EE 423/523 Nanotechnology and Science Time and place: T, R TBD The course has two components: lectures and labs Instructor: Dr. Vladimir Mitin

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Office Hours: V. Mitin: Tuesday and Thursday 14:00-15:00 and 17:00-18:00

Objectives:

The major goals and objectives are to provide undergraduate and graduate students with knowledge and understanding of nanoelectronics as an important interdisciplinary subject. Through the examples, exercises, educational Java applets, and lab experiments the course will cover electrical properties of materials and nanostructures, chemically-directed assembly of nanostructures, biomolecules, traditional and nontraditional methods of nanolithography, heterostructures, and nanotubes. Students will learn about nanodevices: resonant-tunneling diodes, transistors, single-electron transfer devices, nanoelectromechanical systems, etc.

Grading: Quizzes: 10 %, Homework: 20%, Term paper: 10 %, Two Exams: 30 %, Lab: 30 %. Straight scale will be used for grading with:

Textbook: V. V. Mitin, V. A. Kochelap, and M. A. Stroscio **"Introduction to Nanoelectronics: Science, Nanotechnology, Engineering, and Applications"**, Cambridge University Press, 2008.

References:

1. C. P. Poole and F. J. Owens, "Introduction to nanotechnology", John Wiley & Sons, 2003.

2. M. A. Ratner and D. Ratner, "Nanotechnology: a gentle introduction to the next big idea", Prentice Hall, 2003.

3. S. E. Lyshevski, "Nano- and micro-electromechanical systems fundamentals of nano and microengineering", 2nd Edition, CRC Press, 2004.

4. http://idol.union.edu/~malekis/ESC24/ESC24MainPage/NanoMainPage.htm

Prerequisites: Senior standing for undergraduates (EE 423) and graduate standing for EE 523

Corequisites: None

LECTURES

Topics:

1. Introduction (survey of modern electronics and trends towards nanoelectronics)

- 2. Materials for nanoelectronics
 - 2.1. Semiconductors
 - 2.2. Crystal lattices: Bonding in crystals
 - 2.3. Electron energy bands
 - 2.4. Semiconductor heterostructures
 - 2.5. Carbon nanomaterials: nanotubes and fullerenes

3. Growth, fabrication, and measurement techniques for nanostructures

3.1. Bulk crystal and heterostructure growth

- 3.2. Nanolithography, etching, and other means for fabrication of nanostructures and nanodevices
- 3.3. Techniques for characterization of nanostructures
- 3.4. Spontaneous formation and ordering of nanostructures
- 3.5. Clusters and nanocrystals
- 3.6. Methods of nanotube growth
- 3.7. Fabrication of nano-electromechanical systems

4. Electron transport in semiconductors and nanostructures

- 4.1. Time and length scales of the electrons in solids
- 4.2. Statistics of the electrons in solids and nanostructures
- 4.3. Electron transport in nanostructures

5. Electrons in low-dimensional structures

- 5.1. Electrons in quantum wells
- 5.2. Electrons in quantum wires
- 5.3. Electrons in quantum dots

6. Nanostructure devices

- 6.1. Resonant-tunneling diodes
- 6.2. Field-effect transistors
- 6.3. Light-emitting diodes
- 6.4. Single-electron-transfer devices
- 6.5. Quantum-dot cellular automata
- 6.6. Nano-electromechanical systems

LABS

Nanoscience and Nanotechnology Laboratory, 312B Bonner Hall

The goal of the labs is to explore the experimental basis of nanotechnology and nanoelectronics.

LAB MANUAL: The students are required to purchase the "**EE423/523 Nanotechnology and Science Lab Manual**" from the University bookstore located at the UB Commons (North Campus). The handouts for all the experiments are contained in the Lab manual.

GRADING: 30 % of the Final EE 423/523 Grade is determined from your lab reports. A grading curve will be used to determine the Lab Grade.

LAB REPORTS: Reports are due at the next regular session after each completed experiment. You will work with lab partners in taking data, but you must prepare the report by yourself.

PREPARATION FOR THE LABORATORY: Each student MUST read the appropriate lab before coming to lab each week and make an effort to understand the relevant material. Bring your Manual to each lab session.

LAB LOCATION: Labs 2-9 will be performed in 312B Bonner Hall. We will update you on the place for the first lab.

EACH LAB TAKES APPROXIMATELY 1.5 HOURS

The lab schedule will be arranged to accommodate each student if preferable time will be not the time of class schedule.

EXPERIMENTS:

Nine lab experiments will be carried out by all students. Students will work in groups of two. Students with disabilities or special requirements (e.g. military service) should inform the TA as early as possible.

