SYLLABUS

Proposed course outlines

For

Ph.D (Physics) Semester System

Effective from the Academic Session 2017 onward

Ph.D (Physics) Semester System

Effective from the Academic Session 2017 onward

Total Credit Hours: [Theory course 18 credit hours + Research]

NOTE:

- Theory courses of 18-credit hours (6-courses each of 3 credit hours) have to be completed in first two semesters (i.e. 1st & 2nd semesters) during ONE academic year.
- Scholars will have to complete FOUR compulsory and TWO optional courses.
- Candidates will have to publish ONE Journal Paper from their research work before the final defense.

COMPULSORY COURSES

SNo.	Course Code	Course Title	Credit Hours	Marks
1	Phy-801	Condensed Matter Physics	3	100
2	Phy-802	Micro-Electro Mechanical Systems and Nano-Electro Mechanical Systems	3	100
3	Phy-803	Nanomaterials and Nanotechnology	3	100
4	Phy-804	Characterization of Solid Surfaces	3	100
5	Phy-805	Metal Oxide Nanostructures	3	100
6	Phy-806	Advance Signal Processing	3	100

OPTIONAL COURSES

SNo.	Course Code	Course Title	Credit Hours	Marks
1	Phy-807	Quantum field theory	3	100
2	Phy-809	Artificial neural networks	3	100
3	Phy-810	Quantum Optics	3	100
4	Phy-804	Advanced Optical Techniques	3	100
5	Phy-811	Atmospheric Dynamics & Modeling	3	100
6	Phy-812	Quantum Theory of Solids	3	100
7	Phy-813	Electron Microscopy	3	100
8	Phy-814	Superconductivity	3	100
9	Phy-815	Biophysical techniques and Instrumentation	3	100
10	Phy-816	Radiation Physics	3	100

11	Phy-817	Microwave communication	3	100
12	Phy-818	Satellite Communication System	3	100
13	Phy-819	Microprocessor	3	100
14	Phy-820	Optoelectronics Materials and Devices	3	100
15	Phy-821	Plasma Physics-II	3	100
16	Phy-822	Experimental Plasma Physics	3	100
17	Phy- 823	Optical Networks	3	100
18	Phy- 824	Nanostructured device Fabrication	3	100

COMPULSORY COURSES

CONDENSED MATTER PHYSICS (03) **Phy-801**

1. **Introduction:** Overview of modern condensed matter Physics, more is different, emergent properties.
2. **Scattering from ordered structures:** General Theory of scattering from a crystal. X-ray, neutron and electron scattering. Magnetic and small angle scattering.
3. **Electron Transport Phenomenon in bands:** Motion of electrons in bands. Boltzmann transport equation, relaxation time approximation. Onsager relations and reciprocity. Electrical conductivity, generalized treatment of conductivity in bands. Thermoelectric phenomenon (Seebeck and Peltier effects.) Introduction to Fermi liquid theory.
4. **Dielectric and Optical Properties:** General background: Maxwell equations, dielectric functions, Kramers–Kronig relations. Absorption of electromagnetic radiation; Optical properties of semiconductors, direct and indirect transitions, excitons. Optical properties of insulators. Longitudinal amd transverse normal modes, local field, Polarization, and polarization catastrophe, Ferroelectrics and ferroelctricty. Optical modes in ionic crystals, coupling of electromagnetic and lattice modes (polarons and polaritons), point defects and color centers. Optical properties of metals, plasma frequency, metals at low frequencies, plasmons, Brillouin scattering.
5. **Electrons in low dimensional systems:** Electronic states in bands: review of free, nearly free and tightly bound electrons. Confined states in zero, one and two dimensions. Effects of confinement on band structures and optical properties: band gap variations and surface plasmon effects. Density of states in quantum wells, wires and dots. Quantum Hall effect. Semiconductor laser action. Single electron tunneling. Tunneling structures and devices.
6. **Critical phenomenon and phase transitions:** Molecular field theory and application to simple systems e.g. ferromagnetism or Van der Waals equation of state. Generalized theory of phase transitions (Landau theory), order parameter, Free energy, equilibrium behavior, temperature dependence of order parameter and generalized susceptibilities, coherence lengths, specific heats. Application to different examples e.g. ferromagnetic, ferroelectrics, superconductors (Ginzburg-Landau theory). Basic ideas of fluctuations and of critical exponents.

BOOKS:

1. Michael P Malder, **Condensed Matter Physics**, John Wiley (2000).
2. H. Ibach and H. Luth, **Solid State Physics**, 2nd Edition, Springer Verlag (2003).
3. David L. Goodstein, **States of Matter**, Dover Publications Inc. (2002).
4. E. P. O'Reilly, **Quantum Theory of Solids,** Taylor and Francis (2002).

MICRO-ELECTRO MECHANICAL SYSTEMS (MEMS) AND NEMS (03) Phy-802

1. Introduction: Evolution of Microsensors and Microactuators, MEMS Overview, Emergence of Micromachines, MEMS Applications

2. Fundamentals of MEMS Fabrication: Introduction and Description of Basic Processes, Bulk Micromachining, Surface micromachining, Microstereo Lithography for MEMS

3. Principles of Microsensors and Their Fabrication: Introduction, Fabrication, Examples of Microsensors

4. Principles of Microactuators: Introduction, Electric Field Driven Actuators, Piezoelectric and Magnetic Field Driven Actuator, Examples of Microactuators

5. Computer Aided Design of MEMS: Introduction to Modeling, Analysis and Simulation, MEMS Design Layout, MEMS Design Simulation using Finite Element Analysis

6. Nano-electro mechanical systems (NEMS): Anodic Aluminum Oxide (AAO), template making using AAO, Nano dots, Nano rods, Nano wires, Nano tubes, Carbon nanotubes (CNT) fabrication, Nano actuators, Nano generators.

BOOKS:

1. S.E. Lyshevski: **MEMS and NEMS Systems**, Devices and Structures, CRC Press, 2002
2. J. W.Gardner,V.K. Varadan, O.O. Awadelkarim: **Microsensor MEMS and Smart Devices**, Wiley, 2001
3. T. Fukuda, W. Menz,: **Micromechanical Systems Principles and Technology**, Elsevier, 1998

NANOMATERIALS AND NANOTECHNOLOGY (03) Phy- 803

1. Introduction to Nanomaterials & Nanotechnology: Perspectives of Nanotechnology, History of nanomaterials, concept on atomism, colored glasses, photography, catalysis, integrated circuits and chips, advanced materials, characterization tools of nanotechnology.

