Energy Transport and Conversion at the Nanoscale (24-628)

Spring 2011

Energy transport and conversion processes occur at the nanoscale due to interactions between molecules, electrons, phonons, and photons. Understanding these processes is critical to the design of heat transfer equipment, thermoelectric materials, electronics, light emitting diodes, and photovoltaics. The objective of this course is to describe the science that underlies these processes and introduce the contemporary experimental and theoretical tools used to understand them. Specific topics include: thermal energy storage and transport in gases and solids, electronic transport in metals and semiconductors, and optical properties of matter. The Boltzmann transport equation is introduced to derive classical laws, to explain energy conversion processes between electrons, phonons, and photons, and to provide a modeling tool that can be used for engineering optimization of energy conversion devices. The course includes one hands-on laboratory and concludes with a project. Problem sets will range from standard textbook questions to more complex questions, requiring intelligent assumptions, that relate to contemporary challenges in engineering. Prerequisites- 24-322 & 24-221 or equivalents.

- Professor: Jonathan A. Malen
- E-mail: jonmalen@andrew.cmu.edu
- Phone number: 412.268.4667
- Office: 305 Scaife Hall

- Class Hours: MW 4:30-6:20PM
- Classroom: Scaife Hall 220
- Office Hours: Tuesdays 4-5PM, 305 Scaife Hall (or by appt. made through email)
- Blackboard: Blackboard is an online tool that will be used to distribute homework assignments, handouts, and solutions. The URL is : http://blackboard.andrew.cmu.edu

Textbook:

(1) Nanoscale Energy Transport and Conversion: A Parallel Treatment of Electrons, Molecules, Phonons, and Photons; Gang Chen (Oxford, 2005).

(2) Microscale Energy Transport; Chang-Lin Tien, Arunava Majumdar, and Frank M. Gerner (CRC Press, 1997). [*I will provide the necessary excerpts from this textbook*]

Supplemental References:

(3) Introduction to Solid State Physics; Charles Kittel (Wiley, 2004)

Grading:

A: 90-100, B: 79-89, R < 79 (Plus and minus grades will be given at the instructor's discretion. The minimum score to earn a certain letter grade may be lowered, but it will not be raised.)

- 6 Homework assignments: 30% (only 1 late homework will be accepted)
- Midterm (Thursday, March 3, 4:30-6:20 in 208 Scaife Hall): 35%
- Final Project: 35%

Course Policies:

There are two 2-hour meetings per week. You are responsible for all material discussed in class, whether you attended or not. Use of electronic devices (laptop computers, cell phones, mp3 players, dvd players, etc.) is not permitted in lecture. No student may record or tape any classroom activity without the express written consent of the instructor. If a student believes that he/she is disabled and needs to record or tape classroom activities, the student should

contact the Office of Disability Resources to request an appropriate accommodation. In the event that such an accommodation has been arranged, the material may not be further copied, distributed, published, or otherwise used for any other purpose without the express written consent of the instructor.

Homework is intended to provide the students with a deeper understanding of the material covered in lecture. Homework is due in class and will be graded based on apparent effort. You will receive credit for a problem, if, judging by what you have handed in, you made a good faith effort to do all or most of the problem. If a problem has more than one part, you can get credit for each part of the problem. Homework can be completed in groups, but it is my experience that students who work separately and struggle with the problems alone before discussing with the group, glean a better understanding of the material. Each student must hand in their own written solutions. If you have special needs or concerns about these policies, please discuss them with me.

Policy on Cheating and Plagiarism:
Cheating and plagiarism is unethical behavior that is not tolerated in this course or at Carnegie Mellon University. Students with questions about the definition of cheating or plagiarism are referred to the Carnegie Mellon Student Policies Handbook. URL: http://www.cmu.edu/policies/documents/Cheating.html

Tentative Week by Week Schedule (subject to change):

Week	Monday	Wednesday	Text(s) Reading
1/10	Introduction to Electrons, Photons, and Phonons	Molecular Transport: Maxwell Boltzmann Distribution for Gases	(1) Chapter 1
1/17	No Class (MLK Day)	Molecular Transport: Kinetic Theory of Gases	(1) Chapter 1 (2) Sec 1-6-2
1/24	Molecular Transport: Introduction to liquids- intermolecular forces	Molecular Transport: viscosity of liquids by transition state theory	Primarily notes, (1) Chapter 9
1/31	Relevant concepts from quantum mechanics	Phonon Transport: Crystalline solids, phonon dispersion	(1) Chapter 2 Sec 3.1, 3.3; (2) Sec 1-3-1
2/7	Phonon Transport: energy storage and transport	Phonon Transport: thermal transport in disordered solids	(1) Sec 3.4, 4.2.3; (2) Sec 1-3-2, 1-3-3, 2-3
2/14	Phonon Transport: Nanoscale effects on phonon transport	Electron Transport: free electron dispersion for metals	(1) Sec 3.2 (2) Sec 1-4-1, 1-4-2
2/21	Electron Transport: energy storage and transport by electrons in metals	Electron Transport: Semiconductors	(1) Sec 3.2 (2) Sec 1-4-2 to 1-4-5
2/28	**Mon:** Electron Transport: Semiconductors	**Wed:** Electron Transport: Nanoscale Effects / **Thu: Midterm** (@ 430PM, 208 SH)	(1) Sec 3.2 (2) Sec 1-4-2 to 1-4-5
3/7	(Spring Break)	(Spring Break)	
3/14	No lecture (ASME/JSME Conf.) Individual project meetings	No lecture (ASME/JSME Conf.) Individual project meetings	
3/21	Measurement techniques for thermal transport; Lab demonstration	Boltzmann Transport Equation (BTE)	(1) Sec 6.1-6.3 (2) Sec 2-2, 1-6-3
3/28	Conservation Equations and Seebeck Coefficient from BTE	Thermoelectric energy conversion: ZT & Nanoscale approaches	(1) Sec 6.3.4, 8.4 (2) Sec 1-6-3
4/4	Optical Properties of Matter	Optical Properties of Matter	(2) Sec 1-5
4/11	Photon electron and Photon phonon interactions	Solar Cells & Thermophotovlotaics	(1) Sec 8.4.2
4/18	**Mon:** Presentations	**Wed:** Presentations / **Thu:** Presentations (@430PM, 208 SH)	
4/25	No Class (MRS Spring Meeting)	No Class (MRS Spring Meeting)	