I. Solid state physics - an introduction

Lecturer: prof. dr hab. B. Mróz
Number of hours: 15

Short description

The main aim of this introduction is to give students the basic knowledge about the influence of the symmetry of solid material for its physical properties. This will be done by explanation of the origin of the energy gap in crystals. Both phonons and electron dynamic will be discussed. Then the set of three different ferroic materials (electric, magnetic and elastic) will be introduced and described with the respect to their potential application as an information carries.

Outline:

1. Static picture of the crystal lattice
2. Dynamical approach
   a. Dispersion relations
   b. Phonons
   c. Electrons
3. Heat capacity in solids
4. Drude theory and Fermi surface
5. Origin of the energy gap
6. Photoelectric effect
7. Double states crystallographic systems
   a. Ferroelectrics
   b. Ferroelastics
   c. Ferromagnetics
8. Examples of application in the nanoelectronics

II. Electron properties in 1D and 2D systems

Lecturer: dr hab. Maciej Zwierzycki (IFM PAN)
Number of hours: 15

Short description

Low dimensional structures determine unusual properties of electron transport. Physical phenomena and their theoretical models will be presented during the lecture.

Outline:

1. Fundamental equations (Dirac equation, Schrodinger equation)
2. Current carriers (fermions and bosons**,** Dirac fermions, Majorana fermions)
3. Electron transport (ballistic and diffusive transport, topological states, potential barrier and energy bands, tunneling effect, quantum Hall effect, Coulomb blockade, spin transfer)

III. Unique properties of nanomaterials

Lecturer: dr hab. Lesław Smardz (IFM PAN)
Number of hours: 15

Short description

Using nanotechnologies, the properties of materials can be controlled for special applications and a great deal of research work in nanotechnology aims for the control of physical and chemical properties. During the lecture complex characterization of thin layers, nanoparticles, quantum dots, carbon materials, photonic and phononic materials, nanocomposites will be given.

Outline:

1. Structural properties
2. Thermal properties
3. Chemical properties
4. Mechanical properties
5. Magnetic properties
6. Optical properties
7. Electronic properties

IV. Principles of photovoltaics

Lecturer: Dr. Marcin Ziółek
Number of hours: 15

Short description

The lecture will present principles and methods of characterization for the first, the second and the third generation of photovoltaic. The physical basis for the construction of photovoltaic semiconductor will be discussed. The current knowledge and achievements in the field of research on a new generation of solar cells (polymer, dye-sensitized and nanocrystalline) will be presented. The key processes underlying the operation of the solar cells, belonging to the frontier of physics (thermodynamics, physics of semiconductors, charge transport) and chemistry (photochemistry, electrochemistry, chemical synthesis) will be discussed. Part of the lecture will be devoted to the use of modern measurement techniques (especially the impedance spectroscopy and laser spectroscopy) to study charge transfer and transport in solar cells.

Outline:

1. The human demand for solar energy, the characteristics of sunlight.
2. Thermodynamics of the conversion of radiation energy into electricity, limits of the solar cells efficiency.
3. Properties of semiconductors and their nanostructures from the point of view of charge transport and the use in photovoltaics.
4. The construction and operation of silicon photovoltaic devices of different generations (monocrystalline, polycrystalline, amorphous).

5. Operation basis of thin-film photovoltaic cells and multi-junction solar cells.
6. The studies of a new generation of solar cells (polymer, dye-sensitized and nanocrystalline).
7. Methods of the fundamental characteristics of solar cells (J-V curves, IPCE spectra).
8. Impedance spectroscopy and optical spectroscopy in photovoltaic studies.

V. Nanomaterials in photovoltaics

Lecturer: Dr. Marcin Ziółek
Number of hours: 15

Short description

During the lecture will be presented on selected topics of modern research on nanomaterials, with particular emphasis on their application in photocatalysis and photovoltaics. The nanostructures and nanocomposites formed from metal oxides, organic semiconductors, carbon materials, aluminosilicate sieves and quantum dots will be discussed. In addition the selected methods for nanostructure preparation and characterization will be presented.