2. Fabrication methods: top down fabrication: mechanical methods, thermal methods, high energy methods, chemical fabrication methods, Lithographic methods, bottom up fabrication: gaseous phase methods, liquid phase methods, solid phase bottom up fabrication, Template synthesis, Biomimetic processes

3. Materials, structure, and the Nanosurface: Importance of the surface, Engineering material materials, Particle shape and the surface, surface and volume, Atomic structure, Particle orientation

4. Properties of materials due to the scaling of size: Nano Optics, the Surface Plasmon Resonance, Quantum Dots, Near-Field Microscopies, Photonic Crystals, The Nanoscale Electronics, The Current State of Microelectronics and Extensions to the Nanoscale, Nanotechnology-Based Strategies: Single-Electron Tunneling, Molecular Wires, Nano Magnetism, Characteristics of Nanomagnetic Materials, Magnetization and Nanostructures, Physical Properties of Magnetic Nanostructures, Nano Mechanics, Mechanical Properties of Carbon Nanotubes

BOOKS:

1. G. Louis Hornyak, Joydeep Dutta, Harry F. Tibbals and Anil K. Rao, **Introduction to NanoScience,** (CRC Press of Taylor and Francis Group LLC), May 2008
2. G. Louis Hornyak, John J. Moore, Harry F. Tibbals and Joydeep Dutta **Fundamentals of Nanotechnology** (CRC Press of Taylor and Francis Group LLC), 2008
3. Janos H.Fendler, **Nanoparticles and nanostructured films**: preparation, characterization and applications, Wiley VCH, (1998)
4. Kenneth J. Klabunde **Nanoscale materials in chemistry**, Wiley, John & Sons, (2001)
5. Zhon Ling Wang, **Characterization of nanophase materials**, Wiley-VCH Verlag GmbH (2000)

CHARACTERIZATION OF SOLID SURFACES (03) Phy- 804

1. Methods for characterization of surfaces: The methods include photon-, electron-, and ion-induced spectroscopic methods

2. Imaging Techniques (Theory & Applications): Optical Microscopy, Electron Microscopy, Secondary electron scattering, back scattering, Scanning Probe Microscopes (SPM), Focused Ion Beam Technique, X-ray imaging, Atomic Force Microscopy (AFM), STM, XPS (X-ray photoemission spectroscopy), UPS (ultraviolet photoemission spectroscopy),

3. Surface and Material Analytical Techniques (Theory & Applications):
AUGER Electron spectroscopy, ESCA, SIMS, Trace elemental analysis with XPS, SIMS, XRF, Optical, electronic and vibrational spectroscopic tools, X-Ray Diffraction LEED (low energy electron diffraction), IRAS (infrared reflection absorption spectroscopy), RAS (reflection anisotropy spectroscopy), second harmonic generation at surfaces (SHG) and SPM (scanning probe microscopy).

BOOKS:

1. Stephen Blundell, Magnetism in Condensed Matter, (2007), Oxford University Press.
2. Philip F. Kane, Graydon B. Larrabee, Characterization of solid surfaces. (1974), Plenum Press.
3. Alvin Warren Czanderna, Methods of surface analysis. (1975), Elsevier Scientific Pub. Co.
4. David Briggs, M. P. Seah, Practical Surface Analysis: Auger and X-ray photoelectron spectroscopy. (1990), Wiley.

METAL OXIDE NANOSTRUCTURES (03) Phy- 805

1. Nanostructured Titanium Oxides: Introduction, Preparation of Nanosized Titanium Oxide Powders, Wet Chemistry Routes, Chemical Vapor Deposition, Vapor-Phase Hydrolysis, Physical Vapor Deposition, Other TiO_2 Nanostructures, Preparation of Nano-$Li_4Ti_5O_{12}$, Nano-$Li_4Ti_5O_{12}$ Spinel Applications in Energy Storage Devices, High-Power Li-Ion Batteries, TiO_2 Role in DSSC.

2. Alumina nanoporous membrane: structure of anodic aluminum oxide (AAO) membrane (pore diameter, inter pore distance, wall thickness, Barrier layer thickness, porosity, pore density, cell wall structure, crystal structure of oxide), synthesis of AAO membrane, types of anodization (one step and two step mild anodization, hard anodization, pulsed anodization), Prepatterned-Guided Growth of AAO (nanoimprint, patterning using Fe_2O_3 particles, hard replica patterning), metallic replica of AAO membrane, Order Degree and Defects in Nanopores of AAO.

3. Zinc oxide nanostructures: Different structures of ZnO (hexagonal rods, belts, tubes/rings, Twinning, Hierarchical structures, Heterostructures Basic properties (Crystal Structure, Lattice Parameters, Electronic Band Structure, Mechanical Properties, Pyroelectricity), Synthesis of ZnO Nanostructures (Vapor Transport Process, Metalorganic Vapor-Phase Epitaxy and Molecular Beam Epitaxy, Hydrothermal Synthesis, Growth of ZnO in general alkaline solutions, Growth mediated by hexamethylenetetramine, Seeded growth on general substrates, Electrodeposition, Templated growth), patterned growth

BOOKS

1 Richard C. Alkire, Yury Gogotsi, Patrice Simon, Ali Eftekhari, "**Nanostructured Materials in Electrochemistry**" WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim 2008

2 Hadis Morkoç and Ümit Özgür, "**Zinc Oxide: Fundamentals, Materials and Device Technology**" WILEY-VCH Verlag GmbH & Co. KGaA, 2009

3 Ulrike Diebold, (Article) "**The surface of titanium dioxide**", ELSEVIER, Surface Science report, vol 48, (2003), pp 53-229

