NPTEL: STRUCTURE OF MATERIALS
Instructor: Anandh Subramaniam [Lecture-1 to Lecture-45]

Lec	Chapter	Titles
1.	**Overview (C1)** **(Time: 49:06)**	• Different types of materials (metals and alloys, ceramics, polymers) • Classification of materials: (i) Based on state, atomic structure, band structure, size, (ii) monolithics and hybrids • Properties of materials and their origin (role of bonding) • The concept of microstructure
2.	**Geometry of Crystals: Symmetry, Lattices (C2)** **(Time: 1:08:58)**	• Symmetry (Motivation to study symmetry) • Symmetry of lattice, crystal, motif, unit cell • Symmetry operators and their classification, combination of symmetry operators and compound symmetry operators • Symmetry operators: translation, rotation, mirror, inversion, screw axes, glide reflection • Point groups and space groups • Concept of identity points/objects
3.	” **(Time: 56:29)**	• Classification of solids based on structure (crystals, quasicrystals and amorphous materials) • Definition of crystal (crystal = lattice + motif) • Lattices, Motifs • Constructing 1D, 2D crystals • Unit cells (primitive and non-primitive unit cells), choice of unit cells (10-05-10)
4.	” **(Time: 1:01:18)**	• Revision of important concepts related to lattices, motifs, crystals and unit cells • Detailed treatment of lattices (1D and 2D), 2D lattices (square, rectangle, centred rectangle)
5.	” **(Time: 50:00)**	• 2D lattices continued (120° rhombus, parallelogram) • Mystery of missing lattices
6.	” **(Time: 1:18:31)**	• Detour: concept of space filling • Concept of sublattice and subcrystals • Solved examples

7.	” **(Time: 55:31)**	• Solved examples (continued) • 3D lattices (14 Bravais lattices: cubic, tetragonal, orthorhombic, hexagonal)
8.	” **(Time: 59:58)**	• 14 Bravais lattices (continued): trigonal, monoclinic, triclinic • Mystery of missing Bravais lattices in 3D • 'Making crystals' (examples): 1D
9.	” **(Time: 55:04)**	• 'Making crystals' (examples): 2D, 3D (simple cubic crystal) • Types of models used to understand crystal structures
10.	” **(Time: 58:21)** **57:30**	• 'Making crystals' (examples): 3D (body centred cubic crystal, face centred cubic lattice, NaCl crystal, diamond cubic crystal) • Is there any connection between geometry and symmetry? • Crystal systems: 7 crystal systems (cubic crystals)
11.	” **(Time: 1:07:26)**	• Crystal systems: 7 crystal systems (tetragonal, orthorhombic, hexagonal, trigonal, monoclinic, triclinic) • Minimum symmetry requirement for the 7 crystal systems • Why do we need to consider 'arbitrary' motifs? • Advanced ('official') definition of a crystal: crystal = symmetry + space group (+ asymmetric unit) • Ideal versus real crystals (ideal crystal → real crystal → microstructure → component) • 'Functional' definition of microstructure: [(microstructure = phases + defects + residual stress) and their distributions] (31-05-10)
12.	• Geometry of Crystals: Symmetry, Lattices (continued) • **(C3) Miller Indices** • **(Time: 1:08:07)**	• Microstructure (continued) • Miller indices (for directions) • Concept of family of directions
13.	” **(Time: 56:53)**	• Family of directions (Continued) • Miller Indices for planes, family of planes • Planes in the cubic Lattice, members of a family of planes in cubic lattice • How does the (hkl) plane divide the cell edge, the face diagonal and the body diagonal? • Hexagonal crystal- Miller-Bravais Indices (the four index notation)

