M.TECH- NANOTECHNOLOGY AND RENEWABLE ENERGY

ThisisatwoyearcourseinNanotechnologyandRenewableEnergy withanapplicationfocus onenergy devicetechnologiessuchasPV,Batteries,Supercapacitors, HydrogenStorageand Carbon Capture. The course isdesignedasper the guidelinesof the Nanomissionprogramof theGovernmentofIndia. Therearebasicfoundationcoursesinengineering physicsand materials,followed by subjectcorecoursesdealingwithnanotechnologyspecializationsuchas designof nanosystems,nanomaterialsand their processing,properties and characterization, applications of nanomaterialsto energy, etc.

CURRICULUM

First Semester

Course Code	Type	Course	LTP	Credits
18MA613	FC	Statistical Data Analysis	101	2
18NT601	FC	Introduction to Classical &QuantumMechanics	300	3
18NS621	SC	Science andProperties of Nanomaterials	300	3
18NT621	SC	Physics of Semiconductor Nanostructures	300	3
18NS622	SC	Nanomaterials Synthesis	300	3
18NS624	SC	Lab: Nanomaterials Lab-I	102	3
18NT622	SC	Lab: Optoelectronis Lab	002	2
18HU601	HU	Amrita Values Program *		P/F
18HU602	HU	Career Competency-I *		P/F
		Total Credits		**19**

*** Non Credit Course**

Second Semester

Course Code	Type	Course	LTP	Credits
18NS625	SC	Characterization of Nanomaterials	300	3
18NT623	SC	EnergyConversion Scienceat Nanoscale	300	3
18NT624	SC	Thin Film Science and Technology	300	3
18NT625	SC	EnergyStorageScience at Nanoscale	300	3
18NS629	SC	Lab: Nanomaterials Lab-II	102	3
18NT626	SC	Lab: Energy Devices Lab	002	2
18HU603	HU	Career Competency-II	100	1
		Total Credits		**18**

Third Semester

Course Code	Type	Course	LTP	Credits
18RM601	FC	Ethics in Research and Research Methodology	101	2
18NT627	SC	Introduction to Nanodevice Fabrication	300	3
18NT628	SC	Nanomaterials for Hydrogen Storage and Carbon Capture	300	3
18NT798	P	Dissertation		8
		Total Credits		**16**

Fourth Semester

Course Code	Type	Course	LTP	Credits
18NT799	P	Dissertation		12
		Total Credits		**12**
		Overall Total Credits		**65**

FIRST SEMESTER

18MA613 STATISTICAL DATA ANALYSIS 1-0-1-2

Introduction to Statistics-Need for Statistical Methods –Their uses and Misuses, Types of Variables, Data collection Methods, Population and Sample.
Descriptive Data Analysis Methods-Statistical Tables, Diagrams & Graphs, Measures of Averages, Measures of Dispersion, Correlation Analysis Methods, Regression Analysis Methods.
Theory of probability and Standard Distributions - Binomial, poisson& Negative Binomial, Standard univariate continuous distributions – Normal, Log normal & Exponential. Sampling distributions – Chi- square distribution and F & 't' distributions.
Tests of Significance of Statistical Hypotheses- Concept of Statistical Hypotheses –Null and Alternative hypotheses, Type I and Type II errors, Significance level, Critical region and Power of a test , P- value and its interpretation; Large and Small Sample Test – Normal test, Student's 't' test, Chi-square tests, Analysis of variance & Non parametric methods.
Nonparametric methods-Non-parametric methods for estimation, Methods for tests of significance for the independent and correlated samples, Nonparametric Methods for more than two populations.
Multivariate analysis Methods- Principles of Multivariate analysis, Multivariate regression analysis, Multivariate logistic regression analysis.
Practicals- (Statistical Software to be used: SPSS & SAS): (i) Practicals in Descriptive Data Analysis Methods, (ii) Practicals in Sampling Theory, (iii) Practicals in Biostatistical Inference, (iv) Practicals in Testing of Hypotheses, (v) Practicals in Nonparametric Methods, (vi) Practicals in Multivariate Regression Analysis.