ADVANCE SIGNAL PROCESSING (03) **Phy-806**

Elective for Artificial Intelligence: Signal representation and convolution, Discrete-time Fourier transforms and Z-transforms, Fast Fourier transform (FFT) algorithms, FIR and IIR filter structures, FIR designs using windowing and frequency sampling, Introduction to adaptive filters. State space model. Cost functions. Correlation matrix, autoregressive and moving average models. Spectral analysis. Linear Prediction. Mean Square Estimation, Wiener filtering. FlI~ Adaptive Filters. Elements of Statistical Decision Theory, Decision theoretic approach to pattern classification. Bayes decision rule. Optimum error' acceptance trade-off. Learning algorithms. Nearest Neighbour (NN) Technique,' k-NN pattern classifiers. Error bounds. Discriminant functions and learning algorithms. Deterministic learning. The least square criterion and learning scheme. Perceptron. Multilayer Perceptron. Neural nets. Stochastic approximation. Probability Density Function Estimation. Classification Error Rate Estimation. Feature Selection. Algorithms for selecting- optimal and sub-optimal sets of features. Feature Extraction. Feature extraction techniques based on the Karhunen-Loeve expansion. Discriminant analysis. Cluster Analysis, hierarchical methods, minimum spanning tree methods, clustering algorithms. Contextual Classification Methods. Heuristic approaches to contextual pattern recognition. Labeling of objects arranged in networks. Neighbourhood systems. Classifier Fusion - Fusion System architecture. Fusion rules and their properties

BOOKS:

1. Wysocki T. A., Darnell M., Honary B. **Advance Signal Processing for Communication System,** Kluwar Academic Publishers, 2002.
2. Poularikas, A and Ramadan, Z. **Adaptive Filtering Primer with MATLAB** Taylor & Francis, 0849370434 Webb, A, Statistical Pattern Recognition Arnold 0340741643.
3. Therrien, C. W. Decision, **Estimation & Classification** Wiley 0-471-50416-5

OPTIONAL COURSES

QUANTUM FIELD THEORY (03) **Phy-807**

Review of Relativistic Theory: Spiner Quantum electrodynamics, the free Dirac equation and its solution, scalar quantum electrodynamics, the free Klein Gordan equation and its solution, spin particles and their polarization, the propagation for the free virtual photon, Fermion-Boson and Fermion-Fermion Scattering, traces and spin summations, the structure of the Form Factor from invariance considerations.

Scattering Reactions and the Internal Structure of Baryons: Simple quark model, the description of scattering reactions, MIT bos Model.

Gauge Theories and Quantum Chromodynamics: Standard Model, A typical gauge theory, the gauge theory of quark interaction. The renormalization coupling constant of QCD. Anomalies in gauge theories and anomalies in QCD.

Pertabative QCD: Deep inelastic scattering, the Griber-Lipator-Alterelli-Parisi equations, an alternative approach to the GLAP equations, renormalization and the expansion into local operators, calculus of Wilson coefficients, the dependent structure functions,The Drell-Yan Process, small x physics.

Non-pertabative QCD: Lattice QCD Calculations, the path integral method, QCD on lattice, Gluons in lattice, Fermionic path integrals, Monte-Carlo methods, Metropolis Algorithm, Langevin Algorithm, the microcanonical algorithm, strong and weak coupling expansions, weak coupling approximation, QCD sum ,the ground state of QCD, Quark-Gluon Plasma.

BOOK:

1. F.J. Dyson, **Advanced Quantum Field Theory**, World Scientific Publishing Co. 2007.
2. Lewis H. Ryder, **Quantum Field Theory**, CUP 2002.
3. Lowell, S. Brown, **Quantum Field Theory**, CUP 1996.
4. M. Srednicki, **Quantum Field Theory**, CUP 2006.

ARTIFICIAL NEURAL NETWORKS (03) **Phy-808**

Introduction to Artificial Neural Network, Neuron models and Network Architecture, Perceptron, Single and Multiple neuron Perceptron, Perceptron learning rule, Supervised, Reinforcement and Unsupervised learning, Signal and weight vector 'spaces, Basis vector, Orthogonality, Gram-Schmidt Orthogonalization, Linear transformations, Eigen values and Eigen vectors, Supervised Hebbian Learning, Performance surfaces, Performance optimization, Steepest Descent, Widrow-Hoff learning, Adaline networks,' LMS algorithm, Adaptive filtering, Back propagation rule, back propagation variations, Radial basis function network, Competitive Learning, Hamming networks, Mexican Hat function, Feature maps, Learning vector Quantization, Simulated annealing, Boltzmann machine, Recurrent network energy functions, Hopfield network, Non-linear dynamical systems, Liapunov stability, attractors. Application to Machine Vision and Audience problem.

BOOKS:

1. Haykin, H. **Neural Networks**. 2nd Ed. Prentice Hall, 1999.
2. Haykin, S. **Neural Networks and Learning Machines**, 3rd Ed. Prentice Hall, 2009.
3. K. Mehrotra, C. Mohan, and S. Ranka, **Elements of Artificial Neural Networks**, MIT Press, 1997.
4. Graupe, D. **Principal of Artifi'cal Neural Networks**, 2nd Ed. World Scientific Publishing, 2007.

QUANTUM OPTICS (03) **Phy-809**

1. Introduction and background: Introduction: What is quantum optics? A brief history of quantum optics.Classical optics: Maxwell's equations and electromagnetic waves, Diffraction' and interference, Coherence, Nonlinear optics.Quantum mechanics: Formalism of quantum mechanics, Quantized states in atoms, The harmonic oscillator, The Stern-Gerlach experiment, The band theory of solids.Radiative transitions in atoms: Einstein coefficients, Radiative transition rates, Selection rules, the width and shape of spectral lines, Line broadening in solids, Optical properties of semiconductors, Lasers.

2. Photons: Photon statistics: Introduction, Photon-counting statistics, Coherent light: Poissonian photon statistics, Classification of light by photon statistics. Super-Poissonian light, Sub-Poissonian light, Degradation of photon statistics by losses, Theory of photo-detection, Shot noise in photodiodes, Observation of sub- Poissonian photon statistics.

Photon antibunching: the intensity interferometer, Hanbury Brown-Twiss experiments and, classical intensity fluctuations, the second-order correlation function $g^2(\tau)$, Hanbury Brown-Twiss experiments with photons, Photon bunching and antibunching, Experimental demonstrations of photon antibunching, Single-photon sources.

3. Coherent states and squeezed light: Light waves as classical harmonic oscillators, Phasor diagrams and field quadratures, Light as a quantum harmonic oscillator, 'The vacuum field, Coherent states, Shot noise and number-phase uncertainty, Squeezed states, Detection of squeezed light, Generation f squeezed states, Quantum noise in amplifiers.

Photon number states: Operator solution of the harmonic oscillator, The number state representation, Photon number states, Coherent states, Quantum theory of Hanbury Brown-Twiss experiments.