14.	• Miller Indices (continued) • **(C4) Crystal Structures** • **(Time: 1:01:53)**	• Miller-Bravais indices for hexagonal crystals (continued) • Perpendicularity of directions to planes • Weiss zone law (& Solved examples) • Classification of solids based on atomic structure (crystals, quasicrystals and amorphous materials) • Order (orientational and positional), average versus perfect order, probabilistic order (positional) • Short range order (SRO) and long range order (LRO) • Molecular and non-molecular crystals (metallic, covalent and ionic) • Metallic crystals
15.	Crystal Structures **(Time: 49:21)**	• Metallic crystals (continued): cubic close packed crystal, BCC, HCP crystals • Coordination polyhedra • Primitive unit cells of FCC, BCC crystals
16.	” **(Time: 57:42)**	• Model: primitive unit cell of BCC crystal • Diamond cubic (DC) crystal • Various definitions of 'density in materials science' • Packing fraction • Atomic density • Voids (CCP)
17.	” **(Time: 1:04:00)**	• Voids (CCP): illustration with models, Voids (HCP), space filling with voids (illustration with models) • Voids in BCC crystal • Size of the void and its role in determining the solubility of interstitial solutes
18.	” **(Time: 1:02:29)**	• Addition of alloying elements (segregation, solid solution, compound formation) • Hume-Rothery rules • Order-disorder transformation, examples of ordered structures (CuAu, Cu_3Au)
19.	” **(Time: 1:08:31)**	• Examples of ordered structures (continued): Fe_3Al • Interstitial solid solutions • Intermediate compounds (valency compounds, interstitial phases, electron compounds, size factor compounds), Laves phases,

		Frank-Kasper phases
20.	” **(Time: 1:02:22)**	• Revision of intermediate compounds • Orientational order (NH_4Cl crystal) • Ionic solids: rules for stable configuration (Pauling's rules), examples (NaCl, SiO_2, ZnS) (21-06-10)
21.	• Crystal Structures (continued) • **(C5) Defects in Crystals** • **(Time: 1:02:39)**	• Further aspects regarding metallic, ionic and covalent crystals (electron density distribution) • Covalent crystals (diamond, graphite), Fullerene crystal (example of molecular crystal) and orientational order therein • Introduction to defects in crystals • Structure sensitive and structure insensitive properties • Concept of 'defect structure'
22.	Defects in Crystals **(Time: 1:07:22)**	• Defect structure (continued) • Classification of defects (based on dimensionality, association with symmetry and symmetry breaking, based on their origin, based on their position, based on the fact that if the defect is with respect to a geometrical entity or a physical property) • Point defects classification (statistical/structural, random/ordered, intrinsic/extrinsic) • Point defects (Vacancies, impurity, Frenkel, Schottky) • Equilibrium concentration of vacancies
23.	” **(Time: 1:03:27)**	• Model to illustrate defects in crystals • Structural point defects and point defect ordering • Association of point defects • Complex point defect structures • Methods of producing point defects (origin of point defects)
24.	” **(Time: 48:30)**	• Dislocations (path to understanding dislocations) • Role of dislocations in materials • Plastic deformation in crystalline materials • Weakening of crystals by dislocations • The Volterra dislocation • Edge, screw and mixed dislocations

25.	” **(Time: 1:06:07)**	• Dislocations: Burgers vector and line vector • Motion of dislocations (glide and climb), formation of surface step • Models to understand dislocations
26.	” **(Time: 1:07:41)**	• Dislocation climb, cross-slip of screw dislocations • Where can a dislocation line end? • Positive and negative dislocations • Dislocations (Energy, dissociation, stress fields, dissociation, Interaction) • Dislocations in CCP crystals (Shockley partial dislocations), dislocation loops and Frank partial dislocations • Dislocations in BCC crystals • Dislocations in ionic crystals • Formation of dislocations and typical values for dislocation densities • Burgers vectors for dislocations in cubic crystals • Slip systems in FCC, BCC & HCP crystal structures • Jogs and Kinks in dislocations • Dislocation-dislocation interactions (edge-edge, edge-screw, screw-screw)
27.	” **(Time: 1:03:05)**	• Dislocation-point defect interaction • Yield point phenomenon • Dislocation-precipitate interactions (Frank-Read source) • Dislocation free-surface interaction (image forces) • Domain deformations due to dislocations (in nanocrystals) • Role of dislocations (crystal growth, phase transformations) • Getting a mental picture of a dislocation • Why are dislocations non-equilibrium defects? • "How are crystals weakened?": the two step process • Random versus structural dislocations • Solved examples

