0	0	12	3
2.	MM6199	Project I**	0	0	30	15
TOTAL			**0**	**0**	**42**	**18**

***Note: Summer Internship (Credit based)**

(i) Summer internship (*) period of at least 60 days' (8 weeks) duration begins in the intervening summer vacation between Semester II and III. It may be pursued in industry / R&D / Academic Institutions including IIT Patna. The evaluation would comprise **combined grading based on host supervisor evaluation, project internship report after plagiarism check and seminar presentation at the Department (DAPC to coordinate)** with equal weightage of each of the three components stated herein.

(ii) Further, on return from 60 days internship, students will be evaluated for internship work through combined grading based on host supervisor evaluation, project internship report after plagiarism check, and presentation evaluation by the parent department with equal weightage of each component.

**** Note: M. Tech. Project outside the Institute**: A project-based internship may be permitted in industries/academia (outside IITP) in 3rd or 4th semester in accordance with academic regulations. In the III Semester, students can opt for a semester long M. Tech. project subject to confirmation from an Institution of repute for research project, on the assigned topic at any external Institution (Industry / R&D lab / Academic Institutions) based on recommendation of the DAPC provided:

(i.) The project topic is well defined in objective, methodology and expected outcome through an abstract and statement of the student pertaining to expertise with the proposed supervisor of the host institution and consent of the faculty member from the concerned department at IIT Patna as joint supervisor.

(ii.) The consent of both the supervisors (external and institutional) on project topic is obtained a priori and forwarded to the academic section through DAPC for approval by the competent authority for office record in the personal file of the candidate.

(iii.) Confidentiality and Non Disclosure Agreement (NDA) between the two organizations with clarity on intellectual property rights (IPR) must be executed prior to initiating the semester long project assignment and committing the same to external organization and vice versa.

(iv.) The evaluation in each semester at Institute would be mandatory and the report from Industry Supervisor will be given due weightage as defined in the Academic Regulation. Further, the final assessment of the project work on completion will be done with equal weightage for assessment of the host and Institute supervisors, project report after **plagiarism check**. The award of grade would comprise **combined assessment based on host supervisor evaluation, project report quality and seminar presentation at the Department (DAPC to coordinate)** with equal weightage of each of the components stated herein.

(v.) In case of poor progress of work and / or no contribution from external supervisor, the student need to revert back to the Institute essentially to fulfill the completion of M. Tech. project as envisaged at the time of project allotment. However, the recommendation of DAPC based on progress report and presentation would be mandatory for a final decision by the competent authority.

Sl. No.	Subject Code	SEMESTER IV	L	T	P	C
1.	MM6299	Project II	0	0	42	21
TOTAL			**0**	**0**	**42**	**21**

Total Credits -87

ELECTIVE GROUPS

Department Elective -I						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	MM6101	Processing technology of metal, ceramic and composites	3	0	0	3
2.	MM6102	Surface Engineering	3	0	0	3
3.	MM6103	Nanomaterials: Structure, Property and Applications	3	0	0	3
4.	MM6104	Field-assisted Sintering Techniques	3	0	0	3

Department Elective -II						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	MM6201	Defects and Diffusion in Materials	3	0	0	3
2.	MM6202	Polymer Matrix Composite	3	0	0	3
3.	MM6103	Functional Ceramics	3	0	0	3

Department Elective -III						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	MM6204	Materials Characterization Techniques	3	0	0	3
2.	MM6205	Selection of alloys and heat treatment	3	0	0	3
3.	MM6206	Thin films- an engineering approach	3	0	0	3
4.	MM6207	Joining of Materials	3	0	0	3

Department Elective -IV						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	MM6208	Crystal Symmetry and Tensor properties	3	0	0	3
2.	MM6209	Coating Technology	3	0	0	3
3.	MM6210	Fabrication of Solid-state Devices	3	0	0	3

Interdisciplinary Elective (IDE) Course for M.Tech. (Available to students other than MME)

IDE						
Sl. No.	**Subject Code**	**Subject**	**L**	**T**	**P**	**C**
1.	MM6105	Structural characterization of materials	3	0	0	3
2.	MM6106	Composite Science and Technology	3	0	0	3

1.0 Core Courses

MM5101 Thermodynamics and Phase Transformation (3-1-0) 4 credits

Course learning objectives (Comply with PLO 1)

- To understand the laws of thermodynamics and their application to materials science
- To learn the phase diagram and Ellingham diagram of materials
- To apply the thermodynamics for engineering problem solving

Course learning outcomes

Upon completion of this course, the student will be able to:

- Understand the laws of thermodynamics
- Understand the importance of phase diagram and Ellingham diagram in the materials processing
- Apply thermodynamics for solving numerous engineering problems

Thermodynamics basic concepts (state variables, the first law, the enthalpy concept, heat capacity) The second law (reversible and irreversible processes, entropy, Gibbs energy, Helmholtz energy, Gibbs-Duhems equation, Maxwell's relationships) Equilibrium conditions (chemical potential, driving force, the third law, Clausius-Clapeyrons equations, P-T diagram, Ellingham diagrams

Thermodynamics of solutions, construction and interpretation of two component phase diagrams, Gibbs's Phase rule, Interpretation of mass fractions using Lever's rule, Hume Rothery rules, Binary Isomorphous, Eutectic alloy, Peritectic alloy system, Invariant reactions, Iron-Iron carbide phase diagram, ceramic phase diagram, ternary phase diagram, phase separation, spinodal decomposition, Thermodynamics and kinetics of Nucleation and growth, JMAK equation.

Temperature-Time-Transformation (TTT) and Continuous Cooling Transformation (CCT) Diagrams.

Text Books:

1. Introduction to the Thermodynamics of Materials, David R. Gaskell, 5th ed., CRC Press, 2008.
2. Phase Transformations in Metals and Alloys, Porter, Easterling; 3rd ed, CRC Press, 1991.

Reference Books:

1. Thermodynamics in Materials Science, Robert DeHoff; 2nd ed, 2006.
2. Physical chemistry of metals, Lawrence S. Darken, Robert W. Gurry, McGraw-Hill, 1953

3. Phase transformation in materials, A. K. Jena, M. C. Chaturvedi, Prentice-Hall, Englewood Cliffs, New Jersey, 1992

MM5102 Concepts in Materials Science (3-0-0) 3 credits

Course learning objectives (Comply with PLOs 2 and 3)

- To provide a foundational understanding of structure of materials at different length scales
- To understand material's properties and behaviors and how they are influenced by the structure

Course learning outcomes

On completion of the course the students will be able to

- Differentiate between different types of materials and their structures
- Understand the structure dependence of properties and design materials for various engineering applications

Atomic structure: Review of atomic structure, electronic configuration, Characteristic quantum numbers. Electronic distribution in solids, Density of energy states and Fermi energy, band theory of solids.

Bonding in solids: Primary and secondary bonding is solids, bond strength and bond energy. Properties of differently bonded solids. Molecular orbital theory.

Basic crystallography: crystalline and amorphous materials. Packing of atoms, coordination number, unit cell, Bravais lattice, simple crystal structures. Crystal symmetry, Miller indices. defects in solids. Quasi crystals, amorphous materials. Order and disorder in solids, Defects and impurities. Solid Solutions, Hume Rothery Rules.

Classification of materials: engineering materials and their classification, metallic materials, ceramic materials and polymeric materials. Composite materials.

Microstructure-property correlation in materials.

Materials selection and design: General principles of materials selection and design based on requirements of function and property. Introduction to materials selection charts, Ashby maps, materials performance index, processibility and cost.

Case studies:

(i) Applications of advanced metallic materials in aerospace, automotive, and energy sectors.

(ii) Applications of ceramics in electronics, wear resistance, and high-temperature environments.

Text Book:

1. Materials Science and Engineering, an Introduction: William D. Callister, 7th Ed., John Wiley and Sons, 2007
2. Materials Science and Engineering: V. Raghavan, 6th Ed., Prentice Hall India, 2015.

