PH5011 Science and Technology of Solid-state

Description: The course will deal with interesting phenomena that are relevant from a fundamental point of view and often have important applications. The aim is to bring students into contact with modern research topics and, at the same time to lay a good foundation in the physics of atoms, molecules, and condensed matter. The course deals with the exploration of materials with novel physical characteristics, applying these fundamental properties in engineering artificial, mostly nanoscale, device structures.

Course content:(1) Crystal Structure: Fundamental properties of condensed matter: Crystal systems, Bravais lattices, space groups, reciprocal lattice, crystal symmetries, packing fraction), bonding in materials (covalent, ionic, metallic, van der Waals, hydrogen), X-ray diffraction for structure determination, neutron diffraction for (magnetic) structure determination, and electron diffraction. Relate the reciprocal lattice to the crystal lattice (structure), lattice vibrations (thermal, acoustic, and optical properties)(2) Physical Properties: From atoms to solids, classification of solids (crystalline, nanocrystalline, protocrystalline, amorphous), the band structure of metals and semiconductors, superconductivity, dielectric and ferroelectrics, and magnetic properties of materials; Density of States, mobility bandgap and optical bandgap (direct and indirect), Electrical conductivity in crystalline, polycrystalline and amorphous materials, Theory of optical absorption â€“ absorption processes, direct and indirect, recombination processes in crystalline and amorphous materials, photoconductivity, luminescence. (3) Semiconductors: Introduction and basics of semiconductor physics, Metal/semiconductor junction, Ideal p-n junction, electrostatic and current conduction, the effect of voltage and light bias, and recombination at the junction.(4) Modern Condensed Matter, Devices, and Applications: Various phenomena and solid-state systems in modern condensed matter; the quantum Hall effect, single-electron tunneling, spintronics, plasmonics, (nano)photonics, photonic crystals, coherent atoms in optical lattices, quasicrystals, Hot carriers, Upconversion, Downconversion, Intermediate bandgap (IBG), multiple carrier generation, metamaterials, phase change materials, plasma dust, quantum dots, quantum wires, (Carbon) nanotubes, graphene, nano-antenna, (moth-eye) ARC, organic semiconductor device applications; semiconductor lasers, (O)LED, solar cells, TFT, Displays, memory, sensors, Plastic electronics

TextBooks: J.R. Hook & H.E. Hall, Solid State Physics (Publisher: Wiley) (2nd Edition) (e.book available)Ashcroft, And Mermin Solid State Physics,
Harcourt Asia PTE Ltd. (1976).

Reference books: B.D. Cullity Elements of X-ray Diffraction, Addison-Wesley (1956).C. Kittel Introduction to Solid State Physics, John Wiley & Sons 8 Ed. (2004).M. Ali Omar Elementary Solid State Physics, Addison-Wesley (1975). A. J. Dekker Solid State Physics, Macmillan Publishers India (2000).F. Reif Statistical Physics: Berkeley Physics Course, McGraw-Hill (1967).Arthur Beiser Concepts of Modern Physics, McGraw-Hill (2006).Rolf E. Hummel Electronic Properties of Materials, Springer (2001). David J. Griffiths Introduction to Quantum mechanics, Prentice Hall (1994).David Jiles Electronic Properties of Materials, Nelson Thornes Ltd. (2001). B.D. Cullity Introduction to Magnetic Materials, Addison-Wesley (1972). S.M. Sze Physics of Semiconductor Devices, John Wiley & Sons 8 Ed. (2007). P.R.L. Regtien Measurement science for engineers, Springer-Verlag London Limited

(2007).Stephen Blundell Magnetism in Condensed Matter, Oxford University Press (2001)

PH6022 Introduction to nanoscience

Description: To develop an understanding of the science behind various unique physical phenomena associated with the nano-metric scale.