Outline:

1. Properties of inorganic semiconductor at the nano-scale.
2. Semiconductor metal oxides (titanium oxide, zinc oxide, etc.) and the formed nanostructures: nanoparticles, nanotubes, nanorods, and others.
3. Methods for nanostructures preparation of metal oxides (sol-gel, hydrothermal, anodization).
4. The interaction of semiconductor nanostructures with organic dyes, metal surface and liquid phase.
5. Semiconductor quantum dots in photovoltaics (CdS, CdSe, PbS, CdTe).
6. Carbon nanomaterials in photovoltaics.
7. Organic semiconductors, bulk heterojunction.
8. Aluminosilicate molecular sieves (zeolites and mesoporous materials of the MCM-41 type), the effect of doping on their properties.
9. The use of nanomaterials in photovoltaics.
10. Examination of charge transport in nanostructures, the role of trap states in inorganic semiconductors and excitons in organic semiconductors.
11. The use of time-resolved laser spectroscopy for nanostructures studies.

VI. Multiferroics – switchable electronic components

Lecturer: prof.dr hab. B. Mróz
Number of hours: 15

Short description

A ferroelectric crystal exhibits a stable and switchable electrical polarization that is manifested in the form of cooperative atomic displacements. A ferromagnetic crystal exhibits a stable and switchable magnetization that arises through the quantum mechanical phenomenon of exchange. There are very few multiferroic materials that exhibit both of these properties, but the magnetoelectric coupling of magnetic and electrical properties is a more general and widespread phenomenon. There has been a recent resurgence of interest driven by possible new applications of such materials in the information technologies via possibility of manipulating the magnetic state by an electric field or vice versa.

Outline:

1. Multiferroicity and magnetoelectric coupling
2. Classification of ferroelectricity and magnetism coexistance
   a. Independent systems
   b. Ferroelectricity induced by lone pair
   c. Geometric ferroelectricity
   d. Spiral spin-induced multiferroicity
   e. Charge ordered systems
3. Multiferroic nanoscale heterostructures
4. Case studies and relevant experiments

VII. New materials and physical phenomena in nanoelectronics

Lecturer: Dr. hab. Maciej Wiesner
Number of hours: 15

Short description

Scaling down structures to nanometers size allows to explore unusual properties of electron transport. Physical phenomena, observed in such scale, are directly applied to nanoelectronic devices and components. During lectures selected applications of such phenomena will be presented.

Outline:

1. Nanoelectronic devices based upon electron tunneling (physical background, Josephson junctions, Resonant tunneling diodes, low temperature thermometers, fabrication and characterisation)
2. Nanoelectronic devices of FET geometry based upon Coulomb blocade (physical background, single-electron transistor, application of graphene, carbon nanotubes, nanowires to electronic devices such as transistors, fabrication and characterisation)
3. Nanoelectromechanical resonators (physical background, metallic NEMS, graphene and CNT based NEMS, fabrication and characterisation)
4. Nanoelectronic devices based on electron spin (GMR – physical background, spin valve, qbits and logic devices, fabrication and characterisation)

VIII. Magnetic materials in nanoelectronics – properties and fabrication

Lecturer: dr hab. Maciej Urbaniak (IFM PAN)
Number of hours: 15

Short description

Methods of fabrication and properties of magnetic nanomaterials will be discussed. To enable the development of the next generation of magnetic nanostructures fabrication and characterization it is critical to advance the ability of accurately observing and analyzing magnetic phenomena at the nanoscale. Moreover, special attention will be paid to spintronics.

Outline:

1. Giant magnetoresistance
2. Multilayer systems
3. Nanocomposites
4. Storage devices
5. Spintronics systems

IX. Methods of preparation and investigation of nanostructures

Lecturer: Dr. Mariusz Jancelewicz
Number of hours: 10

Short description

The crucial point and the main goal of this lecture is to present issues concerning fabrication and investigation of nanostructures and nanomaterials. The nanostructures from metal oxides, organic semiconductors, carbon materials will be discussed. Moreover, the selected methods for nanostructure characterization will be also presented.