4. Atom-photon interactions: Resonant light-atom interactions: Introduction, Preliminary concepts, The time-dependent Schrodinger equation, The weak-field limit: Einstein's B coefficient, the strong-field limit; Rabi oscillations, The Bloch sphere. Atoms in cavities: Optical cavities, Atom-cavity coupling. Weak coupling, Strong coupling, applications of cavity effects. Cold atoms: Laser cooling, Bose-Einstein condensation, Atom lasers.

5. Quantum Information processing: Quantum cryptography: Classical cryptography, Basic principles of quantum cryptography, Quantum Key distribution according to the BB84 protocol, System errors and identity verification, Single-photon Sources, practical demonstrations of quantum cryptography.

6. Quantum computing: Introduction, Quantum bits (qubits), Quantum logic gates and circuits, Decoherence and error correction, Applications of quantum computers, Experimental implementations of quantum computation.

7**. Entangled states and quantum teleportation:** Entangled states, Generation of entangled photon pairs, Single-photon interference experiments, Bell's theorem, Principles of teleportation, Experimental demonstration of teleportation,

BOOKS:

1. Mark Fox, "**Quantum Optics, An Introduction**", Oxford Master Series in Physics (2006).
2. Mikio Nakahara & Tetsuo Ohmi, "**Quantum Computing**" , A Taylor & Francis Group New York (2008).
3. Marian O. Scully & M. Suhail Zubairi, "**Quantum Optics**", The Press Syndicate of the University of Cambridge (2001).'
4. R. R. Puri, "**Mathematical Methods of Quantum Optics**", Berlin (2001).
5. D. F. Walls & G. J. Milburn, "**Quantum Optics**", Auckland, New Zealand, St. Lucia, Australia (1994).

ADVANCED OPTICAL TECHNIQUES (03) **Phy-810**

Introduction: Spectrometry, Spectrography and applications.

Interferometry: Interferometry, Principle, Imaging Interferometry.

Imaging: Imaging methodology and techniques, types of imaging, digital imaging, geophysical imaging, medical imaging,. Magnetic resonance imaging, molecular imaging, optical imaging, radar imaging, reprography, cinematography, photography, xerography, speckle imaging, stereo imaging, thermography, infrared' imaging, holographic, radiography, magnetic resonance imaging (MRI), nuclear medicine, photo acoustic imaging, breast thermography, tomography, ultrasound, maximizing imaging procedure use, creation of three-dimensional images, compression of medical images, non-diagnostic imaging, archiving and recording, open source software for medical image analysis, use in pharmaceutical clinical trials.

Experimental setups: Spectrometry, Interferometry, Imaging. Measurement of Basic material Properties: Fourier transforms infrared spectroscopy, photoluminescence, and Raman scattering.

Project: Designing of a system to study: Absorption, Reflection, and Transmission of photovoltaic Thin Films, Quantum efficiency, of Silicon solar cells, interference Lithography.

BOOKS:

1. J. Wilson, J. Hawkes, Optoelectronics: An Introduction, 3rd edition, Prentice hall, 1998.
2. F. Graham Smith, Terry A. King, Dan Wilkins, Optics and Photonics, 2nd Edition An introduction, 2007.
3. V. Lihong Wang, Hsin-I Wu, Biomedical Optics Principles and imaging, 2007.
4. Diter Meschede, Optics, Lights and Lasers, 2nd Edition, The Practical Approach to modern Aspects of Photonics and Laser Physics, 2007.
5. K. Okan Ersoy, Diffraction, Fourier, Optics and Imaging, 2006.

ATMOSPHERIC DYNAMICS & MODELING: (03) **Phy-811**

Equations of motion in spherical co-ordinates, rotating frame, Coriolis force, quasi-static approximation. Energy and angular momentum consistency of quasi-static approximations, Scale Analysis. Rossby number, Natural Co-ordinate System, Trajectory and Stream lines Blatons Equation. balanced flow-Geostrophic Flow, Inertial Flow, Cyclostrophic Flow and Gradient Flow. Equations of continuity in spherical and Cartesian co-ordinates. Thermodynamic energy equation, pressure as vertical co-ordinate and Basic equations in Isobaric Coordinates. Generalized vertical coordinates. Differential Properties of wind Fields Translation. Divergence, Rotation and Deformation, Differtial equation for stream lines

Vertical Variation or Winds Thermal Wind, veering and backing, hodograph Kinematics of Pressure Fields: Intensification and Weakening: Deepening and Filling. Circulation, vortices, divergence, Stokes Theorem, Divergence Theorem, Circulation theorems - Kelvin's Theorem and Bjerknes Theorem and applications of Circulation theorems - Sea Breeze and Land Breeze: General Circulation. Solenoidal Vector, Barotropic and baroclinic t1uids. Helmholtz theorem for split of horizontal wind vector. Vortices and divergence equations, Scale Analysis, Balance Equation. split of vorticity and divergence equations into rotational and irrotational terms. Principles or dynamical similarity, laboratory simulation of some atmospheric phenomena like general circulation, monsoon flow-tornadoes etc. Elements of numerical modeling or atmospheric phenomena.

Basic physical and mathematical concepts; the fundamental and apparent forces, Momentum, continuity and thermodynamic equations; spherical coordinates; scale analysis, isobaric coordinates, balanced flow, trajectory and streamlines; thermal wind; vertical motion: surface pressure tendency. The circulation theorem: the vorticity equation, the barotropic and baroclinic potential vorticity equations. Atmospheric turbulence; turbulent kinetic energy; boundary layer momentum equation; secondary circulation and spin-down. Quasi-geostrophic approximation and prediction diagnostic of vertical motion; baroclinic disturbance. The perturbation method; simple wave types; gravity waves; Rossby waves. Filtering meteorological noise; the finite difference method; the spectral method; primitive equation models; data assimilation.

BOOKS:

1. Jonathan E. Martin, (2006), Mid-Latitude Atmospheric Dynamics: A First Course, Wiley.
2. Amanda H. Lynch & John J. Cassano, (2006), Applied Atmospheric Dynamics, Wiley.
3. Bernard Etk in. (2005), Dynamics of Atmospheric Flight, Dover Publications.
4. Mark Z. Jacobson, (2005). Fundamentals of Atmospheric Modeling, Second Edition, Cambridge University Press.

<u>QUANTUM THEORY OF SOLIDS</u> (3) **<u>Phy-812</u>**

Introduction to the Hamiltonian, basic approximations: Interacting electrons and nuclei; Born-Oppenheimer and adiabatic approximations

Second quantization and green functions: quantum gases Free Fermi Gas (Fermiology), Introduction to Fermionic fields and second quantization, Green's function for free electrons; Lattice dynamics, Introduction to Bosonic fields Green functions for phonons.