MM5103 Mechanical Behavior of Materials (3-0-2) 4 credits

Course learning objectives (Comply with PLOs 2 and 3)

- To understand how the strength of metals and alloys can be altered
- To identify the properties of metals, ceramics, and polymers and their failure mechanisms against a mode of stress applied.
- To understand the behaviour of the different material systems during their service in terms of fatigue, fracture, and creep

Course learning outcomes:

Upon completion of this course, the student will be able to:

- Understand the limiting values of loads that a component can withstand without failure
- Optimize the stress applied for mechanical applications of different materials
- Classify and distinguish different types of mechanical properties and correlate the same with relevant industrial applications

Theory Syllabus

Elastic modulus – Stress-strain curves - Tensile test of ductile material – properties evaluation, Hardness measurement tests – Plasticity, yield strength, yield criteria, theory of dislocation, dislocation mechanisms, strengthening mechanisms in metals
Creep and high-temperature deformation
Fracture of materials – Mechanisms of Ductile and Brittle fracture; fracture toughness, Impact testing
Fatigue – Endurance limit – Fatigue test, crack growth
Fracture behaviour of ceramic materials, The Weibull distribution, Toughening mechanism, and R curve behaviour
Mechanical behaviour of polymer and soft matter, Viscoelastic behaviour with models

Lab Syllabus

Tensile/compression test: Introduction to the Universal Testing Machine (UTM) for conducting tensile and compression tests on materials such as aluminum, copper, steel, and polymers. Plotting engineering and true stress-strain curves and calculating tensile properties like yield strength, ultimate tensile strength, elongation, and modulus of elasticity, as well as examining the effects of strain rate and strain rate sensitivity.
Hardness testing: Encompasses micro and macro-hardness methods for metals, alloys, ceramics, and polymers, including fracture toughness, nanoindentation, and the determination of elastic modulus and ductility.
Non-destructive testing methods: Liquid Penetrant Testing (LPT), Eddy Current Testing (ECT), Magnetic Particle Inspection (MPI), Ultrasonic Testing (UT), and Radiographic Testing (RT).

Text Books:

1. Mechanical Behaviour of Materials, Thomas H. Courtney; 2nd (ed.), Waveland press Inc.,2000
2. Mechanical Metallurgy, George E. Dieter; MCGRAW-HILL Publications, 1998.

Reference Books:

1. Fatigue of Materials, S. Suresh; 2nd (ed.), Cambridge University Press, 2003.
2. Deformation and Fracture Mechanics of Engineering Materials, Richard W. Hertzberg, Richard P. Vinci, Jason L. Hertzberg; Wiley, 2012.

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MM5104 Nano-structured Materials
(3-0-0) 6 credits

Course Learning Objective (Comply with PLO 4)

- To understand the nature and magnitude of the changes in behaviour and properties of nanomaterials
- To correlate and decode the underlined reasons due to which such changes in properties are observed at reduced length scales
- To learn about different crystallization pathways in nanocrystals and their implications on final properties

Course Learning Outcome

Upon completing of this course, the student will be able to

- Identify the reasons behind new novel properties emerging at nanoscale for different classes of materials
- Classification of properties at different length scales along with their possible market applications
- Distinguish between different synthesis and crystallization pathways in nanomaterials and their correlation with the observed novel properties

Classification: Nanocrystals, thin films & coatings, definitions, Effect on properties and phase stability in lower dimension compared to the bulk state,

Materials at Reduced Dimensions: Two-dimensional nanostructures – surfaces and films, One-dimensional nanostructures – nanotubes and wires, Zero dimensional nanostructures – fullerenes, nanoparticles, nanoporous materials, Nanoclays, Graphene, polyhedral oligomeric silsesquioxane (POSS) nanoparticles, Colloidal Monodisperse Nanocrystals, nanocrystals of ferrite, oxide and chalcogenides, core-shell nanoparticles, micelle assisted nanoparticles, surfactant coated nanoparticles, microemulsion synthesis, self-assembly routes, Inorganic-organic hybrid materials, hydrophobic and hydrophilic nanoparticles, water-dispersable nanoparticles.

Preparation: Synthesis routes, Sol-gel technique, Nonaqueous Sol–gel route for Metal Oxide nanoparticles, hydrothermal synthesis, co-precipitation, preparation of nanocomposites,

Properties and applications at the nanoscale: Electrical, Mechanical, Magnetic, (Electro)Chemical, Optical, Thermal and thermoelectric properties, Health and regulatory issues with Nanomaterials

Text Book:

1. Nanostructures and Nanomaterials: Synthesis, Properties, and Applications, 2nd ed., Guozhong Cao, Ying Wang; Imperial College Press, 2004.
2. Nanoparticles: From Theory to Application, Günter Schmid, Wiley, 2005.
3. Synthesis, Properties, and Applications of Oxide Nanomaterials, José A. Rodriguez, Marcos Fernández-García, Wiley, 2007
4. Monodispersed Particles, T. Sugimoto, Elsevier.
5. Characterization of Nanophase Materials, Zhong Lin Wang, Wiley

6. Nanomaterials, Nanotechnologies and design: an introduction for engineering and architects, Michael Ashby and Paulo J. Ferreira; Elsevier, 2009.

Reference Books:

1. Nanoscale Materials in Chemistry, Kenneth J. Klabunde, Ryan M. Richards, 2nd Edition, Wiley, 2009
2. Nanoparticulate Materials: Synthesis, Characterization, and Processing, Kathy Lu, Wiley.
3. Nanostructured Materials (Processing, Properties and Applications), Carl C. Koch, Elsevier, 2006
4. Nanoparticles and Nanostructured Films: Preparation, Characterization, and Applications, Janos H. Fendler, Wiley, 2008 Nanostructured Materials and Nanotechnology, Hari Singh Nalwa (ed.); Elsevier, 2001.

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MM5201 Advanced Polymer Technology
(3-0-2) 4 credits

Course learning objectives (Comply with PLOs 3 and 4)

- To explain the basic and advanced concepts of macromolecules.
- To gain knowledge of the mechanics underlying various polymerization techniques and polymer reactions.
- To disseminate information on the variables controlling the physical characteristics of polymers.
- To gain knowledge about the processing of different polymers

Course learning outcomes:

Upon completion of this course, the student will be able to:

- Recognize how polymers' structures and properties relate to one another and
- Select appropriate polymerization processes for the synthesis of polymer
- Select proper characterization techniques for the analysis of the polymers
- Select right molding techniques for the processing of polymers

Introduction

Basic definitions, molecular weight, degree of polymerization, polymerization and functionality, copolymers, molecular architecture and classification of polymers

Polymerization

Step growth polymerization, free radical polymerization, copolymerization, dispersion and emulsion polymerization and ionic and coordination polymerization, metathesis polymerization, controlled polymerization methods, viz, NMD, ATRP, GTP, and RAFT

Characterization

Polymer solutions, molecular weight and size measurements, polymer testing and analysis, and polymer crystallinity

Structure and properties

Polymer structure and morphology, rheological characteristics, viscoelastic characteristics, mechanical characteristics, and polymer structure and physical properties.

Industrial polymers

Thermosetting polymers, heterochain thermoplastics, hydrocarbon polymers, and other carbon-chain polymers

Smart polymers

Explanation of smart polymers with physical shapes, pH sensitive polymers, magnetic field sensitive polymers and ionic intensity sensitive polymers

Polymer processing

Mixing and compounding, molding, calendaring, spinning, coating and extrusion processes

Lab Syllabus

Polymer processing: injection, compression, and extrusion molding of polymer. Impact of fillers and additives. Effect of processing conditions, 3D printing of selected designs in polymer.

Demonstration of basic polymerization techniques

Text books:

1. F.W. Billmeyer, "Textbook of Polymer Science", Wiley international publishers, 1984.
2. Alfred Rudin, "The Elements of Polymer Science and Engineering", Academic Press, 1999.

Reference books:

1. Premamoy Ghosh, "Polymer Science and Technology of Plastics and Rubbers", Tata McGraw - Hill, New Delhi, 1990.
2. V. R. Gowariker, N. V. Viswanathan, Jayadev Sreedhar, "Polymer Science", New age international publishers, 2015.
3. R.J. Young and P. Lovell, "Introduction to Polymers", 2nd Ed., Chapman & Hall, 1991.
4. George Odian, "Principles of Polymerization", 4th Edition., A John Wiley & Sons, Inc., Publication, 2004.
5. J A Brydson, "Plastics Materials", 7th Edition, Elsevier, 1999.
6. Joel R. Fried, "Polymer Science and Technology", Prentice Hall, NJ, 1995.

