Nanoscale Heat Transfer and Energy Conversion

ME 244, Spring 2017
Instructor: **Alex Greaney**
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Class: CHASS South 1125, Tu/Th 19:10–21:00
Office hours: MSE 339, We. 15:00–18:00, or by appt.

Course Content

ME 244 — *Nanoscale Heat Transfer and Energy Conversion* explores fundamental processes of energy transport and conversion at short length and time scales. Introduces classical and quantum-mechanical size effects on electrons, phonons, and photons. Topics include modes of energy storage, coupling between energy carriers, and electrical and thermal transport using the Boltzmann transport equation and/or kinetic theory.

Course Objectives

1. Calculate the allowed modes of energy storage by electrons, phonons, and photons, in bulk and in the presence of nanoscale quantum confinement effects.
2. Use the Boltzmann transport equation and/or kinetic theory to calculate transport properties including electrical conductivity, thermal conductivity, and Seebeck coefficient.
3. Evaluate the impact of classical size effects on the transport properties in nanostructures.
4. Apply these classical and quantum size effects to engineering problems such as: heat removal from computer chips, thermoelectric energy conversion, and/or improving the efficiency of solar photovoltaics.

Course Units: 4 units: 4 hours of lecture per week.

Prerequisites: At least *two* of EE 201/MSE 207, EE 202/MSE 217, ME 100A, ME 116A, or equivalents.

Office Hours

Office hours will be held in MSE 339 on Monday from 4–5pm, or by appointment if you can not make this time.

Evaluation of Student Performance

- 2 Homeworks: 20 each%
- Midterm: 20%
- Project Presentation: 10%
- Final Project: 30%

Homeworks: there will be two homework sets assigned through out the term. These homework sets are intended as an exercise to help you assimilate and internalize the concepts covered in class and so you are strongly encouraged to complete them. They will include short questions similar to those you will see on the exams, along with longer more open-ended project like questions The assignments will involve writing simulations in MATLAB that will help you in the process of understanding the key concepts — the homework is intended to help you learn rather than test what you have leant. The frist homework will cover all material up to the midterm on thermal physics and vibrations in crystals. The second homework will cover Boltzmann transport theory and the develop models to solve it.

Exams: The midterm will be held in class and will be closed book. A data sheet will be provided but you may also bring one page of hand written notes. The final will be a take home exam. Missing an exam will result in a zero grade for that exam unless alternative arrangements are made with the instructor prior to the exam. (Exceptions may be made for severe medical or family emergencies.) When granted, makeup exams may be oral or written, and may be more difficult than the original exam.

Final Project: The centerpiece of the class will be individual final projects. These include a written report and brief oral presentation in the last week of class. Your topic should be chosen in consultation with the instructor, and you are encouraged to choose a topic related to your research area. The goal is to make this something that will be useful for your thesis. Possible projects include:

- Perform a critical literature review of a particular topic, identify unsolved problem(s), and discuss how the concepts studied in this class can advance the state-of-the art.
- Develop an initial analysis of an emerging or proposed research problem.
- Development of a simple analytic or numerical model of a nanoscale heat transport process.
- Use your new knowledge from this class to strengthen your approach to a current research problem.

Final Project Presentation: These will be 10-15 minute in class presentations of your final project. A rubric for the grading of these will be posted online. These will be graded by the rest of the class.

Announcements and Documents

iLearn will be used as the primary means of communication for announcements, and for posting lab instructions, lecture handouts, homeworks, and their solutions. **Students are encouraged to download and print lecture notes and to bring them to class.**

Homeworks Assignments

Four homework assignments will be given through the term. You will have two weeks to complete each homework set. Solutions to the problem will be provides online on the day following the due date. Late homework will not be graded. Homework problems are a fundamental part of the learning process, and students are strongly urged to complete these learning exercises.

Policy on Absences Late Homework and Missed Exams.

Lectures: Obtain the notes from a classmate. Come to office hours if there are toipics you are conffused on.

Homework: Less than 48 hours late: 50% penalty. More that 48 hours late: not graded.

Exams: Every possible effort must be made on the student's part to inform the instructor *a least one week prior* to missing a midterm exam. Given an appropriate reason, accommodations will be made to provide an alternative time. (Exceptions may be made for severe medical or family emergencies.) If the instructor is not informed 1 week prior to the exam, the possibility of a makeup exam will be at the instructor's discretion, and if granted, makeup exams may be oral or written, and may be more difficult than the original exam.