Interacting electrons: Hartree-Fock; Lindhard dielectric function; Correlation functions and measurements; Density-Density correlation function, particle hole excitations, plasmons, sum rules; Fermi-liquid theory; Density-Functional Theory.

Magnetism in solids Magnetic impurities, Anderson model; RKKY; The Kondo problem; Quantum Hall effect.

Electron-phonon interaction: The electron-phonon Hamiltonian; Migdal's theorem; Effective electron-electron interaction.

Superconductivity: Cooper pairs; BCS theory; Josephson effect

Special topics: Graphene, Dirac electrons in solids, Klein paradox; Spin-Orbit interaction: Solid Helium, Supersolid.

BOOKS:

1. Eoin P. O'Reilly, Quantum theory of solids. (2002), Taylor & Francis
2. Daniel 1.Khomskii, Basic Aspects of the Quantum Theory of Solids: Order and Elementary Excitations. (2010), Cambridge University Press.

3. Charles Kittel, Quantum theory of solids. (2008), Wiley;
4. Lev Kantorovich, Quantum theory of the solid state: an introduction. (2004), Springer
5. H. Ibach, Hans Luth, Solid-state physics: an introduction to principles of materials science (2003), Springer.

ELECTRON MICROSCOPY AND DIFFRACTION (03) **Phy-813**

Introduction: The theory and advanced analysis techniques in transmission electron microscopy (TEM) and electron diffraction.

Diffraction theory: kinematic theory, dynamical two beam theory, dispersion surface, many beam solutions and absorption effects.

Contrast analysis in microscopy: Contrast analysis in high resolution microscopy and defect studies.

The theory behind advanced analysis techniques: EDS (X-ray micro analysis), EELS electron energy loss spectroscopy), EFTEM (energy filtered TEM), CBED (convergent beam electron diffraction), and HAADF/STEM (high angle annular dark field/scanning TEM).

BOOKS:

1. Brent Fultz, James M. Howe, Transmission electron microscopy and diffractometry of materials. (2007), Springer.
1. David Bernard Williams, C. Barry Carter, Transmission electron microscopy: a textbook for materials, science, Volume 1: a textbook for materials science. (1996), Springer.
2. Marc De Graef; Introduction to conventional transmission electron microscopy. (2003), Cambridge University Press.
3. David C. Joy, Alton D. Romig, Joseph Goldstein, Principles of analytical electron microscopy (1986), Springer.
4. Ludwig Reimer, Transmission electron microscopy: physics of image formation and microanalysis. (1997), Springer.
5. Manfred Ruhle, Frank Ernst, High-resolution imaging and spectrometry of materials (2003), Springer.

SUPERCONDUCTIVITY (03) **Phy-814**

Overview of superconducting materials, Physics of superconductivity, both microscopic quantum theory and phenomenological Ginzburg-Landau theory.

Discovery zero resistance and critical temperature, Magnetization, perfect diamagnetism, Meissner effect, trapped flux, type-I and type-II Behaviour, superconducting elements and compounds, cuprate superconductors, structures and preparation, doing phase diagram

Quatitative description of superconducting state, the pair state, effective wave function, Y(r) time and space dependence of the phase, Ahoronov-Bohm effect, London equations, penetration depth, flux quantization, gauge invariance.

Thermodynamics of superconductors, free energy, critical heat capacity, Second order phase transition, demagnetization effects. Applications of superconductors, both on the small scale and on the large scale.

BOOKS:

1. Ashcraft and Mermin, Solid State Physics, 1976
2. C Kittle, introduction to solid state Physics, National Book Cor., 7 e/d 2005
3. Stephen Blundell, Superconductivity -A short Introduction, (2009), Oxford University Press.
4. Kristian Fossheim and Asle Sudbo: Superconductivity. Physics and applications(2004) Wiley & Sons.

<u>BIOPHYSICAL TECHNIQUES & INSTRUMENTATION</u> (3) **<u>Phy-815</u>**

1. Spectroscopic Techniques: Principle, Instrument Design, Methods & Applications of UV-Visible Spectra, IR Spectra, Raman Spectra, Fluorescence spectra, NMR and ESR Spectra.

2. Hydrodynamic Techniques: Principle, Instrument Design, Methods & Applications of all types of Adsorption & Partition Chromatography, Centrifugation & Ultracentrifugation, Viscometry, Osmosis, Diffusion and Surface tension.

3. Electroanalytical Techniques: Principle, Instrument Design, Methods & Applications of Free & Zone (Paper, gel, Pulsed-field, PAGE, SDS-PAGE, Capillary) Electrophoresis, isoelectric focusing, Potentiometry, pH meter, ion selective electrodes, conductometry.

4. Optical Techniques: Principle, Instrument Design, Methods & Applications of Polarimetry, ORO, CD, Light scattering, Refractometry, Flowcytometry, Cytophotometry, Compound, Phase contrast, Interference, Fluorescence, Polarizing, Scanning & Transmission Electron Microscopy, CCD Camera, Introduction to Atomic Force Microscopy.

5. Diffraction Techniques: Crystals, Molecular crystal symmetry, X ray diffraction by crystals, Bragg's Law; Laue powder and rotation methods, Calculating electron density and patterson maps (Fourier transform and Structure factors, convolutions), phases, model building & evaluation, Neutron diffraction, Electron diffraction, Application in Biology.

BOOKS:

1. Wilson. K and Walker. J., (2006); Biophysical techniques, Cambridge University Press.
2. Ackerman E.A. Ellis, L.E.E. & Williams L.E. (1979), Biophysical Science, Prentice-Hall Inc.
3. Bulter l.A.V. And Noble D.Eds. (1976), Progress in Biophysics and Molecular Biology Pergamon, Oxford.
4. Casey E.J. (1967), Biophysics, concepts and mechanisms. Affiliated East west press.
5. Chang R. (1971), Basic principles of spectroscopy..Mcfiraw-Hill.

<u>RADIATION BIOPHYSICS</u> (03) **<u>Phy-816</u>**

Radiological Physics Atomic structure models, Constituents of atomic nuclei, Isotope, Radioactivity, laws of Radioactivity, Alfa, Beta, Gamma rays, Properties of Electromagnetic radiation, Particle accelerate absorbed cyclotrons & synchrotrons, Radiation units- Units of radioactivity, exposure & dose, Dose equivalent unit, Particle flux & fluence, X & Gamma ray interaction with matter; 'Photoelectric & Compton effect, Ion pair production, dependence on atomic weight, Interactions, absorption & scattering of electron, Heavy charged particles & Neutrons, attenuation coefficient- linear, mass, electronic & atomic, HVL, Mean free path, Absorption edges, LET.