Experiment 1: Propagation of Errors
Experiment 2: Introduction to Atomic Force Microscopy (AFM)
Experiment 3: Study of the Morpho Butterfly Wing Structure Using AFM
Experiment 4: Introduction to Scanning Tunneling Microscopy (STM)
Experiment 5: Diffraction of Electrons from Graphite
Experiment 6: Diffraction of Light by a Double Slit
Experiment 7: Optical Absorption by CdSe Nanocrystals
Experiment 8-9: Solid-State Lighting

Short descriptions of the experiments are given below.

Experiment 1: Propagation of Errors

In this experiment students will explore how the uncertainty σ_x of parameter *x* determines the uncertainty σ_y of parameter *y* if we know the dependence of *y* on *x* (we assume that we know the function y(x)). The second topic of this lab examines how the uncertainty σ_y of parameter *y* that is determined by *N* parameters $x_1, x_2, ..., x_N$ (we assume that we know the function $y(x_1, x_2, ..., x_N)$) depends on the uncertainties $\sigma_{x1}, \sigma_{x2}, ..., \sigma_{xN}$ of the parameters $x_1, x_2, ..., x_N$. These concepts are demonstrated in a simple optical experiment that involves a lens whose focal length *f* will be determined by measuring the object-lens distance *o* and the image-lens distance *i*.

Experiment 2: Introduction to Atomic Force Microscopy (AFM)

In this experiment students will learn the basic principles of operation of Atomic Force Microscope (AFM). Using this knowledge they will study the surface of the silicon oxide microstructure. They will obtain with the help of AFM the images of the periodic structure of the holes in the silicon oxide layer, including three-dimensional image of the silicon oxide surface layer, and measure the thickness of the microstructure.

Experiment 3: Study of the Morpho Butterfly Wing Structure Using AFM

In this experiment students will be introduced with the help of AFM to fascinating world of tropical Morpho butterflies. They will study the fine complex structure of the butterfly wings on the nanoscale level. Using the obtained data they will be asked to explain the origin of the brilliant iridescent blue color of the Morpho butterfly wings.

Experiment 4: Introduction to Scanning Tunneling Microscopy (STM)

In this experiment students will learn: 1) basic principles of operation of the Scanning Tunneling Microscope (STM) and 2) user-oriented STM software. Using this knowledge they will obtain images of (111) Au film surface.

Experiment 5: Electron Diffraction

In this experiment electrons are accelerated by a known potential difference, V, applied between the cathode and the anode of a cathode ray tube. The electron beam is diffracted by a thin polycrystalline

graphite sheet. The resulting characteristic ring diffraction pattern is observed on the front face of the tube which is internally covered with a fluorescent coating. The diffraction data can be analyzed and the lattice parameters of the graphite can be determined. Within this experiment the wave nature of electrons is clearly demonstrated, and the relationship between the electron de Broglie wavelength and the electron momentum is established. The wave character of matter is a fundamental concept in quantum mechanics and this experiment demonstrates it qualitatively and explores it quantitatively at a level suitable for the second- and third-year undergraduate students.

Experiment 6: Two-Slit Diffraction Experiment

In this experiment the students will first record the interference pattern from two slits using a white light source. The students will then reduce the source intensity down to 10^5 photons per second and approach a regime in which the average time between two successive photon arrivals at the detector greatly exceeds the time-of-flight of the photon through the apparatus. Under these "one photon at a time" conditions the diffraction pattern is gradually formed. The light intensity distribution is detected using a photomultiplier tube. This experiment clearly demonstrates the wave-particle duality of light which is a central concept in quantum mechanics.

Experiment 7: Absorption of Light by CdSe Nanocrystals

In this experiment the students measure the intensity of light transmitted through a solid or liquid solution of crystalline (CdSe) quantum dots (QD) of known average size. The absorption edge due to the fundamental gap is determined from these measurements as a function of QD diameter, and the characteristic blue shift with decreasing QD diameter is clearly demonstrated. This is a simple but quite a dramatic experiment which demonstrates the effect of confinement on the energy states of quantum dots. It also makes the connection between quantum confinement and the onset wavelength of the widely used glass/CdSe filters. A quantitative analysis of the onset wavelength slope yields the QD average size.

Experiment 8-9: Solid-State Lighting

In this experiment the students will study the properties of solid-state lighting (SSL) and realize the advantages and existing limitations of SSL over other lighting sources. In particular, students will measure the current-voltage characteristics of six different LEDs and the spectra of these LEDs. Also, they will record the emission spectra of InP QDs excited with an ultraviolet diode. Students will evaluate the radii of QDs from their emission spectra.