Text Books

The required text for this class is:

- Gang Chen, *Nanoscale Energy Transport and Conversion: A Parallel Treatment of Electrons, Molecules, Phonons, and Photons*, New York: Oxford University Press, 2005. ISBN: 019515942X.

Some alternative books that you might find useful are:

- Microscale Energy Transport, eds. Tien, Majumdar, Gerner.
- Thermal Physics, by Kittel and Kroemer
- Nano/Microscale Heat Transfer, by Z. Zhang
- Introduction to Solid State Physics, by C. Kittel
- Electrons and Phonons, by J. M. Ziman
- Fundamentals of Semiconductors, by Yu and Cardona

Course Schedule

Below is the planned sequence of topics covered. The is time tabel is not set in stone and could change as the class progresses:

Week	Lect.	Date	Topic	Reading
1	1	04/04	Preliminaries & Overview	Chen Ch. 1.2–1.5
	2	04/06	Review classical HT & Kinetic theory of ideal gas.	
2	3	04/11	Thermal Physics: 2 level system	Chen Ch. 4.1
	4	04/13	Thermal Physics: Photons	
3	5	04/18	Energy States: photons and phonons	Chen Ch. 4.1
	6	04/20	Phonons: optical and acoustic	Chen Ch. 3.3–3.4
4	7	04/25	Phonons. Specific heat. Debye T^3 limit.	Chen Ch. 3.3–3.4
	8	04/27	Electrons. Schrödinger Eqn. and wavefunctions	Chen Ch. 3.1–3.2, 3.4
5	9	05/02	Free electrons, Fermi-Dirac, Specific Heat	Chen Ch. 3.1–3.2, 3.4
	—	05/04	**Midterm Exam**	
6	10	05/09	Transport theory: Boltzmann transport equation	Chen Ch. 6.1–6.3
	11	05/11	Transport theory: BTE to Fourier's law	
7	12	05/16	Transport theory: Carrier scattering	Chen Ch. 62–6.3, 8.1
	13	05/18	Classical size effects-I	Chen Ch. 7.1–7.2
8	14	05/23	Classical size effects-II	Chen Ch. 7.1–7.2, 7.5
	15	05/25	Quantum size effects	Chen Ch. 5
9	16	05/300	Phonons in low dimensions	Chen Ch.5
	17	06/01	Energy conversion I	
10	18	06/06	Energy conversion II	TBD
	–	06/08	**Project Presentations**	

UCR Academic Resource Center

The Academic Resource Center (ARC) is the central resource for academic support at UCR. All students are strongly encouraged to visit the ARC, which is staffed by professional and student employees who are well trained to provide academic support and dedicated to fostering academic excellence. Resources provided by the ARC include Tutoring, Supplemental Instruction, Study Skills Workshops, as well as several peer mentoring programs. Staff work with all students, at all skill levels, in all stages of their undergraduate careers. Participating in these services is most useful to students when used pro-actively for academic enrichment. Visit arc.ucr.edu or call 951-827-3721 for more information about hours, location and the schedule of services.

Collaboration

Collaboration and discussion on the homework is encouraged in this class, particularly on home work problems that require the use of the computer. Collaborative or group final projects will also be considered for ambitious projects. However assignments turned in for a grade must represent a student's own work. Consulting with your colleagues on homework problems and your projects is encouraged for, but *copying from somebody else's homework solution is considered academic misconduct*. You should first attempt every homework problem on your own, and only then meet with your colleagues to check and improve your work. The best learning usually comes after getting stuck on your own. While the homework and project are a learning exercises, the final exam is meant as an assessment of your individual mastery of the material and thus no collaboration is permitted on this.

Academic Integrity

As a respected research institution, UCR values academic integrity. UCR students should uphold this value and avoid academic misconduct and its consequences. Academic misconduct is any act that improperly distorts (or could distort) a student's grades or other academic record. Students caught cheating, plagiarizing, or participating in any form of academic dishonesty may receive an F or other penalty on the assignment or test and possibly in the course. The universities definitions of and policies regarding academic misconduct are clearly described here: conduct.ucr.edu/policies/academicintegrity.html.