



| Code<br>(Prefix"CU<br>TM") | Course Title                                    | Credit | Type<br>(T+P+Pj) |
|----------------------------|-------------------------------------------------|--------|------------------|
| 1399                       | Energy storage materials                        | 4      | 3+1+0            |
| 1400                       | Bio and bimimetic nanomaterials                 | 4      | 3+0+1            |
| 1401                       | Photovoltaic technology and nanocatalysts       | 4      | 3+1+0            |
| 1402                       | Advanced characterization techniques            | 4      | 3+1+0            |
| 1403                       | Smart and electronic materials                  | 4      | 3+0+1            |
| 1404                       | Corrosion and advanced coating<br>application   | 4      | 3+0+1            |
| 1405                       | Synthesis and application of nano<br>composites | 4      | 3+1+0            |
| 1406                       | Material behavior of nanostructures             | 4      | 3+1+0            |
| 1407                       | Emerging materials                              | 4      | 3+0+1            |
| 1408                       | Synthesis routes of nanomaterials               | 4      | 3+1+0            |
| 1409                       | Computational materials science                 | 4      | 2+2+0            |
| 1410                       | Plasma technology                               | 4      | 3+0+1            |
| 1411                       | Essentials of nanomaterials                     | 4      | 3+1+0            |
| 1412                       | Advanced quantum mechanics                      | 4      | 2+0+2            |
| 1413                       | Physics of solids and semiconductors            | 4      | 3+1+0            |
| 1414                       | Laser technology                                | 4      | 2+1+1            |



| Code      | Course Title             | T-P-Pj (Credit) | Prerequisite            |
|-----------|--------------------------|-----------------|-------------------------|
| CUTM 1399 | Energy Storage Materials | 3-1-0           | Basics of Nanomaterials |

### Objective

- This course will educate the students the concepts and operation of accessible energy storage systems, significance of energy storage in current scenario, reason and transfer of efficiency losses in different energy storage systems.
- This course is designed to help the students to provide adequate knowledge regarding nanomaterials in fuel cells, hydrogen Storage, thermoelectric materials (in nano scale), super capacitors.
- The students will also learn various types of batteries used in modern technology and the intercalation of nanomaterials inside them.

### Learning outcome

- The students will be able to know the usage of nano-materials in various battery applications (Li ion battery, K ion battery, Na ion battery)
- The students will be able to know the utilization of next generation super-capacitors and its applications.
- The students will be able to understand the use of nanomaterials in fuel cells, various hydrogen storage systems, and thermoelectric materials.

### Course outline

#### Module I

**(4 Hours Theory)**

Nanotechnology in energy research, Fossil fuels, Nanotechnology in fuel production, Renewable energy sources; Advantages of renewable energy sources.

#### Module II

**(4 Hours Theory)**

Thermoelectric materials (bulk), Thermoelectric materials (in nanoscale), Thermoelectric nanocomposites, Applications of thermoelectric nano materials

#### Module III

**(6 Hours Theory + 2 Hours Practice)**

Supercapacitors, Types of supercapacitors, Design of supercapacitors, Carbon based materials for supercapacitors, Necessary parameters for supercapacitors, Applications.

#### Practice-1

To learn the specific charge/discharge characteristics of a supercapacitor through experimental testing of a remote triggered ultracapacitor battery supercapacitor

#### Module IV

**(6 Hours Theory)**

Fuel Cells: Low temperature fuel cells; High temperature fuel cells; Catalysts for fuel cells and electrolytes; Solid oxide fuel cells; Applications



**Module V (4 Hours Theory)**

Semiconductor based Hydrogen production; Selection of nanomaterials for energy harvesting and storage applications; Other significant materials for Hydrogen storage; Thermal energy storage systems

**Module VI (3 Hours Theory+ 4 Hours Practice)**

Batteries: Lithium ion battery; Nanomaterials in Li ion battery; Nanomaterials in K ion battery

**Practice 2:** To learn the specific charge/discharge characteristics of a Lithium- ion (Li- ion) battery through experimental testing of a remote triggered Li- ion Battery

**Practice 3:** To learn the specific charge/discharge characteristics of a Lithium- Polymer (Li- Po) battery through experimental testing of a remote triggered Li- Po Battery.

**Module VII (3 Hours Theory+8 Hours Practice)**

Aluminium ion battery; Graphene battery; Sodium ion battery

**Practice 4:** To learn the specific charge/discharge characteristics of a Lead Acid battery through experimental testing of a remote triggered Lead Acid Battery

**Practice 5:** To learn the specific charge/discharge characteristics of a Nickel Metal Hydride (NiMH) battery through experimental testing of a remote triggered NiMH Battery

**Practice 6:** To learn the specific charge/discharge characteristics of a Nickel-Cadmium (Ni-Cad) battery through experimental testing of a remote triggered Ni-Cad battery.

**Total theory 30 hours and total practice 12 hours**

**Reference Books:**

1. Robert A. Huggins; Energy Storage, Fundamentals, Materials and Applications
2. Kunihito Koumoto, Takao Mori; Thermoelectric Nanomaterials
3. Electrochemical Supercapacitors for Energy storage and delivery; Aiping Yu, Victor Chabot, and Jiujun Zhang.



| Code     | Course Title                     | T-P-Pj (Credit) | Prerequisite |
|----------|----------------------------------|-----------------|--------------|
| CUTM1400 | Bio and Biomimetic Nanomaterials | 3-0-1           | Nil          |

### Objective

- Gain knowledge about biomaterials, their properties, behavior, interaction and use of them over in pharmaceutical science.
- The emphasis of course is to understand the physics of biomaterials in detail and to explore the wide application.

### Learning outcome

- The students will obtain fundamental concepts of biomaterials and their biomedical applications.
- Able to use the knowledge for higher study and research
- Able to explore the possible physics research and their applications in society and health care units.

### Course outline

#### Module-I: Fundamentals (4 Hours Theory)

Definition of biomaterials, requirements & classification of biomaterials, Properties of biomaterials

#### Module-II: Metallic Implant Materials (5 Hours Theory+ 2 Hours Assignment)

Stainless steel, Co-based alloys, Ti and Ti-based alloys. Importance of stress-corrosion cracking.

**Assignment-1:** Orthopedic implants

#### Module-III: Polymeric Implant Materials (5 Hours Theory+ 2 Hours Assignment)

Classification according to thermosets, thermoplastics and elastomers. Importance of molecular structure, hydrophilic and hydrophobic surface properties, Biodegradable polymers for medical purposes

**Assignment-2:** Dental implants

#### Module-IV: Ceramic Implant Materials (5 Hours Theory+ 2 Hours Assignment)



Definition of bioceramics, common types of bioceramics, the importance of wear resistance and low fracture toughness

**Assignment-3:** Soft tissue replacement implants

**Module-V: Biocompatibility & Toxicological Screening of Biomaterials (5 Hours Theory+ 2 Hours Assignment)**

Biocompatibility & toxicological screening of biomaterials

**Assignment-4:** Percutaneous and skin implants

**Module-VI: Biomimetic (3 Hours Theory+ 2 Hours Assignment)**

Inspiration from animals, self-healing materials

**Assignment-5:** Vascular implants

**Module-VII Biomimetic in Photonics (3 Hours Theory+ 2 Hours Assignment)**

Biomimetic in photonics, various applications of Biomimetic

**Assignment-6:** Heart valve implants

**Total theory 32 hours and total project 12 hours**

**Text Books:**

1. Biomimetic Biomaterials Structure and Applications

By Andrew Ruys, ISBN: 9780857094162

2. Biomimetics in Photonics

By Olaf Karthaus, ISBN 9781439877463



| Code      | Course Title                              | T-P-Pj<br>(Credit) | Prerequisite                                               |
|-----------|-------------------------------------------|--------------------|------------------------------------------------------------|
| CUTM 1401 | Photo-Voltaic Technology & Nano-Catalysis | 3-1-0              | Basics of Nanomaterials & Physics of Semiconductor Devices |

### Objective

- This course will educate students on the design, working of photo voltaic technology and use of materials in nanoscale in these photovoltaics.
- This course will provide the study of several types of nanocatalysts for various industrial applications.

