Revised Aug. 25, 2015

030.403 "Optoelectronic Materials and Devices" | Syllabus

Instructor Information:

Professor Thomas J. Kempa

Description:

This course provides an introduction to the vast chemistry and physics of solid-state materials. The course begins with a fundamental description of bonding in crystalline solids and calculation of electronic band structure. We then extend our discussion to methods for the synthesis of low-dimensional materials and hierarchical structures, including quantum dots (0D), nanowires/nanotubes (1D), graphene and other atomic monolayers (2D), and thin-film superlattices. An in-depth discussion of spectroscopic and characterization techniques for solid-state materials will follow and focus on some of the foundational studies of quantum devices and cooperative phenomena. At this stage we will describe recent advances in electron and other microscopies (*e.g.* aberration-corrected and energy filtered TEM, atom-probe tomography) that are revolutionizing the structural, compositional, and electronic characterization of materials. The course will conclude with a survey of contemporary topics in solid-state and nanomaterials science, including functional devices and circuits, assembly, energy conversion, and biological sensing.

Materials:

Lecture notes and additional references will be provided on a weekly basis. Supplementary reading materials and some assignments will be drawn from the following online and print academic literature:

- *Physics of Semiconductor Devices*, 2nd edition, S. M. Sze, John Wiley & Sons, 2004.
- *Nanoelectronics and Information Technology, Advanced Electronic Materials and Novel Devices*, 2nd edition, R. Waser (Ed.), Wiley-VCH, 2005.
- Sheridan Libraries (JHU) – http://www.library.jhu.edu/
- Web of Science – http://databases.library.jhu.edu/databases/proxy/JHU03259

Grading Policy:

Final Exam (40%) – You will be asked to develop an original research proposal, submit a 1 page written summary, and deliver an in-class oral presentation, which will include a Q&A session. Dates: November 19, December 1 and 3.

Midterm Exam (30%) – A traditional multiple choice and short-answer exam focused on the lecture materials covered during the first 8 weeks of class. Date: November 3.

Literature Review (20%) – You and your partners (as applicable) will be asked to select a recent paper(s) related to any of the topic areas covered in the course and deliver a short (~25 min) critical review while leading in-class discussion. Date: October 8 and 13.

Class Participation (10%) – To get the most out of this, or indeed any, course stay actively engaged with the material covered during formal lectures and student contributions. Don't be shy, ask as many questions as possible!

Lecture Outline:

1. Introduction
2. Fundamental Structure-Property Relationships in Solid-State Materials
    a. Bonding, crystal lattices, and crystallographic notation
    b. Surfaces and interfaces
    c. Electronic structure
3. Synthesis and Fabrication of Optoelectronic Materials and Devices
    a. Fabrication: Lithography (PL, EBL, FIB, etc.), etching, and deposition
    b. 0D systems: Nanocrystals and quantum dots
    c. 1D systems: Nanowires and nanotubes
    d. 2D systems: Graphene, other atomic monolayers, chalcogenides
    e. Hierarchical systems: Superlattices, van der Waals heterostructures
4. Spectroscopy and Characterization Techniques
    a. Optical techniques
        i. EL, PL, Raman, pump-probe, non-linear processes
    b. Electronic techniques
        i. 4-point probe, Hall effect, STM, XPS, XANES
    c. Electron microscopy techniques
        i. SEM, TEM/STEM, (V)EELS, EDS, Atom-probe, Precession diffraction
5. Foundational Studies in Condensed Matter and Materials Science
    a. Field-effect transistor (FET) architectures
    b. Weakly and strongly coupled nanostructures
        i. Coulomb blockade, Fabry-Perot cavities, Kondo effect
6. Devices and Applications
    a. Photonic devices
        i. LEDs, lasers, photonic bandgap architectures, plasmons
    b. Electronic devices
        i. nanoscale FETs, nano/micro electromechanical systems, spin-based devices, memory elements, integrated systems
    c. Energy conversion and storage
        i. solar cells, thermoelectrics, piezoelectric devices
    d. Tools for biology
        i. optical/magnetic probes, sensing, drug delivery
    e. Assembly
        i. equilibrium/non-equilibrium self-assembly, patterning phenomena