References

Essential Readings:

1. Mathematical Tools for Physics, James Nearing, 2010, Dover Publications
2. Theory and Problems of Linear Algebra, Seymour Lipschutz, 1987, McGraco-Hill Inc.
3. Theory and Problems of Vector Analysis and an introduction to Tensor Analysis, Murray R. Spiegel, 1974, McGraw Hill, Inc.
4. Introduction to Matrices & Linear Transformations, D.T.Finkbeiner,1978, Dover Pub.
5. Matrices and tensors in Physics: A.W. Joshi, New Age International Pvt. Ltd (2017).

Additional Readings:

1. Mathematical Methods for Physicists, G.B. Arfken, H.J. Weber and F.E.Harris,1970, Elsevier.
2. Elementary Linear Algebra, Applications Version, Howard Anton and Chris Rorres, Wiley Student edition.
3. Modern Mathematical Methods for Physicists and Engineers, C.D. Cantrell, 2011, Cambridge University Press.
4. Mathematics for Physicists, Susan M. Lea, 2004, Thomson Brooks/Cole
5. Introduction to Vectors and Tensors, Ray M Bowen, C -C Wang, Dover Publications (2009)
6. An Introduction to Linear Algebra and Tensors, M A Akivis, V V Goldberg, Richard and Silverman, Dover Publications (2012)
7. Vector Analysis and Cartesian Tensors, D.E. Bourne and P.C. Kendall, CRC Press (1992).

DSE: Nano Materials and Applications (32227612)
Credit : 06 (Theory-04, Practical-02)
Theory : 60 Hours
Practical : 60 Hours

Course Objective

The syllabus introduces the basic concepts and principles to understand nanomaterial. Various nanomaterial synthesis/growth methods and characterizations techniques are discussed to explore the field in detail. The effect of dimensional confinement of charge carries on the electrical, optical and structural propertie are discussed. The concept of micro- and nano- electro mechanical systems (MEMS and NEMS) and important applications areas of nanomaterials are discussed.

Course Learning Outcomes

On successful completion of the module students should be able to

- Explain the difference between nanomaterials and bulk materials and their properties.
- Explain the role of confinement on the density of state function and so on the various properties exhibited by nanomaterials compared to bulk materials.
- Explain various methods for the synthesis/growth of nanomaterials including top down and bottom up approaches.
- Analyze the data obtained from the various characterization techniques
- Explain the concept of Quasi-particles such as excitons and how they influence the optical properties.
- Explain the Interger Quantum Hall Effect and the concept of Landau Levels, and edge states in conductance quantization.
- Explain the conductance quantization in 1D structure and its difference from the 2DEG system.
- Explain various applications of nano particles, quantum dots, nano wires etc
- Explain why nanomaterials exhibit properties which are sometimes very opposite, like magnetic, to their bulk counterparts.
- In the Lab course students will synthesize nanoparticles by different chemical routes and characterize them in the laboratory using the different techniques, learnt in the theory. They will also carry out thin film preparation and prepare capacitors and evaluate its performance. They will fabricate a PN diode and study its I-V characteristics.

Unit 1

NANOSCALE SYSTEMS: Density of states (3D, 2D, 1D,0D),Length scales in physics, Nanostructures: 1D, 2D and 3D confined nanostructures (thin films, nanowires, nanorods, nanodots), Schrodinger equation- Infinite potential well, potential step, potential box,Band structure and density of states of materials at nanoscale (Quantitative for 3D, 2D, 1D, 0D), Size Effects in nano systems, Applications of quantum confinement of carriers in 3D, 2D, 1D nanostructures and its consequences on electronic and optical properties. Numerical problems based on above topics.

(14 Lectures)

Unit 2

SYNTHESIS OF NANOSTRUCTURE MATERIALS (Qualitative): Top down and Bottom up approach, Photolithography. Ball milling. Spin coating, Vacuum deposition: Physical vapor deposition (PVD): Thermal evaporation, Sputtering, Pulsed Laser Deposition (PLD), electric arc deposition for CNT, C_{60}, grapheme, Chemical vapor deposition (CVD). Preparation through colloidal methods (Metals, Metal Oxide nanoparticles), Molecular Beam Epitaxy (MBE) growth of quantum dots.

(5 Lectures)

Unit 3

CHARACTERIZATION: Structure and Surface morphology: X-Ray Diffraction (XRD). Scanning Electron Microscopy (SEM). Transmission Electron Microscopy (TEM).Atomic Force Microscopy (AFM).Scanning Tunneling Microscopy (STM).
Spectroscopy: Working principle of UV-Vis spectroscopy, IR Spectroscopy, Raman and Photoluminescence Spectroscopy and study the size dependent properties using these techniques.