28.	” **(Time: 54:09)**	• 2D defects, classification (surface, grain boundary, stacking faults, twin boundaries, anti-phase boundaries) • Coherent and semi-coherent interfaces • Surface (creating a surface by a cut, surface energy, liquid versus solid surfaces) • Surface energy, surface tension and surface stress • Surface structure (terraces, ledges & kinks) • Equilibrium shape of a crystal • Solved example (importance of surface energy)
29.	” **(Time: 44:20)**	• Interfaces (including classification, degrees of freedom) • Grain boundary (video of dendritic solidification) • Low angle grain boundaries (tilt, twist), misfit dislocations, Grain boundary energy • Amorphous grain boundaries • Twin boundaries, type of twins (mirror, rotation, inversion), annealing and deformation twins • Stacking faults • Comparison of energy of various 2D defects
30.	**(C6) Diffusion in Solids** **()** **8 May 2013**	• Roles of diffusion in materials science • Kirkendall effect • Fick's I law (Concept of flux, gradient and diffusivity) • Steady and non-steady state diffusion • Fick's II law, error (erf) function solution, utility of error function solutions • Temperature dependence of diffusivity • Approximate formula for depth of penetration
31.	" () **9 May 2013**	• Atomic models of diffusion • Substitutional and interstitial diffusion • Diffusion paths with lesser resistance (surface, grain boundary and pipe diffusion) • Applications of Fick's II law: carburization of steel
32.	**(C7) Phase Diagrams** **()**	• Overview of phase diagrams and definitions

	13 May 2013(51:21)	• The Gibbs phase rule (with variables in a phase diagram)
33.	" () 15 May 2013	• Single component (unary) systems (example of Iron P-T phase diagram) • Binary phase diagrams (overview) • Isomorphous system (Gibbs free energy versus composition plots at various temperatures)
34.	" () 16 May 2013	• Tie line and lever rule • Extensions of the simple isomorphous system: Congruently melting alloys • Examples of isomorphous phase diagrams
35.	" () 20 May 2013	• Isomorphous systems with phase separation and compound formation • Congruent transformations • Eutectic phase diagram (terminal solid solution, examples of eutectic microstructures) • Gibbs free energy versus composition plot at various temperatures (Eutectic system) • Solidification of Eutectic and Off-eutectic compositions • Examples of eutectic phase diagrams
36.	" () 22 May 2013	• Peritectic phase diagram (Pt-Ag Peritectic system) • An important phase diagram (The Fe-Cementite phase diagram)
37.	**(C8) Phase Transformations** **()** **23 May 2013**	• Overview of phase transformations • Microstructural transformations • Energies involved in a phase transformation (bulk Gibbs free energy, interfacial energy and strain energy)
38.	" () 27 May 2013	• First order transformation and nucleation and growth • Liquid to solid phase transformation (undercooling, homogeneous nucleation, critical size for nuclei, 'nucleation barrier') • Melting point of nanocrystals and its relation to the nucleation barrier • Atomic perspective of nucleation, Nucleation Rate
39.	" 29 May 2013	• Heterogenous nucleation (Choice of heterogeneous nucleating agent) • Heterogeneous versus homogenous nucleation rates • Growth, Transformation rate, Sigmoidal growth curve

		• Time – Temperature – Transformation (TTT) diagrams
40.	" (50:57) 30 May 2013	• Models for computing transformation rate (Avrami Model, Johnson-Mehl Model) • Applications of the concepts of nucleation & growth and TTT diagrams • Phase transformations in steel (eutectoid, hypoeutectoid and hypereutectoid steels)
41.	" (52:24) 3 June 2013	• Continuous Cooling Transformation (CCT) Curves • CCT curves for steel • Common heat treatments involving cooling • Pearlite, Bainite and Martensite
42.	" () 5 June 2013	• Hardness of Martensite • Overview of heat treatment (bulk and surface heat treatments) • Annealing, normalizing, hardening and Tempering • Special heat treatments: Martempering and Austempering
43.	" (48:42) 6 June 2013	• Alloy steels and the role of alloying elements • Effect of carbon content and heat treatment on the properties of steel • Precipitation hardening (example of Al-Cu system) • Aging curves
44.	" () 10 June 2013	• GP zones, metastable precipitates and stable phase • Understanding aging sequence using extended phase diagrams and TTT diagrams • Precipitate coarsening • Solidification and crystallization • Glass transition
45.	" () 12 June 2013	• Recovery, Recrystallization & Grain Growth • Cold work and its effect on properties • Hot working versus cold working