2.996 – Nanoscale Science and Engineering

Course Objectives:

This course focuses on how device physics change as materials approach the nanoscale and quantum effects become significant. Specifically, this class covers nanoscale phenomenon in the areas of (1) Thermodynamics and Heat Transfer, (2) Fluid Mechanics, (3) Electronics, and (4) Solid Mechanics. Within each of these topic areas, this class will discuss how nanoscale effects can be used to make or improve devices beyond what is possible at the micro and macro scales. Classical and quantum mechanical calculations will be used to model and design nanoscale devices in each of the four topic areas. Homework assignments will focus on the discussion and analysis of current state-of-the-art literature in each of the four topic areas.

Grading Policy:

The course grade will be based on:

- Homework (50%)
- Class Project (50%)

Useful Textbooks:

Quantum mechanics for Scientists and Engineers by David Miller
Introductory Applied Statistical Mechanics by Peter Hagelstein
Introduction to Quantum Mechanics by David Griffiths
Quantum Transport: Atom to Transistor by Supriyo Datta
Nano/microscale Heat Transport by Zhuomin Zhang
Nanoscale Energy Transport: A Parallel Treatment of Electrons, Molecules, Phonons, and Photons by Gang Chen
Nanofluidics by Patrick Abgrall
Introduction to Solid State Physics by Charles Kittel
Physics of Semiconductor Devices by M. Sze
Foundations of Nanomechanics by Andrew Cleland
Nanomaterials – Mechanics and Mechanisms by K.T. Ramesh

Class Project:

The class project consists of a research proposal that should: i) Summarize the state of knowledge of the topic, ii) Identify critical unresolved science and/or technology issues, and iii) Propose specific new research, for a 3 year period, to resolve these critical issues. The proposal text should be organized as follows:

i) Cover Page
ii) Executive Summary
iii) Introduction and Background
iv) Critical Unresolved Issues
v) Proposed Research
vi) References

Cass Schedule

Date	Week	Topic	Homework
2/3	1	**Introduction:** Quantum Mechanics and Schrödinger Equation • Schrödinger Equation • Quantum Wells • Harmonic Oscillators • Reciprocal Lattice Space	
2/10	2	**Thermal:** Statistical Thermodynamics and Quantum Theory • Phonon Density of States • Maxwell-Boltzmann Statistics • Bose-Einstein Statistics • Fermi-Dirac Statistics • Ideal Molecular Gasses	HW1: Review of Quantum Mechanics
2/17	3	**Thermal:** Thermal Properties of Nanoscale Materials • Debye Model • Einstein Model • Quantum Size Effect on Heat Capacity	
2/24	4	**Thermal:** Phonon Transport • Wiedmann-Franz Law • Classical Size Effects on Thermal Conductivity • Quantum Conductance • Phonon Scattering	
3/3	5	**Fluids:** Mass Transport at the Nanoscale • Continuum Assumptions • Kinetic Theory • Knudsen and Hindered Diffusion	HW2: Nanoscale Thermodynamics and Heat Transfer
3/10	6	**Fluids:** Nanopore and Nanochannel Transport • Electrokinetics • Capillary Flow	
3/17	7	**Electronics:** Solid State Physics Review • Band Structure • Electronic Density of States • Bravais Lattices • Bloch's Therom	
3/24	8	Spring Break	
3/31	9	**Electronics:** Electron Transport in Quantum Dots and Wires • Quantum Capacitance • Electrostatic Capacitance • Ballistic Transport • Ohm's law • Drude Model	HW3: Nanofluidics
4/7	10	**Electronics:** Electronic Structure of Materials • The Hydrogen Atom • Tight Binding Approximation • First Brillouin Zone	

4/14	11	**Electronics:** Single Molecule Electronic Devices • Molecular FETs • Ballistic Quantum Dot and Quantum Wire FETs • Comparison to Conventional MOSFETs	
4/21	12	**Mechanics:** Stress and Strain and the Nanoscale • Linear atomic Chains and Lattices • Interatomic Potentials and Force Fields • Molecular Mechanics	HW4: Nanoelectronics
4/28	13	**Mechanics:** Strength and Failure of Nanomaterials • Hall-Petch Model • Discrete vs. Bulk Nanomaterials • Fracture in Nanomaterials • Plastic Deformation • Hardness	
5/5	14	**Mechanics:** NEMS Fabrication – Top Down and Bottom Up • Nanolithography • Nucleation • Field-Directed and Template Self Assembly • Synthesis of Nanowires and Nanotubes	
5/12	15	**Mechanics:** NEMS Applications • Resonators • Sensors • Actuators • Energy	HW5: Nanomechanics and Nanofacrication