Annexure-I

MANGALORE UNIVERSITY
DEPARTMENT OF MATERIALS SCIENCE

SYLLABUS AND SCHEME OF EXAMINATIONS FOR TWO – YEAR (FOUR SEMESTERS) M.Sc. DEGREE COURSE IN MATERIALS SCIENCE UNDER CHOICED BASED CREDIT SYSTEM (CBCS-2016)

HIGHLIGHTS:

The PG Programme comprises "Core" and "Elective" Courses. Core courses are related to the discipline of the programme. This is further divided into hard core and soft core. Hard core courses are compulsorily studied by a student as a core requirement to complete the programme in the discipline. Soft core courses are electives, but related to the discipline the progamme. Open elective is a course chosen by a student unrelated to the discipline within the faculty or across the faculty. Open electives are offered in the II and III semesters. The students will have to pass the open elective course and earn the credit for the completion of the programme, but the credit will not be counted for the calculation of CGPA.

The total Credit requirement for M.Sc. degree programme in Materials Science is 81, out of which the Hard Core (H) is 51 and Soft Core(S) is 30, while the open electives (E) will have a fixed 6 credits. The distribution of courses and credits among the four semesters is shown in the table below.

CBCS PROGRAMME STRUCTURE

SEMESTER	COURSES	TYPE	CREDITS/ COURSE	CREDITS			TOTAL CREDITS
				HARD	SOFT	ELECTIVE	
I	4 Theory	Hard	4	16	-	-	22
	2 Lab	Soft	3	-	06	-	
II	2 Theory	Hard	4	08	-	-	20+3*
	3 Theory	Soft	3	-	09	-	
	1 Lab	Soft	3	-	03	-	
	1 Theory	Elective	3	-	-	03*	
III	3 Theory	Hard	4	12	-	-	21+3*
	2 Theory	Soft	3	-	06	-	
	1 Lab	Soft	3	-	03	-	
	1 Theory	Elective	3	-	-	03*	
IV	1 Project/ Internship	Hard	-	18	-	-	18
Total Credits of the Programme				54	27	06*	81+6*

***Not to be counted for CGPA**

SCHEME OF INSTRUCTION, EXAMINATION AND EVALUATION

Semester	Courses	Type & Credits	Teaching Hours/Week /Course	Duration of Examination Hours	Marks Exam+IA*	Total Marks/ Course
I	4 Theory	Hard 4	4	3	70+30	100
	2 Lab	Soft 3	16**	4	70+30	100
II	2 Theory	Hard 4	4	3	70+30	100
	3 Theory	Soft 3	3	3	70+30	100
	1 Lab	Soft 3	8**	4	70+30	100
	1 Theory	Elective 3	3	3	70+30	100
III	3 Theory	Hard 4	4	3	70+30	100
	2 Theory	Soft 3	3	3	70+30	100
	1 Lab	Soft 3	8**	4	70+30	100
	1 Theory	Elective 3	3	3	70+30	100
IV	1 Project Report	Hard 18 3-months		-	400	500
	Viva			-	100	

***IA- Internal Assessment**

**The duration of the lab courses is 8 hours per week and includes tutorials.

BASIS FOR INTERNAL ASSESSMENT:

Internal assessment marks in each theory course shall be based on two tests and an assignment. Internal assessment marks in each laboratory course is assessed by the faculty members of the department based on the regular performance in the laboratory, the viva conducted on each experiment, the internal test and the laboratory records submitted by the student.

QUESTION PAPER PATTERN

Each hard core and soft core theory course examination is for 70 marks. Two questions from each unit of the course, with internal choice shall be given. One question with 5 or 10 short questions/problems carrying 2 or 1 mark respectively, is compulsory. The question paper for open elective shall have 10 questions of 10 marks each, out of which the student shall answer any seven questions.

PRACTICAL EXAMINATION:

End semester examination for each practical course is based on the consensus evaluation by both the examiners.

PROJECT REPORT:

A project/internship work shall be carried out by the student in IVth semester. The project report and viva voce examination shall be evaluated by the examiners.

ELIGIBILITY FOR THE M.Sc. PROGRAM IN MATERIALS SCIENCE

The eligibility criteria for admission in M.Sc. Materials Science is as follows:

(i) B.Sc. degree of Mangalore University or any other University considered as equivalent thereto with Physics/Chemistry as one of the optional/ major/special subject with a minimum of 45% marks (40% for SC/ST/Category-I) (or equivalent CGPA) are eligible to apply for admission to M.Sc. in Materials Science Programme. The candidates should have secured 45% (or equivalent CGPA) aggregate marks in the other optional subjects also. The candidates who have not studied Chemistry/Physics at the undergraduate level must have studied Chemistry/Physics at P.U.C./Higher Secondary level. OR

(ii) Bachelor's degree in Engineering/Technology from any of the recognized University in India/abroad with a minimum of 45% marks (40% for SC/ST/Category-I) (or equivalent CGPA).

COURSES OFFERED:

COURSE CODE	COURSE TITLE	Type & Credit	Type & Credit
I SEMESTER			
MSH 401	MATHEMATICS FOR MATERIALS SCIENCE AND ENGINEERING	H4	-
MSH 402	ELEMENTS OF MATERIALS SCIENCE	H4	-
MSH 403	FUNDAMENTALS OF ELECTRONIC MATERIALS AND DEVICES	H4	-
MSH 404	THERMODYNAMICS & PHYSICAL METALLURGY	H4	-
MSP 405	MATERIALS SCIENCE LAB - I	-	S3
MSP 406	MATERIALS SCIENCE LAB - II	-	S3
	CREDITS REQUIRED	**22**	
II SEMESTER			
MSH 451	MECHANICAL BEHAVIOUR OF MATERIALS	H4	
MSH 452	MATERIALS TESTING AND CHARACTERIZATION	H4	
MSS 453	SURFACE PHENOMENA AND ELECTROCHEMISTRY		S3
MSS 454	POLYMER SCIENCE		S3
MSS 455	THIN FILMS	-	S3
MSS 456	QUANTUM MECHANICS		S3
MSS 457	NANOSCIENCE & NANOTECHNOLOGY - I		S3
MSP 458	MATERIALS SCIENCE LAB - III	-	S3
MSE 459	SCIENCE OF MATERIALS IN DAILY LIFE		OE3
	CREDITS REQUIRED	**20+3***	
III SEMESTER			
MSH 501	DIELECTRIC MATERIALS	H4	
MSH 502	MAGNETIC MATERIALS & MAGNETIC RESONANCE	H4	
MSH 503	SOLID STATE ENGINEERING MATERIALS	H4	
MSS 504	NEW MATERIALS & TECHNOLOGIES		S3
MSS 505	COMPOSITE MATERIALS		S3
MSS 506	NANOSCIENCE & NANOTECHNOLOGY - II		S3
MSS 507	CRYSTAL GROWTH		S3
MSS 508	MATERIALS SCIENCE LAB - IV		S3
MSE 509	MATERIALS FOR ENERGY PRODUCTION		OE3
	CREDITS REQUIRED	**21+3***	
IV SEMESTER			
MSH 551	PROJECT	H18	
	CREDITS	**18**	**-**
	TOTAL CREDITS	**51**	**30**
		81+6 *	

***Open Elective**

PRE-REQUISITES FOR THE COURSES:
Nanoscience and Nanotechnology-I is pre-requisite for Nanoscience and Nanotechnology-II.

MANGALORE UNIVERSITY

TWO YEAR M.Sc. DEGREE PROGRAMME IN MATERIALS SCIENCE

(CHOICE BASED CREDIT SYSTEM- 2016)

The MSc Material Science syllabus is framed based on the manpower requirements of industry and academic research.

Learning Objectives: Materials Science is an interdisciplinary field in science and technology which integrates the physical, chemical and engineering aspects of materials. It comprises the study of the structure, properties, performance, and applications of materials.
The objectives of this course are to (i) impart basic knowledge in the areas of physics, chemistry, and mathematics and how they can be correlated to acquire a deep understanding of the materials and their applications. (ii) introduce the student to the behaviour and properties of different types of materials, such as dielectrics, magnetics, semiconductors, superconductors, etc., and their specific areas of application (iii) create awareness among the students that manipulation of matter at the atomic level can be carried out to develop new materials with the desired properties for a particular application (iv) provide the necessary learning environment so that the student becomes capable of demonstrating and applying this fundamental knowledge in various fields of Materials Science (v) produce qualified Materials Scientists with strong ethical, moral and social values who can confidently build a career either in the academic research or in industries.

Programme outcome: M.Sc. Materials Science graduates have an in-depth understanding of the physical, chemical and engineering aspects of almost all kind of materials. The following attributes summarizes the programme outcome

(i) **Interdisciplinary Approach**: Students will realize how developments in any area of science helps in the development of other fields and how this interdisciplinary approach helps in providing better solutions and new ideas for the sustainable developments.

(ii) **Knowledge Skills**: Students are able to independently analyze concepts logically, think objectively from a reasoned perspective, and draw reasonable conclusions, a major requirement in knowledge assimilation and dissemination.

(iii) **Skills in research and industries:** The rigorous laboratory training and teaching methods, encouraging open debate and discussions, serve to boost self-confidence and personality development in the students, thereby enabling them to be successful in interviews and placements in research laboratories or industries.

(iv) **Project/internship:** The students imbibe effective scientific and technical experience in real-world challenges relevant to their field of study. Enhance the soft skills like communication, oral and writing abilities, teamwork, and problem solving.

(v) **Entrepreunership:** Apply knowledge to build up small-scale industry for developing endogenous products.

(vi) **Personality Development**: Students will imbibe ethical, moral, and social values in personal and social life leading to a highly cultured and civilized personality. They will also realize that the pursuit of knowledge is a lifelong activity combined with untiring efforts and a positive attitude.

Programme specific outcome: By the end of the programme, our students will (i) excel in their career in premier research/scientific institutions such as IISc, IITs, NITs, ISRO, DRDO, DAE etc. (ii) able to be placed in industries like HindHigh Vacuum, Samsung, GE, HAL; material testing companies like AMTEK, Emirates Industrial Laboratory and, chemical and pharmaceutical laboratories in India and abroad. (iii) be able to develop industrial products and excel as entrepreneurs. (iv) be able to continue as interns in industries and laboratories. (v) excel as teachers in educational institutions. (vi) be able to design an original plan of action on a research problem.

Course Outcomes: Each of the courses is designed in such a way that they equip the graduate with necessary knowledge for pursuing a career in Materials Science and becomes masters in the field of materials science. The course starts from the basics and gradually scales up to deliver an in-depth understanding of the field.

(i) At the end of the first semester, the student acquires a strong mathematical foundation to have a theoretical understanding of materials and their behavior. He/she is introduced to an overall view of the fundamentals of materials science, semiconductors and the thermodynamics of materials.

(ii) The courses in the second semester focus on the mechanical properties of metals, ceramics and polymers. The emphasis on the different aspects of failure of materials due to stress or due to inherent defects in them helps the student to realize the importance of choosing the right materials for different applications. Students also acquire knowledge of the different techniques available to characterize materials for their strength, structure, purity etc.

(iii)The third semester is dedicated to introduce the student to the different technologically important materials such as dielectric materials, magnetic materials, superconductors, composites, glasses their applications. Various semiconductor based present day technologies such as solar cells, lasers and LEDs are also included. Students also learn the basics and applications of currently developing fields such as nanotechnology, conducting polymers, and smart materials.

(iv) The student will be trained in a research laboratory/industry for project/internship work in the fourth semester which also provides an opportunity to explore career opportunities in industries. Students gain practical hands-on experience, real-world experience relevant to their study, and build professional connections with peers, mentors and industry professionals with personality development.

I SEMESTER

MSH 401: MATHEMATICS FOR MATERIALS SCIENCE AND ENGINEERING (4 Credits)

Objectives:
The course is designed to (i) create mathematical problem-solving skills in students for the engineering aspect of materials. (ii) analyze the importance of mathematical tools in the design of materials and technologies of today's world. (iii) solve numerical problems in materials science in competitive examinations.

Expected course outcomes: At the end of the course, (i) students will demonstrate a comprehensive understanding of mathematical tools applied in materials engineering such as heat conduction, vibrations, and stress analysis. (ii) students will be able to apply critical thinking and problem-solving skills in research and professional practice. (iii) students will recognize the mathematical problems, and solve them in competitive exams.