### Learning outcome

- The students will be able to obtain adequate knowledge regarding several photovoltaic technologies and its various applications in nano-scale.
- The students will be able to gain significant knowledge about industrial catalytic processes and catalysts at nano-levels which helps them to apply for several industrial applications and help them for higher research and employability.
- The course will help the students to apply for various internship opportunities available in various Photovoltaic start-up organizations. Also this course is a boost for the students to apply into various R&D organizations to work as a project scholar.

### Course outline

#### Module I (4 Hours Theory + 4 Hours Practice)

Electro-Magnetic visible spectrum, Optical absorption, Direct bandgap & indirect bandgap semiconductors, Minority carrier transport properties

**Practice 1:** To calculate the sun position at a given place and time and thereby study the variation in power production in a solar photovoltaic panel with respect to the change in incidence angle.

**Practice 2:** Learn how to assess the solar energy potential of a site

#### Module II (4 Hours Theory + 8 Hours Practice)

Surface and interface recombination; PN junctions and transport of charge carriers; Solar cell parameters; Photo current & spectral responses; Types of different generation of PV systems: 1st, 2nd, 3rd generation PV systems

**Practice 3 :** Find the GHI using the pyranometer data and assess the feasibility of a solar PV station in the area

**Practice 4:** Learn how to assess the solar energy potential of a site using a pyr heliometer.



**Practice 5:** To measure the outlet and inlet temperatures of the parabolic trough collector as a function of angle of incidence of solar radiation.

**Practice 6:** To measure the outlet and inlet temperatures and flow rate of the parabolic trough collector as a function of flow rate variation.

**Module III**

**(4 Hours Theory)**

Si photovoltaics; Thin film solar cell production; Nano coating on photovoltaics; ;CdTe PV systems

**Module IV**

**(6 Hours Theory)**

CIGs PV Systems; Dye-sensitized solar cell; III-V multi junction solar cells; Organic solar cell; OPV working principles; Perovskite solar cell;

**Module V**

**(3 Hours Theory)**

Quantum dots based solar cells; Nanowire based solar cells; Carbon nanomaterials based solar cells,

**Module VI**

**(5 Hours Theory)**

Nano catalyst production; Use of graphene as nano catalytic applications; Artificial photosynthesis; CO<sub>2</sub> conversion;

**Module VII**

**(4 Hours Theory)**

Photocatalysis; Au nanoparticle as effective catalyst; Hydrogen production using nanocatalyst, Nano titanium oxide as photocatalyst.

**Total theory 30 hours and total practice 12 hours**

**Reference Books:**

- Solar Energy: The physics and engineering of photovoltaic conversion, technologies and systems; Olindo Isabella, Klaus Jäger, Arno Smets, René van Swaaij, Miro Zeman.
- Nanomaterials in catalysis; Philippe Serp, KarinePhilippot.



| Code     | Course Title                         | T-P-Pj<br>(Credit) | Prerequisite |
|----------|--------------------------------------|--------------------|--------------|
| CUTM1402 | Advanced Characterization Techniques | 3-1-0              | Nil          |

### Objective

- The objective of the subject is that the student acquires knowledge of the different existing experimental techniques for the microstructural and physicochemical characterizations of materials.
- Students gain knowledge about the principles of various techniques.

### Learning outcome

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

- Depending on the problem or needs of each case, the student must have sufficient criteria to select the most appropriate technique, as well as the interpretation of their results.
- The knowledge gained from this subject definitely help students to optimize material research and and make ready them for higher R &D and enhance their technical knowledge for employability in handling different advanced characterization techniques.

### Course outline

#### Module-I Practice)

(3 Hours Theory+4 Hours

#### Compositional and Structural Characterization

Principle of X-ray diffraction (XRD), Importance of Rietveld refinement in XRD (fundamental), Lattice parameters, Structure analysis, Phase identification, Crystallite size analysis using Scherrer's formula, X-ray photoelectron spectroscopy (XPS), X-ray fluorescence (XRF), Energy dispersive X-ray analysis (EDAX).

#### Practice-1

Crystal structure and phase identification determination by XRD (Biovia MS and phase identification by using relevant software)

#### Practice-2

Study on molecular spectroscopy by fluorescence instrument

#### Module-II

(5 Hours Theory)

#### Advanced Microscopy Techniques for Nanomaterials





Field emission scanning electron microscope (FESEM), Atomic force microscopy (AFM), Scanning tunneling microscopy (STM), Transmission electron microscopy (TEM), High-resolution transmission electron microscopy (HRTEM).

**Module-III (5 Hours Theory+4 Hours Practice)**

**Spectroscopic Techniques**

Ultraviolet-visible spectroscopy, Photo-luminescence spectroscopy, Fourier transform infrared (FTIR) spectroscopy, Raman spectroscopy, Nuclear magnetic resonance (NMR).

**Practice-3**

Familiarization with the ultraviolet-visible absorption spectroscopy

**Practice-4**

Band gap calculation from photo-luminescence spectra

**Module-IV (4 Hours Theory)**

**Nanomaterials Electrical and Magnetic Characterization Techniques**

Measurement of resistivity by 4-probe method, Hall measurement, Measurement of magnetic properties of nanomaterial (Magnetic hysteresis and dielectric properties by LCR meter), Vibrating sample magnetometer.

**Module-V (5 Hours Theory+4 Hours Practice)**

**Mechanical Characterization Techniques**

Elastic and plastic deformation-mechanical properties of materials, models for interpretation of nanoindentation load-displacement curves, Nanoindentation data analysis methods-Hardness testing of thin films and coatings, Mechanical properties evaluation by universal testing machine (UTM), Dynamic mechanical analysis.

**Practice-5**

Evaluation of mechanical properties of material by nanoindentation technique

**Practice-6**

Measurement of tensile strength of material by UTM

**Module-VI (4 Hours Theory)**

**Physical and Optical Characterizations of Nanostructured Materials**

Introduction to particle size characterization, Zeta potential measurement – Particle size analysis, specific surface area by BET analysis, Photoconductivity.

**Module-VII (4 Hours Theory)**

**Thermal and Electrochemical Characterization**

Differential scanning calorimeter (DSC), Differential thermal analyzer (DTA), Thermogravimetric analysis (TGA), Electrochemical analysis (Charging-discharging cyclic voltammetry).

**Total theory 30 hours and total practice 12 hours**

**Reference Books:**

1. ASM Handbook: Materials Characterization, ASM International, 2008.



2. Yang Leng: Materials Characterization-Introduction to Microscopic and Spectroscopic Methods, John Wiley & Sons (Asia) Pte Ltd., 2008.
3. Robert F. Speyer: Thermal Analysis of Materials, Marcel Dekker Inc., New York, 1994.
4. Nanotechnology-Basic Science and Emerging Technologies, Mick Wilson, KamaliKannangra Geoff Smith, Michelle Simons and BurkhardRaguse, Overseas Press.

| Code     | Course Title                   | T-P-Pj (Credit) | Prerequisite |
|----------|--------------------------------|-----------------|--------------|
| CUTM1403 | Smart and Electronic Materials | 3-0-1           | Nil          |

### Objective

- To acquaint with various kinds of smart materials for device application
- To have the knowledge about the different types of structure of the materials which affect their properties
- To understanding the theories behind electric and magnetic properties
- To use the nanotechnology in electronics
- Application of different kinds of materials

### Learning outcome

- Students will capable of gaining the knowledge about different kinds of materials
- Students may aware about the structure property relation of materials
- Students may know the use of materials with response to external stimuli

### Course outline

#### Module I (4 Hours Theory+2 Hours Assignment)

**Introduction: Overview** of smart materials, Sensors and actuators, Pyroelectrics, Piezoelectrics, Electrostrictors, Magnetostrictors, Electrochromic, Shape memory alloys

#### Assignment-1

Application of high-k dielectric materials and Topological insulators

#### Module II (4 Hours Theory+ 2 Hours Assignment)

**Structure Property Relation:** Structure phase transition of different types of materials and their properties such as Perovskite structure materials, Tungsten Bronze, Aurivillius structure materials,