Radiochemistry & radiobiology: Radiolysis of water, Production of free radicals & their interactions, Competition kinetics, Kinetic constants studies of transient species, Pulse radiolysis, Diffusion kinetics & Physicochemical effects. Role of scavengers, Gvvalue, Direct and Indirect action, Oxygen and temperature effect, OER, Action of radiation on living system - Viruses, Prokaryotic & Eukaryotic.cells, Cellular radiation action, Radio sensitization and protection, Target theory, Single hit & Multi hit theory, Multi target theory, Calculation of target, Mass, Volume & Molecular weight, Effect of radiation on Nucleic acids, Proteins, Enzymes & Carbohydrates, Cellular effects of radiation, Mitotic delay, Inhibition of mitosis, Giant cell formation, Cell death, Cell recovery & Modification of Radiation damage, Genetic Effect of radiolysis, Factors affecting frequency of radiation induced mutation, Chromosomal breakage and Aberrations, Somatic effect of radiation, Physical factors influencing somatic effects, Dependence on dose, Dose rate, Type & Energy of radiation, Temperature, Anoxia age, Acute radiation damage, LD-50, Radiation syndrome, Early and late effects of radiation, Effect of Chronic exposure to radiation, Dose effect relationship, Genetic burden, Concept of doublin-g dose' &."ltseffect on genetic equilibrium.

Radiation detection and Measurement: Principles of radiation detection and measurement, General requirements of Dosimeters, Radiation sources, Telegamma Unit (Cobalt unit), Gamma chamber, Nuclear reactors, Thermal & fast neutron sources, Basic principles, Design & Working of physical dosimeters- Ionization chamber, Proportional counters, GM- Counter, Concepts of Gas amplification, Resolving time & Dead time, Scintillation Detectors, Thennolumeniscent Dosimeter, Semiconductor, Surface barrier & Lithium detectors, Area survey meter & Pocket dosimeter, Film badge, General principle of chemical dosimetry, Salient Features of Chemical dosimeter, Dose evaluation formula for chemical 'dosimetry, Principles of radiolytic reaction, Experimental methods- Influencing factors of Fricke dosimeter methyl orange, FBX dosimeter, Free radical dosimeter, Ceric sulphate dosimeter, PMMA, PVC, chlorobenzene dosimeter, High & low dose indicators.

Radiation safety measures: Natural & Man-made radiation exposures or Principles of dose equivalent limit (DEL) radiation protection, Maximum permissible dose (MPD), Evaluation of external & internal radiation hazards, Radiation protection measures in industrial establishment, Radioisotope labs, diagnostic & therapeutic installation & during transportation of radioactive substances; disposal of radioactive waste, administrative & legislative aspect of radiation protection.

Applications of Radioactivity: Radioisotopes in biology, Agriculture, Plant breeding, Soil plant relationship & plant physiology, Medicine, (Therapy & diagnosis), Radioimmunoassay, Radio tracer techniques with illustrative examples, Autoradiography, General principles, Types & constitutions of photographic emulsion, Auto radiographic technique, Image quality, Resolution, Evaluation of autoradiograms, Specialized radio-isotopic applications in industries .

BOOKS:

1. Michael G. Stabin, Radiation.Protection and Dosimetry: An Introduction to Health Physics (20I0) Springer
2. Castellan A. and Querela I.F. (1979), Synchrotron Radiation, Applied to Biophysical and Biochemical Research, Plenum Press.
3. Howard L. A. (1974), Radiation Biophysics, Prentice Hall Inc.
4. Knoll G.E.(1979), Radiation detection and measurement, John willey and sons.
5. Martin A. & Harbisan S.A. (1982), An introduction to Radiation Protection, Chapman and hall Publication

MICROWAVE COMMUNICATION **Phy-817**

Signal Analysis: Continuous spectrum of signals, Transmission of signals based on frequency and time division, Sampling of signals, Coding and errors.

Network Theory: Series and parallel tuned circuits, characteristic impedance, the T-Network and the π-Network, Low pass, band pass, and band stop filters.

Transmission lines: Transmission line equations, secondary line constants, attenuation, propagation co-efficient “β”, impedance matching, quarter-wave and half-wave transformers.

Antennas: Radiation from half-wave dipole and quarter-wave monopole, radiation pattern, impedance, gain and polarization of antenna, linear antenna arrays, printed antennas.

Radio wave Propagation: Ionospheric reflection, ionospheric scattered mode, tropospheric refraction, tropospheric scatter, refractivity.

Satellite Communication: FDMA, TDMA, and CRMA systems, transponder system, VSAT and, USAT systems, satellites in synchronous and asynchronous orbits.

Digital Systems: Digital modulation, digital filtering, the IIR and FIR filters.

Modulation: AM and FM modulation, FM modulators and demodulators.

BOOKS:

1. R.E.Collin, Antennas and Radio wave Propagation.
2. David M. Posar, John Wiley & sons, Inc. 2006.
3. Stephan C. Harsany, Principles of Microwave Engineering, Prentice-Hall 1997.
4. A. Rudge, K. Milne, Dolver, P. Knight, The Handbook of "Antenna Design, Peter Perigrinus, lEE Press,1984.