Unit I

Complex Variables: Argand plane-polar representation of complex numbers, DeMoivre's theorem. Analytic functions - Cauchy's theorem, Cauchy's integral formula. Series expansion- Laurent's Theorem. Residue Theorem and evaluation of simple contour integrals. Evaluation of Improper integrals and Integrals involving trigonometric functions by the method of residues - Problems. Group Theory: Basic concepts - multiplication tables - subgroups - direct product. Properties of groups. Representations of finite group - reducible and irreducible representations and example of C_{4V} group. Continuous groups. Related problems. 18 hours

Unit II

Matrices: Matrices as operators. Properties. Symmetric, orthogonal, Hermitian and unitary matrices. Determinant, inverse and rank of a matrix. Eigen values and eigen vectors of a matrix. Similarity, orthogonal, unitary and congruent transformations. Diagonalisation of a real symmetric matrix. Related problems and applications.

Tensors: Definition - Contravariant, Covariant and Mixed tensors. Sum, inner and outer products - Contraction - Quotient law. The line element and the metric tensor. Length of a vector. Raising and lowering of indices. Christoffel symbols and covariant differentiation of tensor. Related problems and applications - Stress and strain tensors. Analysis of strain tensor of an elastic medium - Navier's conditions of equilibrium. Symmetric stress tensor. Generalised Hooke's law - elastic constants of an isotropic homogeneous media - equations of motion - elastic waves –velocity of longitudinal and transverse waves. 18 hours

Unit III

Ordinary differential equations: First-order equations, integrating factor, orthogonal trajectories, Second order linear differential equations with constant coefficients, The Cauchy-Euler equation, Method of undetermined coefficients, variation of parameters, matrix method, Sturm-Liouville problems, trigonometric Fourier series. Partial differential equations: Linear equations, superposition, separation of variable, Second order wave equation, unsteady heat conduction equation, Laplace equation.

Special Functions: Bessel functions of the first kind -derivation of the basic form-Recurrence relations - Fraunhofer diffraction and vibrations of membranes. Legendre and Associated Legendre functions - Recurrence relations and differential equations. Related problems and applications. 18 hours

References:

1. Mathematical Methods for Physicists – G Arfken (Academic Press,1968)
2. Elements of Group Theory for Physicists – A W Joshi (Wiley Eastern,1975)
3. Symmetry Groups and Their Applications – W Miller (Elsevier, 1972)
4. Mathematics of Physics and Chemistry – H Margenau and G M Murphy (Affiliated East West Press, 1966)
5. Matrices and Tensors in Physics – A W Joshi (Wiley Eastern, 1975)
6. Tensor Analysis – I S Sokolnikoff (Wiley, 1974)
7. Mathematical Methods in Physical Sciences – Mary L Boas (Wiley, 2011)
8. Mathematical Methods for Physics and Engineering – K F Riley (Cambridge University Press, 2012)
9. Formal Groups and Applications – Michel Hazewinkel (American Mathematical Society, 2017)

MSH 402 ELEMENTS OF MATERIALS SCIENCE (4 Credits)

Objectives: This course serves as a basic foundation for Materials Science programme. It aims to(i) develop an understanding of how the behaviour/properties of materials are intricately connected to their structure and the type of bonding at the atomic level (ii) correlate the relationship between the atomic structure and crystal energy leading to changes in properties (iii) connect the theories necessary for a deeper understanding of structure-property correlations.

Expected course outcomes: On completing this course, (i) students will be able to analyze the key concepts of structure and bonding in covalent, ionic, metallic, and coordination compounds. (ii) students will relate the fundamentals with the structure property correlations in materials (iii) students acquire the basics required to understand the properties of different class of materials which will be dealt with separately in the forthcoming semester courses (iv) students will be able to apply XRD techniques to identify the crystal structure, lattice parameter and purity of materials using XRD (v) students have opportunities to carry out fundamental research in crystallography/solid state physics.

Unit I

Formation and Structure of Materials: Condensed state of matter-crystalline and amorphous states. Bonding in Materials: Ionic bond - Lattice energy - Madelung constant. Covalent, metallic and molecular bonds. Bond angle, bond length and bond energy – simple problems. Hybridisation - Delocalised chemical bonding. Inert gas crystals - van der Waals' interaction - Lennard Jones' potential. Correlation between bonds and physical properties. Simple crystal structures - Sodium chloride, cesium chloride, diamond and zinc sulphide structures. Close packed structures in two and three dimensions- packing efficiency and density of materials, related problems. 18 hours

Unit II

Crystal Geometry and Structure Analysis: Crystal structure – lattice and basis, primitive and non-primitive unit cells. Variation from periodicity - Quasi crystals. Crystal morphology - symmetry elements - Crystal systems. Point group symmetry - derivation of point groups. Space groups and Bravais lattices. Crystal planes and directions - Miller indices - interplanar separations – related problems. Structure analysis by X-rays - Atomic scattering factor. Laue conditions for diffraction and Bragg's law – Lattice and Geometrical structure factor - systematic absences – simple cubic, body centered cubic, face centered cubic, NaCl and diamond structures. Reciprocal lattices - of cubic systems - Ewald's construction. Laue, Rotation and Powder methods of X-ray analysis, related experiments – structure analysis from powder XRD. 18 hours

Unit III

Structure of crystalline solids-alloys, structure of non-crystalline solids- silicates, alumino-silicates, polymers.

Metals-coordinate bond and metal complexes, Valence bond theory- Formation of octahedral complex - outer and inner orbital complex, Formation of tetrahedral and square planar complexes – Limitation of valence bond theory. VSEPR theory and shape of molecules. Crystal field theory – important features - crystal field splitting of d-orbitals in octahedral, tetrahedral, and square planar complexes, applications of CFT- Distortion of octahedral complex and Jahn – Teller theorem, crystal field stabilisation energy and its uses – Limitations of CFT. Molecular orbital theory – comparison of different theories. 18 hours

References

1. Elements of Materials Science and Engineering – Lawrence H van Vlack (Addision Wesley, 1975)
2. Materials Science and Engineering – V Raghavan (Prentice Hall India, 1993)
3. The Structure and Properties of Materials Vol. I-IV – Rose, Shepard and Wulff (Wiley Easterrn, 1987)
4. The Nature of Chemical Bond – L Pauling (Oxford & IBH, 1960)
5. Introduction to Solids – L V Azaroff (McGraw Hill, 1960)
6. X-Ray Crystallography – M J Buerger (John Wiley, 1942)
7. Introduction to Solids – A J Dekker (McMillan India, 1981)
8. Solid State Physics – R L Singhal (Kedarnath Ramnath, 1988)
9. Electronic Processes in Materials – L V Azaroff and J J Brophy (McGraw Hill, 1963)
10. Materials Science and Technology – A comprehensive treatment – R W Cahn, P Haasen & E J Kramer- Electronic and Magnetic properties of metals and ceramics, Vol. -3A & -3B (VCH Weinheim, 1992 & 1994)
11. Crystallography Applied to Solid State Physics – A R Verma and O N Srivastava (New Age Int., 2008)
12. Elements of X-ray Diffraction – B D Cullity (Addison Wesley, 1978)
13. Elementary Solid-State Physics; Principles and Applications – M A Omar (Addison Wesley, 2001)
14. Principle of Materials Science – William F Smith (McGraw Hill, 2014)
15. Materials Science and Engineering: An Introduction – William D Callister (Wiley, 2014)

16. Structure and Properties of Engineering Materials – V S R Murthy (Tata McGraw Hill, 2003).
17. Inorganic Chemistry – Mallik, Tuli and Madan (S Chand & Co., 1990)
18. Chemistry of Transition Elements – Adkin & Holiday (Oxford Uni. Press, 1985)
19. Inorganic Chemistry: Principles of structure and reactivity – Huheey James E (Harper and Row, 1983) Principles of Materials Science and Engineering – William F Smith (McGraw Hill, 1996)
20. Chemistry in Engineering and Technology (Vol 1&2) – J C Kuriacose and J Rajaram (McGraw Hill, 1988)

MSH 403: FUNDAMENTALS OF ELECTRONIC MATERIALS AND DEVICES (4 Credits)

Objectives:

The course aims to (i) outline the fundamentals of the electronic structures of different types of electronic materials, especially metals and semiconductors. (ii) correlate the band structures of the materials with optical and electrical properties. (iii) extend the theory of semiconductors to the fabrication of the devices and basic circuit designs.

Expected course outcomes: At the end of the course, (i) students will be able to define the concepts of band structure of materials, and interpret the optical and electrical data. (ii) students will be able to execute the IC fabrication techniques in semiconductor industries (iii) students will experiment with basic electronic circuits in the laboratory and be familiar with the electronics part, which will help them troubleshoot any possible minor faults in electronic equipment. (iv) students get the basic training required for placements in semiconductor industries.

Unit I

Metals: Band structure - Brillouin zones- Wigner Seitz approximation-construction of Brillouin zones. Energy wave vector curves. Brillouin zones relation with Bragg planes. Density of states. Fermi surface - F.C.C & B.C.C- De Haas van Alphen effect. Electronic properties of metals- Boltzmann transport equation. Electrical conductivity, thermal conductivity, galvanomagnetic effects, thermionic and field emission in metals. Problems and related experiments. 18 hours

Unit II

Conductors, Resistors and Semiconductors – Types of metals - The resistivity range - Quantum free electron theory of metals. Semiconductors: Energy bands-formation of energy bands, effective mass. Direct and indirect band gaps. Determination of band gaps. Donors and acceptors, carrier concentrations at thermal equilibrium. Calculation of Fermi level. Degenerate and non-degenerate semiconductors. Semiconductor Crystal growth – Introduction, methods - Bridgman, Czochralski, zone melting/refining techniques. Contact phenomenon- semiconductor-semiconductor, metal-semiconductor contacts. Schottky and Ohmic contacts. Preparation of semiconductor devices - Fabrication of junctions- wafer preparation, IC technology: monolithic IC- masking and etching - elements of lithography. Recent developments. Problems and Areas of applications. 18 hours

Unit III

p-n junctions under equilibrium and under bias, generation- recombination currents Transistors-amplifiers: Types of transistor amplifiers - small signal amplifiers-design calculation, power amplifiers. Oscillators: Feedback concepts - negative and positive.

Oscillators-phase shift oscillators, crystal oscillators, LC oscillators - Hartly and Colpitt's oscillators. FET, MOSFET, MESFET.

Operational amplifiers: Introduction - characteristics. Applications - inverting, non-inverting, difference, and summing amplifier. Differentiation and integration circuits using opamp. Related experiments. 18 hours

References

1. Semiconductor Devices – J Brophy (George Allen, 1964)
2. Solid State Electronic Devices – Ben G Streetman (Prentice-Hall, 1995)
3. Electronic Devices and Circuits – A Mottershead (Prentice-Hall, 1991)
4. Integrated Electronics – Millman and Halkias (McGraw Hill, 1995)
5. Digital Principles and Applications – A P Malvino and Lach (McGraw-Hill, 1986)
6. Microprocessors: Principles and applications – C M Gilmore (McGraw-Hill, 1995)
7. Introduction to Microprocessors – A P Mathur (Tata McGraw-Hill, 1995)
8. Solid State Physics – A J Dekker (McMillan, 2000)
9. Introduction to Solid State Physics – C Kittel (Wiley India Publications, 2018)
10. Solid State Physics –N W Ashcroft and N D Mermin (W B Saunders, 1976)
11. Electronic Materials and Devices – D K Ferry (Academic Press, 2001)
12. Semiconductor Physics – P S Kireev (MIR Publishers, 1978)
13. Physics of Semiconductors Devices – S M Sze (Wiley Eastern, 2006)
14. Solid State and Semiconductor Physics – John Mckelvey (John Wiley, 1976)
15. Introduction to Properties of Materials – Daniel Rosenthal and Robert M Asimow (AffiliatedEast –West Press, 1974)
16. Solid State Physics – Giuseppe Grosso, Giuseppe Pastori Parravicini (Academic Press, 2014)

MSH 404: THERMODYNAMICS AND PHYSICAL METALLURGY (4 Credits)

Objectives: This course aims to (i) record the basic concepts of heat and dynamics in a system under various thermodynamic conditions. (ii) apply the concepts of thermodynamics in phase equilibrium, phase diagrams and phase transformations to understand industrially important alloys and polymer blends. (iii) formulate targeted physical properties by using the principles of physical metallurgy, and processing of metals and alloys.

Expected course outcomes: By the end of this course, students will be able to(i) apply the laws of thermodynamics to various processes. (ii) analyze the numerical problems on heat and dynamics. (iii) sketch free energy curves for different compositions of alloy systems in industries. (iv) apply the principles of metal extraction, purification and alloying technology in industries.