#### Assignment-2

Electrical properties of Pyrochloro-type Materials and hexaferrite materials

#### Module III (4 Hours Theory+ 2 Hours Assignment)



**Multiferroic and Magneto electric Materials:** Multiferroic materials, Ferroelectric materials, Ferromagnetic materials, Ferroelastic materials, requirement for multiferroic materials. Magnetoelectric material and ME coefficient

**Assignment-3**

Origin of magnetism, Ferro-, Antiferro-, Ferri-magnetic materials and their application

**Module IV**

**(5 Hours Theory)**

**Nanoelectroinc:** Overview of nano electronics, Quantum dots, Quantum wire and Quantum well, 2D Materials: Graphene

**Module V**

**(4 Hours Theory+ 2 Hours Assignment)**

**Spintronics:** Introduction to spintronics, Generation of Spin Polarization, Theories of spin Injection, Spin accumulation, spin relaxation, Spin current, Spin hall effect and spin dephasing,

**Assignment-4**

Spintronic devices and applications

**Module VI**

**(4 Hours Theory+ 2 Hours Assignment)**

**High Temperature Superconductor: Discovery** and experimental facts of superconductor, High TC superconductors, High-Tc Superconducting Oxides: Structure, properties, comparison on the basis of BCS Theory, Structure and properties of Iron based High temperature superconductor

**Assignment-5**

Structure, properties and application of Hg and Fe based High temperature superconductor

**Module VII**

**(5 Hours Theory+2 Hours Assignment)**

**Application:** Sensors (conductive sensor, capacitive sensor), Optoelectronics, Supercapacitors, Radiofrequency identification

**Assignment-6**

Development of solar energy devices, silicon solar technology for clean energy

**Total theory 30 hours and total assignment 12 hours**

**Textbook:**

**Reference Books:**

4. Dielectric Phenomena in Solids by Kwan Chi Kao, Academic Press, 2004



5. High Temperature Superconductivity: The Road to Higher Critical Temperature by Shin-ichi Uchida, Springer Japan 2015

| Code         | Course Title                                | T-P-Pj (Credit) | Prerequisite |
|--------------|---------------------------------------------|-----------------|--------------|
| CUTM<br>1404 | Corrosion and advanced coating applications | 3-0-1           | Nil          |

### Objective

- To impart knowledge on surface coating and engineering of nanomaterials and their applications.
- Role of surface coating and surface modification technologies in obtaining required surface characteristics (mechanical, chemical, thermal, electrical, electronic, optical) of a product.
- Learn about different surface coating technologies ( chemical vapour deposition, physical vapour deposition, electro-deposition, thermal spray, etc).
- Substrate technology and its significance in obtaining high performance coating. Various methods for evaluating the performance of the coating.

### Learning outcome

- Student can able to understand the knowledge on surface coating and engineering.
- Able to do surface coating and surface modification for different practical application.
- Able to pursue higher study/research on surface technology.
- Able to understand different surface coating technologies and their application.
- Able to use nano technology on surface coating for practical application

### Course outline

#### Module I (4 Hours Theory+2 Hours Assignment)

**Introduction to surface engineering fundamentals:** Introduction to surface science, Surface degradation, corrosion, importance of corrosion, Corrosion studies: Atmospheric, Galvanic, Pitting, Crevice corrosion, Intergranular corrosion, Stress corrosion & cracking

#### Assignment-1

Corrosion effects on degrading the properties of materials

#### Module II

(4 Hours Theory+ 2 Hours Assignment)



**Surface preparation methods:** Surface cleaning and finishing processes, Electrochemical, Mechanical- Sand blasting, Hydroblasting, Vapor phase degreasing

**Assignment-2**

Surface preparation for advanced coating applications

**Module III**

**(5 Hours Theory+ 4 Hours Assignment)**

**Advanced coating practices:** Cold spray, Sputter deposition, Electrolysis techniques, Physical vapor deposition(PVD), Chemical Vapor deposition (CVD), Carburising, Aluminizing

**Assignment-3**

Current and advanced coating technologies for industrial applications

**Assignment-4**

Coating surface characterization techniques

**Module IV**

**(3 Hours Theory)**

**Plasma coating:** Plasma deposition, Sputtering, Plasma spray mechanisms & applications, Laser processing.

**Module V**

**(5 Hours Theory+ 2 Hours Assignment)**

**Characterization of coating:** Physical characterization and porosity, Assessment of coating hardness, Assessment of friction and wear of coating, Assessment of surface roughness and thickness of Coating, Assessment of Adhesion of coating

**Assignment-5**

Coating for wear resistant applications

**Module VI**

**(4 Hours Theory+2 Hours Assignment)**

**Application-I :**Wear resistant coating. Thermal barrier coating, CVD Diamond coated tool, Biomedical coatings

**Assignment-6**

Advanced coating applications

**Module VII**

**(5 Hours Theory)**

**Application-II:** Super hydrophobic application, Coating in semiconductor, Zinc coating, Coating for marine atmosphere,Antireflective Coating

**Total theory 30 hours and total Assignment 12 hours**

**Text Book:**



1. Advanced Coating Materials book Online ISBN:9781119407652  
|DOI:10.1002/978111940765
2. Advanced Surface Coating Techniques for Modern Industrial Applications  
by Supriyo Roy (Haldia Institute of Technology, India) and Goutam Kumar Bose  
(Haldia Institute of Technology, India)

### References:

1. <https://nptel.ac.in/courses/112/105/112105053/>
2. <https://link.springer.com/book/10.1007%2F978-94-017-0631-5>
3. [http://home.ufam.edu.br/berti/nanomateriais/8403\\_PDF\\_CH13.pdf](http://home.ufam.edu.br/berti/nanomateriais/8403_PDF_CH13.pdf)
4. <https://www.azom.com/article.aspx?ArticleID=17081>
5. <https://www.hindawi.com/journals/ijc/2018/4749501/>



| Code      | Course Title                                | T-P-Pj (Credit) | Prerequisite |
|-----------|---------------------------------------------|-----------------|--------------|
| CUTM 1405 | Synthesis and Application of Nanocomposites | 3-1-0           |              |

### Course Objectives

- To provide knowledge of the advantages of using different types of nanocomposites.
- To make the students familiar with the mechanism of nanocomposites.
- To make them aware the manufacturing and testing methods of nanocomposites.

### Learning outcome

- Students will understand and appreciate the significance of the nanocomposites as an important class of materials.
- Students will be well equipped to design and develop nanocomposites for specialized applications.
- They will be able to predict the appropriate synthesis and application for different classes of nanocomposites
- This course will develop the career competency of students in composite materials and help them in joining R & D and industry based composite sector.

### Course content

#### Module-I: Introduction to Nanocomposite Materials(5 Hours Theory)

Definition of nanocomposites, Classification based on matrix and topology, Constituent of nanocomposites, General characteristics of particle reinforced composites- classification, Terminology used in fiber reinforced composites, Core-Shell nanocomposites

#### Module-II: Basic Constituents materials in Nanocomposites (4 Hours Theory)

Role and Selection of reinforcement materials, Glass fibers, Carbon fibers, Boron Fibers, Natural fibers, Multiphase fibers, Aramid fibers

#### Module-III: Fabrication of various types Nanocomposites(5 Hours Theory)

Ceramic/Metal nanocomposite Systems, Nanocomposites based on polymer matrix, Carbon carbon, Carbon-metal nanocomposites, Bio-inspired nanocomposites

#### Module -IV: Nanocomposite Processing Methods (4 Hours Theory+4 Hours Practice)



Nanocomposite processing: In-situ polymerization technique, Solution casting, Electro spinning, melt mixing, Filament Winding, Injection and compression molding, Vacuum bag moulding Method, Pultrusion Process

**Practice 1:** Synthesis of polymer nanocomposite using solution casting techniques

**Practice 2:** Preparation of different polymer blends using BIOVIA materials studio

**Practice 3:** Fabrication of nanocomposite fibers using electro spinning technique

#### **Module -V: Mechanical Properties -Stiffness and Strength (4 Hours Theory)**

Geometrical aspects – volume and weight fraction, Unidirectional continuous fiber, Determination of stiffness and strengths of unidirectional composites, tension, compression, flexure and shear

#### **Module -VI: Application of Nanocomposites I (4 Hours Theory+4 Hours Practice)**

Application of Nanocomposites in Aerospace, Coating, Mechanical, Electrical & Electronics, Fuel cell

**Practice 4:** Determination of tensile properties of nanocomposite

**Practice 5:** Determination of Dielectric constant for a given nanocomposite material

#### **Module -VII: Applications of Nanocomposites II (4 Hours Theory+4 Hours Practice)**

Hybrid Nanocomposite materials for food packaging, graphene-carbon nanotube nanocomposite for energy storage applications, Nanocomposites for solar cells, Nano composite materials for Lithium ion battery.