TEXT BOOKS/REFERENCES:

1. *Statistical Techniques for data Analysis: J.K. Taylor & Cheryl C, 2004 Chapman & Hall (CRC).*
2. *Performing Data Analysis Using IBM SPSS: Lawrence S Meyers, 2015, John Wiley.*

18NT601 INTRODUCTION TO CLASSICAL & QUANTUM MECHANICS3-0-0-3

Classical mechanics: review of Newtonian mechanics, introduction to Lagrangian and Hamiltonian formulations, failures of classical mechanics, Planck's quantum hypothesis, photo-electric effect, Compton effect, Bohr model of H-atom, particle in a box, correspondence principle, wave-particle duality, uncertainty principle, observables and operators, Schrodinger equation for free electron, particle in a box, linear harmonic oscillator, tunneling, applications of quantum mechanics in nanotechnology.

TEXT BOOKS/REFERENCES:

1. Classical Mechanics by Herbert Goldstein, John Safko, Charles P. Poole, Pearson Publishers, 3rd Edition (2011).
2. Introductory Quantum Mechanics for Applied Nanotechnology by D. M. Kim, Wiley-VCH; 2015.

18NS621 SCIENCE AND PROPERTIES OF NANOMATERIALS 3-0-0-3

Basic Materials Science:

Materials classification by bonding, amorphous and crystalline materials, crystal lattices, Miller indices, defects in crystal structure, principles of dislocations, theory of diffusion, mechanical properties, phase diagrams, polymeric materials, composite materials, electrical and optical properties

Nanomaterials science:

Types of Nanomaterials, definition of nanoscale, surfaces and particle size, surface energy and surface tension and relation to size, phase transformation in nanomaterials, specific heat and heat capacity of nanomaterials, mechanical properties of nanomaterials, optical properties of nanomaterials, electrical and magnetic properties of nanomaterials.

Inclusion and importance of surface energy, equations of thermodynamics with surface energy Equilibrium Particle size, internal pressure and stability, nucleation processes

Kinetics of reactions at nanoscale, Diffusion at nanoscale, ripening among nanoprecipitates.

TEXT BOOKS/ REFERENCES:

1. *Materials Science and Engineering – An Introduction, William D Callister, 12th Edition, John Wiley (Available in Amazon India, Rs. 287)*
2. *Nanomaterials – An introduction to synthesis, properties and applications, D. Vollath, Wiley-VCH, Second Edition 2013.*

18NT621 PHYSICS OF SEMICONDUCTOR NANOSTRUCTURES 3-0-0-3

Semiconductors review; elemental and compound semiconductors; oxide semiconductors; electrical properties: electrons in semiconductors; band structures in semiconductors; intrinsic, extrinsic and compensated semiconductors; carrier concentration in semiconductors; carriers under thermal equilibrium and out of thermal equilibrium; current density in semiconductors; carrier drift and diffusion; conductivity and mobility; Hall effect, carrier transport and recombination; radiative, Auger and SRH recombination models, low dimensional semiconductors, emerging layered semiconductors, quantum size effects in semiconductor nanostructures.

TEXT BOOKS / REFERENCES:

1. *Nanoscale Physics for Materials Science, By Takaaki Tsurumi, Hiroyuki Hirayama, Martin Vacha, Tomoyasu Taniyama, CRC Press, 2009*
2. *Leonid V. Azaroff, "Introduction to Solids", Second Edition, Tata McGraw- Hill Publishing Company Limited, 2006*

18NS622 NANOMATERIALS SYNTHESIS 3-0-0-3

Synthesis Methods of Nanomaterials: Top down : Milling; Bottom up approaches – Synthesis of zero dimensional metal, metal oxides, semiconductor nanoparticles by different routes – Colloidal method, Sol-gel, Electrodeposition; Kinetically Confined Synthesis of Nanoparticles