CourseContent:1.What is Nanoscience: Bulk, polycrystalline and single-crystalline materials. Bulk physical properties -- electrical conductivity, thermal conductivity, specific heat, bandgap, reflectivity, magnetic property, etc.Brief Historical perspective of nanoscience: Colored Glasses, IC Chips.Physics of low dimensional systems.[12 classes] 2. Band Theory, Optical, and Electronic Properties at the Nanoscale: Band theory considerations to understand nanoscience. SchrÃ¶dinger equation, quantum confinement effects: particle in a box, energy level quantization, Tunneling, Electronic band structure, Brillouin zone boundary scattering, basic aspects of diffraction. The complete account of the density of states formalism for low-dimensional systems.
[12 classes] 3. Low Dimensional Systems: Dependence of key physical properties on dimensionality: Classification of nanomaterials - 2D, 1D, 0D systems with examples. 0D materials. Nano-clusters of metals and semiconductors, Bandgap tuning, Oxide Nanoparticles, and Their Optical Properties. 1D materials: Nanowires. Charge Transport in Nanowires. 2D materials: 2D electron gas, Hall effect, quantum Hall effect, Heterostructures, interfacial epitaxy, blue LED, Q-cascade lasers. Classical Interpretation of Magnetic Phenomena. Magnetism in low-dimensional systems. Magnetic Nanostructures.[10 classes] 4. Structure and Kinetics at the Nanoscale: Macro-, micro-, crystal- and atomic-structure aspects.Types of nanomaterials and nanostructures.Different shapes and sizes of nanosystems.Geometric Surface-to-Volume Ratio.Diffusion kinetics in nanoparticles, theories to explain size-dependent cohesive energy. [10 classes]

TextBooks:1. Introduction to Nanoscience and Nanotechnology, By Gabor L. Hornyak, H.F. Tibbals, Joydeep Dutta, John J. Moore, CRC Press, (2008).
2. Nanoscience and Nanotechnology: Fundamentals to Frontiers, M.S. Ramachandra Rao, Shubra Singh, Wiley India Pvt. Ltd., (2013).

ReferenceBooks:1. Introduction to Nano: Basics to Nanoscience and Nanotechnology, A. Sengupta (Editor), C.K. Sarkar (Editor), Springer, (2015). 2.
Nanostructures and Nanomaterials: Synthesis, Properties, and Applications (World Scientific Series in Nanoscience and Nanotechnology), G. Cao, Y.
Wang, World Scientific, (2011). 3. Introduction to Nanoscience, Stuart Lindsay, OUP Oxford, (2009)

PH5310 Synthesis and Characterization of Functional Materials

Description: This course will give learners an understanding of the various forms of crystals, principles of their synthesis techniques, and some characterization techniques and will enable them to synthesize and characterize different materials. The unit covers a range of materials, some of which learners may not be familiar with initially. This unit will enable learners to identify the synthesis techniques of a bulk polycrystal, single crystal, and thin films of metals, ceramics, alloys, and intermetallics. Learners will also be able to describe the principle, mechanism, and effects of processing on the behavior of given materials. Learners will apply their understanding of different destructive and non-destructive characterization techniques to study the structures, physical and mechanical properties of materials, design requirements, and availability to specify materials for given applications.â€•

Course content: Introduction to Functional materials; Polycrystalline, single-crystalline, and amorphous materials; Ceramics, metals, alloys, and intermetallics: Relationship between physical properties and crystallographic symmetry; Chemical energetics and atomistics of reactions Preparation of bulk polycrystalline materials and composites: Heating methods (thermal and RF); furnaces, types of the thermocouple; Solid-state reaction; self-propagating high-temperature synthesis; chemical precursor methods; coprecipitation; composites, high pressure, and high-temperature techniques. Preparation of nanomaterials: Top-down methods for fabrication of nanocrystalline materials; Bottom-up methods for synthesis of nanostructured solids; Solid-Vapor, Solid-Liquid and Solid-Solid reactions Sol-gel method, Solvothermal and Hydrothermal synthesis, High-energy Milling, combustion synthesis, microwave synthesis, spray pyrolysis, electrospinning; production of fine particles and nano-phase materials. Preparation in the thin-film form: CVD (Carbon, diamond-like carbon, etc.), PLD (multiferroic, GMR films), MBE (Multilayers). Crystal growth techniques: Nucleation and crystallization, e.g., in metals and glass ceramics. Bulk Single Crystal Materials; Principles and methods; Crystal growth from liquids; melt and flux techniques; Bridgman, Czochralski, Kyropoulos, and modifications; chemical vapor transport techniques: hydrothermal synthesis: growth by fused salt electrolysis: mirror furnace method, Zone refining; LPE; solution growth â€“hydrothermal, co-precipitation, sol-gel, polymer precursor processes; Synthesis and fabrication of functional materials: Carbon nanotube, graphene, chalcogenide quantum dots, nanowires and nanobelts, multiferroics, superconducting oxides, and intermetallics, GMR oxides, nonlinear optical crystals, and other novel functional materials; introduction to properties and devices. Techniques of characterization: (i) Destructive Techniques: Principles of chemical analysis, DTA, TGA, DSC. (ii) Non-destructive Techniques: use of x-ray electron and neutron diffraction techniques; density determination, electrical transport, and magnetic properties; Surface area measurements and hardness testing, basics of electron microscopy, microstructure analysis.