SATELLITE COMMUNICATIONS SYSTEM (03) **Phy- 818**

1. **Introduction to Satellite Communications:** Overview of Satellite System Engineering, Orbital Aspects of Earth Satellites, Orbital Mechanics and Orbital Elements, Azimuth and Elevation, Coverage Angle and Slant Range, Placement of a Satellite in a Geostationary Orbit

2. **Satellite Link Design :** Basic Radio Transmission Theory, System Noise Temperature and G/T Ratio, Uplink and Downlink Design, Interference Analysis, Carrier-to-Noise plus Interference Ratio, Interference to and from Adjacent Satellite Systems, Terrestrial Interference, Cross-polarization Interference, Intermodulation Interference, Design of Satellite Links for Specified Carrier-to-Noise plus Interference Ratio, Digital Satellite Link

3. Propagation on Satellite-Earth Paths and Its Influence on Link Design: Absorptive Attenuation Noise by Atmospheric Gases, Rain Attenuation, Noise due to Rain, Rain Depolarization, Tropospheric Multipath and Scintillation Effects

4. Modulation, Multiplexing and Multiple Access Techniques in Satellite Communications
Classification of Different Analog and Digital Modulation Schemes as Used in Satellite Communications and their Performance, Band-Limited Nonlinear Satellite Channel, Digital Modulation with Error-Correction Coding, Different Multiple and Multiple Access Techniques as Used in Satellite Communication

5. Earth Station Technology: Types of Earth Stations and Design, Types of Antennas in Satellite Communications, Small Earth Station Antennas

6. **Types of Satellite Networks:** Fixed Point Satellite Network, INTELSAT, Mobile Satellite Network, INMARSAT, Low Earth Orbit and Medium Earth Orbit Satellite Systems, Very Small Aperture Terminal (VSAT) Network, Direct Broadcast Satellite Systems

BOOKS:

1. Timothy Pratt, Charles W. Bostian, and Jeremy E. Allnutt, "Satellite Communications, Second Edition," 2002.
2. Dennis Roddy, "Satellite Communications, Fourth Edition," 2006.
3. Tri T.Ha: "Digital Satellite Communications" , McGraw?Hill, 1990

MICROPROCESSOR (03) **Phy-819**

1. 8086 and 8088 microprocessors
Pin-outs and the pin functions of 8086 and 8088, clock generator (8284A), bus buffering and Latching multiplexing the buses, demultiplexing the 8088, demultiplexing the 8086, the Buffered system, the fully buffered 8088 and 8086), bus timing.

2. Microprocessor Architecture
Internal microprocessor architecture, the programming model, multipurpose registers, segment registers

3. Memory Interface
Memory device (memory pin connections, ROM, static RAM devices, dynamic RAM Memory, SIMM, DIMM), address decoding (why decode memory, simple NAND gate Decoder, 3 to 8 line decoder 74LS138, the dual 2 to 4 line decoder 74LS139, PROM address Decoder, PLD programmable decoders), 8088 and 80 188(8-bit) memory interface, 8086, 80186, 80286 and 80386SX (l6-bit) memory interface, 80386DX and 80486 (32-bit) memory Interface, Pentium through Pentium 4 (64-bit) memory interface.

4. Basic I/O Interface

Introduction to I O interface (1/0 instructions, isolated and memory mapped I/O, personal Computer I/O map, basic input interface, basic output interface, handshaking, input devices, Output devices), I/O port address encoding (decoding 8-bit I/O address, decoding 16-bit I/O Address, 8 and 16-bit I/O port, 32-bit wide 1/0 ports), programmable peripheral interface (Basic description of 82C55, programming the 82C55, mode 0 operation, an LCD interface To 82C55, stepper motor interfaced to 82C55, key matrix 'interface, mode 1 strobe input, Mode 1 strobe output, mode 2 bi-directional operation), the 8279 programmable keyboard/display interface] interfacing the 8279 to the microprocessor, keyboard interface, six-digit display interface), analog to digital and Digital to Analog converters.
5. Interrupts: Basic interrupt processing interrupts vectors, interrupt instructions, and interrupt flag bits, hardware interrupts (82C55 key board interrupt), 8259A programmable interrupt controller.
6. Direct Memory Access and DMA Controlled I/O: Basic DMA operation, the 8237 DMA controller, shared Bus operation/ types of buses, the Bus arbiter, 8289 architecture, priority logic using the 8289, parallel priority, print spooler And interface).
7. The Pentium 2,3 and 4.Microprocessors: Introduction to Pentium 2 microprocessor (memory system, 1/0 system, Pentium 2 software changes, the Pentium 3, the Pentium 4.
8. Parallel processing: Concept of parallel processing, pipe lining, dual microprocessor based system, Quarts microprocessor based system.

BOOKS

1. Barrey B. Brey 'The Intel Microprocessors 8086/8088, 80186/81088,80286, 80386, 80486, Pentium and Pentium Pro Processor, Pentium 2, Pentium 3, Pentium 4: Architecture, Programming and Interfacing' The Prentice Hall (2005)

<u>OPTOELECTRONIC MATERIALS AND DEVICES</u> (03) **<u>Phy-820</u>**

1. Electronic properties of semiconductor materials for optoelectronic devices: Theory and electrical characteristics of semiconductor materials for optoelectronic devices.
2. Optical properties of selected semiconductor materials: Optical characteristics of some semiconductor materials, Photonic band gap materials.
3. P-N junction - the basic structure for optoelectronic device realization: Operation of various junctions including Schottky– barrier contacts, Heterojunctions and their importance to optoelectronic device fabrication, Solar cells
4. Light Emitting Diodes: Operation of LEDs, their structures, and applications, Homojunctions and heterojuntions
5. Semiconductor Laser Diodes: Operation of semiconductor laser diodes semiconductor lasers, Types of semiconductor lasers, Multiquatum-well lasers, Beam characteristics and modulation of semiconductor lasers, Role of semiconductor lasers in modern fiber-optic communication systems.
6. Photodetectors: Operation of different types of photodetectors, Materials for their fabrication of photodetectors and their applications.

BOOKS:

1. Pallab Bhattacharya: Semiconductor Optoelectronic Devices, (2nd Edition) 1996.
2. J. Piprek: Semiconductor Optoelectronic Devices: Introduction to Physics and Simulation (1st Edition) 2003

<u>PLASMA PHYSICS-II (03)</u> **<u>Phy-821</u>**

1. Basic concepts of inertial and magnetic confinement fusion schemes, fusion reactor physics, thermonuclear fusion reaction criteria and driver requirements, scenario for ICF, fusion fuel burn physics.
2. The physics of hydrodynamic compression, plasma hydrodynamic, shock wave propagation in plasmas, isentropic compression, hydrodynamic stability of the implosion process, equation of state models, and ablation driven compression.

3. Energy transport in ICF plasmas, electron thermal conduction, thermal conduction inhibition, spontaneous magnetic field generation, suprathermal electron transport, radiation transport models.
4. Nonlinear mechanisms in plasmas, solitary waves and solitons, ion-acoustic solitary wave, the Korteweg-de-Vries (KdV) equation, ion-acoustic and Alfven wave solitons, Nonlinear Schrodinger equation, Nonlinear Landau damping, Bernstein-Greene-Kruskal (BGK) modes, and introduction to dusty plasmas with applications.