**Practice 6:** Synthesis of Graphene Oxide by Modified Hummer's Technique

**Practice 7:** Studies on Dye Sensitized Solar Cell

#### **Text Books:**

- Composite Polymeric Materials – Sheldon
- Lubin - Handbook of composites – (Van Nostrand, 1982)
- Carbon Nanotube and Graphene Device Physics, by H.-S. Philip Wong (Author), DejiAkinwande (Author)
- K. Chawla, Composite Materials – Science &Engg., Springer- Veslag, New York, 1988.
- Mohr - SPIE Handbook of Technology and Engineering of Reinforced Plastics/Composites – (Van Nostrand, 1998)





| Code     | Course Title                                | T-P-Pj (Credit) | Prerequisite |
|----------|---------------------------------------------|-----------------|--------------|
| CUTM1406 | <b>Material Behavior of Nanostructures.</b> | 3-1-0           | Nil          |

### Course Objective:

To understand the influence of dimensionality of the object at nanoscale on their properties;

- To study size and shape controlled synthesis of nanomaterials and their future applications in industry.
- To bring out the distinct properties like mechanical, magnetic, thermal, electronic, optical, and photonic properties of nanostructures.

### Learning Outcomes:

Upon successful completion of this course student should be able to:

- To familiarize about the various properties of nanostructures.
- To bring out the differences between nano and macro structures.
- To discuss applications and specific properties of nanomaterials.

### Course outline

#### Module-I(3 Hours Theory)

**Introduction:** Peculiarities of nanostructured materials: Introduction, Extended internal surface, Increasing of surface energy and tension, Grain boundaries, Instability of three dimensional nanostructured materials due to grain growth, Size effects in nanostructured materials.

#### Module -II (5 Hours Theory+ 2 Hours Practice)

**Mechanical Properties:** Mechanical properties of nanocrystalline metals and alloys, Inverse Hall Petch effect, Strain-rate sensitivity, Ceramics and composites. Types of indentation:



Oliver & Pharr, Vickers indentation process, Nano Indentation by Atomic Force Microscope , Young's modulus, Contact angle.

**Practice-1** :Strength vs ductility of steel bar

### **Module -III (5 Hours Theory+2 Hours Practice)**

**Thermal Properties of Nanostructures:** Thermo electric materials (TEM): Concept of phonon, Thermal conductivity, Specific heat, Exothermic & endothermic processes. Bulk TEM properties, Different types of TEM; One dimensional TEM; Composite TEM; Applications.

**Practice-2:** Thermal conductivity measurement

### **Module-IV(4 Hours Theory+4 Hours Practice).**

**Magnetic Properties:** Introduction of magnetic materials, basics of ferromagnetism – ferro magnetic resonance and relaxation, Magnetic properties of bulk nanostructures, Magnetic clusters, Dynamics of nanomagnets, Nanopore containment of magnetic particles, Nano carbon ferromagnets, Ferrofluids.

**Practice-3:** Exploring magnetic nanoparticles with Diana Borca

**Practice -4:** B -H curve of ferromagnetic material

### **Module-V(5 Hours Theory+ 2 Hours Practice)**

**Electronic Properties :** Energy bands and gaps in semiconductors, Fermi surfaces , Localized particle, Donors, Acceptors, Deep traps, Excitons, Mobility, Size dependent effects, Conduction electrons and dimensionality Fermi gas and density of states, Semiconducting nano particles , Direct and reciprocal lattices of the fcc structure.

**Practice-5:** Determination of band gap energy of semiconductor.

### **Module-VI(4 Hours Theory+ 2 Hours Practice)**

**Optical Properties:** Optical properties , Photonic crystals, Defects in photonic crystals , Optical properties of semiconductors, Band edge energy, Band gap, Dependence on nanocrystallins size, Quantum dots, Optical transitions, Absorptions, Interband transitions.

**Practice- 6:** Explanation of surface plasmon resonance.

### **Module -VII (4 Hours Theory).**



**Luminescence Properties:** Fluorescence/luminescence, Photoluminescence / fluorescence, Optically excited emission Electroluminescence, Laser emission of quantum dot, Photo fragmentation and columbic explosion, Phonons in nanostructures, Luminescent quantum dots for biological labeling.

**Total theory 30 hours and total practice 12 hours.**

**Text books:**

1. Introduction to Nano Technology by Charles. P. Poole Jr& Frank J. Owens. Wiley India Ltd.
2. Solid State physics by Pillai, Wiley Eastern Ltd.

**Reference Books:**

1. Processing & properties of structural naonmaterials -Leon L. Shaw (editor)
2. Nanoscale materials -Liz Marzan and Kamat



| Code     | Course Title       | T-P-Pj (Credit) | Prerequisite |
|----------|--------------------|-----------------|--------------|
| CUTM1407 | Emerging Materials | 3-0-1           | Nil          |

### Objective

- Efficient to understand materials and materials properties
- Develop their confidence on self driven experimental materials research
- Able to work in research and industrial set up on material research
- Understanding of materials behavior, or conceived, designed, and realized useful products and technology

### Learning outcome

- Students will be able to describe the structure of emerging materials at the molecular, microscopic, and macroscopic scales.
- To acquaint the student with common manufacturing processes and recent technological developments that are used in creating products.
- To promote an understanding of the relationship between material structure, processing and properties.

### Course outline

#### Module I (4 Hours Theory)

**Classification of Materials:** Classification of materials: Conductor, Semiconductor, Insulator, Superconductor, Ceramics

#### Module II (4 Hours Theory+ 2 Hours Assignment)

**Carbon Nano science :** Carbon allotropes(Basic), new carbon structures, Carbon Nanotube (CNT), Single Wall Carbon Nanotubes (SWCNT), Multi Wall Carbon Nanotubes (MWCNT), Carbon fiber

#### Assignment-1

Advanced Carbon Materials and Technology

#### Module III (5 Hours Theory+ 2 Hours Assignment)



**Graphene Science:** Introduction of Graphene, Graphene Reinforced Metal (aluminum) composites, From a Graphene Sheet to a Nanotube -Achiral and Chiral Nanotubes, Graphene Reinforced Non-Metal (aluminum oxide) composites

**Assignment-3**

Graphene for industrial applications

**Module IV**

**(5 Hours Theory+ 2 Hours Assignment)**

**Synthesis Techniques:** CNT: Arc discharge, Laser ablation, Chemical vapour deposition; Graphene: Mechanical exfoliation, Hummers' method, Chemical vapour deposition

**Assignment-3**

Method of preparation of Graphene

**Module V**

**(4 Hours Theory+ 2 Hours Assignment)**

**Properties of Carbon Nanotubes and Graphene:** Mechanical, Electronic, and Optical properties of Carbon Nanotubes and Graphene; Raman spectroscopy of carbon nanotubes, Absorption spectroscopy of carbon nanotubes and Transmission Electron Microscopic (TEM) of carbon nanotubes.

**Assignment-4**

Study of the XRD of CNT through experimental/MS Studio

**Module VI**

**(4 Hours Theory+ 2 Hours Assignment)**

Application of nanostructure graphene: carbon material for energy storage, hydrogen storage in carbon nanotubes, Role of carbon nano-tubes in Li ion battery (electrodes), Supercapacitor

**Assignment-5**

Application of CNT and Graphene in developing advanced electrodes used in Li ion battery

**Module VII**

**(4 Hours Theory+2 Hours Assignment)**

Other Advanced Materials: High-temperature material, Bulletproof, material Amorphous Materials, Nano Quasicrystals

**Assignment-6**

Material for high temperature and bulletproof applications

**Total theory 30 hours and total project 12 hours**

**Textbook:**

1. .