TextBooks:1) â€œMaterials Science and Technology: A Comprehensive Treatmentâ€•, Volume â€“ 13, 15, 16, 17, R.W. Cahn, P. Haasen, E.J. Kramer
(eds), Wiley, 1996. 2) â€œNovel Synthesis and Characterization of Nanostructured Materialsâ€•, A. K. Alves, C. P. Bergmann, and F. A. Berutti., Springer-Verlag Berlin Heidelberg, 2013. 3) â€œInorganic Materials Synthesis and Fabricationâ€•, J N. Lalena, D. A. Cleary, E. Carpenter, and N. F. Dean, John Wiley and Sons, Inc., 2008. 4) â€œSol-Gel Science: The Physics and Chemistry of Sol-Gel Processingâ€•, J. D. Wright and N. A. J. M. Sommerdijk, Academic Press, 1990. 5) â€œNanostructures & Nanomaterials: synthesis, properties, and applicationsâ€•, G. Cao, Imperial College Press, 2004. 6) â€œThe growth of crystals from the meltâ€•, J. C. Brice, North-Holland Publishing company, 1965. 7) â€œMaterials Science of Thin Films,

Deposition and Structureâ€•, M. Ohring, Academic Press, 2002. 8) â€œPulsed Laser Deposition of Thin Films: Applications-Led Growth of Functional Materialsâ€•, R. Eason, Wiley-Interscience. 9) â€œElements of X-Ray Diffractionâ€•, B. D. Cullity and S. R. Stock, Pearson, 2001.

ReferenceBooks:10) â€œThe Inorganic Chemistry of Materialsâ€•, P. J. van der Put, Plenum Press, New York, 1998. 11) â€œBasic Solid State Chemistryâ€•, A.R. West, 2nd edition, Wiley, Student Edition, 2014. 12) â€œSolid state chemistry â€“ an introductionâ€•, L. Smart and E. Moore, CRC Press, 4th ed. (2012). 13) â€œNanowires and nanobelts: materials, properties, and devicesâ€•, L. Wang (eds.), Kluwer Academic Publishers (2003). 14) â€œNanochemistry: A Chemical Approach to Nanomaterialsâ€•, G. A. Ozin and A. C. Arsenault, Royal Society of Chemistry (2005). 15) â€œCarbon nanotubes: synthesis, structure, properties, and applicationsâ€•, M. S. Dresselhaus, G. Dresselhaus and P. Avouris (eds.), Springer (2001). 16) â€œNanomaterials: Synthesis, Properties and Applicationâ€•, A. S. Edelstein and R. C. Cammarata (eds.), Institute of Physics Publishing (1996). 17) â€œFundamental Properties of Nanostructured Materialsâ€•, D. Fiorani, G. Sberveglieri, World Scientific (1994).

PH5320 Techniques of Characterization of Materials and Physical Measurements

Description: The course will deal with interesting phenomena that are not only relevant from a fundamental point of view but often have important applications. The aim is to bring students into contact with modern experimental techniques and, at the same time to lay a good foundation in the characterization of materials. The course deals with the exploration of materials with novel physical characteristics, applying these fundamental properties in engineering artificial, mostly nanoscale, device structures.