Unit 1

Thermodynamics- energy conversion, heat flow, zeroth law, thermodynamic equilibrium and reversibility. Laws of thermodynamics - First law - Internal energy, work in various systems, heat capacity, enthalpy, flow processes, Second law - Carnot theorem, Clausius inequality. Combined law of thermodynamics- entropy calculations for various processes, T-S diagram. Advanced engineering applications. Thermodynamic properties of pure substances in solid, liquid, and vapour phases, P-V-T behaviour of simple compressible substances- ideal and real gases, equation of state, compressibility factor. Free energy functions and thermodynamic potentials - Helmholtz and Gibbs free energy functions, Gibbs-Helmholtz equations. General conditions for equilibrium, thermodynamic potential functions-Maxwell relations. Applications: TdS equations, energy and heat capacity equations. Problems.

Phase transitions: Condition for equilibrium between phases, first, second, and higher order phase changes with specific examples interpretations- lambda transition, Clapeyron and Clausius-Clapeyron equation. Specific heat and latent heat anomalies. Problems. 18 hours

Unit II

Phase rule- Introduction- phase, component, degrees of freedom, crystalline and amorphous solids, cooling curves. Phase diagrams of binary alloy systems- Mixtures, solid solution, compound, eutectic, peritectic, and eutectoid reactions. Microstructural changes during cooling- pearlite, austenite, ferrite, bainite phases. Lever rule. Typical systems-Ag-Pb, Cu-Ni, Pb-Sn, Iron-Carbon, TTT and CCT diagrams, Martensitic transformation. Free energy-composition diagrams, Ternary alloy systems.

Phase transformation- Free energy changes, Nucleation and grain growth, kinetics. Application - transformation in steel-annealing, normalizing, austempering, quenching, tempering, precipitation process, solidification and crystallization. Glass transition. Problems and related experiments. 18 hours

Unit III

Diffusion in solids: Fick's laws of diffusion - solutions to Fich's second law - Gaussian and error function solutions. Determination of diffusion coefficient - diffusion couple. Applications based on the second law. Kirkendall effect, atomic model of diffusion -other diffusion processes. Alloys: Long-range order theory-Super lattices and transitions. Diffusion in alloys - Darken's equations, determination of diffusion coefficient.

Theoretical principles of extraction of Metals – Ellingham diagram. Extraction of Iron and copper, preparation of steel, effect of alloying elements, and heat treatment on property improvement. Cold working of steel. Some special alloys - ferrous and non-ferrous. Examples and areas of applications. 18 hours

References

1. Heat and Thermodynamics – Mark W Zemansky, (McGraw-Hill, 1968)
2. Thermodynamics of Solids – Richard A Swalin, (John Wiley & Sons 1972)
3. Equilibrium Thermodynamics – C J Adkins (Cambridge University press, 1983)
4. Solid State Phase Transformation – V Raghavan (Prentice Hall, 1992)
5. Principles of Materials Science and Engineering – William F Smith (McGraw Hill, 1988)
6. Phase Rule – Gurdeep Raj (Goel pub., 1991)
7. Phase Rule and its Applications – Findlay Alexander (Dover, 1951)
8. Understanding Phase Diagrams – John V B (Macmillan, 1974)
9. Phase Diagrams: Understanding the basics- Flake C Campbell (ASM International, 2012)
10. Physical Metallurgy, Principles and Practice – V Raghavan (PHI Learning Pvt. Ltd. 2015)

11. Chemistry in Engineering and Technology (Vol 1&2) – J C Kuriacose and J Rajaram (McGraw Hill, 1988)
12. Materials Science and Engineering – V Raghavan (Printice Hall, 1995)
13. An Introduction to Metallurgy – A H Cottrell (Edward Arnold, 1971)
14. Materials Science and Processes – B S Narang (CBS, 1983)
15. Advanced Physical Chemistry – Gurdeep Raj (Goel, 1992)
16. Inorganic Chemistry – Mallik, Tuli and Madan (S Chand & Co, 1990)
17. Chemistry of Transition Elements – Atkin & Holiday (Oxford, 1985)
18. Text book of Materials Science and Metallurgy – O P Khanna (Dhanpat Rai & Sons, 1984)
19. Physical Metallurgy Principles – R E Reed Hill (Affiliated East –West Press, 1974)
20. Physical Metallurgy – S H Avner (Tata McGraw-Hill, 1997)
21. Mechanical Metallurgy – George R Dieter (McGraw-Hill, 1988)
22. Physical Metallurgy – V Raghavan (Printice Hall, 1989)
23. Engineering Chemistry – Jain & Jain (Dhanpat Rai & Sons, 1993)
24. Elements of Materials Science – L H van Vlack (Addison-Wesley, 1989)
25. An Introduction to Ancient Indian Metallurgy – K T M Hegde (GSI, 1991)
26. Physical Metallurgy – Haasen Peter (Cambridge CUP, 1996)
27. Physical Metallurgy and Advanced Materials – Smallman R E (Oxford Butterworth, 2010)
28. Introduction to Physical Metallurgy – Sidney H Avner (McGraw Hill Ed., 2016)
29. Inorganic Chemistry: Principles of Structure and Reactivity- Huheey James E (Hharper and Row, 1978)

II SEMESTER

MSH 451 MECHANICAL BEHAVIOUR OF MATERIALS (4 Credits)

Objectives: The objectives of this course are to, (i) discuss the mechanical properties of metals, ceramics, and polymers, (ii) explain different types of crystal imperfections and their importance, (iii) describe the elastic and plastic deformations in various materials, (iv) explain fracture in materials including ductile and brittle fracture, and the tribology of materials.

Expected course outcomes: At the end of this course, students will be able to
(i) classify various types of defects in materials and their connection with elastic and plastic deformations, (ii) students will correlate the mechanical properties with the nature of bonding in materials. (iii) students will be able to identify the conditions under which materials fail (iv) students will be able to apply knowledge to select appropriate materials for various applications in industries and research.

Unit I

Crystal Imperfections: Introduction to defects- Point imperfections - configurational entropy - Schottky and Frenkel defects - equilibrium concentrations. Line imperfections - edge and screw dislocations - Buerger's vector in cubic crystals. Surface imperfections - grain boundary - tilt and twin boundaries. Problems and related experiments.

Deformation of a material: Types of deformation, temporary deformations, permanent deformation. Elastic behaviour of materials: atomic model of elastic behaviour - modulus as a parameter in design - rubber-like elasticity - anelastic behaviour -

viscoelastic behaviour- Maxwell element, Voigt-Kelvin model, and related experiments. 18 hours

Unit II

Plastic Deformation in Crystalline Materials: The tensile stress-strain curve – different types of plastic deformation, slip and twinning - Plastic deformation by slip - the shear strength of perfect and real crystals - CRSS - the stress to move a dislocation. Interactions between dislocations - multiplication of dislocations during deformation – Frank- Reed Source. Work hardening and dynamic recovery. Effect of temperature on plastic deformation. Strengthening against plastic deformation – strain hardening – grain refinement – solid solution – precipitation strengthening. Creep in crystalline materials - mechanism of creep and creep resistant materials. Problems and related experiments.

Fracture in metals and ceramics –introduction, ductile fracture, ductile-brittle transition, brittle fracture- Griffith theory. Notch effect. Compressive and tensile strength - size effect, stress intensity factor, toughness measurements. Protection against fracture, Fatigue failure - characteristic of fatigue failure - statistical nature of fatigue - correlation of fatigue strength and plastic properties. Factors affecting fatigue strength. problems and related experiments. 18 hours

Unit III

Tribology: Introduction, wear of metals–mechanisms, factors influencing wear, wear resistance-protection against wear. ASTM number and their significance. Metallurgical microscopes, sample preparation, grain size measurements of typical ferrous and non-ferrous alloys.

Mechanical properties- static and dynamic tensile, flexural, compressive, abrasion, endurance, tear, resilience, impact, toughness.

Heat deflection temperature- Vicat softening temperature, brittleness temperature, glass transition temperature. Thermal expansion, shrinkage, flammability.

Polymer rheology, measurement of rheological parameters by capillary rotating, parallel plate cone plate rheometer. Control of rheological characteristics. 18 hours

References

1. Elements of Materials Science and Engineering – Lawrence H van Vlack (Addision Wesley, 1975)
2. Materials Science and Engineering – V Raghavan (Prentice Hall,1993)
3. Materials Science and Processes – B S Narang (CBS,1983)
4. Introduction to Solids – L V Azaroff (McGraw Hill, 1960)
5. Introduction to Solid State Physics – C Kittel (II Ed. Asia publishing House, 1965)
6. The Structure and Properties of Materials Vol I-IV – Rose, Shepard and Wulff (Wiley Eastern, 1987)
7. Physical Metallurgy – V Raghavan (Printice Hall, 1989)
8. Materials Science and Metallurgy – O P Khanna (Dhanpat Rai & Sons, 1984)
9. Solid State Physics Source Book – Sybil P Parker (McGraw Hill, 1987)
10. Materials Science and Technology, A Comprehensive Treatment – (Ed.) R W Cahn, P Haasen & E J Kramer – Electronic and Magnetic properties of metals and ceramics, Vol – 3A & 3B (VCH, 1991 & 1993)

11. Introduction to Properties of Materials – Daniel Rosenthal and Robert M Asimow (Affiliated East-West Press, 1974)
12. Physical Metallurgy Principles – R E Reed Hill (Affiliated East –West Press, 1974)
13. Physical Metallurgy – S H Avner (Tata McGraw-Hill, 1997)
14. Mechanical Metallurgy – George R Dieter (McGraw-Hill, 1988)
15. Structure and Principle of Engineering Materials – V S R Murthy (Tata McGraw Hill- 2003)
16. Polymer Science –V R Gowarikar, N V Viswanath, Jayadev Sridhar (Wiley Eastern, 2015)
17. Polymer Science and Technology – Joel R Fried (Prentice Hall, 1993)
18. Principles of Polymer Science – Bahadur P, Sastry N V (Narosa, 2005).

MSH 452 MATERIALS TESTING AND CHARACTERIZATION (4 Credits)

Objectives: The key objectives are to (i) familiarize students with various non-destructive techniques for material characterization. (ii) prioritize the requirement of vacuum technology in the design of instrumentation for materials testing. (iii) categorize the selection of relevant characterization techniques for specific materials.
Expected course outcomes: By the end of this course, (i) students will be able to describe various non-destructive testing techniques and basic vacuum technology. (ii) students will select the suitable characterization technique to study the given property of a material (iii) students able to analyse the test results obtained. (iv) the student acquires the necessary skills for working in industries associated with vacuum technology and in companies dealing with the sales and service of scientific instruments.
Unit I
Fundamentals of vacuum techniques: Basic concepts of pumping: idealgas -pressure, density, mean free path. Regions of gas flow - molecular and viscous flow. Conductance of a pipework, pipework in parallel and series - fundamental equation of vacuum technology, simple problems. Vacuum pumps: operating limits of a pump. Rotary, vapour diffusion, turbomolecular, cryogenic, UHV and ion pumps - a brief survey of working principles. Vacuum measurement: thermal conductivity gauges, Pirani and thermocouple gauges, ionisation gauges, hot and cold cathode ionisation gauges - working principle and operating limits. Vacuum materials. 18 hours

Unit II
Non-destructive testing of materials: Introduction, different types of testing, ultrasonics- principles - ultrasonic receivers and oscillators - transducers, probes. Reference and calibration blocks. Identification and seizing of defects.

X-Ray radiography: principles -factors affecting contrast and resolution.

Neutron radiography: neutron sources and detectors. Methods- criteria for evaluating flaw detection by neutron radiography method. Factors limiting the contrast. Comparison of X-ray and neutron radiography methods.

Mechanical testing of materials: Tensile and compression tests - Brittle and ductile failure - Universal testing machine. Hardness test – Moh's scale, indentation hardness- Brinell, Vicker and Rockwell hardness numbers and related experiments. Impact test - Izode and Charpy tests. Fatigue test - a brief discussion. 18 hours

Unit III

Materials characterisation: Electron microscopy- Interaction of electron with matter. Transmission microscopy (TEM) - principles, sample preparation. Kinematic theory of contrast. Imaging modes – bright and dark field modes. Scanning Microscopy (SEM) - principles, beam diameter, image contrast. Applications to microstructure determination. Scanning probe microscopy- principles and applications.