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MM5202 Advanced Engineering Materials
(3-0-2) 4 credits

Course learning objectives (Comply with PLOs 2 and 4)

- To introduce the basic concepts of different categories of engineering materials that are being used in day-to-day life
- To develop an understanding of electronic materials, engineering ceramics, and metals
- To develop an understanding of the properties of engineering materials and characterize different engineering materials

Course learning outcomes:
Upon completing this course, the student will be able to

- Understand the structure-property relationship of advanced engineering materials
- Will be able to select suitable material for critical industrial application
- Will be able to analyze phases, structures and microstructure of different engineering materials

Electronic materials: structure of semiconductors and insulators, Diamond structure, packing fraction, nature of bonding, allotropes of carbon, the structure of graphite, characterization of diamond, graphite, and graphene via Raman spectroscopy, Zinc blende/sphalerite structure, examples of II-VI, III-V, and IV-IV group semiconductors, the concept of the band gap, direct, indirect semiconductors, Applications of Semiconductors
Engineering ceramics: crystal structure and polymorphism Al_2O_3, the concept of hexagonal close packing, c/a ratio, the structure of fully and partially stabilized zirconia structures and polymorphs, transformation toughening, theories behind zirconia stabilization, Basics of Perovskite $BaTiO_3$ and PZT structure, Goldschmidt tolerance factor, Applications of $BaTiO_3$ and PZT in functional devices
Abrasives & cutting tools: crystal structure of abrasives like silicon carbide, tungsten carbide, diamond and boron nitride, structure-property correlations, origin of high hardness, bulk modulus,
Steel and superalloy: Structure of Metals (Al, Cu, Zn, Fe, etc), key phases in Iron-Carbon phase diagram and their crystal structures, martensite, close-packed metallic structures, Application & behaviour of crystalline metals in rolling, stretching, heat treatment, Development of superalloys, uses and properties, Alloy composition and crystal structure, Origins of strength
Smart materials: Piezoceramic actuators, Magnetostriction, magnetostrictive materials, Shape memory effect (SME), alloys with SME, Mechanical and thermal characterization of shape memory alloys

Lab Syllabus
Practical aspects of X-ray diffraction analysis will be emphasized; hands-on experience in qualitative and quantitative analysis techniques, use of electronic databases, and phase analysis using XRD data.

Thermal properties of materials, identification of materials based on their TG, DSC, and DMA characteristic responses.

Hands-on experience in the applications of metallography and optical microscopy, phase analysis using microscopic information, hands-on experience in the area of microstructures of metal, ceramic, and polymer materials using optical microscopy and SEM.

Standard laboratory practices including safety, report writing, and error analysis are also emphasized.

Text books:

1. Electronic Materials: Science and Technology: Shyam P. Murarka, Martin C. Peckerar, Academic Press, 1989.
2. Ceramic Materials: Science and Engineering: C. Barry Carter, M. Norton, Springer, 2nd Ed., 2013.
3. Steels: Structure, Properties, and Design, H.K.D.H. Bhadeshia, R.W.K. Honeycombe, Elsevier
4. Brian Culshaw, Smart Structures and Materials, Artech House, 2000
5. Electronic Materials Science: Eugene A. Irene, Wiley, 2005.

Reference Books:

1. Introduction to Ceramics: W.D. Kingery, H.K. Bowen, D.R. Uhlmann, 2 nd Ed., Wiley, 1976.
2. Introduction to the Electronic Properties of Materials: David C. Jiles, 2nd Ed., CRC Press, 2001.
3. Antonio Concilio, Vincenza Antonucci, Ferdinando Auricchio, Leonardo Lecce, Elio Sacco., Shape memory alloy engineering for aerospace, structural, and bio-medical applications, Second edition, 2021.
4. Structure of Metals: Crystallographic Methods, Principles and Data, 3rd Edition, by C. S. Barrett, T. B. Massalski.
5. Cullity, B. D., & Stock, S. R. (2001). Elements of X-ray Diffraction, Third Edition. Prentice-Hall.
6. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Yang Leng; 2nd ed., Wiley, 2013
7. Scanning Electron Microscopy and X-Ray Microanalysis, Joseph Goldstein, Eric Lifshin, Charles E. Lyman, David C. Joy and Patrick Echlin; 3rd ed., Springer, 2003

2.0 Elective Courses

2.1 1st Semester

MM6101 Processing technology of metal, ceramic and composites (3-0-0) 6 credits

Course learning objectives (Comply with PLOs 1 and 3)

- To introduce students to the different processing technology
- To understand the connection between material properties and characteristics with the processing technologies involved

Course learning outcomes:

Upon completion of this course, the student will be able to:

- Will gain knowledge in metal processing, ceramic processing, and polymer processing.
- Understand the challenges involved in the processing of different materials

Metal Forming: Introduction to rolling, forging, extrusion, drawing and its engineering aspects, Development of microstructures with different processing technologies and its effects on forging, extrusion, rolling, and drawing on metallic alloy components. Effect of alloying additions.

Solidification: Thermodynamics of solidification, Nucleation and growth, Pure metal solidification, Gibbs Thomson effect, Alloy Solidification, Constitutional undercooling, Dendritic growth, Casting Pattern and Mould, Melting and Pouring, Heat transfer, Design of riser and gating

Ceramic Processing: Overview of different ceramic processing techniques, Colloidal processing of ceramics, DLVO theory, porous ceramics and ceramic fibres, Co-precipitation method, Sol-Gel process, technology for ceramic powder preparations, solid state reactions, science of sintering, Types of sintering, sintering mechanisms, products for engineering applications, powder metallurgy

Recommended text books:

1. Hosford, W. F., and Cadell, R. M., 2007, Metal Forming: Mechanics and Metallurgy, Cambride University Press, Cambridge.
2.George Dieter, 1986, Mechanical Metallurgy, Mc-Graw Hill
3.Solidification Processing; Fleming, M.C., McGraw-Hill, N.Y., 1974
4. Science and Engineering of Casting Solidification; Stefanescu, D.M., Kluwar Publications, 2002
5. Ceramic Materials: Science and Engineering, C. Barry Carter, M. Grant Norton; Springer, 2nd ed. 2013.
6. Fundamentals of Ceramics, M.W Barsoum; McGraw Hill, 1997.
7. Introduction to Ceramics, 2nd Ed, W. David Kingery, H. K. Bowen, Donald R. Uhlmann, Wiley,1976.

MM6102 Surface Engineering
(3-0-0) 3 credits

Course learning objectives (Comply with PLO 2)

- To make them understand the significance of surfaces and bulk property.
- To familiarize the students with a different kind of degradation of surfaces such as wear, corrosion
- To impart knowledge on different types of coatings techniques and their characterizations.

Course learning outcomes

Upon completion of this course, the student will be able to:

- Students understand the differences between the surface and bulk property
- Students acquire fundamental knowledge about the different kind of degradation mechanism.
- Students will have the better clarity on the thin film and thick coating techniques as well as its characterization techniques.

Syllabus

Introduction: Introduction to surface Engineering, Differences between surface and bulk, Properties of surfaces, surface energy concepts

Modification of surface: Changing the surface metallurgy: Localized surface hardening (flame, induction, laser, electron-beam hardening, Laser melting, shot peening), Changing the surface chemistry: Phosphating, Chromating, Anodizing (electrochemical conversion coating), Carburizing, Nitriding, Ion implantation, Laser alloying, boriding, Organic coatings (paints and polymeric or elastomeric coatings and linings), Hot-dip galvanizing (zinc coatings), Ceramic coatings (glass linings, cement linings, and porcelain enamels), Advanced surface coating methods: Gaseous State (CVD, PVD etc), Solution State (Chemical solution deposition, Electrochemical deposition, Sol gel, electroplating), Molten or semimolten State (Laser cladding and Thermal spraying)

Characterization of surface and coatings: Surface Characterization (physical and chemical methods, XPS, AES, RAMAN, FTIR etc), Structural Characterization, Mechanical Characterization (Adhesion, Hardness, Elastic Properties, Toughness, Scratch and Indentation etc.), Tribological Characterization, Corrosion tests.

Applications of the altered surface: Degradation of surfaces, wear and its type, Adhesive, Abrasive, Fretting, Erosion wear, Surface fatigue, Different types of Corrosion and its prevention, Galvanic corrosion, Passivation, Pitting, Crevice, Mircobial, High-temperature corrosion, Corrosion in nonmetals, polymers and glasses, Protection from corrosion through surface modifications, bio mimicking

Text Books:

1. Introduction to Surface Engineering and Functionally Engineered Materials, Peter Martin; Wiley, 2011.

2. Materials and Surface Engineering: Research and Development, J. Paulo Davim; Woodhead Publishing review, 2012.

Reference Books:

1. Surface Engineering: Processes and Applications, Chinnia Subramanian, K.N. Strafford, R. St. Smart, I.R. Sare; Technomic Publishing Company, 1995.
2. Surface Engineering for Corrosion and Wear Resistance, J. R. Davis; ASM International, 2001.