Outline:

1. Photolithography (stages of the process, photoresists and photomasks, fabrication of monocrystals)
2. Atomic Layer Deposition-ALD (advantages, ALD reactors, ALD processes, ALD process window)
3. Reactive Ion Etching-RIE (types of surface etching, mechanisms of etching)
4. Molecular Beam Epitaxy-MBE (homo- and heteroepitaxy, the most important elements of the MBE: block heater, effusion cells, mechanical shutters, UHV pumping system, RHEED system)
5. Lithography by means of Focused Ion Beam-FIB
6. Nanocomposites (classification and characterisation, nanofillers, methods of fabrication)
7. Cleanroom (Sources of contaminations, particles size, HEPA filters, vibrations, ventilations, processing gases and neutralization)

X. Electron and Scanning Probe Microscopy in nanomaterials studies

Lecturer: Dr. Grzegorz Nowaczyk
Number of hours: 15

Short description

The aim of the lecture is to present advanced microscopic methods that can be used for characterization of nanomaterials. The lecture will cover topics concerning physical background of electron microscopy including properties of electron beam to image acquisition and methods for elemental analysis and electron tomography. During the lecture principles of scanning probe microscopy will be also discussed. Special attention will be paid to characterization of the nanomaterials used in semiconducting devices by means of High Resolution Transmission Electron Microscopy.

Outline:

1. Electron microscopy
   a. Physical properties of electron beam
   b. Construction of electron microscopes – transmission and scanning
   c. Types of electron sources and lenses
   d. Interactions of electrons with matter
   e. Electron diffraction
   f. Elastic and inelastic scattering of electrons
   g. Detection of electrons and image formation in transmission and electron microscopes
   h. High resolution Transmission Electron Microscopy
   i. Energy filtered images in TEM
   j. Chemical analysis by means of Energy Dispersive Spectroscopy
   k. Elemental analysis by means of Electron Energy Loss Spectroscopy
   l. Basis of Electron Tomography
   m. Additional features of electron microscope
   n. Preparation of samples (Focused Ion Beam – cutting edge technology for ultra-thin samples
2. Scanning Probe Microscopy
   a. From Interactions at atomic level to the image of topography
   b. Atomic Force Microscopes – constructions and types
   c. Measurements modes in AFM
   d. Scanning Tunneling Microscopy-STM (tunneling effect, STM modes, image resolution, STM scanners, STM manipulations)

XI. Spectroscopy of nanomaterials

Lecturer: dr Adam Rachocki (IFM PAN)
Number of hours: 15

Short description

During this lecture basics of NMR and dielectric spectroscopy will be presented.

Outline:

1. Nuclear Magnetic Resonance
2. Relaxation processes in NMR
3. High resolution spectroscopy
4. Solid state NMR spectroscopy
5. Relaxation processes in dielectric spectroscopy
6. Relaxor and glassy state

XII. The application of X-Ray diffraction in the studies of structure of single-nanowire silicon solar cell

Lecturer: Prof. H. Drozdowski
Number of hours: 15

Short description

In recent photovoltaic research, nanomaterials have offered two new approaches for trapping light within solar cells to increase their absorption: nanostructuring the absorbing semiconductor and using metallic nanostructures to couple light into the absorbing layer.

Photovoltaic conversion of sunlight to electricity is a promising and proven technology for large-scale production of energy from a renewable source. To generate electricity efficiently, however, a photovoltaic cell must absorb most of the solar spectrum as well as collect the photogenerated carriers with minimal losses to recombination. For planar solar cells, this combined task can be difficult because the thickness of material required for adequate absorption of light is often greater than the distance over which photogenerated charges can be efficiently collected.

Experimental measurements and numerical simulations show that the nanowire solar cell exhibits peaks in its photocurrent at wavelengths corresponding to the wire's optical resonances.

The application of the X-Ray diffraction method for study the structure of single-nanowire silicon solar cell as well as issues concerning numerical analysis of data and sources of errors will be discussed during the lecture.

Outline:

1. X-Ray diffraction: general considerations
2. X-Ray diffraction: determination of molecular parameters
3. Structure of molecular crystals and non-crystalline semiconductors
4. The application of X-Ray diffraction in the studies of structure of single-nanowire silicon solar cell