Atomic and molecular spectroscopies: atomic absorption, Infrared, and Raman spectroscopies for the determination of impurities. Low energy electron diffraction (LEED), X-ray photoelectron spectroscopy (XPS/ESCA) and Auger electron analysis - principles and applications for surface studies. Electron probe micro analysis (EPMA) and Energy dispersive analysis of X-rays (EDAX) - principles and applications for compositional analysis. 14 hours

References

1. Fundamentals of Vacuum Techniques - A Pipco et al (MIR, 1984)
2. Vacuum Technology - A Roth (North Holland Pub. Co., 1982)
3. Modern Vacuum Physics - Austin Chambers (Chapman and Hall, 2005)
4. Ultrasonics - B Carlin (Mc Graw Hill, 1960)
5. Applied X– Rays - George L Clark (Mc Graw Hill, 1955)
6. Principles of Neutron Radiography - N D Tyufyakov and A S Shtan (Amerind, 1979)
7. Modern Metallographic Techniques and Their Applications - V A Phillips (Wiley Interscience, 1971)
8. Handbook on Ultrasonic Testing of Materials - Ramesh B Parikh (Electronic & Engineering Co., 1984)
9. Testing of Metallic Materials - A V K Suryanarayana (Prentice Hall India, 1990)
10. Physical Metallurgy Part 1 - R W Cahn and P Haasen (Ed) (North Holland, 1983)
11. Ultrasonic Testing of Materials - Krautkramer, (Narosa Publishers, 1990)
12. Instrumental Methods in Chemical Analysis - G W Ewing (Mc Graw Hill, 1975)
13. Scanning Electron Microscopy and X-ray Micro Analysis - Joseph I Goldstein, (Plenum Press, 1992)
14. The Principles and Practice of Electron Microscopy: Ian M Watt, (Cambridge Univ. Press, 1997)

MSS 453 SURFACE PHENOMENA AND ELECTROCHEMISTRY (3 Credits)

Objectives: This course aims to (i) provide a comprehensive structure-property relationship between the surface of a material and the chemical and physical phenomena. (ii) introduce various catalytic reactions of industrial use. (iii) interpret kinetics and mechanisms in solid-state reactions. (iv) explain the theory of electrolytic conductance and electrochemical phenomena of strong electrolytes on electrode surfaces and their applications (iv) teach corrosion behaviour in materials and protection from corrosion.

Expected course outcomes: By the end of the course, students will be able to (i) distinguish between physical and chemical adsorption phenomena in different catalytic processes in industry and research. (ii) measure the surface area of catalytic powders and classify them based on their porosity. (iii) apply the principles of electrochemical measurements to develop electrode materials for sensors and battery applications in their careers. (iv) describe the nature of corrosion in materials and protection.

Unit I
Surface phenomena - Adsorption, characteristics of adsorption, classification of adsorbents, molecular interactions in adsorption, desorption and energetics, physical and chemical adsorption. Types of adsorption curves- porous, mesoporous and nanoporous materials. Adsorption isotherms- Freundlich, Langmuir, BET, determination of surface area of adsorbent, application of adsorption. Related problems.

Catalysis: Characteristics of catalytic reaction, activation energy, Classification of catalyst and examples, kinetics of homogeneous and heterogeneous catalytic reactions, Catalytic poisoning and retarders. Application of catalysis in industries, hydrogen production.

Solid-state chemical reactions: Introduction, classification, and thermodynamics. Chemical transport in solid-state reaction- Wagner's theory, Kirkendall effect, diffusion mechanism, kinetic features. Methodology in solid-state reaction, experimental techniques to study solid-state reactions. Factors affecting the reactivity of solid-state reaction. 14 hours

Unit II
Electrochemistry: Electrolytic conduction- equivalent conductance, ionic atmosphere, Debye-Huckel theory of interionic attraction, Debye-Huckel limiting law. Electrochemical reactions- Electrode potential and EMF, thermodynamic parameters of a cell reaction, application of EMF measurements- potentiometric titration. Electrochemical devices: Galvanic cells (primary and secondary)- concentration cells and fuel cells and recent developments. Polarisation, over-voltage, decomposition potential, and electrodeposition techniques. Problems. 14 hours

Unit III
Corrosion – Introduction, importance of corrosion studies. Theories of corrosion- factors influencing corrosion, corrosion of iron, copper. Classification- types- Forms of corrosion. Corrosion control measures - paints, metal coatings, anodic and cathodic protection, inhibitors. Polarization studies - corrosion rate measurement, Tafel extrapolation, passivity, analysis of corrosion failure, nanotechnology in corrosion protection. Related problems. Design and selection of materials for application. 14 hours

References

1. Principles of Material Science and Engineering – William F Smith (McGraw Hill, 1988)
2. Material Science and Engineering – V Raghavan (Printice Hall, 1998)
3. An Introduction to Metallic Corrosion and its Prevention – Raj Narayan (Oxferd and IBH, 1983)
4. Introduction to Electrochemistry – S Glasstone (East West, 1942)
5. Advanced Physical Chemistry – Gurudeep Raj (Goel, 1992)
6. Solid State Chemistry – Hannay (Printice Hall, 1967)
7. Text Book of Material Science and Metallurgy – O P Khanna (Dhanpat Rai & Sons, 1984)
8. Engineering Chemistry – Jain & Jain (Dhanpat Rai and Sons, 1993)
9. Solid State Chemistry – Ram Prakash (Radha Publications, 1989)
10. Adsorption – J Oseik (Chichester: Ellis Horwood, 1982)
11. Thermodynamics of Surface Phenomena – Dadesher R K (Viva Books, 2009)

12. Surface Chemistry: Adsorption – Sylvin Morris (Sarup and Sons, 2005)
13. Adsorption: Surface Chemistry – Tusher P (Rajat Publ., 2004)
14. Solid State Chemistry – Chakrabarty D K (New age Int., 2010)
15. The Physics and Chemistry of Solids – Elliott Stephen (Wiley, 2010)
16. Industrial Electrochemistry – Pletcher Derek (Chapman and Hall, 1982)
17. Principles and Applications of Electrochemistry – Crow D R (Chapman and Hall, 1984)
18. Solved Problems in Electrochemistry: For University and Industry; including answers to unsolved problems – Dominique L Piron (Overseas Press Ltd., 2009)
19. Nano electrochemistry – Amemiya Shigeru (CRC Press, 2015)

MSS 454 POLYMER SCIENCE (3 Credits)

Objectives: The objectives of this course are to (i) teach the basic concepts and terminology of polymer science, structure and properties of polymers. (ii) comprehend the principles behind synthesis and processing of polymer materials. (iii) identify and discuss the various applications in industries and daily life. (iv) focus on physical, chemical, thermal, optical, mechanical, and electrical properties of polymers.

Expected course outcomes: By the end of this course, students will be able to (i) describe the structure, properties and applications of plastics, resins, and rubbers. (ii) distinguish between polymers and small molecules in terms of their chemical and physical behaviour. (iii) characterize the polymers such as molecular weight, glass transition temperature, melting point, crystallinity, viscosity and mechanical properties. (iv) list and identify several polymers of industrial and household applications. (v) acquire knowledge and skills for placements in plastics/polymer industries.

Unit I

Introduction - Monomers, polymers - Linear, branched, cross linked, stereo regular, thermoplastic, thermoset, copolymers, crystalline & amorphous polymers, degree of crystallinity, molecular interactions & chemical bonding, flexibility, free volume, free volume & packing density- WLF parameters & free volume, configuration and conformation. Dimensions of polymer coil, polymer melting & glass transition. Polymer blends & interpenetrating network.

Molecular weight distribution-weight, number & viscosity average molecular weight, determination-end group, viscosity, light scattering, ultracentrifuge, gel permeation chromatography. Criteria of polymer solubility - thermodynamics of polymer dissolution, solubility parameter, Flory Huggins theory, Newtonian & non-Newtonian flow, size & shape of polymer in solution. Problems. 14 hours

Unit II

Synthesis & Processing - Chain polymerization- free radical, cationic, anionic, coordination- mechanism and kinetics. Step polymerization- polyaddition, polycondensation –mechanism and kinetics. Copolymerisation - kinetics, reactivity ratios.

Methods of polymerization - bulk, suspension, solution, emulsion, condensation Processing- moulding, compression, injection, blow, extrusion, casting, spinning. Synthesis, properties & applications of thermoplastics-vinyl polymers, polyvinilidine chloride, polycarbonate, polyamide, polyimide, polyurethanes. Rubber – natural and synthetic – processing, vulcanization, properties and applications. Cellulose and its

derivatives. Thermosets- phenolic, amino, epoxy, polyester, silicone, PEKK, and PEEK. Liquid crystal polymers, biomaterials, biomedical polymers, packaging materials, adhesives, and significances. Recent developments in polymer engineering.
14 hours

Unit III
Physical properties and characterization - free volume, viscosity, Mechanical properties- Tensile testing, stress-strain plots of different types of polymers. Viscoelastic behaviour, rubber like elasticity, factors influencing the strength of polymer. Electrical properties- dielectric relaxation, capacitance, CV measurement, applications.

Optical properties- refractive index, birefringence, UV, IR spectroscopy. Thermal properties - heat capacity of amorphous and crystalline polymers, polymer degradation, Thermal analysis – DSC, TMA, TG. Acoustic properties- dynamic modulus of elasticity, loss modulus, velocity of propagation and absorption coefficient of elastic waves in polymers. Experimental determination of modulus of elasticity. Properties and characterization of polymer blends. 14 hours

References
1. Polymer Science – V R Gowarikar, N V Viswanath, Jayadev Sridhar (Wiley Eastern, 1987)
2. Polymer Chemistry – Bill Meyer Fred (Wiley Interscience, 1984)
3. Polymer Chemistry – An Introduction – Raymond B Seymour & Charles E Carraher Jr (Marcel Dekker, 1987)
4. Polymer Chemistry – M Mishra (Wiley Eastern, 1993)
5. Physical Chemistry of Polymers – A Tager (Mir Pub., 1978)
6. An Introduction to Polymer Physics – I Perepechko (Mir Pub., 1978)
7. Principles of Polymer Science – F Rodrigues (McGraw Hill, 1974)
8. Acoustic Methods of Investigating Polymers – I I Perepechko (Mir Pub., 1975)
9. Polymer Science and Technology – Joel R Fried (Printice Hall, 1993)
10. Polymer Science and Technology – Premamoy Ghosh (McGraw Hill, 2011)
11. Developments in Polymer Degradation – Grassie N (Applied Science, 1984)
12. Experiments in Polymer Science – Hundiwale D G (New Age Int., 2009)
13. Applied Polymer Science – Arun Kumar Singh (Anmol, 2012)
14. Principles of Polymer Science – Bahadur P, Sastry N V (Narosa, 2005).

MSS 455 THIN FILMS (3 Credits)
Objectives: The objectives of this course are to (i) prepare the students with a strong foundation on thin film technology, its importance and applications. (ii) discuss various deposition techniques for the growth of thin films and their limitations. (iii) explain unique optical and electrical properties with suitable examples. (iv) relate their applications in new fields such as quantum well devices and spintronics.
Expected course outcomes: By the end of this course, (i) students will acquire a comprehensive knowledge of fundamentals of thin films. Students will be able to (ii) distinguish characteristic properties of thin films from thick films. (iii) describe various deposition parameters and their effect on structure and properties of thin film. (iv) undertake research on thin film growth and their characterization techniques and in academic/industries. (v) acquire the necessary knowledge and skills for placements in semiconductor, microprocessor industries.

Unit I

Preparation of thick and thin film materials: Definition of thick and thin films. Physical vapour deposition - thermal evaporation - Knudsen cosine law. Sputtering- DC glow discharge and low-pressure sputtering. Reactive sputtering. Chemical vapour deposition. MBE, MOCVD, ALD methods of preparing device grade films. Spray pyrolysis and other chemical methods of film preparation for large area applications. LB films and their applications. Thickness measurement techniques- electrical, and mechanical methods. Optical methods- spectrophotometric and interference methods. Microbalance methods – quartz crystal oscillator technique. Related problems and applications. 14 hours

Unit II

Nucleation and growth of thin films: Theories of nucleation-capillarity theory, effect of deposition parameters. atomistic theory and rate equation approach of nucleation. Growth of thin films- mechanisms and influence of deposition parameters. Epitaxial growth - theory of epitaxial nucleation. Durability of films - adhesion and internal stress.

Optical properties of thin films: Reflection and transmission at interface between isotropic transparent media. Reflectance and transmitance in thin films. Methods for determining optical constants - spectrophotometer and polarimetric methods. Antireflection coatings - theory and design of single layer coatings. Double and multilayer coatings - brief description. Related problems and applications. 14 hours

Unit III

Electron transport phenomena in thin films: Electrical conduction in discontinuous metal films - quantum mechanical tunneling model. Conduction in continuous metal films- size effect and specular scattering. Thermoelectric power in metal films. Electrical conduction in semi-conductor and insulator films - hybrid microcircuits, thin film resistors, thermopiles. Quantum Hall effect- quantum well devices. Spintronics-GMR and TMR. Related problems and applications. 14 hours

References

1. Handbook of Thin Film Technology – L I Maissel and R Glang (Ed) (McGraw Hill, 1970)
2. Vacuum Deposition of Thin Films – L Holland (Wiley, 1956)
3. Thin Film Phenomena – K L Chopra (Mc Graw Hill, 1969)
4. Physics of Thin Films Vol.1-4 – G Hass and R E Thun (Ed) (Academic, 1963)
5. Electrical Conduction in Thin Metal Films – T J Coutts (Elsevier, 1974)
6. Optical Properties of Thin Solid Films – O S Heavens (Dover, 1955)
7. Thin Film Technology and Applications – K L Chopra and L K Malhotra (Ed) (Tata Mc Graw Hill, 1985)
8. Materials Science of Thin Films- Milton Ohring (Academic, 2010)

MSS 456 QUANTUM MECHANICS (3Credits)

Objectives: This course introduces the concept of the language of Physics which makes use of the mathematical tools, learnt earlier, in abundance. As some of the concepts are far removed from the classical picture, they need to be understood well. The objectives of the course include (i) providing an enhanced level of understanding of the principles of quantum mechanics (ii) understanding the use of quantum mechanics to solve simple to not-so-simple textbook examples/problems.