Course content: Optical microscopy techniques -phase contrast, interferometric and polarization microscopes, confocal scanning microscopy, and ellipsometry (4). Transmission and scanning electron microscopy (8). Atomic force microscopy and scanning tunneling microscopy (3). X-ray photoelectron spectroscopy, Auger electron spectroscopy, and X-ray fluorescence techniques (4). Laser-based techniques holography, electron holography, and Laser Raman spectroscopy (4 + 4). X-ray diffraction techniques - small-angle scattering, texture and stress distribution, and particle size analysis (6). Resonance spectroscopy â€“ NMR, ESR, and Mossbauer spectroscopy spectrophotometers. Radioactive tracer techniques and neutron activation analysis (6). Improvement of signal-to-noise ratio-Fourier transformation techniques and boxcar average (4).
TextBooks:1. Douglas B. Murphy and Michael W. Davidson, Fundamentals of light microscopy and electronic imaging, 2nd Edition, John Wiley & sons, inc., 2013. 2. David B. Williams and C. Barry Carter, Transmission electron microscopy, a Textbook for Materials Science, 2nd Edition, Springer Science Business Media, 1996. 3. Yang Leng, Materials Characterization - Introduction to Microscopic and Spectroscopic Methods, 2nd Edition, Wiley-VCH Verlag GmbH & Co., 2013.
ReferenceBooks:1. Hiroyuki Fujiwara, Spectroscopic ellipsometry principles and applications, John Wiley & Sons Ltd., (2007). 2. John F. Watts and John Wolstenholme, An Introduction to Surface Analysis by XPS and AES, John Wiley & Sons Ltd, (2003). 3. Paul van der Heide, X-ray photoelectron spectroscopy, John Wiley & Sons, Inc., (2012). 4. Peter Eaton and Paul West, Atomic force microscopy, Oxford university press, (2010). 5. John R. Ferraro, Kazuo Nakamoto and Chris W. Brown, Introductory Raman spectroscopy, 2nd Edition, Elsevier, (2003). 6. Duward Shriver, Mark

Weller, Tina Overton, Jonathan Rourke, Fraser Armstrong - Inorganic Chemistry-Macmillan Education (W. H. Freeman) (2014)

PH6011 Nanomaterials and nanotechnology

Description: As a follow up to the first-semester course, where the students would have received nice introductory lectures on the basic aspects of low dimensional systems, quantum confinement, etc., in this course, students will learn more about how to synthesize nanomaterials and how the synthesis methods influence the size and shape of nanosystems. They will learn about various characterization techniques. They will also get a glimpse of various technological aspects of nanosystems, including some useful industrial applications.

Course content: Introduction to nanoscale objects: Nanoclusters, Nanosheets, Nanowires, Nanostructures. Basic synthesis methods of nanosystems: Top-down and bottom-up approaches. Experimental tools for nanoscience: Preparation, fabrication, and manipulation of nanostructures. Lithography and etching processes: Photoresists, subtractive and additive pattern transfer, Lithographic methods; UV-and coherent UV lithography, electron beam lithography, x-ray and proton beam lithography, ion projection lithography, focused ion beam (FIB) lithography; Emerging nanolithographic methods; Nanoimprint Lithography, Nanoembossing, soft lithography, Near-Field lithography, Dip-pen lithography. Characterization of Nanomaterials and nanostructures: X-ray crystallography, peak broadening (Scherrer method), Optical techniques: Confocal Raman spectroscopy and Raman mapping, Time-resolved spectroscopy Electrical conductivity and Impedance, Specific heat measurements, Electron microscopy (FESEM, HRTEM, STEM), and spectroscopy techniques (Atomic resolution EDS and EELS), ARPES, XAS, EXAFS, and atom probe techniques. SPM techniques (STM, AFM, PFM, MFM, SNOM, etc.). Properties and Applications: Molecular electronics Nanomagnetism, nano-piezotronics, and Spintronics Information storage; Magnetic recording. Magnetic nanoparticles, drug delivery, and cancer therapy. Optronics: Surface plasmons and nanoscale optics; semiconductor quantum dots; Photonic crystals Nanocrystalline diamond, nanostructured films for sensor and space applications. Nano Electromechanical Systems (NEMS) etc.

TextBooks: Nanoscience and Nanotechnology: Fundamentals to Frontiers, MSR Rao and Shubra Singh, Wiley

Reference books:Nanomaterials: An Introduction to Synthesis, Properties and Applications, 2nd Edition, Dieter Vollath (2013)
Nanoscience: Nanotechnologies and Nanophysics, C. Dupas P. Howdy M. Lahmani (Eds.), Springer 2004 Editions Belin, France. Nanophysics and
Nanotechnology: An Introduction to Modern Concepts in Nanoscience, Edward L. Wolf, Wiley-VCH Verlag GmbH and Co. (2004). Introduction to
Nanoscience and Nanotechnology, Chris Binns, Wiley