- Aerosol synthesis, Micellar growth, Spray pyrolysis, Template-based synthesis; Synthesis of one dimensional nanosystems by different routes – VLS and SLS methods, Electrospinning; Synthesis of two dimensional nanosystems – Fundamentals of Film Growth; Vapor phase deposition methods - Physical and chemical methods; Superlattices; Self Assembly; Langmuir-Blodgett Films; Electrochemical Deposition; Special Nanomaterials – Core/shell structures, Carbon-based Nanomaterials, Micro and Mesoporous Materials, Organic-Inorganic Hybrids

TEXT BOOK/REFERENCES:

1. G. Cao, Nanostructures and Nanomaterials – Synthesis, Properties and Applications, Imperial College Press 2006.

2. *Nanostructured materials: Processing, Properties and Potential Applications, Edited by Carl. C. Koch, Noyes Publications, 2002.*

18HU601 AMRITA VALUES PROGRAM

Culture – definition and scope. Values and culture, cultural freedom
Culture and Education
Culture of Research – creativity and responsibility in research
Spirituality and Culture – spirituality as a way of life, spirituality and religion
Culture and women – gender oppression, motherhood
Culture and the Media
Culture and Politics – national values and political harmony
Philosophy and Culture, epistemology

18NS624 LAB: NANOMATERIALS LAB-I 1-0-2-3

1. Metal Nanoparticles : Synthesis of plasmonic silver nanoparticles
2. Metal-oxide Nanoparticles: Synthesis of ZnO nanoparticles through non-aqueous route.
3. Absorption Spectroscopy of metal oxide (ZnO) nanoparticles and particle size calculation using Brus equation
4. Semiconductor Nanoparticles: Synthesis of doped ZnS nanoparticles through aqueous method; characterize fluorescence property using spectrofluorimeter
5. Silica Nanospheres: Synthesis and characterization by sol-gel chemistry
6. Surface Plasmon Resonance (SPR) analysis of differently shaped and sized gold nanoparticles by absorption spectroscopy
7. Nanoparticle imaging by Atomic Force Microscope for size and shape analysis

18NT622 LAB: OPTOELECTRONICS LAB 0-0-2-2

Synthesisofquantumdotsbychemicalmethodandsize-property correlation.Thin-filmmetalsandsemiconductorsusing sputtering andevaporation,Thicknessmeasurementusingprofiler, ellipsometry,opticalreflectance…etc.Bandgapmeasurementsusingabsorptionandluminescence. Electricaltransportmeasurementsof bulkandthinfilmsin2and4probe configurations.

TEXTBOOKS/ REFERENCES:

1. *S. M.Sze,"Physics of Semiconductor Devices",Wiley-Interscience, 1969.*

2. *D KSchroder,"SemiconductorMaterialandDeviceCharacterization",3rd Edition, WileyPublishers, 2006.*

SECOND SEMESTER

18NS625 CHARACTERIZATION OF NANOMATERIALS 3-0-0-3

X-ray diffraction and Reciprocal lattice, Bragg's law, Ewald'sspherecons truction, XRD of nanolayers, effects of nanosize and shape anisotropyofnanostructures, texture and strain measurements, SEM: scattering of electrons, secondary and backscattered electrons, electron sources, imaging modes in SEM and its use for nanomaterials size and shape analysis, TEM: Interaction of high energy electrons with matter, elastic and inelastic scattering, TEM instrumentation, imaging and diffraction modes of operation, imaging and contrast in TEM, HRTEM, Energy dispersive analysis of x-rays, Nanomaterials size and size distribution analysis, shape and structural analysis, SPM: Principle of operation, contact and non-contact AFM, dynamic force microscopy, and various other modes of SPM including STM. Chemical Characterization – Optical Spectroscopy, IR spectroscopy: vibrational modes, theory of IR spectroscopy, infrared spectrometers, single and group frequencies, advantages of FTIR. Raman spectroscopy, surface enhanced Raman spectroscopy, X-ray photoelectron spectroscopy.Use of these techniques for nanomaterials and biomaterials analysis.