**Reference Books:**



| Code     | Course Title                       | T-P-Pj (Credit) | Prerequisite |
|----------|------------------------------------|-----------------|--------------|
| CUTM1408 | Synthesis Routes of Nanomaterials. | 3-1-0           | Nil          |

### Course Objective:

- To equip the students with the concepts of synthesis routes in nanoscience that he/she needs for understanding theoretical treatment in different courses taught in this class and for developing a strong background to pursue research in Nanotechnology as a career.
- This course is intended to cover the two groups of synthesis of nanostructures namely top-down and bottom-up approach various synthesis methods, including biological methods, advantages and disadvantages etc.

### Learning Outcomes:

- The students will be exposed to various structure specific synthesis methods, their advantages etc.
- To know about Top-down to Bottom up approach techniques.
- To optimize the methods for specific material applications.

### Course outline

#### Module-I

(4 Hours Theory)

**Introduction :** Introduction to synthesis of nanostructure materials, Bottom-up approach and Top-down approach with examples-Trapped particles-quantum dots and artificial



atoms-quantum wires and quantum wells. Conductivity and enhanced catalytic activity compared to the same materials in the macroscopic state.

**Module-II (5 Hours Theory+ 2 Hours Practice)**

**Physical Methods:** Inert gas condensation, RF-plasma, MW plasma, Ion sputtering, Laser ablation, Laser pyrolysis, Ball milling, Molecular beam epitaxy, Electro-deposition.

**Practice-1:** Ball-milling method of synthesis of nanomaterials.

**Module -III (4 Hours Theory)**

**Chemical Methods (I):** Chemical precipitation and co-precipitation, Sol-Gel synthesis; Microemulsions synthesis, Hydrothermal, Solvothermal synthesis methods.

**Module - IV (4 Hours Theory)**

**Chemical Methods (II):** Microwave assisted synthesis Core-Shell nanostructure, Quantum dot (QDs) synthesis, Sonochemical, Ultraviolet, Sonication

**Module-V (6 Hours Theory)**

**Thermolysis Route:** Flame spray pyrolysis, Flame spray Hydrolysis, solvated metal atom dispersion, hydrothermal routes, solution combustion synthesis, reaction types, boundaries and flow, PVD, CVD.

**Module VI: (2 Hours Theory+ 2 Hours Practice)**

**Different Lithography Route:** M based nanolithography and nanomanipulation, E beam lithography and SEM based nanolithography and nanomanipulation, Ion beam lithography, X-ray based lithography.

**Practice 2:** Electron beam lithography.

**Module VII (5 Hours Theory+ 8 Hours Practice)**

**Preparation of Some Special Nanomaterials:** Preparation of metal nano particles like gold, silver, Iron and Copper, different types of nanooxides, TiO<sub>2</sub>, ZnO etc.

**Practice-3:** Synthesis of TiO<sub>2</sub> nanotubes by hydrothermal method.

**Practice-4:** Synthesis of copper nanoparticles.



**Practice-5:** Synthesis of gold nano particles.

**Practice-6:** Synthesis of ZnO nano particles by sol-gel route.

**Total theory 30 hours and total practice 12 hours.**

**Text Books:**

1. Inorganic Materials Synthesis and Fabrication by J.N. Lalena, D.A. Cleary, E.E. Carpenter, N.F. Dean, John Wiley & Sons Inc.
2. Introduction to Nano Technology by Charles P. Poole Jr and Frank J. Owens. Wiley India PvtLtd.
3. The Chemistry of nanomaterials: Synthesis, Properties and Applications, Vol-I by C.N.R. Rao, A. Muller and A.K. Cheetham.
4. Fabrication of fine pitch gratings by holography, electron beam lithography and nano-imprint lithography (Proceedings Paper) Author(s): Darren Goodchild; Alexei Bogdanov; Simon Wingar; Bill Benyon; NakKim; Frank Shepherd.

**Reference Books:**

1. Encyclopedia of Nanotechnology by M.Balakrishna Rao and K.Krishna Reddy, Vol I to X,
2. Encyclopedia of Nanotechnology by H.S. Nalwa
3. Nano: The Essentials – Understanding Nano Science and Nanotechnology – by T.Pradeep; Tata Mc.Graw Hill
4. Handbook of chemical Vapor deposition (cvd), Principles, technology, and applications, By Hugh o. Pierson, Second edition, Noyes publications, William Andrew Publishing, LLC.





| Code     | Course Title                    | T-P-Pj (Credit) | Prerequisite |
|----------|---------------------------------|-----------------|--------------|
| CUTM1409 | Computational Materials Science | 2-2-0           | Nil          |

### Objective

- Expose the students to the challenges in the analyses of materials and how to address those challenges
- Impart practice of developing Toy Models of Molecular Dynamics, HartreeFock and Density Functional Theory in Python for small scale systems using various Pseudo-Potentials
- Hands-on training on open source tools in Molecular Dynamics (LAMMPS) and Hartree-Fock and Density Functional Theory (Quantum Espresso); Data Visualization Tools like OVITO and VMD

### Learning outcome

A student who completes this course should be able to:

- Get an idea of the issues and challenges involved in calculations of atomic, molecular and bulk properties of materials and how to approach their resolution using open source classical and quantum mechanical tools.
- Code and execute concepts of Molecular Dynamics, Monte Carlo Methods in Molecular Dynamics and derive thermodynamic properties of materials ensuing from Classical Statistical Mechanics
- Code and execute concepts of HartreeFock Theory and Density Functional Theory using Python and derive various molecular and bulk material properties ensuing from electronic structure calculations involving Quantum Mechanics and Quantum Statistics
- Use open source software like LAMMPS, Quantum Espresso, OVITO and VMD for analysis and visualization of various types of materials and their properties



## Course outline

### **Module I** **(2 Hours Theory + 3 hours Practice)**

**Models of Molecular Interactions:** Model Van der Waals interaction potentials between neutral atoms and molecules: The Lennard-Jones potential, Other Van der Waals Interactions: the Buckingham Potential, the Stockmayer Potential

#### **Practice (1 hour sessions):**

1. Understanding the Lennard-Jones (LJ) Potential and its Parameters
2. Python simulation of Equation of State of Ideal Gases using LJ Interaction
3. Python simulations of Equation of State of Ideal Gases with Buckingham and Stockmayer Potentials

### **Module II** **(3 Hours theory + 4 hours Practice)**

**Molecular Dynamics**  
Molecular Dynamics theory and numerical implementation, Statistical Ensembles and Molecular Dynamics, Diffusion and Osmosis.

#### **Practice (1 hour sessions):**

4. Thermodynamics of a Real Gas using LJ potential using Python
5. Introduction to Molecular Dynamics in LAMMPS; Visualization using OVITO & VMD
6. Simulation of Diffusion in LAMMPS
7. Simulation of Osmosis using LAMMPS

### **Module III** **(6 Hours Theory + 5 Hours Practice)**

**Monte Carlo Methods**  
Monte Carlo Simulations, Metropolis algorithm, 2D Ising Model and its simulation, Phase Transitions, Monte Carlo Grand Canonical (MCGC) simulation of Lennard Jones (LJ) Fluid Flow and Heat Transfer

#### **Practice (1 hour sessions):**

8. Introduction to Monte-Carlo-Metropolis Algorithm: Python Implementation
9. Simulation of 2D-Ising Model using Monte-Carlo-Metropolis algorithm
10. Simulation of Phase Transitions Using LAMMPS
11. Simulation of Lennard-Jones (LJ) Fluid Flow Using LAMMPS
12. Thermal Conductivity and Viscosity simulation using LAMMPS

### **Module IV** **(3 Hours Theory+4 Hours Lab)**

**HartreeFock Methods:**  
The Variational Principle, The Hartree Approximation, The Hartree-Fock Approximation, Electron Density Distribution in Many-Electron atoms and simple Di-atomic molecules, Beyond HF Theory: Coupled Cluster Approximation

