DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 8-3: NANOSCIENCE AND NANOTECHNOLOGY

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Nanoscience and Nanotechnology DSE 8-3	4	3	0	1	Quantum Mechanics

COURSE OBJECTIVES

The objective of this course is to introduce students to the fundamental principles of nanoscience and nanotechnology, with a focus on size-dependent properties of materials and their interdisciplinary applications. It aims to develop an understanding of nanomaterial synthesis, characterization techniques, and emerging applications in electronics, energy, environment, and healthcare.

LEARNING OUTCOMES:

Upon successful completion of this course, students will be able to:

- Explain the fundamental concepts of nanoscience and the distinct properties of nanomaterials compared to bulk materials.
- Classify nanomaterials based on their dimensions and understand quantum confinement effects on their behavior.
- Apply suitable top-down and bottom-up techniques for the synthesis of nanomaterials.
- Use standard characterization methods (e.g., XRD, SEM, TEM, UV-Vis) to analyze structural and optical properties of nanomaterials.
- Evaluate the potential of nanomaterials in real-world applications such as electronics, energy devices, sensors, and environmental solutions.

SYLLABUS OF DSE 8-3
THEORY COMPONENT
(Hours: 45)

Unit I **(12 Hours)**

Introduction to Nanoscience and Nanomaterials

Basic Concepts of Nanoscience and Nanotechnology: Introduction to nanoscience and its implications in Physics, Chemistry, Biology, and Engineering. Classification of nanostructured

materials: 0D (quantum dots), 1D (nanowires, nanotubes), 2D (thin films, graphene), and 3D (multi-layered materials, superlattices). Comparison of nanomaterials with bulk materials (metals, semiconductors, ceramics, polymers).
Properties at Nanoscale: Overview of mechanical, electronic, optical, magnetic, and thermal properties at nanoscale (qualitative). Effects of size reduction on these properties. Introduction to quantum confinement and its role in altering Bandgap widening, enhanced reactivity, and surface-to-volume ratio effects.

Unit II **(6 Hours)**

Nanoscale Systems and Their Properties
Band structure and density of states in 3D, 2D, 1D, and 0D systems (detailed for 3D and 2D, qualitative for 1D and 0D). Quantum confinement effects on electronic and optical properties.

Unit III **(15 Hours)**

Synthesis and Characterization of Nanomaterials
Synthesis Techniques: Top-down vs. bottom-up approaches. Top-down: Ball milling, lithography. Bottom-up: Physical Vapor Deposition (PVD) - thermal evaporation, sputtering; Chemical Vapor Deposition (CVD); Spin coating; Preparation of colloidal solutions (metals, metal oxides). Chemical and electrochemical synthesis of conducting polymers (intrinsic and extrinsic).
Characterization of Nanomaterials: Basic techniques for characterizing nanomaterials: Structural (e.g., SEM, TEM, AFM, XRD), optical (e.g., UV-Vis spectroscopy), and electronic properties (e.g., conductivity measurements).
Nanomaterials in Electronics: Introduction to carbon-based nanomaterials (CNTs, graphene) for electronic applications. Conductance quantization in 1D and 2D systems and their relevance to nanoelectronics.

Unit IV **(12 Hours)**

Applications of Nanomaterials
Nanomaterials in Energy and Environment: Nanotechnology for sustainable energy: Nanomaterials in solar cells (silicon-based, LEDs for displays), fuel cells, and electrochemical storage (primary, secondary, lithium, solid-state batteries). Environmental applications: Photocatalysts, nanomaterial-based membranes, and adsorbents for water/wastewater treatment (metal oxide surfaces, hybrid adsorbents).
Nano Devices and Sensors: Gas sensors: Chemiresistive (semiconducting metal oxides, CNT-based), electrochemical, and optical sensors.
Applications: Medical diagnostics (nanoprobes, targeted drug delivery), consumer products (sunscreens, lotions, paints).

PRACTICAL COMPONENT: NANOSCIENCE AND NANOTECHNOLOGY
(Hours: 30)

At least 05 experiments from the following:
1. Synthesis of metal/metal oxide nanoparticles by chemical route and study its optical absorption properties.

2. Synthesis of semiconductor (CdS/ZnO/TiO2/Fe2O3 etc) nanoparticles and study its XRD.
3. Analysis of XRD pattern of given nanomaterial and estimate lattice parameters and particle size.
4. Growth of thin films using thermal evaporation/spin coating or any available technique in lab.
5. Investigation of grain size/ particle size distribution from SEM/TEM images using imagej software (free ware: https://imagej.en.softonic.com/).
6. Prepare a ceramic disc of a given compound and study I-V characteristics / measure its dielectric constant with frequency or other property.
7. To study variation of resistivity or sheet resistance with temperature of the fabricated thin films using four probe method.

REFERENCES

Essential Readings for the theory component

1. C.P. Poole, Jr. Frank J. Owens, Introduction to Nanotechnology 1st edition (2003) Wiley India Pvt. Ltd..
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. Electronic transport in mesoscopic systems by Supriyo Datta (1997) Cambridge University Press.
8. Fundamentals of molecular spectroscopy by C. N. Banwell and E. M. McCASH, 4th edition, McGrawHill.
9. Introduction to Nanomaterials and Devices, Omar Manasreh, Wiley, 1st Edition, 2011
10. Textbook of Nanoscience and Nanotechnology, B.S. Murty, P. Shankar, Baldev Raj, B.B. Rath, James Murday, 2013, Springer, e-ISBN 978-3-642-28030-6

Additional Readings for the theory component

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) for extra reading (Available as Arxiv).
3. Solid State Physics by J. R. Hall and H. E. Hall, 2nd edition (2014) Wiley

References for the laboratory work

1. C.P. Poole, Jr. Frank J. Owens, Introduction to Nanotechnology 1st edition (2003) Wiley India Pvt. Ltd..
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
4. Technology (2009) (PHI Learning Private Limited).
5. Richard Booker, Earl Boysen, Nanotechnology for Dummies (2005) (Wiley Publishing Inc.)