Expected course outcomes: On completion of the course the student the student should be on a sound footing with the concept of quantum mechanics and its mathematical tools. Therefore the students should be able to (i) utilize the postulates of quantum mechanics to describe quantum systems (ii) use operator techniques to solve relevant problems (iii) use the properties of angular momentum and spin to describe quantum systems such as the hydrogen atom and an electron in a magnetic field (iv) analyze the time dependence of quantum systems. (v) apply the principles to solve physical problems in condensed matter.

Unit I

Quantum Physics: Matter waves. Uncertainty principle. Interpretation of the wave particle dualism and complimentarity.
Wave Equation and Operators: The Schroedinger equation - free particle in one and three dimensions-the operator correspondence and commutating relations. Mean squared deviation. Commutation of operators. Simultaneous eigen functions. Normalization of wave functions and statistical interpretation-Box normalization, the Dirac delta functions- expectation values - Ehrenfest's theorem. Postulates of quantum mechanics. Stationary states - the time independent Schroedinger equation - particle in one dimensional square well potential, potential barriers-transmission and reflection coefficients. Simple problems and applications. 14 hours

Unit II

Eigen values and Eigen functions; One dimensional simple harmonic oscillators – the angular momentum operator - the eigen value equation for the square of the angular momentum - orbital angular and magnetic quantum numbers- the hydrogen atom-solution of the radial equations – Degeneracy. Ground state of hydrogen atom. Rigid rotator– energy eigen values. 14 hours

Unit-III

General formalism of quantum theory: Linear operators. Operator methods**,** Hilbert space and observables, Dirac notation, Bra and Ket spaces. Momentum and space representations. Schroedinger, Heisenberg and interaction pictures, simple harmonic oscillator by operator method. Ladder operators, matrix representations of angular momentum operators, Pauli matrices, addition of angular momentum, Clebsch-Gordan coefficients. Related problems and applications. 14 hours

References

1. Applied X-rays – G W Clark (McGraw Hill, 1955)
2. Quantum Mechanics – Leonard I Schff, 4th edition (McGraw HillEducation Pvt Limited, 2014)
3. Quantum Mechanics – Sokolov (MIR Publications Moscow, 1984)
4. Quantum Mechanics – Mathews and Venkatesan (Tata McGraw Hill, 1981)
5. Quantum Mechanics – Powel and Craseman (Oxford & IBH, 1985)
6. The Feynman Lectures on Physics, Vol. 3- R. P. Feynman, R.B. Leighton and M. Sands,(Pearson New York, 2013).
7. Introduction to Quantum Mechanics – R. L. Liboff (Pearson Education, 2003).

8. Introduction to Quantum Mechanics – D J Griffiths (Cambridge University Press, New Delhi,2017)
9. Quantum Mechanics – Eugen Merzbacher (John Wiley, 1970)

MSS 457: NANOSCIENCE AND NANOTECHNOLOGY – I (3 Credits)

Objectives: This course offers an opportunity for the interested student to acquire a basic knowledge about nanoscience and associated technology - one of the most researched topic in the past decade. It aims to (i) serve as an introductory course in the topic and is designed so that any student having just a basic knowledge of science is able to understand the fundamentals involved (ii) deliver the necessary basics required for a proper understanding of (a) the behaviour of nano systems (b) chemistry involved to in their synthesis (iii) familiarize the student with the techniques available for the characterization of nanomaterials.

Expected course outcomes: The student acquires information about (i) the physics behind why nanomaterials exhibit properties different from that of the bulk (ii) the chemistry involved in their synthesis which equips them with knowledge of how matter can be manipulated to give materials with new properties (iii) impart skills for characterization and synthesis of nanosystems (iv) placement opportunities in nanotechnology industries

Unit I
Introduction – Nanostructured materials, nanoparticles, nanorods, nanotubes etc. Brief survey of metals, insulators and semiconductors. Free electron theory and band theory, Low dimensional structures, Particles in a box, Strong and weak confinements, Excitons.
Colloid Chemistry: Introduction. Kinetic properties- Sedimentation rate, Brownian motion. Surface energy, Surface potential and Zeta potential and their consequences. Thermodynamics of surfaces. Coagulation- Kinetics of coagulation. Stability of colloids. 14 hours

Unit II
Chemical Synthesis of Nanoparticles: Bottom-up approach. Chemical reduction. Microwave synthesis, Sol-gel technique, Reverse micelle methods. Functionalized nanoparticles in different medium. Size control. Self assembly. Nanoparticle arrays. Porous nanoparticles, Nanocoatings.

Physical Methods of Nanostructure Fabrication: Top-down approach. High energy ball milling, Vapour condensation, Laser ablation, MBE, MOCVD, LPE.

Nanopatterning- Lithography- Optical, X-ray and Electron beam lithography. Ion-beam lithography, SPM, Dip pen lithography. 14 hours

Unit III
Analysis of Nanostructures: Atomic Force Miscroscope, Scanning Tunneling Microscope, High Resolution Transmission Electron Microscope, Field Emission Scanning Electron Microscope, X-ray Diffraction, Small angle X-ray diffraction, UV-

Vis-NIR spectroscopy, Photoluminiscence, IR spectroscopy, Raman spectroscopy. Zeta potential measurements. Micro SQUID Magnetometry. 14 hours

References:

1.The Science and Engineering of Microelectronic Fabrication – S A Campbell (Oxford, 1996)
2. Nanoscale Materials - (Ed) L M Liz Marzan and P V Kamat, (Kluwer, 2003)
3. Nanostructured Materials and Nanotechnology (Ed) – H S Nalwa (Academic, 2002)
4. Colloidal and Surface Chemistry - M Satake, Y Hayashi, Y Mido, S A Iqbal, M S Sethi (Discovery, 1996)
5. Colloid Chemistry – S Voyutsky (MIR, 1978)
6. Introduction to Nanotechnology – C P Poole and F J Owens (Wiley- Intersci., 2006)
7. Nanotechnology and Nanoelectronics – W R Fahrner (ed) (Springer, 2006)
8. Quantum Dots – L Jacak, P Hawrylak, A Wojs, (Springer, 1997)
9. Physics of Low Dimensional Structures – J H Davis, (Cambridge, 1998)
10. Sol-Gel Science – Scherrer and Brinker (Academic Press, 1990)

MSE 459: SCIENCE OF MATERIALS IN DAILY LIFE (open elctive-1) (3 Credits)

Objectives: Objectives of this course is to (i) provide elementary idea about materials science to the interested students in the open elective system. (ii) introduce different properties and applications of metals, semiconductors, polymers, composites and ceramics. (iii) teach the relevance of these materials in technologically important applications.

Expected course outcomes: By the end of the course, students will be able to (i) distinguish the different classes of materials used in daily life. (ii) explain the nature of bonding in different materials and their properties. (iii) explain how manufacturing processes can bestow materials with different/desirable properties.

Unit I

Conductors: metals, alloys, semiconductors- Definition, elementary ideas of electrical properties, optical properties, mechanical properties, thermal properties. Specific examples of metals- copper, aluminium, iron, gold, silver. Uses of metals. Drawbacks of metals. Alloys- advantages of alloying-brass, bronze, steel, stainless steel, gold alloys, silver alloys and their uses.

Semiconductors: Elemental semiconductors- silicon, germanium. Doping- n-type and p-type semiconductors, p-n junctions, I-V characteristics- diode equation. Qualitative ideas of devices- diodes to ICs. Compound semiconductors. 14 hours

Unit II

Polymers and composites: Plastics- Introduction. Types of plastics. Rubber- types of rubber. Vulcanization of rubber. Thermoplastics and thermosets. Fibres- different types of natural and synthetic fibres – cellulose acetate fibres. Resins, adhesives and polymer coatings. Physical, chemical, mechanical properties and applications of polymers. Recycling of polymers.

Composites- introduction, types. Wood, concrete, FRP and some advanced composites. Properties and applications. 14 hours

Unit III

Ceramics- Introduction, classification, raw materials, fabrication methods, properties and applications. Types of ceramics- oxide and non-oxide ceramics. Allotropes of carbon- graphite, diamond and fullerene – structure dependent properties. Primary refractory materials.

Glasses- introduction, raw materials, manufacture of glass, properties and applications. Types of glasses, properties and applications. Photochromic and photosensitive glasses. 14 hours

References:

1. The Physics of Materials: How Science Improves Our Lives, Solid State Sciences Committee, (National Research Council, 1997)
2. The Science of World Around Us, Solid State Sciences Committee, (National Research Council, 2007)
3. Materials Science and Engineering – V Raghavan (Prentice Hall India, 1993)
4. Introduction to Solids – A J Dekker (McMillan India, 1981)
5. Plastics-How Structure Determines Properties – G Gruenwald (Hanser)
6. Understanding Materials Science – R E Hummel (II Ed.) (Springer, 1993)
7. Materials Science – Nagpal (Khanna, 1983)
8. Polymer Science – V R Gowarikar, N V Viswanath, Jayadev Sridhar (Wiley Eastern, 1987)
9. Composite Materials Engineering & Science – F L Mathews & R D Rawlings (Chapman & Hall, 1990)
10. Introduction to Ceramics – W D Kingery, H K Bower and U R Uhlman (John Wiley, 1960)
11. Glasses and Vitreous State – J Zarzycki (Cambridge University Press, 1982)

III SEMESTER

MSH 501 DIELECTRIC MATERIALS (4 Credits)

Objectives: The objectives of this course are to (i) introduce the students to a class of important insulating materials, viz: dielectrics, (ii) explain the physics behind dielectric behaviour of insulating materials. (iii) classify dielectric materials and their applications. (iv) discuss the optical properties of the dielectrics including colour of crystals, excitons. (vi) study the thermal properties of dielectrics including the concept of heat transport, phonons and the influence of elastic properties on thermal behaviour.

Expected course outcomes: At the end of the course, students will be able to (i) distinguish between dielectric materials and other insulators. (ii) recognize how these differences will be attributed to specific applications (iii) summarize the understanding of lattice dynamics.(iv) develop dielectric materials for energy applications

Unit I

Dielectric polarisation and atomic forces - electronic polarisation. Dielectric law and the generalisation. Atomic or ionic polarisation, orientational polarisability. Static dielectric constant of materials. Determination of dielectric constants. Lorentz internal field. Clausius-Mosotti relation. Polarisation catastrophe. electromechanical coupling - dielectric breakdown - electric energy stored in dielectrics. General applications of dielectric materials. Problems and recent developments. The complex dielectric constant, dielectric losses and relaxation time - Debye equations - theory of electronic polarisation and optical absorption. Optical Phenomena in Insulators Colour of crystals - Excitons - weakly bound and tightly bound excitons, photoconductivity. Colour centers – F-centers and other electronic centers in alkali halides. 18 hours

Unit II

Ferroelectrics: General characteristics - piezoelectric, pyroelectric and ferroelectric materials - transducer and detector applications. Classification of ferroelectrics and representative materials. Structure of KDP and explanation for its ferroelectric behaviour. Objection against dipole theory, Ionic displacement theory Barium titanate and its ferroelectric behaviour. Crystal structure and theory of spontaneous polarisation in barium titanate and related experiments. Zeroes and poles of the dielectric function – Lyddone-Sachs-Teller relation. Problems. Ferroelectric domains. Thermodynamics of ferroelectric phase transitions. Remarks on antiferroelectric materials - Materials with paired properties like ferroelectric-ferroelastic, ferroelectric-ferromagnetic and recent developments. 18 hours

Unit III

Thermal Properties of Insulators: Heat capacity - Einstein's model - quantisation of lattice vibration - continuum model - Debye's theory –phonons – problems. Vibrations of monoatomic lattice - specific heat of one-dimensional lattice of identical atoms. Vibrations of diatomic lattice - phonon spectra and phonon modes - optical properties in infra-red region and their applications. Scattering of electromagnetic waves and neutrons by phonons – phonon spectra from neutron diffraction. Thermal conductivity of insulators - lattice thermal resistivity – normal and Umklapp process – related problems. Thermal expansion: potential wells in crystal binding - anharmonic interactions and thermal expansion of insulators. 18 hours

Reference

1. Introduction to Properties of Materials – D Rosenthal and R M Asimov (East West, 1974)
2. Elements of Materials Science and Engineering – L H van Vlack (Addison Wesley, 1975)
3. Introduction to Solid State Physics – C Kittel (II & IV Ed. Wiley & sons, 1961 & 1964)
4. Solid State Physics – A J Dekker (McMillan, 1971)
5. Advances in Solid State Physics, Vol. II & V –Seitz and Turnbull (Ed) (Academic, 1957)
6. Physics of Dielectric Materials – B Tareev (MIR, 1979)
7. Crystal Structures, Vol.1-3 – W G Wyckoff (Interscience, 1963)
8. Electronic Properties of Materials – Hummel (Springer-Verlag, 1985)
9. Solid State Physics Source Book – Sybil P Parker (Ed) (McGraw Hill, 1987)
10. Principles of Solid-State Physics – Robert A Levy (Academic Press inc., 1968)
11. Elementary Solid-State Physics; Principles and Applications – Omar M A (Addison Wesley, 2001)

MSH 502 MAGNETIC MATERIALS & MAGNETIC RESONANCE (4 Credits)

Objectives:

The objectives of this course are to (i) impart an understanding of the basic phenomena in condensed matter (ii) introduce the different classes of magnetic materials, their origin, and the theories to understand their behaviour (iii) introduce the resonance concept in NMR and Mossbauer with rigorous theory (iv) enable the student to apply this theoretical foundation in spectroscopic techniques for research and other applications.