#### **Practice: (1 hour)**



13. Introduction to HartreeFock Implementation in Python
14. Creation of data files and running the HF code
15. Electron Density Distribution in H, He, Li atoms
16. Electron Density Distribution in simple diatomic molecules: H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, CO

### **Module V**

#### **Density Functional Theory-I**

**(2 Hours Theory)**

Introduction to Density Functional Theory, The Hohenberg-Kohn Theorems, The Kohn-Sham Theory, Numerical Implementation

### **Module VI**

#### **Extensions of Density Functional Theory**

**(2 Hours Theory)**

The Local Density Approximation (LDA), The Generalized Gradient Approximation (GGA), Meta GGA, Adiabatic Connections-Hybrid Orbitals, Perdew-Burke-Ernzerhof (PBE) Approximation, the Born-Oppenheimer Molecular Dynamics (BOMD), the Car-Parrinello Molecular Dynamics (CPMD)

### **Module VII**

**(2 Hours Theory+8 Hours Practice)**

Introduction to Quantum Espresso: Modules and Possibilities

#### **Practice (1 hour sessions)**

17. Introduction to Quantum Espresso software: Implementation of DFT
18. Loading Data Files and Execution of Quantum Espresso; Interpretation of Output
19. Ground State Electron Density Distributions in C, N, O using LDA
20. Ground State Electron Density Distribution in C, N, O, Si using GGA, Meta GGA, PBE
21. Ground State Properties of Simple Molecules like N<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub>O, CO<sub>2</sub>
22. Material Property Simulations in DFT with LDA/GGA/Meta GGA/PBE and their various combinations
23. Liquid-Gas Phase Transition Simulations in Born-Oppenheimer Molecular Dynamics
24. Liquid-Gas Phase Transition Simulations in Car-Parrinello Molecular Dynamics

**Total theory 20 hours and total practice 24 hours**

#### **Textbook:**

2. Introduction to Computational Materials Science, Richard LeSar, (Cambridge University Press, 2016).
3. Modern Quantum Chemistry: Introduction to Advanced Electronic Structure Theory. Attila Szabo, Neil S Ostlund. (Dover Publications Inc. 1996)



### Reference Books:

Computational Materials Science: An Introduction. June Gunn Lee, (CRC Press, 2011).

| Code     | Course Title      | T-P-Pj (Credit) | Prerequisite |
|----------|-------------------|-----------------|--------------|
| CUTM1410 | Plasma Technology | 3-0-1           | Nil          |

### Objective

- To explore the fourth state of matter, Plasma.
- To understand fundamental characteristics of plasma, various plasma generation methods, various applications of plasma technology in nanomaterial synthesis, energy production and storage, medicine/health care, etc.



- To acquire comprehensive knowledge of how plasmas are utilized for different types of materials processing specially in nanotechnology and developing advanced materials

### **Learning outcome**

- Upon successful completion of this course the student should be able to
- Learn using fundamental plasma parameters, under what conditions an ionised gas consisting of charged particles (electrons and ions) can be treated as a plasma to set feasible criteria on the plasma-assisted processes.
- Assess relations between the process and properties of the treated surface and/or material.
- Assess suitability of individual kinds of plasma for application in materials and surface engineering, nanomaterial production applications and in environmental technologies.
- Understand application of plasma technology for eco-friendly future "green" energy.

### **Course outline**

#### **Module-I**

**(5 Hours Theory)**

##### **Fundamentals of Plasma Physics**

Plasma-the fourth state of matter, Plasma parameters, Debye length, Plasma sheath, Plasma oscillations & frequency, Saha's theory of thermal ionization, Concept about plasma equilibrium and types of plasma (only classification), Plasma classification on basis of temperature and pressure (only fundamental)

#### **Module-II**

**(6 Hours Theory+ 2 Hours Assignment)**

##### **Plasma Production Techniques**

DC discharges, Glow discharge, I-V characteristic of electrical discharge, Paschen curve, Arc discharge, Transferred and non-transferred arcs, RF discharge, Capacitively and inductively coupled plasmas, Microwave discharge, Vacuum arcs

##### **Assignment-1**

Gases break-down, Paschen Curves, Advanced plasma generation techniques

#### **Module-III**

**(3 Hours Theory+ 2 Hours Assignment)**

##### **Plasma Diagnostics**

Basic plasma diagnostics: electric probes (single and double), Optical emission spectroscopy (basic idea), Laser based diagnostics

##### **Assignment-2**

Plasma diagnostic for understanding the basic plasma

#### **Module-IV**

**(4 Hours Theory+ 2 Hours Assignment)**

##### **Plasma Etching, Spraying and Atomization processes**

Etching, Plasma cleaning, Surfactants removal, Non transferred plasma torches, Advanced plasma atomization process

##### **Assignment-3**

Advanced plasma atomization for nano material production



**Module-V (5 Hours Theory+ 2 Hours Assignment)**

**Plasma Sputtering Deposition Processes**

Introduction of thin film coatings by plasma, Plasma-Enhanced Chemical Vapor Deposition (PECVD), Physical vapor deposition (PVD), Pulsed laser deposition (PLD), Plasma nitriding

**Assignment-4**

Surface treatment and thin film coating by advanced plasma techniques

**Module-VI (4 Hours Theory+ 2 Hours Assignment)**

**Plasma Melting, Cutting and welding**

Arc plasma melting, Synthesis of nanomaterials ( $Al_2O_3$  and SiC) by plasma reactor/furnace, Plasma cutting, Plasma Welding

**Assignment-5**

Plasma cutting and welding

**Module-VII (3 Hours Theory+ 2 Hours Assignment)**

**Special Plasma Applications**

Controlled thermo-nuclear fusion: the green technology-Tokamaks (fundamental), Plasma waste processing (Plasma pyrolysis), Biomedical and health applications

**Assignment-6**

Plasma Technology: An emerging clean and green energy technology for future

**Total theory 30 hours and total assignment class 12 hours**

**Reference Books:**

1. Principles of Plasma Discharges and Materials Processing, M. A. Lieberman and A. J. Lichtenberg (John Wiley and Sons, 2005)
2. Introduction to Plasma Physics and Controlled Fusion, 3rd edition, Francis F. Chen, (Springer, 2018)
3. Plasma Technology, B. Gross, B. Greyz and K. Miklossy, (Ilfiffe Books Ltd., London, 1968).
4. Handbook of Advanced Plasma Processing Techniques, Eds. R.J. Shul and S.J. Pearton.
5. Fundamentals of Plasma Physics, J. A. Bittencourt, Springer-Verlag New York Inc., 2004.
6. Handbook of Plasma Processing Technology: Fundamental, Etching, Deposition and Surface Interactions, S. M. Rosnagel, J. J. Cuomo, W. D. Westwood, (Noyes Publications, 1990) SAP 4005 Plasma Processing of Materials.

| Code         | Course Title                      | T-P-Pj (Credit) | Prerequisite |
|--------------|-----------------------------------|-----------------|--------------|
| CUTM<br>1411 | Essentials<br>of<br>Nanomaterials | 3-1-0           | Nil          |

**Objective**

- Understand and use the properties of Nano-materials in diverse fields.
- Gain knowledge about the Nanomaterials, their properties, behavior, interaction and use of them over many discipline of science.



- The emphasis of the course is to understand the physics of Nanomaterials in detail and to explore the wide application.
- Highlights of the course is to provide virtual way of understanding the courses materials. Especially the application based approach.

### **Learning outcome**

- Understand the constituents of matter, Nanomaterials, properties and usefulness.
- Able to learn how to understand the basic behavior of Nanomaterials.
- Able to compete with International Student in Nanomaterial Sciences.
- Able to use the knowledge for higher study and research.
- Able to explore the possible physics research, their applications in society and health care unit.

### **Course outline**

#### **Module I**

**(4 Hours Theory)**

**Fundamentals of Nanomaterials:** Introduction to Nanomaterials, Definition of Nano, Atomic Structure and atomic size, significance of nano material over micro/macro, size dependent properties.

#### **Module II**

**(4 Hours Theory+ 2 Hours Practice)**

**Material structure and the Nano-surface:** Importance of surface at Nanoscale, Significance of Particle shape and Size in Nanomaterials, Surface to Volume Ratio, Particle orientation.