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MM6103 Nanomaterials: Structure, Property and Applications (3-0-0) 6 credits

Course Learning Objective (Comply with PLO 4)

- To comprehend how materials' behavior and properties change when examined at smaller scales
- To establish connections and decipher the underlying reasons for the observed changes in properties as length scales decrease
- To understand various crystallization pathways in nanocrystals and their impact on final properties

Course Learning Outcome

Upon completing this course, the student will be able to

- Able to investigate the origins of novel properties emerging at the nanoscale across different material classes
- Understand the categorization of properties depending on the length scales
- Understand the crystallization pathways in nanomaterials and their correlation with the observed novel properties

Nanomaterials: Definition, history, and brief background, Synthesis: Top-down and bottom-up techniques, Hybrid assembly of nanomaterials, micelle, surfactant, self-assembly, nanopatterning, surfactant assisted growth in nanocrystals.

Thermodynamics at nanoscale: Size effects on equilibrium vapor pressure, surface energy, Young-Laplace equation, Kelvin equation, Size Dependent Physical Properties in nanomaterials: melting point, sintering temperature, shape dependence on melting, size-dependent phase transformations at nanoscale, Surface properties of nanomaterials, surface energy for solids, broken bond theory, calculations of surface energy involving cubic structures, Wulff construction.

Nucleation and growth of Nanocrystals: different types, growth of nanocrystals via diffusion and surface process, contribution of surface energy on free energy for nanomaterials, size effects in nucleation, Ostwald ripening, Burst nucleation in nanomaterials, Classical (La Mer theory) and Non-classical crystallization, Oriented attachment in nanocrystals, Mesocrystallisation.

Size dependent Properties at nanoscale and their application: Chemical, Mechanical, Adhesion, Electrical, Magnetic, Optical, Applications of nanomaterials, shape memory polymer, Nanomaterials in Nature (Nacre, Gecko, Teeth), Biomimetic nanocomposites, Hydrogel, Nanotechnology in marketplace, ferro-fluids, Biomedical applications etc.

Text Book:

1. Nanoparticles: From Theory to Application, Günter Schmid (Editor), ISBN: 978-3-527-60404-3, 2006
2. Nanoparticles: From Theory to Application, Günter Schmid, Wiley, 2005. Synthesis, Properties, and Applications of Oxide Nanomaterials, José A. Rodriguez, Marcos Fernández-García, Wiley, 2007
3. Monodispersed Particles, T. Sugimoto, Elsevier.

4. Nanostructures and Nanomaterials: Synthesis, Properties, and Applications, 2nd ed., Guozhong Cao, Ying Wang; Imperial College Press, 2004.

Reference Books:

1. The Chemistry of Nanomaterials: Synthesis, Properties and Applications, Editors: C. N. R. Rao, Achim Müller, Anthony K. Cheetham, ISBN: 978-3-527-30686-2, March 2004
2. Nanoscale Materials in Chemistry, Kenneth J. Klabunde, Ryan M. Richards, 2nd Edition, Wiley, 2009
3. Nanostructured Materials (Processing, Properties and Applications), Carl C. Koch, Elsevier, 2006
4. Nanoparticles and Nanostructured Films: Preparation, Characterization, and Applications, Janos H. Fendler, Wiley, 2008

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM6104 Field-assisted Sintering Techniques
(3-0-0) 3 credits

Course learning objectives (Comply with PLOs 2 and 4)

- To understand the influence of electric field on the sintering behavior of materials
- To understand the technology and theoretical concepts of major field-assisted sintering techniques
- To understand the relation between processing parameters and properties of sintered materials

Course learning outcomes
Upon completion of this course the student will be able to:

- Understand how electric field can affect the sintering of materials
- Understand the fundamental principle, hardware and applications of various field-assisted sintering techniques
- Correlate the lower processing temperature and/or sintering time to obtain unique properties in materials compared to conventional sintering techniques

Introduction: Historical overview of field-assisted powder consolidation methods. Categorization of field-assisted sintering technologies. Underlying physical mechanism: Thermal and athermal factors influencing mass transport
Spark plasma sintering: Characteristic features, sintering equipment. Issue of spark and plasma in SPS. Effect of heating rate and applied pressure, sinter-forging. Temperature gradients and temperature measurements, electromigration
Flash sintering: Characteristic features of flash sintering, experimental setup. Influence of electrical parameters on densification. Power dissipation in samples, temperature measurements and luminescence. Mechanism of flash sintering. Reactive flash sintering.
Microwave sintering: Principles and mechanism of microwave heating and sintering, effective medium approximation, influence of ponderomotive forces. Microwave non-thermal effects.
Other field assisted sintering techniques: Magnetic pulse compaction, resistance sintering, sintering in noncontact mode and sintering in a magnetic field. Electromagnetic radiation (IR, visible and UV) for sintering, Laser assisted sintering.

Textbook:

1. Field-Assisted Sintering: Science and Applications, Eugene A Olevsky and Dina V Dudina, Springer, 2018.
2. Spark Plasma Sintering Current Status, New Developments and Challenges, Giacomo Cao, Claude Estournes, Javier Garay, Roberto Orru. 1st Ed., Elsevier, 2019.

Reference book:

1. Review articles on various field assisted sintering techniques

2.2 2nd Semester

MM6201 Defects and Diffusion in Materials

(3-0-0) 6 credits

Course learning objectives (Comply with PLOs 1 and 2)

- To understand the structure of crystalline materials and defects present at various dimensions in materials and their influence on properties
- To understand various methods to control and quantify the amount of defects in various materials
- To understand how material transport is fundamental to understand the materials processing including phase transformation

Course learning outcomes

At the end of the course, the student will be able to

- Understand how defects impact numerous properties of materials - from the conductivity of semiconductors to the strength of structural materials
- Understand and quantify the equilibrium and non-equilibrium defects that are present in crystals
- Correlate diffusion process and kinetics with temperature, concentration and time

Bonding and structure in crystalline solids: Bonding in solids- primary and secondary, unit cells, crystal systems, indexing planes and direction

Defects in crystalline materials: Point, linear, planar and volume defects. Equilibrium concentration of vacancies, doping in semiconductors. Point defects in ionic crystals, Frenkel and Schottky defects, Kröger-Vink notation. Edge and screw dislocations, Burger vector. Concept of slip, dislocation structures in fcc and bcc crystal systems. Slip systems, dislocation locks, Kear-Wilsdorf lock, partial dislocations, stacking faults, Orowan looping. Atomic structure and nature of grain boundaries, Energy of grain boundaries. Twin boundaries. Observation of defects. Role of defects on the properties of materials.

Diffusion: Atomistic mechanisms of diffusion, substitutional and interstitial diffusion. Fick's first and second law. Diffusion kinetics. Chemical potential gradient – Uphill diffusion, Surface, lattice, grain boundary and pipe diffusion. Kirkendall effect. Tracer diffusion.

Case studies: (i) Role of microstructure in transparency of alumina
(ii) Electromigration in integrated circuits
(iii) Ionic conductivity in cubic zirconia
(iv) Carburization and decarburization in steel
(v) Role of Kirkendall voids on weld joints

Text Book:

1. Introduction to dislocation theory: D. Hull and D.J. Bacon, Butterworth-Heinemann, Elsevier, 2011.
2. Diffusion in Solids: Paul Shewmon, 2nd Ed., Springer, 2016.

Reference Book:

1. Defects in Solids, R. J. D. Tilley, JW Wiley Press, 2008.
2. Fundamentals of Materials Science, the microstructure – property relationship using metals as model systems: Eric J. Mittemeijer, Springer, 2011.
3. Phase Transformation in Metals and Alloys: D.A. Porter, K.E. Easterling and M.Y. Sherif, 3rd Ed., CRC Press, 2009.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM6204 Materials Characterization Techniques
(3-0-0) 3 credits

Course learning objectives (Comply with PLOs 1 and 3)

- To enlighten students with the fundamental arrangement of atoms in materials and characterization of material's structure
- To understand how characterization of phases, composition and grain morphology is performed
- To understand the strength and weaknesses of different characterization techniques

Course learning outcomes:

Upon completion of this course, the student will be able to:

- Able to understand different structures in materials and identify the phases and structure of materials through XRD
- Analyze the phase and grain morphology through SEM and elemental composition through EDS
- Understand the which characterization technique will be suitable for a given material

Theory Syllabus

Introduction: Importance and the need for materials characterization, highlights of various characterization techniques, Crystal structure, miller indices, Bravias lattice.

Diffraction: Basics of diffraction and interference of light, Young's double slit experiment, interpretation of diffraction from the single slit and multiple slits

X-ray diffraction: Generation of X-ray, X-ray diffraction (XRD), Bragg's Law, Atomic scattering factor, structure factor, indexing of diffraction, selection rules, estimation of peak intensity, phase identification and analysis by XRD, stress calculation, crystallite size measurements through XRD.