TEXT BOOKS / REFERENCES:

1. Harold P. Klug and Leroy E. Alexander, "X-Ray Diffraction Procedures: For Polycrystalline and Amorphous Materials", Second Edition, Wiley-Interscience, 1974

2. C. N. Banwell and E. McCash, Fundamentals of Molecular Spectroscopy, McGraw Hill Education (2017).

3. N. Yao and Z. L. Wang, Handbook of Microscopy for Nanotechnology, Springer Science and Business Medi (2005).

18NT623 ENERGY CONVERSION SCIENCE AT NANOSCALE 3-0-0-3

Basics of Energy Conversion Science:
Introduction: need for energy-types of energy-sources of energy-energy consumption, Functional materials: semiconductors-dielectrics-metals-transparent conductors, work function-bandgap-electron affinity-mobility-conductivity, absorption and their influence in device design, Photovoltaics: basic principles-Physics of electronic junctions: pn-pin-metal/semiconductor-Shockley–Queisser limit-band energy analysis-electrical and optical characteristics of solar cells: I-V, EQE, CV, and V_{OC} decay, wafer and thin film based solar cells: homojunction-heterojunction- Schottky barrier-tunnel junction-tandem structure-carrier transport and loss mechanisms, recombination models-anti-reflective coating-surface texturing, excitonic solar cells.

Energy conversion in nanoscale structures: size effects in light-matter interactions, 0D, 1D and 2D quantum confined functional materials for energy conversion, size driven advantages and

disadvantages of functional materials in devices, charge carrier dynamics at nanoscale in energy conversion devices.

TEXT BOOKS/REFERENCES:

1. *Jenny Nelson, "The Physics of Solar Cells", First Edition, Imperial College Press, 2003.*
2. *Stephen Fonash, Solar Cell Device Physics - 2nd Edition, Academic Press,2010*

18NT624 THIN FILM SCIENCE AND TECHNOLOGY 3-0-0-3

Vacuum science and technology: kinetic theory of gasses, gas transport and pumping, vacuum systems, physical vapor deposition: process and systems, thermal evaporation, electron beam evaporation, sputtering (DC, RF magnetron) chemical vapor deposition, film formation and nanostructure, characterization of thin films, epitaxial quantum systems, applications of thin films in nanotechnology.

TEXT BOOKS / REFERENCES:

1. *Handbook of Thin Film Technology, H. Frey and H. R. Khan, Springer Science and Business Media (2015)*
2. *The Materials Science of Thin Films, Milton Ohring, Academic Press(2002).*

18NT625 ENERGY STORAGE SCIENCEAT NANOSCALE 3-0-0-3

Introduction to electrochemistry, potentials and thermodynamics of cells, galvanic and electrolytic cells, kinetics of electrochemical reactions, mass transfer by migration and diffusion, non-Faradaic and Faradaic reactions, nanomaterials as anode and cathode for batteries and electrochemical capacitors, advanced batteries with nanoscale materials and surface/interface modifications, liquid and solid electrolytes, cycle-life, capacity, energy and power density assessments, safety concerns and solutions. Electrochemical methods: potentiostatic and galvanostatic, cyclic voltammetry, chronoamperometry, chronopotentiometry and electrochemical impedance.