BOOKS:

1. Inertial Confinement Fusion, by J. J. Duderstadt and G. A. Moses, publisher: John Wiley & Sons, New York; 1st edition, (1982).
2. Plasma Waves, by D. G. Swanson, publisher: IoP, Bristol and Philadelphia; 2nd edition, (2003).
3. Introduction to Dusty Plasma Physics, by P. K. Shukla and A. A. Mamun, publisher: IoP, Bristol and Philadelphia; 1st edition, (2002).

EXPERIMENTAL PLASMA PHYSICS (03) Phy-822

1. **Plasma generation:** Energy storage and transfer for high temperature plasma generation and current drive techniques. Z-pinch, θ-pinch, and plasma focus devices. Cold plasma generation, characteristics of DC glow discharge, RF discharges and cold plasma reactors.
2. **Probes for plasma diagnostics:** Rogowski coil, high voltage probe, magnetic probe, Langmuir probe, voltage loops and Mirnov coils.
3. **Charged particle and neutron diagnostics**: Faraday cups and solid state nuclear track detectors for detection and analysis of charged particles, Time-resolved and time-integrated neutron measurement.
4. **Laser as a diagnostic tool:** Propagation of (optical frequency) electromagnetic wave through plasma both in the absence and presence of magnetic field, shadowgraphy and schlieren imaging, interferometry and determination of plasma density, measurement of magnetic field by Faraday rotation, Thomson and Rayleigh scattering.
5. **X-ray diagnostics of plasmas:** X-ray emission from plasmas, absorption filters and their selection, time-resolved x-ray detectors, pinhole imaging camera, estimate of plasma electron temperature.
6. **Plasma Spectroscopy**: Radiative processes in plasmas, Collisional processes in plasmas, statistical plasma models, plasma optical spectroscopy, and evaluation of plasma parameters.

BOOK:

1. Industrial Plasma Engineering, by J. Reece Roth, Institute of Physics Publishing Bristol (2000).
2. Principles of Plasma Diagnostics, by I. H. Hutchinson, Cambridge University Press New York (1999).
3. Handbook of Radiation Effects, by A. H. Siedle and L. Adams, Oxford University Press (2002).
4. Principles of Plasma Processing, F. F. Chen and J. P. Chang, Kluwer Academic/ Plenum Publishers New York (2003).
5. Principles of Plasma Spectroscopy, by H.ans R. Griem, Cambridge University Press (1997).

OPTICAL NETWORK AND ENERGY COMMUNICATION NETWORKS (03) Phy-823

1. Wavelength-routed optical wide-area networks (WANs): Motivation for optical networking, Wavelength division multiplexing (WDM) networks, Static dimensioning of optical WAN, Routing and wavelength assignment (RWA), Network optimization with integer linear programming (ILP), RWA under physical constraints on transmission, Recovery from link and node failures, Roles of optical wavelength conversion, Dynamic RWA for WANs, Distributed light path setup and release,

2. Optical metro-area networks (MANs): Topology designs for MANs, RWA for regular topologies, Static traffic grooming, Dynamic traffic grooming

3. Optical local-area networks (LANs): Topology designs for LANs, Passive optical networks and their physical limits, Multiple access control (MAC) for optical LANs, Contention-based protocols, Reservation-based protocols, Packet scheduling algorithms with quality of service (QoS) awareness

4. Alternative architectures for optical networks: Optical packet switching (OPS), Optical burst switching (OBS), RWA and scheduling for OPS/OBS, Roles of optical fiber delay lines (FDLs)

5. Smart Grids & Communication Networks: Smart grid and its role in our energy future, Elements of the energy grid and the need for communication networks, Energy Transmission: wireless and wired networks

BOOKS:

1. Gerd Keiser, "Optical Fiber Communications, Fourth Edition" 2010.
2. Rajiv Ramaswami, Kumar Sivarajan, and Galen Sasaki, "Optical Networks: A Practical Perspective, Third Edition," 2009.
3. Jane M. Simmons, "Optical Network Design and Planning," 2010.

<u>NANOSTRUCTURED DEVICE FABRICATION</u> (03) **<u>Phy- 824</u>**

1. Device fabrication using AAO: metal-isulator-metal super capacitor, AAO solar cell, microfluidic devices, light emitting diode fabrication, LED display.

2. Device fabrication using ZnO: Optically excited light emission (Photoluminescence, Optically pumped lasers, Nonlinear optics), Electrically driven light emission (ZnO homojunction LEDs, Inorganic heterojunction LEDs, Inorganic–organic hybrid LEDs, Schottky diode-based LEDs, Light extraction, Electrochromic displays), Solar cells(Enhancement of light absorption, Dye sensitized solar cells, Quantum dot-sensitized solar cells, Inorganic p–n junction solar cells, Hybrid solar cells), Piezoelectric nanogenerators (Fundamentals, Atomic force microscopy-based nanogenerators, Direct current nanogenerators, Alternating current nanogenerators), Photonic crystals, Water splitting, Field effect transistors, Sensors.

3. Device fabrication using CNT: Carbon nanotubes as AFM probes, Fabrication of nanotube probe tips, AFM imaging with nanotube probes, Applications of carbon nanotube probes, Applications in structural biology, Nanolithography, SWNT probe functionalization, Nanoelectrode scanning probes, Metallic carbon nanotubes (Ballistic transport, Resonant scattering centers and resonant tunneling Current-carrying capacity, current saturation), Semiconducting carbon nanotubes (Nanotube field effect transistor, Schottky barriers, Gate-oxide scaling, Ambipolar transistor , High-performance FETs)

BOOKS

1. “Nanostructured Materials in Electrochemistry” Richard C. Alkire, Yury Gogotsi, Patrice Simon, Ali Eftekhari, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim 2008
2. “Zinc Oxide: Fundamentals, Materials and Device Technology” Hadis Morkoç and Ümit Özgür, WILEY-VCH Verlag GmbH & Co. KGaA, 2009
3. “Carbon Nanotubes and Related Structures Synthesis, Characterization, Functionalization, and Applications” Dirk M. Guldi and Nazario Martín, WILEY-VCH Verlag GmbH & Co. KGaA, 2010

Recommended Articles

1. One dimensional ZnO Nanostructures: Solution growth and functional properties.
2. Sheng Xu and Zhong Lin Wang, June 2011, Springer
3. Zinc Oxide Nanostructures: growth properties and applications, Zhong Lin Wang, June 2004, Journal of Physics: Condensed Matter, R829-R858