Expected course outcomes: By the end of the course, students will be able to (i) identify the basic differences and causes of various types of magnetism in materials (ii) identify the magnetic interactions with electric and magnetic fields and their applications in magnetic resonance (iii) explain the principles of resonance based spectroscopic tools in materials research (iv) acquire knowledge about the characterization techniques for magnetic materials (v) apply the knowledge in applications such as magnetic storage devices, MRI, NMR.

Unit I

Introduction to magnetic materials – magnetic susceptibility and permeability. Classification – dia- para- and ferro-magnetic materials. Amperian concepts. Langevin's theory of diamagnetism. Origin of magnetic moments. Classical and quantum theories of paramagnetism- Curie law- Effective number of Bohr magneton- Quenching of orbital magnetic moments- Experimental determination of diamagnetic and paramagnetic susceptibility- anisotropy in susceptibility. Cooling by adiabatic demagnetization. Ferromagnetism – characteristic features- hysteresis loop. Weiss concepts- Curie-Weiss law. Related problems and applications. 18 hours

Unit II

Exchange interaction and spontaneous magnetization in ferromagnetic materials - temperature dependence- Heisenberg's theory- Exchange integral. Heusler alloys. Gyromagnetic experiments- g factor. Ferromagnetic domains - origin of domains - anisotropy energy - Bloch wall - magnetostriction. Hard and soft magnetic materials – hysteresis loss – applications - Transformers, electromagnets, permanent magnets – magnetic recording - memory devices. Giant magnetoresistance, Ultrafast magnetism. Antiferromagnetism - sub lattice model - Neutron diffraction in magnetic structure analysis – Super-exchange phenomena - Ferrimagnetism and structure of ferrites and their applications. Spin waves - quantisation of spin waves - magnons. 18 hours

Unit III

Magnetic Resonance and material analysis - Nuclear Magnetic Resonance - Elements of theory –instrumentation. Population of states - rate of energy absorption – Spin-lattice and spin-spin relaxation processes-Bloch equations – Wide line NMR – Knight shift. Applications of NMR – structure of molecules, MRI. Paramagnetic resonance – principles and comparison of PMR with NMR. Electron spin resonance -– principles –comparison with NMR. Related experiment – determination of Lande splitting factor g. Areas of applications and related problems.

Mossbauer effect - elements of theory – Mossbauer spectroscopy – centre shift, chemical shift, Zeeman shift, experimental techniques and applications. Related problems. 18 hours

References

1. Modern Magnetism – L F Bates (Cambridge University Press, 1963)

2. Elements of Materials Science and Engineering – L H van Vlack (Addison Wesley, 1975)
3. Introduction to Properties of Materials – D Rosenthal and R M Asimov (East West, 1974)
4. Introduction to Solid State Physics – C Kittel (II & IV Ed. Wiley & sons, 1961 & 1964)
5. Solid State Physics – A J Dekker (McMillan, 1971)
6. Advances in Solid State Physics, Vol. II & V – Seitz and Turnbull (Ed) (Academic, 1957)
7. Mossbauer Effect and its Applications – V G Bhide (Tata McGraw Hill, 1973)
8. Magnetic Resonance – C P Slichter (Harper and Row, 1985)
9. Solid State Chemistry – C N R Rao (Ed) (Marcel Dekker, 1974)
10. Solid State Physics Source Book – Sybil P Parker (Ed) (McGraw Hill, 1987)
11. Materials Science and Technology-A Comprehensive Treatment (ed.) – R W Cahn, P Haasen & E J Kramer - Electronic and Magnetic properties of metals and ceramics, Vol 3A & 3B (VCH Weinheim, 1992 & 1994)
12. Fundamentals of Molecular Spectroscopy – Colin M Banwell and Elaine M McCash, (Tata McGraw Hill, 2013)
13. Introduction to Magnetism and Magnetic Materials – David Jiles (CRC Press-2016)

MSH 503: SOLID STATE ENGINEERING MATERIALS (4 Credits)

Objectives: Objectives of this course are to (i) introduce the students to a detailed basic knowledge of technologically important materials such as superconductors, liquid crystals, and ceramics. (ii) impart the applications of solid-state engineering materials in semiconductor devices such as lasers and solar cells. (iii) introduce the students to application of dielectrics in the optical fibers for communication.

Expected course outcomes: By the end of this course, students will be able to (i) identify the behaviour of superconductors and their applications in magnetic levitation and high-field magnets. (ii) explain the electrical and optical phenomena in liquid crystals, lasers, and solar cells. (iii) further their interest in research work/career in industries.

Unit I

Superconductivity: Nature and properties of superconducting materials - Type I and II superconductors –mixed state- fluxon lattice. Thermodynamical approach to superconducting state- Phenomenological theories - BCS theory – concept of energy gap. Superconducting tunneling phenomena: metal-insulator-superconductor (MIS) and superconductor-insulator-superconductors (SIS). AC and DC Josephson effect, Applications - superconducting magnets, SQUID and magnetic levitation, High temperature (High T_c) superconductors: material preparation - ceramic technique, structure.

Liquid Crystalline Materials: Introduction - classification of thermotropic liquid crystals. Lyotropic and metallotropic liquid crystals- elementary ideas. Elementaryideas on material. Properties of liquid crystals - birefringence, dielectric anisotropy, viscosity, conductivity anisotropy. Elasticity of liquid crystals, electro-optic, thermo-optic effects – Freederickz transition. LCD devices and applications.

18 hours

Unit II

Lasers and applications: Introduction to lasers- spontaneous emission - stimulated transitions and rate equation balance, amplifications in a medium, population inversion methods, oscillation threshold, optical resonator theory. Gas lasers, He-Ne, Solid state lasers, Ruby, Nd:YAG lasers, - applications.

Solid state lasers: Semiconductor lasers – absorption-direct and indirect band gaps, material requirement, conditions for laser oscillations, homojunction and heterojunction lasers – Excimer-femtosecond lasers and recent developments - applications.

Photovoltaic solar cells and LEDs: Material requirement, efficiency, efficiency limits, spectral response, types of solar cells -conventional tandem-junction in solar cells, heterojunction solar cells, thin film solar cells, amorphous silicon solar cells. Organic, Perovskite and hybrid solar cell. Light emitting diodes- materials requirements, fabrication, efficiency. Problems and related experiments. 18 hours

Unit III

Ceramics: Ceramics and their structure- silicate structure - polymorphism and allotropy. Processing - recrystallization and grain growth, sintering, hot pressing, fire shrinkage. Basic refractory materials. Areas of applications.

Glasses: Preparation and structure - types of glasses -borate glasses, silicate glasses, oxide glasses, metallic and semiconducting glasses. Properties of glasses – electrical, optical, thermal, mechanical properties, Applications - photo sensitive, photochromic glasses, optical fiber- principle of fiber communication. Recent developments and applications. Optical properties: Luminescence: Frank Condon principle, excitation process - thermoluminescence and electroluminescence. Luminescent materials and industrial applications. 18 hours

References

1. Introduction to Superconductivity – A C Rose Innes and E H Rhoderick (Pergamon Press, 1978)
2. Superconductivity and Superconducting Materials – A V Narlikar and S N Ekbote (South Asian Pub., 1983)
3. Physics of high T_c Superconductors – J C Phillips (Academic Press, 1989)
4. Liquid Crystals – S Chandrasekhar (Cambridge University Press, 1977)
5. The Physics of Liquid Crystals – P G de Gennes (Oxford, 1975)
6. Electronic Materials and Devices – D K Ferry (Academic Press, New York, 2001)
7. Semiconductor Physics – P S Kireev (MIR Publishers, 1978)
8. Physics of Semiconductors Devices – S M Sze (Wiley Eastern, 1991)
9. Solid State Devices – Ben G Streetman (Prentice-Hall, 1995)
10. High Efficiency Silicon Solar Cells – M A Green (Tran. tech., 1987)
11. Solid State and Semiconductor Physics – John Mckelvey (John Wiley, 1976)
12. Introduction to Ceramics – W D Kingery, H K Bower and U R Uhlman (John Wiley, 1960)
13. Glasses and Vitreous State – J Zarzycki (Cambridge University Press, 1982)
14. Materials Science and Technology Vol. 9: Glasses and Amorphous Materials, (Ed.) R W Cahn, P Haasen, E J Kramer, (VCH Weinheim, 1991)
15. Optical Fiber Communications – G Keiser (McGraw-Hill, 2000)
16. Introduction to Superconductivity – Michael Tinkham, (McGraw Hill, 1996)

17. Superconductivity Today: An Elementary Introduction – Ramakrishnan T V (University Press, 1999)
18. Liquid crystals: Natures Delicate Phase of Matter, Peter Collings (Princeton University Press, 2007)
19. Solar cells: Materials, Manufacture and Operation – Markvart and Castaner (Elsevier, 2005)

MSS 504: NEW MATERIALS AND TECHNOLOGIES (3 Credits)
Objectives: This course aims to (i) provide the idea of new materials and technologies in current science and research including shape memory alloys, conducting polymers and nanomaterials. (ii) introduce the properties, synthesis, processing, and applications of new materials(iii) instil in the students the urge to explore newer materials for modern-day challenges.

Expected course outcomes: At the end of the course, students will be able to (i) discuss on new technology materials and their properties. (ii) distinguish the characteristic properties between alloys vs superalloys, polymers vs conducting polymers, and bulk vs nanomaterials. (iii) apply the synthetic techniques for conducting polymers and nanoparticles in their laboratory. (iv) apply the knowledge of the design of materials for new technologies and develop an interest in research in the field of materials science. (v) find equal opportunities in polymer, nanotechnology industries and also as researchers in universities/institutes.