Textbooks/References:

1. *L. R. Martinez and N. Omar, Emerging Nanotechnologies in Recahrgeable Energy Storage Systems, 1st Edition, Elsevier (2017).*
2. *G. A. Nazri and G. Pistoia, Lithium Batteries, Springer, 2009.*
3. *Allen Bard and Larry R. Faulkner, Electrochemical Methods, John Wiley & Sons Inc, 2001.*

18NS629 LAB: NANOMATERIALS LAB-II 1-0-2-3

1. Polymeric Nanoparticles: Synthesis of alginate nano and micro particles; characterization of particle size by Dynamic Light Scattering (DLS) and Zeta analysis
2. Fourier Transform Infra-red Spectroscopy(FTIR): Preparation of Chitosan Nanoparticles and characterization using FTIR

3. Electrospinning: Fabrication of electrospun PVA nanofibres and microfibers; characterization of fibers morphology and diameter using SEM
4. Thermal characterization of polymers using Thermogravimetric – Differential thermal Analysis (TGA-DTA)
5. X-ray diffraction spectrometer (XRD): Structural characterization of crystalline and amorphous nanomaterials
6. Raman spectroscopy: Characterization of polymeric and inorganic samples using Raman Spectroscopy
7. Mechanical Testing and Rheology: Characterization of materials mechanical properties by studying stress-strain curve.

18NT626 LAB: ENERGY DEVICES LAB 0-0-2-2

1. Dye sensitized solar cell fabrication and testing.
2. Thin film heterojunction photovoltaic device fabrication and testing.
3. Quantum dot solar cell fabrication and testing.
4. Li ion battery anode and cathode half-cell fabrication and testing.
5. Li ion battery full-cell fabrication and testing.
6. Supercapacitor/Pseudocapacistor fabrication and testing.

THIRD SEMESTER

18RM601 ETHICS IN RESEARCH AND RESEARCH METHODOLOGY1-0-1-2

Plagiarism, regulatory principles, safety in research, ethics in stem cell research, ethics in clinical research, ethics in nanomaterials based research

Principles of data documentation, protocol development, research questions and hypothesis driven research, technical writing fundamentals

TEXTBOOK:

1. Research Ethics for Scientists, C. Neal Stewart Jr., Wiley-Backwell Publishers, 2011
2. Ethics in Science, Ethical Misconduct in Scientific Research, John D'Angelo, CRC Press, 2012.

18NT627 INTRODUCTION TO NANODEVICE FABRICATION 3-0-0-3

Introduction to nanodevices - methods and techniques; scaling effects; concepts of micro-/nano-physics for design and analysis; Lithography: optical and e-beam lithography, projection printing; soft lithography, replication, embossing/nanoimprint, focused ion beams,nano-electronics; nano-sensors; micro-/nano-electromechanical systems; fabrication and testing; key advances in the recent years especially about fabrication and testing of nanodevices.

TEXT BOOKS/REFERENCES:

1. *Z. Cui, Nanofabrications: Principles, capabilities and limits, Springer (2017).*

2. *T. Li and Z. Liu, Outlook and challenges in Nanodevices, Sensors and MEMS, Springer (2017).*

18NT628 NANOMATERIALS FOR HYDROGEN STORAGE AND CARBON CAPTURE 3-0-0-3

Hydrogen energy - Hydrogen: Its merit as a fuel, Hydrogen storage methods - Metal hydrides, Intermetallic hydrides, complex hydrides, Physisorption of hydrogen on porous materials. thermodynamics and kinetics of metal hydrides, tailoring reaction enthalpy of hydrides, nanoparticles for hydrogen storage. nanoparticles in 3D support. Various methods of nanomaterial synthesis, Carbon based materials for hydrogen storage. Introduction to climate change and issues related to greenhouse gas emissions, CO_2 capture-post and pre combustion capture, oxy fuel combustion, CO_2 capture using adsorption and absorption materials, advantage of metal oxide based nanomaterials for CO_2 capture.

TEXT BOOKS / REFERENCES:

1. *Handbook of Hydrogen Storage: New Materials for Future Energy Storage edited by Michael Hirscher, Wiley-2010.*
2. *Nanomaterials for solid state hydrogen storage-Robert A. Varin, springer 2007.*
3. *Introduction to carbon capture and sequestration, The Berkeley lectures on energy-vol 1, Berendsmit, imperial college press, 2014.*