Principles of optical microscopy-resolution, magnification, depth of focus; electron diffraction, imaging, construction of SEM, SE/BSE mode, EDS, EBSD, TEM, BF/DF imaging, contrast in TEM, crystal structure identification through Selected area diffraction pattern (SADP), Sample preparation for TEM

Instrumentation and principles of techniques used for thermal analysis (DSC, DTA, TG) and a combined method of thermal analysis and their applications in materials characterization.

Text Books:

1. Cullity, B. D., & Stock, S. R. (2001). Elements of X-ray Diffraction, Third Edition. Prentice-Hall.
2. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods, Yang Leng; 2nd ed., Wiley, 2013
3. Scanning Electron Microscopy and X-Ray Microanalysis, Joseph Goldstein, Eric Lifshin, Charles E. Lyman, David C. Joy and Patrick Echlin; 3rd ed., Springer, 2003

Reference Books:

1. Structure of Materials: An Introduction to Crystallography, Diffraction and Symmetry, Marc De Graef, Michael E. McHenry; 2nd (ed.), Cambridge University Press, 2012.
2. Crystal Structure Determination, Werner Massa; 2nd (ed.), Springer, 2010.

3. Crystal Structure Analysis: Principles and Practice, Peter Main, William Clegg (ed.), Alexander J. Blake, Robert O. Gould , Vol 6, Oxford Science Publication, 2001.

MM6208 Crystal Symmetry and Tensor properties
(3-0-0) 6 credits

Course learning objectives (Comply with PLO 1)

- To enlighten students with the fundamental arrangement of atoms in materials
- To visualize the illustration of crystal structure with the mathematical theory of crystallography

Course learning outcomes:
Upon completion of this course, the student will be able to:

- Connect the properties of the material with the atomic arrangement.
- Connect the physical properties of a material with crystal symmetry

Crystal structure: Direct and Reciprocal lattice (2D, 3D), Stereographic projection, Symmetry, Point groups, Space groups, and Systematic absences due to symmetry elements. Wyckoff Notation, Bravais lattices, and Crystal systems.

Tensors and Physical Properties: Tensor and scalar notation, ranks, transformations, effect of crystal symmetry on properties, transformation of axes, paramagnetic and diamagnetic susceptibility, electric polarization, stress tensor, strain tensor, thermal expansion, piezoelectricity- third rank tensor, elasticity- fourth rank tensor.

Text Books:

1. Crystals and crystal structure by Richard Tilley.
2. M.J. Buerger, Elementary Crystallography.
3. 3. J. F. Nye, Physical Properties of Crystals (1995), Oxford Science Publications

Reference Books:
1. Robert E. Newnham, “Properties of Materials: Anisotropy, Symmetry, Structure”, Oxford Pr.
2. International Tables of Crystallography A, International Union of Crystallography
3. D.R. Lovett, Tensor Properties of Crystals (1999), Institute of Physics Publishing
4. Fundamental of powder diffraction and structural characterization of Materials by Vitalij K. Pencharsky and Peter Y. Zavalij

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM6202 Polymer Matrix Composite
(3-0-0) 3 Credit

Course learning objectives (Comply with PLO 3)

- To educate the knowledge about the fundamentals of polymer composites and structures
- To comprehend the manufacturing, properties, and applications of various polymer matrix composites

Course learning outcomes:

Upon completion of this course, the student will be able to:

- Choose the suitable materials to fabricate novel polymer composites materials.
- Recognize the principles involved in choosing reinforcing agents and incorporating them into polymer matrices

Syllabus:

Introduction: Fundamental definitions, classification, and outline of composite materials, together with its constituents (interface, matrix, and reinforcements/fibers)

Matrices: Rubber matrices, Thermoplastic matrices, Thermoset matrices–polyesters, epoxides, phenolics, vinyl esters, polyimides and cyanate esters.

Fibers: Natural fibers, glass, carbon, kevlar, and surface treatment—sizing and coupling agents, Interfaces: optimal interfacial bond strength, forms of bonding at the interface, wettability, and crystallographic nature of interfaces.

Processing: Sheet molding compounds, bulk molding compounds, hand layup process, spray layup process, resin transfer molding, pressure bag molding, vacuum bag molding, autoclave molding, filament winding and pultrusion. Post processing techniques – Electroplating, vacuum metallization, joining, welding, bonding of polymers, hot foil stamping process, in mold decoration and recycling.

Mechanics of Composite: Macromechanics of Composites- elastic constants of laminate, elastic constants of an isotropic material, relationship between engineering constants and reduced stiffness and compliances. Micromechanics of Composites- Iso-strain and iso-stress models, Halpin-Tsai equation, longitudinal tensile strength prediction and transverse tensile strength prediction. Failure criteria - maximum strain theory, maximum stress theory, and Tsai-Wu failure criteria.

Testing of Composite: Degree of cure, viscosity, gel time, void content, density, shrinkage, flexural, shear, fatigue, tensile, compression, creep and impact properties. Non-destructive testing – Ultrasonic, acoustography, radiography, shearography, acoustic emission/ultrasonics, thermography, X-rays, tap test and visual test.

Text books:

1. F. R. Jones (Ed.), Handbook of Polymer-Fibre Composites, Longman Group (1994).

2. K. Friedrich, S. Fakirov, Z. Zhang (Eds.), Polymer Composites – from Nano to Macro scale, Springer (2005).

Reference books:

1. P. K. Mallick, Composites Engineering Handbook Part-1&2, CRC Press (2016).
2. Bhagwan D. Agarwal, Lawrence J. Broutman, K. Chandrashekhara, Analysis and Performance of Fiber Composites, 4th Edition, Wiley India (2017).
3. Ever J. Barbero, Introduction to Composite Materials Design, 2nd Edition., CRC Press (2011).

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM6205 Selection of alloys and heat treatment
(3-0-0) 3 credits

Course learning objectives (Comply with PLO 3)

- To understand the basic concept/design of adopting different engineering alloys (ferrous and non-ferrous) and their processing based on their applications.
- To understand heat treatment's basic concept and effect on the relationship between processing, microstructure, properties, and applications for different engineering alloys.

Course learning outcomes

After completion of this course, the student will be able to

- Understand the processing for the development of different alloys along with suitable heat treatment process
- Able to obtain required microstructure and properties for their respective applications in industrial practice.

Syllabus:

Selection of engineering alloys, including steels (carbon, alloy, stainless, dual phase, TRIP/TWIP), cast irons, aluminium, magnesium, titanium, nickel and cobalt-based superalloys and zirconium alloys.
In depth understanding of the microstructures and their development for the most common classes of engineering alloys.
Overview of microstructures, processing and properties in engineering alloys.
State-of-the-art approaches to the design and development of new alloys for the 21st century.

Principles of heat treatment, heat treatment of steels; Use of heat treatment to produce required metallurgical properties. Cooling curves and equilibrium diagrams. Hardenability, Strength, and Toughness; Case hardening, Carburizing, Nitriding, De-carburizing Re-heat treatment, Re-tempering, Annealing, and Normalizing.

Heat treatment of Aluminum alloys, Annealing, Solution treatment, Natural ageing, Artificial ageing, Over ageing explanation of the heat treatment of Aluminum alloys, Control testing.

Theory of Heat Treatment, Heat Treatment Environment, Different Heat Treatment Techniques, Fundamentals and Properties; Annealing, Tempering, Hardening, Thermomechanical treatment; Economy of Heat Treatment Processes.

Text Books:

1. Principles of Heat Treatment of Steels, R.C. Sharma; New Age International (P) Ltd, 2003.
2. The Heat Treating Source Book, ASM International, 1986.

Reference Books:

1. Physical Metallurgy, Vijendra Singh, Standard Publishers Distributors, Delhi, 2015.
2. Engineering Physical Metallurgy and Heat Treatment; Y. Lakhtein, Mir Publisher, 1979.
3. Materials and Design, M.F. Ashby and Kara Johnson; Butterworth-Heinemann Ltd, 2002.

MM6203 Functional Ceramics
(3-0-0) 6 credits

Course Learning Objective (Comply with PLO 4)

- To understand the physics and chemistry of the ceramic material
- To understand the structure-property correlation in ceramic
- To learn about state of the art regarding the application of functional ceramic materials

Course Learning Outcome

Upon completing this course, the student will be able to

- Identify the reasons behind new novel properties emerging for ceramic materials
- Classification of properties along with their possible market applications
- Distinguish between different functional ceramic materials

Bonding in ceramic, Structure of ceramic, Pauling’s rule

Defects in ceramics, Defect Classes, Point Defects, Kröger-Vink Notation, Point Defect Formation, Thermodynamics of Intrinsic Defects, and Defect Reactions.