**Practice 1:** Polarization of light

#### **Module III**

**(5 Hours Theory+ 2 Hours Practice)**

**Energy at the Nanoscale:** Surface energy, surface energy of Liquids, surface energy of solids, Surface energy of crystallographic planes in fcc& bcc, surface energy minimization mechanism.

**Practice 2:** Surface tension of liquid

#### **Module IV**

**(6 Hours Theory+ 6 Hours Practice)**

**Nanostructured Materials :**Zero Dimensional: Nano particles through homogenous nucleation; Nano particles through heterogeneous nucleation, Quantum Dots; One Dimensional: Nano wires and nano rods, Two dimensional: Fundamentals of film growth; Carbon Nanotubes. hierarchical structure, Quantum size effect and scaling law

**Practice 3:** Particle/wave nature of particle

**Practice 4:** Quantum dot

**Practice 5:** Quantum tunneling

#### **Module V**

**(5 Hours Theory+ 2 Hours Practice)**



**Nano thermodynamics:** Classical equilibrium in thermodynamics, Nano Thermodynamics, Modern Nano Thermodynamics. hermodynamics of surfaces: surface and interfacial energy, uses of Wulff plot.

**Practice 6:** Seebeck effect

**Module VI**

**(5 Hours Theory)**

**Chemical interaction at the Nanoscale:** Long range and short range order forces, electrostatic forces, hydrogen bonding, Vanderwaal forces, hydrophobic forces

**Module VII**

**(7 Hours Theory)**

**Essentials of nanoscience in diverse Emerging area :**Nano-electromechanical systems, Nano sensors, Nano Optics, Nano-electronics, Nano medicine, environmental, health and safety issues.

**Total theory 36 hours and total practice 12 hours**

**Text Book:**

1. Introduction to nanoscience by G.Louis Hornyak
2. Introduction to nanotechnology by C. P. Poole

**References:**

1. NPTEL (Nano materials)
2. MIT (Nano material)

| Code     | Subject Name             | Type of course                                                           | T-P-P | Prerequisite |
|----------|--------------------------|--------------------------------------------------------------------------|-------|--------------|
| CUTM1412 | Advanced Quantum Physics | <ul style="list-style-type: none"> <li>• Theory &amp; Project</li> </ul> | 2-0-2 | Nil          |

**Objective**

- Learn methods to solve Schrodinger's equation by WKB method, Variational method and perturbation method.





- Learn Practical application of these methods to real time problems
- Learn to apply these methods to solve several problems.

### **Learning outcome**

On completion of this course students will be able to

- Solve Schrodinger's equation for different systems using WKB method, Variational method and perturbation method.
- To write Python code to solve Schrodinger's equation and find energy eigen values

### **Course outline**

#### **Module-I (Theory 4 hours, Project 2 hours)**

Time independent Perturbation Theory: Energy Shifts and Perturbed Eigen states, Nondegenerate and degenerate perturbation theory, spin orbit coupling.

##### **Assignment 1:**(Any one)

- Develop solution for shifting and splitting of spectral lines of atoms - The Stark Effect
- Develop solution for shifting and splitting of spectral lines of atoms - Zeeman Effect

#### **Module -II (Theory 4 hours + Project 2 hours)**

Pictures of quantum mechanics: The Schrodinger picture, The Heisenberg picture, The interaction picture.

Variational Methods: General formalism, Ground State of One-Dimensional Harmonic Oscillator, First Excited State of One-Dimensional Harmonic Oscillator

##### **Assignment 2:**(Any one)

- Solve the problem for Tunneling of a particle through a Potential Barrier
- Find out the energy of ground state and first excited states of Harmonic oscillator

#### **Module -III (Theory 4 hours + Project 2 hours)**

WKB Approximation: General Formalism, Validity of WKB Approximation Method, Bound States for Potential Wells with no rigid walls.

##### **Assignment 3:**(Any one)

- Gamow's theory of alpha decay – Finding solution with WKB method
- Find out the energy of particle in Bound States for Potential Wells with One Rigid Wall
- Find out the time taken for a can of soft drink at room temperature to topple spontaneously- applications of quantum tunneling

#### **Module -IV (Theory 4 hours + Project 2 hours)**



Time Dependent Perturbation Theory: Introduction, Transition Probability, Transition Probability for Constant Perturbation, Transition Probability for Harmonic Perturbation, Adiabatic Approximations, Sudden Approximations.

**Assignment 4:**

- Calculate the transition probability rate for an excited electron that is excited by a photon from the valence band to the conduction band in a direct band-gap semiconductor by using Fermi golden rule.

**Module -V**

**(Theory 4 hours + Project 2 hours)**

Applications of Time Dependent Perturbation Theory: Interaction of Atoms with Radiation, classical treatment of incident radiation, Transition Rates for Absorption and Emission of Radiation,

**Assignment 5:**(Any one)

- Light absorption and emission - mathematical formulation using electric dipole radiation
- The quantum mechanical selection rules for electric dipole transitions
- Find out expression for transition rates within the dipole approximation

**Module -VI**

**(8 project sessions 2 hours each)**

**Assignment 6:**(Any one)

Group Project

1. One-electron phenomena in strong Laser fields – derivation and Python programming- application of adiabatic approximation
2. Two-electron phenomena in strong Laser fields - application of adiabatic approximation
3. Fermi's golden rule applied to find tunneling current of a scanning tunneling microscope
4. Derivation and Python programming for bound states for potential wells with two rigid walls
5. Ground state of Hydrogen atom - solve using Python programming.
6. Study of the neutron quantum states in the gravity field - Python programming
7. Find an expression for electric-dipole two-photon absorption selection rules and use it to summarize the rules for two photons of unequal frequency.
8. Simulation using Python programming for tunneling through a potential barrier
9. Quantum harmonic oscillator using Python
10. Gamow's theory of alpha decay – solution and simulation using python
11. Time taken for a can of soft drink at room temperature to topple spontaneously- applications of quantum tunneling - Python programming.

**Total theory 20 hours and total project 26 hours**

**Textbook:**

4. Advanced Quantum Mechanics by Satyaprakash, S Chand Publications



### Reference Books:

6. Quantum Mechanics: Concepts and Applications by Nouredine Zettili
7. Introduction to Quantum Mechanics, D J Griffith, Pearson, 2014.
8. Modern Quantum Mechanics, J.J. Sakurai, Pearson, 2013.

| Code     | Course Title                              | T-P-Pj (Credit) | Prerequisite |
|----------|-------------------------------------------|-----------------|--------------|
| CUTM1413 | Physics of solid state and semiconductors | 3-1-0           | Nil          |

### Objective

- To learn about crystal structure, electronic and dielectric properties of solids.
- To learn about basic properties of metals, insulators and semiconductors.



- To learn about semiconductor physics and discuss working & applications of basic devices.

### **Learning outcome**

After learning the course the students will be able to

- Explain different types of crystal structures in terms of the crystal lattice and the basis of constituent atoms.
- Understand the origin of energy bands in solids.
- Explain the physical characteristics such as electronic structure and optical and transport properties, and current-voltage characteristics of semiconductors.
- Apply the knowledge of semiconductors to illustrate the functioning of basic electronic devices

### **Course outline**

#### **Module I**

**(5 Hours Theory+ 2 Hours practice)**

#### **Structure of Solids**

Bravais lattice, primitive vectors, primitive unit cell, conventional unit cell, Wigner-Seitz cell, Symmetry operations and classification of 2- and 3-dimensional Bravais lattices, point group and space group (information only). Common crystal structures- NaCl and CsCl structure, Close-packed structure, Zinc blende and Wurtzite structure, tetrahedral and octahedral interstitial sites, Spinel structure. Crystal diffraction by X-ray, Anomalous scattering. Atomic and geometric structure factors, systematic absences. Reciprocal lattice and Brillouin zone, Electron and neutron scattering by crystals (qualitative discussion)

#### **Practice-1**

V Lab: To study various crystals structures

#### **Module II**

**(4 Hours Theory+ 2 Hours practice)**

#### **Band Theory of Solids**

Bloch equation, Empty lattice band, Number of states in a band, Effective mass of an electron in a band, Concept of holes, Electronic band structures in solids, Nearly free electron model.