Unit I
Super alloys: Alloys and their applications, alloys at high temperature, Types of super alloys – iron based – nickel based – cobalt based super alloys –fabrication – their characteristic features and areas of application.
Smart Materials: Introduction to smart materials – shape memory effect (SME) and martensitic transformation, SME related changes in material properties, SME and Superelasticity. Ti - Ni SM Alloys – Effect of thermal and mechanical cycling Cu - based SM Alloys. Ferrous SM alloys. Fabrication of SM Alloys. Characteristic fundamental properties- Shape memory ceramics and polymers, photo responsive and chemo responsive SME. Experimental determination of phase transformation temperatures in SMA. General applications of Smart materials – design of actuators, couplings, electrical connectors, medical and dental applications. 14 hours

Unit II
Conducting Polymers: Introduction to conducting polymers. Polyacetylene. Structural features – factors affecting conductivity of polymers. Preparation of conducting polymers – doping. Band structures inconducting polymers – charge transport, nature of charge carriers (soliton, polaron, bipolarons). Models of charge transport – structure-property relationship. Mechanisms of conduction in doped polyheterocyclics, polyaromatics, conducting co-polymers. Molecular designing of novel conducting polymers – substitution / fusion, ladder structure formation, copolymerization, donor - acceptor polymer formation, advantages and challenges, practical applications of conducting polymers– electronic, electrochemical, photonic applications, sensors, medical applications. Related experiments - synthesis and mechanism of formation of polyacetylene, polyaniline, polypyrrole. 14 hours

Unit III

Nano-materials: Introduction – nanostructured materials – metals, semiconductors and ceramics. Synthesis of nanoparticles– inert gas evaporation – laser pyrolysis – sputtering techniques, plasma techniques. Various chemical methods of synthesis. Unique properties of nanomaterials. Metal nanoparticles – electronic and optical properties – surface plasmon resonance. Functionalized metal nanoparticles- synthesis, characterization, organization and applications –- semiconductor nanoparticles - synthesis, characterization and applications of quantum dots – size dependent properties – experimental determination of size from absorption studies. Magnetic nanoparticles- assembly and nanostructures. Manipulation of nanoscale biological assemblies. Carbon nanotubes and fullerene as nanoclustures. Nanostructured films. Characterization of nanoparticles and nanostructures– optical spectroscopy, electron microscopy, atomic force microscopy, X-Ray diffraction of nanoscale materials. 14 hours

References:

1. The Science and Engineering of Microelectronic Fabrication- S A Campbell (Oxford,1996).
2. Intrinsically Conducting Polymers: An Emerging Technology- M Aldissi (editor), (Kluwer, 1993).
3. Quantum Chemistry Aided Design of Organic Polymers- J M Andre, J Delhalle & J L Bredas (World Scientific, 1991).
4. Electrical Properties of Polymers: Chemical Principles- C C Ku and Leilpens (Hanser, 1987).
5. Science and Applications of Conducting Polymers- W R Salaneck, D T Clark, E J Samuelson (Adam Hilger, 1991).
6. Special Polymers for Electronics and Optoelectronics- J A Chilton, M T Goosey, (Chapman and Hall, 1995).
7. Langmuir - Blodgett Films - Gareth Roberts (Ed), (Oxford, 1989).
8. Chemistry of Advanced Materials- D Chakravorty and A K Giri (C N R Rao Editor), (Blaclwell, 1992).
9. Physics and Chemistry of Small Clusters- P Jena, B K Rao and S N Khanna (ed) (Plenum Press, 1986).
10. Physics and Chemistry of Finite Systems: From Clusters to Crystals, (Kluwer, 1992).
11. Selection of Engineering Materials- G Lewis, (Prentice Hall, 1990).
12. Engineering Materials and Their Applications- R A Flinn and P K Trojan, (Jaico, 1998).
13. Fundamentals of Ceramics- M W Barsoum, (McGraw Hill, 1997).
14. Shape Memory Materials- K Otsuka and C W Wayman, (Cambridge, 1998).
15. Nanoscale Materials (Ed)- L M Liz, Marzan and P V Kamat (Kluwer, 2003).
16. Nanostructured Materials and Nanotechnology (Ed)- H S Nalwa (Academic Press, 1999).
17. An Introduction to Interfaces and Colloids: The Bridge to Nanoscience- John Berg C (World Scientific, Academic Press, 2002)
18. Conducting Polymers: A New Ira in Electrochemistry- Inzelt Gyorgy (Springer, 2008)
19. Introduction to Nanotechnology- C P Poole and Frank J Owens (Wiley, 2006)
20. Shape Memory Alloys: Manufacture, Properties and Applications – H R Chen (Nova Science, 2010)

MSS 505: COMPOSITE MATERIALS (3 Credits)

Objectives: The objectives of this course is to (i) introduce an engineering technology of mixing the materials for high-performance applications. (ii) explain the basics of composite materials, classification, preparation, properties and applications. (iii) differentiate the composites with monolithic materials in terms of their mechanical and thermal properties. (iv) specify the industrial importance of novel composite materials for aerospace applications.

Expected course outcomes: By the end of this course, students will be able to (i) explain composite materials, classification and preparation methods. (ii) compare the properties of composites with that of monolithic components. (iii) prepare the composite materials for their project and research work and characterize them to solve the problems in the design of new materials for various applications. (iv) have the required skills for industries where materials with high strength coupled with light weight is required, such as aerospace, automotive, space research etc.

Unit I

Introduction –Definition, classification, matrix materials, reinforcing materials, comparison of properties with monolithic materials, applications. Interfaces in composites, contact angle, wetting. Micromechanics of composites – density. Mechanical properties – prediction of elastic constants, Halpin-Tsai equations. Thermal properties – heat capacity, longitudinal and transverse conductivity, thermal expansion coefficient. Mechanism of load transfer from matrix to fiber – (fiber elastic – matrix elastic, fiber elastic- matrix plastic), Micro-Raman spectral analysis. Problems solving.

Strength, fracture and fatigue: tensile strength, compression strength, fracture modes in composite, designing with composite materials. 14 hours

Unit II

Reinforcing materials - fabrication, structure, preparation, and application of boron, glass, carbon, aramid and ceramic fibers. Concrete making materials - structure, composition, properties and applications, special concrete, reinforced and pre-stressed concrete.

Polymer matrix composites- fabrication, structure, interface, properties and applications. Advanced thermoplastic composites and applications. Wood-microstructure, properties, wood-plastic composites, polymer-concrete composites, biopolymer nanocomposites and applications. 14 hours

Unit III

Metal matrix composites- Fabrication, interface, properties and applications. Dispersion strengthened, particle reinforced, fiber reinforced and laminate composites, comparison of properties. Fiber reinforced super alloy composites, Superconducting multifilamentary composites-introduction, types and fabrication.

Ceramic matrix composites – Types, fabrication, interface, properties and applications.

Carbon fiber composites- Fabrication, interface, properties and applications. Advanced C-C composites, C-C composites in aerospace engineering. 14 hours

References

1.Composite Materials Engineering & Science – F L Mathews & R D Rawlings (Chapman & Hall, 1990)
2. Composite Materials Science & Engineering – K K Chawla (Springer-Verlag, 1987)
3. Principles of Materials Science & Engineering – William F Smith (McGraw-Hill, 1988)
4. A Text Book of Materials Science & Metallurgy – O P Khanna (Dhanpat Rai pub., 1999)
5. Selection of Engineering Materials – Gladis Lewis (Printice Hall, 1990)
6. Engineering Materials & Their Applications – R A Flinn & P K Trojan (Jaico pub., 1998)
7. Composite Materials – S C Sharma. (Narosa, 2000)
8. An Introduction to Metal Matrix Composites – Clyne T W (Cambridge University, 1995)
9. Advanced Materials Science and Engineering of Carbon – Inagaki Michio (Oxford Tsinghua University Press, 2014)
10. Introduction to Polymer Clay Nanocomposites – Gurses Ahmet (Composites Pan Stanford, 2015)
11. Biopolymer Nanocomposites Processing, Properties and Applications- Dufresne Alain and Sabu Thomas (John Wiley and Sons, 2016).
12. Fiber Reinforced Composites – Mallick P K (CRC Press, 2008)

MSS 506: NANOSCIENCE AND NANOTECHNOLOGY – II (3 Credits)

Objectives: This course (i) deals with advanced concepts in nanoscience and technology, focusing on the properties of metal and semiconductor nanomaterials (ii) emphasises their applications in electronics and optics. (iii) deals special nanomaterials such as fullerenes, carbon nanotubes and nanocomposites are introduced.

Expected course outcomes: Student (i) gains good knowledge of the size dependent properties of nanostructures which make them a unique class of materials. (ii) attains a broad perspective of still newer materials of interest in this category, such as fullerenes and nanotubes.(iii) is encouraged to undertake start-ups in this new field

Unit I

Metal Nanoparticles: Introduction. Optical, Electrical and Magnetic properties. Surface plasmon resonance. GMR and CMR materials. Spintronics Applications of metal nanoparticles.

Semiconductor Nanoparticles: Introduction. Optical properties- Band gap variation with size- Brus equation. Photoluminiscence. Nonlinear optical processes. Applications of semiconductor nanoparticles. 14 hours

Unit II

Fullerenes: Preparation, properties, nanostructured fullerene films, applications. Carbon nanotubes: Introduction- single-walled and multiple–walled nanotubes. Synthesis, purification and structure. Methods of opening and filling nanotubes.

Physical properties. Non-carbon nanotubes. Applications of nanotubes. Biological applications of nanotechnology. Brief idea of nanobiotechnology. 14 hours

Unit III

Nanocomposites: Introduction to composites and nanocomposites. Ceramic, metal, polymer nanocomposites. Thin film and CNT- based nanocomposites. Polymer and rubber based nanoclay composites. Nanoscale fillers - nanofiber or nanotube fillers. Nanotube processing. Inorganic filler/polymer interfaces. Processing of nanocomposites.

Nanocomposites for electrical, optical and magnetic applications. Mechanical properties - modulus and the load- carrying capability of nanofillers - failure stress and strain toughness. Glass transition and relaxation behaviour.

Natural nanocomposite materials - biologically derived synthetic nanocomposites, templating. Natural nano-biocomposites, biomimetic nanocomposites. 14 hours

References:

1. Nanoscale Materials (Ed) - L.M. Liz, Marzan and P V Kamat (Kluwer, 2003)
2. Nanostructured Materials and Nanotechnology (Ed) - H S Nalwa, (Academic, 2002).
3. Introduction to Nanotechnology- C P Poole and F J Owens (Wiley- Intersci., 2006)
4. Nanotechnology and Nanoelectronics - W R Fahrner (Ed) (Springer, 2006)
5. Quantum Dots - L Jacak, P Hawrylak, A Wojs, (Springer, 1997)
6. Physics of Low Dimensional Structures - J H Davis, (Cambridge, 1998)
7. Nanostructured Magnetic Materials and Applications - Shi D et al (Springer, 2002)
8. Nanobiotechnology Concepts, Applications and Perspectives - Niemeyer C
9. Nanocomposite Science & Technology - Pulickal M Ajayan et. al (Wiley-VCH, 2003)
10. Introduction to Nanocomposite Materials - Thomas Twardowski, (DEStech, 2001)
11. Polymer Clay Nanocomposites - T J Pinnavaia, G W Beall, (Wiley, 2004)

MSS 507: CRYSTAL GROWTH (3 Credits)

Objectives: Objective of the course is to provide a fairly detailed knowledge on the various crystal growth processes. In particular, single crystal growths in bulk form and in epitaxial thin film forms which are essential for various research and development/technological applications.

Expected course outcomes: The student should be familiar with the crystal growth techniques with the necessary nucleation-growth theory. Good foundation on these topics would be helpful during their career in research or industry.

Objectives: Crystal growth is a process of growing crystals from a solution or melt, and it is widely used in fields such as including materials science, electronics, semiconductors, optics, and pharmaceuticals industries.Objective of the course is to provide (i) a fairly detailed knowledge on the various crystal growth processes with necessary nucleation-growth theory (ii) single crystal growth techniques in bulk form and in epitaxial thin film forms which are essential for various research and development/technological applications.

Expected course outcomes: The student should (i) be familiar with the theories on the growth of crystals (ii) be familiar with the different crystal growth techniques (iii) be familiar with the different single crystal growth techniques which are very essential for semiconductor industries. (iv) find a career in research or electronic industries.

Unit I

Crystal growth phenomena: Significance of single crystals – crystal growth techniques, Recent developments. Ideal growth laws – crystal-ambient phase equilibrium – criteria for equillibria in crystal growth – phase diagrams. Classification of growth processes.

Theories of nucleation- energy of formation - homogeneous nucleation – Gibb's Thompson equation for vapour, melt and solution, equilibrium shape of crystals. Heterogeneous nucleation – cap and disc shaped nuclei –constitutional supercooling - velocity of growth. Atomistic, thermodynamical models of crystal growth - Kossel and BCF theory. Problems and related experiments. 14 hours

Unit II

Crystal growth techniques: Bulk crystal growth – solution growth methods - supersaturation - aqueous solution, flux, hydrothermal methods. Melt growth – Kryopoulos, Bridgman – Stockbarger, Czochkralski, float zone and zone refining techniques. Impurity levelling factor – segregation coefficient. Verneuil method.

Low and high temperature solution growth – methods of crystallization – temperature gradient methods - growth of KDP and KTP crystals. Recent developments. Areas of applications. 14 hours

Unit III

Epitaxial growth methods – advantages - PVD – chemical vapour deposition – liquid and chemical vapour phase epitaxy – hot wall epitaxy- molecular beam epitaxy – MOCVD. Recent developments. Surface impurity contamination, defects and dislocations, determination of dislocation density.

Application: Si and Ge in semiconductor industry- IC technology: monolithic IC- masking and etching - elements of lithography- resist systems and patterning.