Introduction to electronic properties; Drude model, its success and failure; energy bands in crystals; density of states; electronic conduction in ceramics; ceramic semiconductors; Ionic conduction in ceramics. Ceramic insulators, dielectric strength, dielectric constant, ferroelectricity; piezoelectricity, polarization theories;

Magnetic properties, hysteresis, microscopic origin, exchange interaction, types of magnetism;

Optical properties, atomic-electronic interaction, refraction, reflection, Absorption Transmission, Luminescence, Lasers, optical fibers

Text Books:

1. Electronic Properties of Materials, R. E. Hummel, Springer-Verlag New York Inc.; 4th ed. CBS Publishers, 2011.
2. An Introduction to Electronic Materials for Engineers, Zhengwei Li, Nigel M. Sammes; World Scientific Publishing Co. Pte. Ltd., 2011.

Reference books:

1. Solid State Chemistry and Its Applications, Anthony R. West; John Wiley & Sons, 1985.
2. Ceramic Materials: Science and Engineering, C. Barry Carter, M. Grant Norton; Springer, 2nd ed. 2013.
3. Fundamentals of Ceramics, M.W Barsoum; McGraw Hill, 1997

MM6206 Thin films- an engineering approach
(3-0-0) 3 credits

Course Learning Objectives (Comply with PLOs 2 and 4)
- To understand the various physical and chemical deposition methods
- To understand and analyze the characteristics of thin films using different instrumentation techniques.
- To understand different types of nucleation theories, growth mechanisms of thin films

Course Learning Outcome
Upon completing this course, the student will be able to:
- Identify various techniques of thin film depositions
- Classify and distinguish different thin film properties and correlate the same with relevant industrial applications
- Understand the fundamentals of nucleation and growth of various thin films

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

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

Solution-based chemical Techniques: Spray pyrolisis, Electrodeposition, electroless deposition and plating for large area industrial coating, chemical bath deposition (CBD), successive ionic layer adsorption and reaction (SILAR) method, Sol-gel (spin coating and dip coating) and Langmuir Blodgett techniques for polymer and soft molecules

Thin film and surface characterization techniques

Application and devices: thin films in MEMS, NEMS, sensors, actuators, transducers and other relevant fields involving surface engineering applications.

Text Books:
1. Milton Ohring, The Materials Science of Thin Films, Academic Press-Sanden, 1992
2. Reference Books:
3. Thin Film Materials: Stress, Defect Formation and Surface Evolution, L. B. Freund, S. Suresh, Cambridge University Press, 2004
4. Thin Film Processes II, Werner Kern, editor: John Vossen, Academic Press, 2012

5. Thin-Film Deposition: Principles and Practice, Donald L. Smith, McGraw Hill Professional, 1995

MM6207 Joining of Materials

(3-0-0) 3 credits

Course learning objectives (Comply with PLOs 1 and 3)

- To know about the relevance of joining materials and the methods involved
- To understand the challenges in joining dissimilar materials
- To understand the different strategies employed in the joining of metals, ceramic, and polymer

Course learning outcomes

Upon completing this course, the student will be able to

- Understand different ways of joining of metal, ceramic, and polymer
- Understand the difficulties of joining materials and come up with solutions
- Understand the advancements in joining technology from research and industrial perspectives.

Syllabus

Welding, theory, and classification of welding, submerged arc welding, gas metal arc welding or MIG/MAG welding, TIG welding, resistance welding. Other joining processes, soldering, brazing, diffusion bonding, and adhesive bonding of metallic materials; adhesive bonding, solvent bonding, and welding of polymer materials; brazing, frit sealing, diffusion bonding, and welding of ceramic materials and composite materials; wire bonding, flip-chip bonding, and wafer bonding of semiconductor materials; nanofoils based bonding

Solid state welding technique: friction welding, friction stir welding, welding defects, characterization of weld: weld microstructure, compositional analysis, tensile test, bend test, hardness test, toughness test and non-destructive test, HAZ, weldability.

Text Books:

1. Metallurgy of Welding, Lancaster, Allen, Unwin; Springer, 1980.
2. Welding and Welding Technology, Little R.L; McGraw-Hill Companies, 1973.
3. Advanced Welding processes, Norrish, J., Woodhead, Woodhead Publishing, 2006.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM6209 Coating Technology
(3-0-0) 6 credits

Course Learning Objective (Comply with PLOs 2 and 4)

- To understand the nature and magnitude of the changes in behaviour of materials at the interfaces
- To understand different methods for processing of coatings
- To learn about different mechanical and functional properties of coatings

Course Learning Outcome

Upon completing of this course, the student will be able to

- Identify the reasons behind new novel properties emerging at the interface for different classes of materials
- Distinguish between different processing technologies for coatings
- Understand the mechanical and functional of properties of coatings along with their possible market applications

Introduction to coatings for different temperature applications, Properties of surfaces-wear, corrosion, optical, roughness, electrical and thermal properties, wetability

Concepts of coating, Thin film coating, Physical Vapour Deposition: Thermal Evaporation, E-Beam Deposition, Sputtering. Chemical Vapour Deposition: Thermal Assisted CVD, Plasma Enhanced CVD, Photo Assisted CVD, Metal-Organic CVD, Sol-gel deposition, Thick Coating: Thermal spray Types of thermals spary and their advantages and disadvantages. Flame Spray, HVOF, Plasma spray- conventional vs. nanostructured coatings, Process parameters, thermal and kinetic history of inflight particle, microstructural features of plasma sprayed coatings, single splat studies, process-structure property relationship-challenges in prepartion, plasma spraying of nanopowders - its microsturcutre – properties –Liquid precurser plasma spray- Thermal barrier coatings and materials including yittria stabilized zirconia

Characterization of film and thick coatings, Coatings –thickness-porosity-hardness, fracture toughness, elastic modulus – adhesion-bending strength-fracture strength- tensile strength, coating tribology, corrosion measurement, phase analysis and microstructure, Surface characterization techniques. Applications of coatings: wear resistance, corrosion, thermal barrier, Anti scratch, Biomedical, near net shape, embedded sensors, Energy applications like Solid oxide fuel cell, Dye sensitized solar cell

Text Books:

1. Introduction to Surface Engineering and Functionally Engineered Materials, Peter Martin; Wiley, 2011.
2. Materials and Surface Engineering: Research and Development, J. Paulo Davim; Woodhead Publishing Ltd.,2012.
3. The Science and Engineering of Thermal Spray Coatings, Lech Pawlowski; Wiley, 2008. The Cold Spray Materials Deposition Process: Fundamentals and Applications, Victor K. Champagne; Woodhead Publishing Ltd, Maney publishing Ltd., 2007

Reference books:

1. Quo Vadis Thermal Spraying? P. Fauchais, A. Vardelle, B. Dussoubs; Journal of Thermal Spray Technology, Vol. 10, 2001. Thermal Spray Coatings, Kurt H Sien (ed); Chapman and Hall, 1996.

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Department of Metallurgical and Materials Engineering

Course Number	**MM6210**
Course Credit **(L-T-P-C)**	**3-0-0 (6 AIU credits)**
Course Title	**Fabrication of Solid-state Devices**
Learning Mode	Lecture
Prerequisite	None
Learning Objectives	To provide basics of semiconductors properties and discussing the working and applications of basic semiconductor devices. To provide a fundamental understanding of materials and devices fabrication used in the semiconductor industry.
Course Description	This course will enable students to understand working principle of various semiconductor devices such as transistors, diodes, solar cells, and light-emitting devices.
Course Content	Fundamental of Semiconductors: Energy band theory, Quantum Free Electron Theory by Drude and Lorentz, Sommerfield free electron theory for metals, Brillouin Zone Theory [Band Theory by Bloch], density of states, Quasi-Fermi levels, Maxwell-Boltzmann distribution, Fermi-Dirac statistics, intrinsic semiconductor, n-type/p-type semiconductor, transport phenomenon of charge carriers, Energy bands in solids, band structure, band diagram of few important semiconductors (Si, Ge, GaAs, GaN), engineering of doping, surface energy of solids, effective mass, Brillouin zone, direct and indirect gaps semiconductor and photovoltaic effect. Fabrication of Semiconductors and devices: Production of single crystal of semiconducting materials, Semiconductor Grade Silicon, metallurgical grade silicon, Lithography, DC/RF magnetron sputtering. Device characterization and application: Heterostructure p-n junctions, Schottky junctions, Ohmic contacts: Metal-semiconductor junctions, Schottky and Ohmic contacts, Metal-Semiconductor contacts, Metal-insulator-semiconductor structures, tunnel diodes, Gunneffect, p-i-n structures, Zener diode, Bipolar transistors, principle of operation of MOSFETs, characteristics of MOSFET, source-drain/transfer characteristics of MOSFET, introduction to JFETs, MESFETs, and MODFETs. carrier statistics under illumination condition, generation and recombination of carriers, emitting diodes (LED), LEDs, laser-diodes and solar cells, Current-voltage characteristics, capacitance-voltage (CV) and impedance measurements.