(11 Lectures)

Unit 4

OPTICAL PROPERTIES: Quasi-particles and collective excitations (Qualitative idea).Quantitative treatment of excitons, Radiative processes: General formalization-absorption, emission and luminescence. Optical properties of nanoparticles as a function of size, defects and impurities: deep level and surface defects. Numerical problems based on above topics.

(10 Lectures)

Unit 5

ELECTRON TRANSPORT: time and length scales of electrons in solids, Carrier transport in nanostructures: diffusive and ballistic transport, Charging effect, Coulomb blockade effect. Single electron transfer devices (no derivation).Conductance quantization: 2DEG in GaAs and integer quantum hall effect (Quantitative), conductance quantization in 1D structures using split gate in 2DEG (no derivation).Numerical problems based on above topics.

(14 Lectures)

Unit 6

APPLICATIONS (Qualitative): Applications of nanoparticles, quantum dots, nanowires and thinfilms for photonic devices (LED, solar cells). CNT based transistors. Nanomaterial Devices: Quantum dots heterostructurelasers, optical switching and optical data storage. Magnetic quantum well; magnetic dots-magnetic data storage.Micro Electromechanical Systems (MEMS), NanoElectromechanical Systems (NEMS).

(6 Lectures)

Practical : 60 Hours

PRACTICALS- DSE LAB: Nano Material and Applications Lab

Sessions on the construction and use of specific measurement instruments and experimental apparatuses used in the nano physics lab, including necessary precautions.

Sessions on the review of experimental data analysis and its application to the specific experiments done in the lab.

At least 06 experiments from the following:

1. Synthesis of metal (Au/Ag) nanoparticles by chemical route and study its optical absorption properties.
2. Synthesis of semiconductor (CdS/ZnO/TiO2/Fe2O3etc) nanoparticles and study its XRD and optical absorption properties as a function of time.
3. Surface Plasmon study of metal nanoparticles by UV-Visible spectrophotometer.

4. Analysis of XRD pattern of nanomaterials and estimation of particle size.
5. To study the effect of size on the color of nanomaterials.
    (i) To prepare composite of CNTs with other materials.
    (ii) Growth of quantum dots by thermal evaporation.
    (iii) Prepare a disc of ceramic of a compound and study its XRD.
    (iv) Fabricate a thin film of nanoparticles by spin coating (or chemical route) andstudy its XRD and transmittance spectra in UV-Visible region.
    (v) Prepare a thin film capacitor and measure capacitance as a function oftemperature or frequency.
    (vi) Fabricate a PN junction diode by diffusing Al over the surface of N-type Si/Geand study itsV-I characteristic.
    (vii) Fabricate thin films (polymer, metal oxide) using electro-deposition
    (viii) To study variation of resistivity or sheet resistance with temperature of the fabricated thin films using four probe method.

References for Theory:

1. C.P. Poole, Jr. Frank J. Owens, Introduction to Nanotechnology 1st edition (2003) Wiley India Pvt.Lt..
2. S.K. Kulkarni, Nanotechnology: Principles & Practices 2nd edition(2011) (Capital Publishing Company)
3. K.K. Chattopadhyay and A. N. Banerjee, Introduction to Nanoscience and Technology (2009) (PHI Learning Private Limited).
4. Introduction to Nanoelectronics, V.V. Mitin, V.A. Kochelap and M.A. Stroscio, 2011, Cambridge University Press.
5. Richard Booker, Earl Boysen, Nanotechnology for Dummies (2005) (Wiley Publishing Inc.).
6. Introductory Nanoscience by Masaru Kuno, (2012) Garland science Taylor and Francis Group
7. Solid State Physics by J. R. Hall and H. E. Hall, 2nd edition (2014) Wiley·
8. Electronic transport in mesoscopic systems by Supriyo Datta (1997) Cambridge University Press.
9. Fundamentals of molecular spectroscopy by C. N. Banwell and E. M. McCASH, 4th edition, McGrawHill. Reference Books for Practicals:
10. C.P. Poole, Jr. Frank J. Owens, Introduction to Nanotechnology 1st edition (2003) Wiley India Pvt.Ltd..
11. S.K. Kulkarni, Nanotechnology: Principles & Practices 2nd edition (2011) (Capital Publishing Company)
12. K.K. Chattopadhyay and A. N. Banerjee, Introduction to Nanoscience and Technology (2009) (PHI Learning Private Limited).

Additional Resources:

1. Quantum Transport in semiconductor nanostructures by Carla Beenakker and HenK Van Houten (1991) (available at arXiv: cond-mat/0412664) open source
2. Sara cronewett Ph.D. thesis (2001).