PH6012 Fundamentals of Semiconductor Physics and Devices

Description: Learning Objectives: At the end of the course, the students are expected to achieve- (a) an understanding of basic physical processes in semiconductors (b) Analysis of the charge conduction across p-n junctions and devices (c) Designing of experiments for measuring semiconductor parameters and properties
Course content: Review of the Band theory of solids, Metal, Insulator, and Semiconductor, Effect of temperature and electric field on the band structure, Concept of Fermi energy, Concept of electron and hole, the concept of effective mass; p and n-type doping, heavy doping and degeneracy. Direct and indirect bandgap semiconductors and their identification. Allowed and forbidden transitions, phonon-assisted transition, and their spectral shapes, Burstein Moss effect; Excitons: free and bound. Electrical conductivity and mobility of charge carriers; mechanisms of scattering; Generation and recombination of charge carriers; Hall-Shockley-Reed theory of recombination Equilibrium and non-equilibrium processes, Charge transport equation Metal-semiconductor junctions, Ohmic and Schottky contacts, Schottky barrier and barrier lowering effects Theory of p-n junction, the concept of depletion later, resistance and capacitance across the depletion layer Charge transport in a p-n junction; Practical junctions and Ideality factor; Space charge and diffusion capacitances. Surface states and related band bending Measurement of carrier type and mobility - Hall effect; Measurement of bandgap- optical absorption spectroscopy; Effective mass- Cyclotron resonance experiment, Impurity profiling through capacitance measurements; Conductivity measurement Diodes â€“ Zener, Tunnel, LED, Gunn, Laser, and other diodes; Transistors â€“ unipolar and bipolar; Solar cells, Photodetectors.

TextBooks: Semiconductor Physics and Devices by Donald Neaman (Tata McGraw Hill), Fundamentals of Semiconductor Devices by Achuthan and
Bhat (Tata McGraw Hill)

Reference books: Physics of semiconductor devices by S O Kasap Semiconductor Devices by S M Sze (Wiley), Physics of Semiconductor Devices by
Michael Shur (Pearson)

PH6013 Functional Materials, Sensors, and Transducers

Description: Functional materials possess particular native properties and functions of their own. Sensors and transducers use the functionality of materials for automation, remote control, and energy applications. The students will acquire knowledge on how materials are tailor-made for specific applications.

Course content: Functional Materials Introduction to Functional Materials and their applications - Transport, Dielectric, Magnetic and Optical properties Functional Materials for Energy applications â€“ Materials for Solar Power, Hydrogen Storage Materials, Materials for Fuel Cells, Materials for Energy Storage Multifunctional and Smart Materials Sensors and Transducers Introduction to Sensors and Transducers, Principles, Classification, Parameters, Static and DynamicCharacteristics, Characterization. Mechanical and Electromechanical Sensors and Transducers: Strain Gauge, Inductive Sensors and transducers, Electromagnetic transducer, Magnetostrictive transducer, Capacitive Sensors, Piezoelectric sensors and transducers, Ultrasonic Sensors. Thermal Sensors: Gas thermometric Sensors, Thermal expansion sensors, Resistance Thermometers, Thermoelectric Sensor, Semiconductor and Diode Sensors, Capacitance sensors,

Low-Temperature Thermometer, and Thermal Radiation Sensor. Magnetic Sensors/Transducers: Yoke Coil and Coaxial Type Sensors, Force and Displacement Sensor, Magnetoresistive Sensors, Hall Sensor, Inductance and Eddy Current Sensors, LVDT,
Angular/Rotary movement transducers, Electromagnetic Flowmeter, SQUID. Radiation Sensors: Photoemissive Cell and Photomultiplier,
Photoconductive Cell, LDR, Photovoltaic and Photojunction Cells, Position-Sensitive Cell, Photo FETs, Ionization Chamber, Scintillation Detector. Solid-State Detectors, Fibre Optic Sensors, Smart Sensors TextBooks:1. Physics of Functional Materials (Includes solved examples, a number of exercises, and answers to the exercises) Hasse Fredriksson and Ulla Ã...kerlind Publisher- Wiley-Blackwell (2008) 2. Sensors and Transducers (2nd Revised Edition) D. Patranabis Publisher: Prentice-Hall of India Pvt.Ltd (2004)

ReferenceBooks:1. Functional Materials for Sustainable Energy Applications Edited by J A Kilner, S J Skinner, S J C Irvine, and P P Edwards Copyright Â© 2015 Elsevier B.V. 2. Sensors and Transducers (Third Edition) Ian R. Sinclair Copyright Â© 2001 Elsevier Ltd. 3. Engineering Materials for Technological Needs: Volume 2 Functional Materials Electrical, Dielectric, Electromagnetic, Optical, and Magnetic Applications Deborah D L Chung Publishers: World Scientific (2010) 4. Advanced Functional Materials (Advanced Material Series) Ashutosh Tiwari and Lokman Uzun Publisher: John Wiley & Sons (2015)