Learning Outcome	Upon completing of this course, the student will be able to Explain the basics properties of semiconductors including the energy bands, band gap, charge carrier concentration, transport phenomenon of charge carriers, basics of compound semiconductors and their devices. Describe the fabrication of semiconductors devices and the applications of various semiconducting devices including p-n junctions, Schottky junctions, Metal-Semiconductor contact, BJTs and FETs and the working and design considerations for the various devices like transistors, LEDs, solar cells.
Assessment Method	Assignments, Quizzes, Mid-semester examination, End-semester examination.

Textbooks:

1. Semiconductor Devices: Physics and Technology Hardcover – by Simon M. Sze (Author), Ming-Kwei Lee, 2012.
2. An Introduction to Semiconductor Devices- D. Neamen, McGraw-Hill Education, 2005.
3. Physics of Semiconductor Devices -S.M. Sze and K. K. Ng, Wiley- Interscience, 3rd edition, 2006.

Reference books:

1. Semiconductor Physics: An Introduction -K. Seeger, Springer-Verlag, Berlin, 9th edition, 2004.
2. Electronic Materials and Devices: David K. Ferry, Jonathan P. Bird, Wiley, 2001.
3. Introduction to the Electronic Properties of Materials: David C. Jiles, 2nd Ed., CRC Press, 2001.

	CLO1	CLO2
PLO1		X
PLO2	X	
PLO3		X
PLO4	X	

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

3.0 IDE

MM6105 Structural characterization of materials (3-0-0) 6 credits

Course learning objectives (Comply with PLOs 2 and 3)

- To understand how material characterization is of paramount importance to the study of materials science
- To understand the basics as well as strengths and weaknesses of different characterization techniques
-

Course learning outcomes

Upon completion of this course, the student will be able to:

- Understand the importance of the different characterization techniques
- Understand the fundamentals of different characterization techniques and application of it in materials characterization

Introduction: Importance and the need for materials characterization, bonding, crystal structure and system, miller indices, Bravais lattice.

Diffraction: Basics of diffraction and interference of light, Young's double slit experiment, interpretation of diffraction from the single slit and multiple slits.

X-ray Diffraction: Generation of X-rays, X-ray diffraction (XRD), Bragg's Law, Atomic scattering factor, structure factor, indexing of diffraction patterns, selection rules, estimation of peak intensity, phase identification and analysis by XRD, determination of structure and lattice parameters, strain and crystallite size measurements through XRD, effect of temperature on XRD.

Electron diffraction: Wave properties of the electron, electron-matter interactions, ring patterns, spot patterns, and Laue zones.

Optical Microscopy: Principles of optical microscopy, magnification, Rayleigh criterion, resolution limitation, Airy disk, depth of focus, and field.

Scanning Electron Microscopy: Principle, construction, and operation of Scanning Electron Microscope, SE and BSE imaging modes, Elemental analysis using Energy dispersive analysis of X-rays,

Transmission electron microscope: Principle, construction, and working of Transmission Electron Microscope (TEM), the origin of contrast: mass-thickness contrast, electron diffraction pattern, Bright field, and dark field images.

Text Books:

1. Elements of X-Ray Diffraction: B.D. Cullity and S.R. Stock, 3rd Ed., Pearson, 2001.
2. Scanning Electron Microscopy and X-Ray Microanalysis: Joseph Goldstein, Eric Lifshin, Charles E. Lyman, David C. Joy and Patrick Echlin, 3rd Ed., Springer, 2003.

Reference Books:

1. Transmission Electron Microscopy: A Textbook for Materials Science: David B. Williams and C. Barry Carter, Springer, 2009.
2. Structure of Materials: An Introduction to Crystallography, Diffraction and Symmetry, Marc De Graef, Michael E. McHenry; 2nd Ed., Cambridge University Press, 2012.

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Department of Metallurgical and Materials Engineering

MM6106 Composite Science and Technology
(3-0-0) 3 Credits

Course learning objectives (Comply with PLO 3)

- To impart knowledge on the fundamentals of polymer/metal/ceramic composites and structures
- To know about the manufacture, properties, and applications of various polymer/metal/ceramic composites
- To understand the effect of reinforcement in composite materials.

Course learning outcomes:
By the end of this course, the students will be able to
- Use appropriate materials in suitable forms for making polymer/metal/ceramic composites and structures.
- Design, analysis, manufacture, and test new composite materials.
- Understand the concepts in selecting reinforcing agents and their incorporation in polymer/metal/ceramic matrices.

Syllabus:
Introduction and Overview of Metal-based composites, overviews of key technologies and issues in the area, Fabrication of Metal Matrix Composites: Commonly used Matrices, Basic Requirements in Selection of constituents, solidification processing of composites - XD process, Spray processes - Osprey Process, Rapid solidification processing, Dispersion Processes - Stir-casting & Compo casting, Screw extrusion, Liquid-metal impregnation technique - Squeeze casting, Pressure infiltration, Lanxide process), Principle of molten alloy infiltration, rheological behaviour of melt-particle slurry, Synthesis of In situ Composites
Resins- Resins used in polymer composites, Fillers- Fibers, conventional fillers, and nanofillers used in polymer composites. Fabrication- Different processing techniques for polymer composites. Testing and characterization, Structure-property relationship in conventional polymer composites and polymer nanocomposites, Applications. Ceramic matrix composites, mechanical properties of ceramic matrix composites, different processing techniques for ceramic matrix composites, process capability, and applications of various techniques. Structure-property correlation in composite

Textbooks:
1. Composite materials, K.K. Chawala; 2nd ed.,Springer-Verlag, 1987.
2. Nanocomposite Science and Technology, P. M. Ajayan, L. S. Schadler, P. V. Braun; Wiley-VCH Verlag GmbH Co, 2013.

Reference Books:
1. Mechanics and Analysis of Composite Materials, V.V. Vasiliev, E.V. Morozov; Elsevier Science Ltd, 2001.
2. Ceramic matrix composites, K.K. Chawala; 1st ed., Chapman & Hall,1993.
3. Advances in composite materials, G. Piatti; Applied Science Publishers Ltd., 1978.
4. Composite Materials, Mel. M. Schwartz; Vol 1 & 2, Prentice - Hall PTR, 1997.

MM6153 Structure-property Correlation in Materials Science (3-0-0) 3 Credit

Course learning objectives (Comply with PLOs 1 and 2)

- To explore various classes of advanced materials, including metals, ceramics, and polymers
- To develop critical thinking skills to select appropriate materials for specific engineering applications.
- To understand how specific material properties and behaviors are determined by the associated structure.

Course learning outcomes

On completion of the course, the students will be able to

- Differentiate between different types of materials, their structures and properties
- Select appropriate materials for various engineering applications
- Design materials for various engineering applications.

Syllabus:

Microstructure and microstructural hierarchy in materials. Relationship between microstructure, processing, properties, and performance.

Classification of materials: engineering materials and their classification:

Metallic materials: Steel, superalloys and lightweight metals. Heat treatment processes (annealing, quenching, tempering) and their effects. Applications of advanced metallic materials in aerospace, automotive, and energy sectors.

Ceramic materials: structure and properties of engineering ceramics. Processing techniques for ceramics (sintering, hot pressing). Applications of ceramics in electronics, wear resistance, and high-temperature environments.

Polymer materials: Structure and properties of various polymer classes (thermoplastics, thermosets, elastomers). Polymer processing methods (injection molding, extrusion). Applications of advanced polymers in aerospace, biomedical engineering, and electronics.

Text Books:

1. Materials Science and Engineering, an Introduction: William D. Callister, 7th Ed., John Wiley and Sons, 2007.
2. Materials Science and Engineering: V. Raghavan, 6th Ed., Prentice Hall India, 2015.