#### **Practice-2**

Determination of band gap of semiconductor by Four probe method

#### **Module III**

**(4 Hours Theory+ 2 Hours practice)**

#### **Lattice Dynamics**

Tight binding method - application to a simple cubic lattice, Band structures in copper, GaAs and silicon, Classical theory of lattice vibration under harmonic approximation, Dispersion relations of one dimension lattices, Mono atomic and diatomic cases, Characteristics of different modes, Long wavelength limit.

#### **Practice-3**

Determination of thermal and electrical conductivity of metals (copper and silver)



#### **Module IV**

**(4 Hours Theory+ 2 Hours practice)**

##### **Specific Heat**

Optical properties of ionic crystal in the infrared region, Inelastic scattering of neutron by phonon, Lattice heat capacity, Debye and Einstein models-comparison with electronic heat capacity, Anharmonic effects in crystals - thermal expansion.

##### **Practice-4**

Determination of specific heat of solids (copper, glass and lead)

#### **Module V**

**(5 Hours Theory+ 2 Hours practice)**

##### **Dielectric Properties of Solids**

Electronic, ionic and orientational polarisation, Static dielectric constant of gases and solids, Clausius-Mossotti relation, Complex dielectric constant and dielectric losses, Relaxation time, Debye equations, Cases of distribution of relaxation time, Cole - Cole distribution parameter, Dielectric modulus, Ferroelectricity, Displacive phase transition, Landau Theory of Phase transition.

##### **Practice-5**

Determination of dielectric constant of air, glass and polystyrenes

#### **Module VI**

**(4 Hours Theory)**

##### **Imperfections in Solids**

Frenkel and Schottky defects, Defects by non-stoichiometry, Electrical conductivity of ionic crystals, Classifications of dislocations, Role of dislocations in plastic deformation and crystal growth, Colour centers and photoconductivity, Luminescence and phosphors, Bragg - Williams theory, Order-disorder phenomena.

#### **Module VII**

**(4 Hours Theory+2 Hours practice)**

##### **Semiconductors**

Kronig Penny model (no derivation required). Band gap. Conductor, semiconductor (P and N type) and insulator. Conductivity of semiconductor, Mobility, Direct and indirect band gap semiconductors and their behaviour to external field, Types of semiconductors, Charge carriers, Intrinsic and extrinsic materials, Carrier concentration, Fermi Level, Electron and hole concentration equilibrium, Temperature dependence of carrier concentration, Compensation and charge neutrality. Conductivity and mobility, Effect of temperature, Doped semiconductors, Doping and high electric field.

##### **Practice-6**

Study of Hall Effect (Determination of nature of charge carriers in a semiconductor)

**Total theory 30 hours and total practice 12 hours**

##### **Textbook:**

1. Introduction to Solid State Physics, C. Kittel, Wiley
2. Principles of Semiconductor devices, Bart Van Zeghbroeck.



**Reference Books:**

1. Solid State Physics, by N. W. Ashcroft and N. D. Mermin (Cornell University)
2. Introduction to Solid State Physics, S. O. Pillai, New Age International-

| Code     | Subject Name         | Type of course                     | T-P-P | Prerequisite |
|----------|----------------------|------------------------------------|-------|--------------|
| CUTM1414 | Lasers<br>Technology | • Theory,<br>Practice & Assignment | 2-1-1 | Nil          |

**Objective**

The aim of this course is

- To acquire a thorough understanding of the theory of modern Laser Physics
- understand different types of modern lasers and their applications



- computationally verify material properties for Laser production.

### **Learning outcome**

After learning the course the students will be able to

- describe and explain fundamental concepts in laser physics
- compare the function and properties of a number of common lasers
- verify properties of materials used for laser production

### **Course outline**

#### **Module-I (3 hours theory, 2 hours practice, 2 hours Assignment)**

Laser Fundamentals: Spontaneous and stimulated emission, Absorption, Einstein's coefficients, Active medium, population inversion, laser-pumping, Laser gain, metastable state, condition for light amplification. Solid state laser: Ruby Laser.

#### **Practice 1:**

Building and operating a Diode laser pumped Nd:YAG laser. Measure its efficiency and spiking effects to be demonstrated OR Any other Laser to explain the operation of Lasers

#### **Assignment 1:**

Neodymium Glass Lasers – Construction, Properties and Applications.

#### **Module-II (3 hours theory, 2 hours Assignment)**

Liquid Lasers: Principle of, Main components of Laser, Levels of laser action, Continuous Wave Lasers, construction and working of Dye laser.

#### **Assignment 2: (Any one)**

- Application of Tuning in Dye laser astronomy as a laser guide star
- Alexandrite Lasers application in dermatology – Working, Properties and Applications in industrial like medical field
- Model-Locked Ring Dye laser application for Optical Data Storage

#### **Module-III (3 hours theory, 4 hours practice, 2 hours Assignment)**

Gas Laser: Principle, working and usefulness of gas laser. He-Ne laser. Lasing Action in Ion Lasers, construction and operation of ion lasers

**Practice 2:** Determine the wavelength and angular spread of He-Ne laser using plane diffraction grating.

**Practice 3:** Argon Ion Laser spectrum- Operating and selecting various wavelengths for a single line operation in an Argon Laser.

#### **Assignment 3: (Any one)**

- Application of Krypton ion laser in medicine



- Application of Copper vapour laser for entertainment purposes
- Application of He-Cadmium laser – Working, Properties and Applications
- Industrial application of Carbon dioxide laser for cutting and drilling
- Application of excimer laser for Photolithography and Medical purposes

**Module-IV (3 hours theory, 2 hours practice, 2 hours Assignment)**

Semiconductor Laser: Principle of semiconductor laser diode, threshold frequency, difference between a diode and laser diode, Characteristics of semiconductor lasers, Semiconductor diode lasers, LED versus Laser diode.

**Practice 4:** Operating characteristics of a Semiconductor diode lasers- measuring its threshold current, output power versus current etc.

**Assignment 4:** (Any one)

- Application of heterojunction structures to optical devices
- Application of Homojunction lasers
- Application of Quantum well lasers for applications in optical information processing

**Module-V (3 hours theory, 2 hours practice, 2 hours Assignment)**

Laser applications: Material processing with lasers, Interaction mechanism, Lattice heating, Material processing mechanism.

**Practice 5:** Drilling process with laser – Either Physical lab or virtual lab.

**Practice 6:** Cutting and Welding process with laser – Either Physical lab or virtual lab.

**Assignment 5:** Industrial application of laser - Material processing with lasers

**Module-VI (3 hours theory, 2 hours Assignment)**

Application of Laser in Medical Science - Medical lasers, Laser diagnostic, Laser for general surgery, Laser in medicine.

**Assignment 6:** (Any one)

- Understanding the properties of GaN for Laser application by Density Functional theory using Biovia Material Studio
- Understanding the properties of InGaN for Laser application by Density Functional theory using Biovia Material Studio
- Understanding the properties of GaAs for Laser application by Density Functional theory using Biovia Material Studio
- Understanding the properties of AlGaAs for Laser application by Density Functional theory using Biovia Material Studio

**Module-VII (3 hours theory, 2 hours Assignment)**

Laser in Optical Communication: Optical source for fiber optical communication, Essential characteristics of Laser in fibre optic communication.

**Assignment 6:** (Any one)

- Understanding the properties of “Tungsten oxide-based mediums” for Laser application by using Biovia Material Studio





- Understanding the properties of “sapphire crystals usually doped with titanium particles” for Laser application by using Biovia Material Studio

**Textbook:**

1. Laser Principles, Types and Application by KR Nambiar, New Age International.

**Reference Books:**

9. Lasers Theory and Applications by K. Thyagarajan and A.K. Ghatak, Mcmillan (1981)
10. Laser Fundamentals, by William T. Silfvast, Cambridge University Press, 2008.
11. Principles of Lasers, by Orazio Svelto; Springer, 2009.
12. Industrial Applications of Lasers, by K. Koebner (ed.), Wiley (1984).