14 hours

References

1. Essentials of Crystallography, 2^{nd} Edition – M A Wahab (Narosa Publishing House Pvt. Ltd, 2011)
2. Statistical Physics of Crystal Growth – Saito Yukio (World Scientific, 1996)
3. Crystal Growth for Beginners: Fundamentals of Crystal Growth, Nucleation and Epitaxy – Ivan V Markov (World Scientific, 1996)
4. Solid State Chemistry – R C Ropp (Elsevier, 2003)
5. Principles of The Solid State – H V Keer (Wiley Eastern, 1993)
6. Crystal Growth 1974, Proc. Of 4^{th} Int. Conf. on Crystal Growth, Tokyo, Japan 24-29 March 1974, Eds. K A Jackson, N Kato and J B Mullin.
7. Current Trends in Crystal Growth and Characterization – Byrappa K (MIT, 1991)
8. Physics of Crystal Growth- Pimpinelli Alberto (Cambridge University, 1998)
9. The Growth of Crystals from Liquids – Brice J C (North Holland Press, 1973)

MSE 509: MATERIALS IN ENERGY PRODUCTION -OPEN ELECTIVE-2
(3 Credits)

Objectives: Objective of the course is to impart a basic knowledge about (i) global energy scenario and energy consumption in various sectors (ii) highlight the necessity for materials for renewable energy sources and energy production (iii) efficient energy production using solar cells, fuel cells (iv) efficient production and storage of energy using superconducting materials.

Expected course outcomes: The students should gain knowledge on (i) global energy scenario such as production and consumption by various sectors and the need for finding efficient and renewable energy sources (ii) the various sources of energy such as solar power, hydrogen energy (iii) how solar power may be efficiently harnessed using solar cells (iii) the basic working principles of hydrogen and fuel cells (iv) efficient power transmission, energy production and storage by superconductors (v) the use of energy resources effectively and efficiently (vi) companies involved in efficient power production and storage.

Unit I

Global energy scene- energy consumption in various sectors, projected energy consumption for the next century. Definition and units of energy, power. Forms of energy, Conservation of energy, second law of thermodynamics. Solar Cells – photovoltaic effect- light absorption- carrier generation and recombination, p-n junction: homo and heterojunctions. Metal-semiconductor interface. Equivalent circuit of the solar cell, analysis of PV Cells - dark and illumination characteristics. Solar cell- efficiency limits; variation of efficiency with band-gap and temperature. Efficiency measurements-high efficiency cells. Types of solar cells. Solar Cell fabrication technology. Recent developments. 14 hours

Unit II

Hydrogen energy – merits as a fuel – production of hydrogen – fossil fuels, electrolysis, thermal decomposition, photochemical and photocatalytic methods. Hydrogen storage – metal hydrides, metal alloy hydrides, carbon nanotubes, sea as source of deuterium. Fuel cells – introduction – difference between batteries and fuel cells, components of fuel cells, principle of working of fuel cell, performance characteristics of fuel cells, efficiency of fuel cell, fuel cell stack, fuel cell power plant: fuel processor, fuel cell power section, power conditioner, advantages and disadvantages of fuel cell power plant. Types of fuel cells - Solid oxide fuel cells (SOFC), Molten carbonate fuel cells (MCFC), Phosphoric acid fuel cells (PAFC) Polymer electrolyte fuel cells. Application of fuel cells – Recent developments-commercially available fuel cells. 14 hours

Unit III

Superconductors - development in the field of superconductivity – properties of superconductors - perfect diamagnetism, Meissner effect – critical field and current – BCS theory. Types of superconductors - high T_c superconductors – properties - synthesis of high T_c superconductors. Applications of superconductors in energy production and storage. Superconducting wires and their characteristics, high field magnets for production of energy by magnetic fusion, energy generation-magnetohydrodynamics (MHD), energy storage, electric generators and role of superconductors. Large scale applications of superconductors- electric power transmission, applications of superconductor in medicine - Magnetic Resonance Imaging (MRI), areas of applications, superconducting quantum interference devices (SQUID). 14 hours

References:

1. Fuel Cell Systems Explained, 2nd Edition - J Larminie and A Dicks (Wiley, 2003)
2. Principles of Fuel Cells - Xianguo Li (Taylor and Francis, 2005)
3. Fuel Cells: From Fundamentals to Applications - S Srinivasan (Springer, 2006)
4. Fuel Cell Fundamentals- O Hayre, S W Cha, W Colella and F B Prinz, (Wiley, 2005)
6. Solid State Devices - Ben G Streetman (Prentice-Hall, 1995)
5. High Efficiency Silicon Solar Cells - M A Green (Tran. tech., 1987)
7. Solar Cells: Materials, Manufacture and Operation, (eds) Tom Markvart, Luis castaner, (Elsevier, 2010)
8. Solar Voltaic Cells - Johnston W D (Marcel Dekker, 1980)
9. Introduction to Superconductivity -A C Rose Innes and E H Rhoderick (Pergamon Press, 1978)
10. Physics of High T_c Superconductors - J C Phillips (Academic Press, 1989)

MSP 405, MSP 406, MSP 458, MSP 508, MATERIALS SCIENCE LAB I – IV***

Objectives of the courses: The laboratory experiments offered in these courses covers almost all aspects of materials science that have been taught in the theory. The rigorous viva voce at the end of each experiment equips them with a deeper understanding of the subject as well as instil more confidence to face interviews. The laboratory courses are designed to (i) impart hands on experience on the measurement of all aspects of the science of materials, such as their structure and their optical, thermal, electrical and mechanical behaviour (ii) expose the students to various simple measurement techniques (iii) impart better understanding of the principles of the measurement techniques as well as the material properties.

Expected course outcomes: The students (i) are able to correlate what is learnt in the theory classes with the results obtained from the measurement of the properties of materials (ii) should gain an understanding of the techniques used as well as the properties studied in each experiment (iii) gain basic skills to work in research field/industries (iv) gain confidence and are better prepared to face job interviews

MSP 405: MATERIALS SCIENCE LAB- I (3 Credits)

1. Thermistor Thermometer
2. Hall Effect and study of temperature dependence of Hall coefficient
3. Electrical conductivity of metals and estimation of Fermi energy
4. Energy Gap of a Semiconductor - Four Probe Method
5. Energy band gap in p-n junctions
6. Full Wave Rectifier and Regulated Power Supply
7. Study of junction capacitance, reverse saturation current, and material constant of a p-n junction.
8. RC Coupled Amplifier
9. R.C. Coupled Phase Shift Oscillator
10. Operational Amplifier
11. Poisson's ratio of rubber
12. Diffraction using He-Ne laser
13. Refractive index of liquids using He-Ne laser
14. Diffraction from powder particles- diameter of lycopodium powder

MSP 406: MATERIALS SCIENCE LAB- II (3 Credits)
1. Thermal Conductivity of a Metal Bar
2. Thermal Conductivity of Insulators
3. Phase Diagram of Two Component System
4. Estimation of Ni in stainless steel by spectrophotometry
5. Phase diagram of Pb-Sn system
6. Analysis of Brass
7. Crystal Structure Analysis using X-Ray Diffraction
   a) Simple Cubic structure b) Face Centered Cubic structure
8. Crystal Structure Analysis using X-Ray Diffraction
   a) Hexagonal structure b) Tetragonal Structure
7. Determination of Heat of Solution
8. Estimation of Cr in stainless steel by spectrophotometry
9. Analysis of Bronze
9. Thermal Conductivity of Amorphous Solids
10. Glass transition temperature
11. Birefringence of Mica
12. Phase diagram of Three component system
13. Determination of molar absorption coefficient

MSP 458: MATERIALS SCIENCE LAB– III (3 Credits)
1. Activation energy of point defects
2. Youngs modulus of materials by Cornu's method
3. Adsorption studies
4. Creep in materials
5. Measurement of Young's modulus by strain gauge.
6. Conductivity of ionic salts
7. Corrosion studies
8. Conductometric titration
9. pH measurement
10.Potentiometric titration
11.Determination of molecular weight by viscosity measurement
12. Functional group analysis of polymer
13. Dimension of polymer coil
14.Viscosity of polymer blends
15. Preparation and processing of polymers (i) bulk and solution polymerisation (ii) compression moulding.
16. Hardness testing of materials
17. Metallurgical Microscope – Grain Size Measurements
   a) Ferrous alloys b) Non-ferrous Alloys

MSP 508: MATERIALS SCIENCE LAB.– IV (3 Credits)

1. Energy gap of CdS thin films
2. Dielectric constant of ferroelectric materials
3. Thickness of thin films

4.Ferromagnetic transition temperature

5. Diamagnetic and paramagnetic susceptibility using Gouy balance
6. Hysterisis loss and determination of Curie temperature
7. Magnetoresistance
8. Electron spin resonance
9. Solar cell I-V characteristics
10.Conducting studies of polyaniline
11.Preparation and characterization of metal nanoparticles
12. Preparation and characterization of semiconductor nanoparticles
13.Study of shape memory alloys
14. Junction voltage and band gap
15. SCR Characteristics

*** Minimum of ten experiments shall be completed in each course.

MSP 551: PROJECT (18 Credits)
Project/Internship-three months

Objectives: This project aims at (i) training the students to take up research as a career in academics and industries. (ii) exposing the student to recent topics in research (iii) training the student to conduct literature survey, material preparation, characterization. (iv) training the student in writing a research report, analysis and data interpretation. (v) encouraging independent and out-of-the box thinking (vi) instilling soft skills like communication, team work and problem solving.
Expected course outcomes: The student is able to (i) learn the methods of literature survey (ii) independently formulate a research problem (iii) carry out experimental methodology (iv)compile the data and write the report. (v) develop presentation and communication skills.(vi) correlate the fundamentals studied in the theory to the hands on experiments carried out (vii) design an original plan of action on a research problem. (viii) acquire skills and knowledge for initiating a start-up.

Annexure-II

Courses Pertaining to Employability/Skill Development/Entrepreneurship

MSH 403: Fundamentals of Electronic Materials and Devices

MSH 452: Materials Testing and Characterization

MSS 453: Surface Phenomena and Electrochemistry

MSS 454: Polymer Science

MSS 455: Thin Films

MSH 502: Magnetic Materials and Magnetic Resonance

MSH 503: Solid State Engineering Materials

MSS 504: New Materials and Technologies

MSS 505: Composite Materials

MSS 507: Crystal Growth

Annexure-III

Mapping

Course/Paper Title	POs as spelt out in the syllabus				
	1	2	3	4	5
MSH 401: MATHEMATICS FOR MATERIALS SCIENCE AND ENGINEERING (4 Credits)		√			
MSH 402: ELEMENTS OF MATERIALS SCIENCE (4 Credits)			√		
MSH 403: FUNDAMENTALS OF ELECTRONIC MATERIALS AND DEVICES (4 Credits)			√		
MSH 404: THERMODYNAMICS AND PHYSICAL METALLURGY (4 Credits)			√		
MSP 405: MATERIALS SCIENCE LAB. - I (3 Credits)				√	
MSP 406: MATERIALS SCIENCE LAB. -II (3 Credits)				√	
MSH 451: MECHANICAL PROPERTIES OF MATERIALS (4 Credits)			√		
MSH 452: MATERIALS TESTING AND CHARACTERIZATION (4 Credits)				√	
MSS 453: SURFACE PHENOMENA AND ELECTROCHEMISTRY (3 Credits)			√		
MSS 454: POLYMER SCIENCE (3 Credits)				√	
MSS 455: THIN FILMS (3 Credits)				√	
MSS 456: QUANTUM MECHANICS (3 Credits)		√			
MSS 457: NANOSCIENCE & NANOTECHNOLOGY – I (3 Credits)			√		
MSP 458: MATERIALS SCIENCE LAB. – III (3 Credits)				√	
MSE 459: SCIENCE OF MATERIALS IN DAILY LIFE (open elective-1) (3 Credits)		√			
MSH 501: DIELECTRIC MATERIALS (4 Credits)		√			
MSH 502: MAGNETIC MATERIALS & MAGNETIC RESONANCE (4 Credits)			√		
MSH 503: SOLID STATE ENGINEERING MATERIALS (4 Credits)			√		

MSS 504: NEW MATERIALS AND TECHNOLOGIES (3 Credits)				√	
MSS 505: COMPOSITE MATERIALS (3 Credits)				√	
MSS 506: NANOSCIENCE & NANOTECHNOLOGY – II (3 Credits)			√		
MSS 507: CRYSTAL GROWTH (3 Credits)			√		
MSP 508:MATERIALS SCIENCE LAB. –IV (3 Credits)				√	
MSE 509: MATERIALS IN ENERGY PRODUCTION -open elective-2 (3 credits)		√			
MSP 551: PROJECT (18 Credits)					√

Annexure-IV

Pos/Cos Attainment based on performance in Examination

% Attainment		
High	Medium	Low
(% of students Scored >60%)	(% of students Scored 50%-60%)	(% of students Scored<50%)
87.5%	**12.5%**	**0**