4.0 Advance courses (7th Level)

MM7171 Rubber Science and Technology
(3-0-0) 3 credits

Course learning objectives (Comply with PLOs 3 and 4)

- To know about the properties, structure-property relationship, and application of different rubbers
- To understand the importance of compounding/shaping/vulcanization techniques of rubbers
- To understand the recent developments in rubber science and technology

Course learning outcomes

Upon completing this course, the student will be able to

- Will be able to summarize the chemical structure, molecular properties, physical/chemical properties, and areas of application of major types of rubbers.
- Will be familiar with the role of compounding ingredients, vulcanization process, and appropriate processing techniques at a basic and advanced level.
- Will be able to clearly decipher the advancements in rubber science and technology from research and industrial perspectives.

Syllabus

Rubbers and rubber blends: Natural rubber, polymerization: synthesis of synthetic rubbers, different synthetic rubbers: polybutadiene rubber, styrene-butadiene rubber, acrylonitrile butadiene rubber, chloroprene rubber, polyisoprene rubber, butyl rubber, halogenated copolymers of butyl rubber, ethylene propylene rubber (EPM and EPDM), ethylene vinylacetate copolymers, chlorinated polyethylene, chlorosulfonated polyethylene, acrylic rubbers and ethylene acrylate copolymers, epichlorohydrin rubber, polypropylene oxide rubber, fluoroelastomer, polynorbornene, polysiloxane and silicone rubber, polysulfide rubber, polyester and polyether rubber, polyurethane elastomer and chemical modification of rubbers. Rubber blends: rubber-rubber blends, rubber-plastic blends, thermoplastic elastomers, thermoplastic vulcanizates and structure property relationship in different rubbers and rubber based blends.

Rubber compounding: Rubber chemicals and additives: Mastication and peptizers, vulcanizing agents, accelerators, activators, retarders, aging, fatigue and ozone protective agents, antioxidants, reinforcing fillers and non-reinforcing fillers, pigments, plasticizers, processing aids and factice, blowing agents and adhesion promoters. Developing formulations for rubber compounding.

Processing of rubbers: Compound preparation using internal mixers and two-roll mixing mill, processing to sheets, manufacturing of extruded products and manufacturing of molded rubber goods.

Rubber testing and analysis: Mechanical testing, rheological studies, viscoelastic studies, adhesion testing, electrical testing, chemical testing, thermal testing and morphological analysis

Rubber latices: Natural rubber latex and modified natural rubber latices, synthetic rubber latices: styrene butadiene rubber latex, nitrile rubber latex, polychloroprene latex, isobutylene isoprene rubber latex and modified synthetic rubber latices, latex compounding, latex processing and testing.

Recent developments in rubber science and technology: Nanofillers and application of nano-fillers in rubbers, alternative vulcanization systems, advancements in rubber processing techniques, sustainable elastomers, smart elastomers, self-healing elastomers, recent advances in the devulcanization technologies and rubber recycling.

Textbooks:

1. Rubber Technology, Maurice Morton; Kluwer Academic Publishers, 1999.
2. Rubber chemistry, JA Brydson (ed), Applied Science Publishers Limited, 1978.
3. Current Topics in Elastomers Research, Anil K. Bhowmick (ed); CRC Press, 2008.

Reference books:

1. Rubber Products Manufacturing Technology, Anil K. Bhowmick, M. M. Hall, H. Benary, (Eds); Marcel Dekker Inc,1994.
2. Rubber Compounding-Principles: Materials and Techniques, Fred W. Barlow (ed), Marcel Dekker Inc, 1996.
3. Physical Testing of Rubber, Roger Brown (ed); Chapman and Hall, 1996.
4. Handbook of Elastomers, AK Bhowmick, Howard L. Stephens (eds); Marcel Dekker Inc, 2001.

INDIAN INSTITUTE OF TECHNOLOGY PATNA

Department of Metallurgical and Materials Engineering

MM7271 Flash sintering of ceramics
(3-0-0) 6 credits

Course learning objectives (Comply with PLOs 2 and 4)

- To understand how flash sintering can be used in various technological applications
- To learn how the structure of dense samples can be modified through flash phenomena to create new states of matter
- To learn how flash sintering can be used for phase reaction and sintering, together

Course learning outcomes

Upon completion of this course the student will be able to:

- Understand the fundamental principle, hardware and applications of flash sintering technique
- Understand the novelty of flash sintering technique
- Understand how flash sintering can be used as a generic tool for materials development

Introduction: Two-electrode method of sintering. Flash sintering phenomena, onset criteria, conductivity at the flash onset, and different stages of flash sintering. Process parameters, atmosphere, and equipment. Temperature measurement: temperature evolution, Modelling temperature evolution, *in-situ* and *ex-situ* temperature measurement, measurements at synchrotrons.

Mechanism: Microstructure evolution. Thermal runaway of Joule heating, grain boundary overheating, electrochemical reaction, and avalanche of Frenkel pairs.

Science to technology: Flash sintering of multi-layered materials, continuous flash sintering, flash joining, Contactless flash sintering, the influence of imposed magnetic field. Sintering maps, constrained sintering.

Reactive flash sintering: Resolving the issue of phase reaction and sintering. Influence of volume change on sintering. *In-situ* measurements of phase reaction. Synthesis of materials for battery and fuel cells.

Flash phenomena on dense samples: Flash experiments on single crystals, bicrystals and dense polycrystals. Materials development through repetitive flash experiments. Quenching experiments to freeze structure.

Case studies:

- Flash assisted synthesis of materials for lithium ion battery
- Development of solid oxide fuel cell in one step
- Superplastic elongation of ceramics through flash phenomena

Textbook:

1. Field-Assisted Sintering: Science and Applications, Eugene A. Olevsky and Dina V. Dudina, Springer, 2018.

Reference papers:

1. C.E.J. Dancer. Flash sintering of ceramic materials. Materials Research Express. 2016;3(10):102001.
2. M. Yu, S. Grasso, R. Mckinnon, T. Saunders, M.J. Reece. Review of flash sintering: materials, mechanisms and modelling. Advances in Applied Ceramics. 2017;116(1):24–60.
3. M. Biesuz, V.M. Sglavo. Flash sintering of ceramics. Journal of the European Ceramic Society. 2019;39(2):115–143.
4. R.I. Todd. Flash Sintering of Ceramics: A Short Review. In: B. Lee, R. Gadow, V. Mitic, eds. Proceedings of the IV Advanced Ceramics and Applications Conference. Paris: Atlantis Press; 2017:1–12.
5. E. Gil-González, L.A. Pérez-Maqueda, P.E. Sánchez-Jiménez, A. Perejón. Flash Sintering Research Perspective: A Bibliometric Analysis. Materials. 2022;15(2):416.

MM7272 Advanced Topics in Ceramic Processing
(3-0-0) 3 credits

Course learning objectives (Comply with PLOs 1 and 2)

- To understand the influence of various parameters like temperature, pressure, and electric field on the sintering of ceramic
- To understand the theoretical concepts of different sintering methods

Course learning outcomes
Upon completion of this course, the student will be able to:
- Understand how different process parameters influence the sintering
- Understand the fundamental of sintering including newer sintering technologies like FAST

Syllabus
Historical overview of the processing of ceramic materials, different ceramic processing techniques, powder processing routes, techniques of powder production

Kröger-Vink notation, defects in ceramic, defect equilibria, Brouwer diagram. Diffusion in ceramics, theory of diffusion, the diffusion equation and Fick's laws, atomistic mechanism of sintering, lattice, grain boundary and surface diffusion, ambipolar diffusion

Thermodynamics of surfaces and interfaces, interfacial free energy, role of surfaces and interfaces on sintering, the change of pressure and chemical potential under a curved surface, Gibbs-Thomson equation

Definitions, stages, and driving force for sintering, geometric model of sintering

Intermediate and final stage theory, the models of Coble, grain growth, grain boundary-pore interaction, two-step sintering, reactive sintering

Liquid phase sintering, transient and persistent liquid phase sintering, microstructural evolution

Effect of pressure on sintering, Plastic Yielding Mechanisms, creep Mechanisms, hot pressing, cold sintering, the effect of electric field on sintering, FAST, and Flash sintering, Numerical Simulation of Sintering, sintering maps, and case studies, Properties of sintered ceramics

Text Books
1. Ceramic Processing and Sintering, Mohamed N. Rahaman,, 2nd Edition, CRC Press, 2003
2. Fundamentals of Ceramics, M.W Barsoum; McGraw Hill, 1997.
3. Introduction to Ceramics, 2nd Ed, W. David Kingery, H. K. Bowen, Donald R. Uhlmann, Wiley,1976.

Reference Books

1. Ceramic Materials: Science and Engineering, C. Barry Carter, M. Grant Norton; Springer, 2nd ed. 2013.
2. A. Upadhyaya, G.S. Upadhyaya, Powder Metallurgy: Science, Technology and Materials, 2011.