Hot Chips: Atoms to Heat Sinks

ECE 598EP, Spring 2009

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Office hours: By appointment

Location/Time: Everitt 260, Tue-Thu 1 PM – 2:20 PM

Catalog Description: This course pursues a parallel treatment of electrical and thermal issues in modern nanoe-lectronics, from fundamentals to system-level issues. Topics include energy transfer through electrons and phonons, mobility and thermal conductivity, power dissipation in modern devices (CMOS, phase-change memory, nanowires, nanotubes), circuit leakage, thermal breakdown, system-level issues, thermometry, and heat sinks.

Purpose: This is a new course, intended to bridge a gap for those of you with Electrical Engineering or Physics backgrounds who are interested in nanoscale power and thermal issues, and for those of you with Heat Transfer (Mechanical Engineering) backgrounds interested in nanoscale electronic issues. Material Scientists, Chemical Engineers and other interested parties are also encouraged to enroll. We will cover fundamentals as well as modern research topics, and would like to accommodate a broad range of backgrounds and interests. If you are unsure of your individual preparation for this class, please check with the instructor. Broadly speaking, a basic knowledge of solid-state physics, transistor operation, and familiarity with Matlab (or similar) would be ideal.

Timeline: There are 25 lectures spread over 16 weeks during the Spring of 2009. Class exceptions:
- Jan 29 (Thu), Feb 3 (Tue), Apr 16 (Thu), Apr 30 (Thu) lectures cancelled due to travel
- March 19 (Thu): one-page conference abstracts are due, with short in-class oral presentations
- Mar 24-26 lectures are not offered due to Spring Break
- Last in-class meeting is Tue May 5: four-page papers due, with final in-class oral presentations

Style: The course will be run like a seminar, rather than an undergraduate class. You are generally assumed to be graduate students engaged in research, with a professional interest in the subject. We will have several guest lecturers during the semester, who are world-class experts in the topics to be covered.

Homeworks: Due approximately every three weeks, and many will contain open-ended "research" problems. That is, not all necessary information will be provided up front, you may have to look up constants, material properties, and make reasonable approximations. Some homeworks will involve computational work with Matlab, including numerical integrals, straightforward finite difference problems, and building a simple Monte Carlo simulator. You may work in groups on the homeworks, although separate write-ups must be submitted.

Wikipedia: Several assignments will involve editing Wikipedia entries. You are highly encouraged to work in pairs on these, and to think about your topics in advance, as the course progresses. Once a Wikipedia assignment is given, you will have at least four weeks to complete it, including time to get your topic approved. You may choose Wikipedia entries that already exist but need updating, or start new articles. In either case, you must convince the instructor in advance (one paragraph over email is sufficient) that your topic is worth undertaking.

Projects: The class involves a final project in lieu of a final exam. This will be an open-ended research project of your choice, written as a four-page IEEE conference paper. You are encouraged to work in pairs, and to think of topics as the course progresses. You are also highly encouraged to pick a topic directly relevant to your cur-

rent research. There will be a one-page abstract, and short in-class pitch due the last lecture before Spring Break, March 19. Final conference-style presentations will occur in early May.

Reading: No single textbook covers all topics. We will rely on handouts, slides, PDFs, and sections from several books including "Nanoscale Energy Transport and Conversion" by G. Chen (Oxford, 2004), "Quantum Transport: Atom to Transistor" by S. Datta (Cambridge, 2006), and "Low-power CMOS VLSI circuit design" by K. Roy and S. Prasad (Wiley, 2000). Two related textbooks are fully available online:

- http://web.mit.edu/lienhard/www/ahtt.html "A Heat Transfer Textbook" by J. H. Lienhard
- http://ece-www.colorado.edu/~bart/book "Principles of Semiconductor Devices" by B. Van Zeghbroek

Grading: Homeworks, including Wikipedia assignments (45%). Midterm, one-page conference abstracts with short (3-5 minute) in-class pitch (20%). Final, group research paper with 15 minute in-class presentation (35%).

Lecture Topics:	Approximate Hours:	
I. Introduction: Why Power Matters in Nano-Electronics	**1.5**	
II. Electronics Overview from Silicon to Package	**1.5**	
III. The Microscopic Origin of Macroscopic Laws:	**8**	
a) Electrons and Ohm's Law		1.5
b) Phonons and Fourier's Law		1.5
c) The Wiedemann-Franz Relationship		1
d) Mobility and Thermal Conductivity		2
e) Breakdown of Classical Laws		2
IV. Low-Dimensional and Boundary effects	**7**	
a) Energy Transport in Thin Films, Nanowires, Nanotubes		3
b) Electrical and Thermal Contacts		2
c) Materials Thermometry (guest: Prof. David Cahill, MSE)		2
V. Power in Electronic Devices	**9**	
a) Thermal Healing Lengths and Diffusion Lengths		1.5
b) Power Dissipation in Silicon Devices		1.5
c) Temperature Dependence of Device Behavior		1.5
d) Thermal Data Storage Devices		1.5
e) Device Thermometry		1.5
f) MIDTERM In-Class Presentations		1.5
VI. Power in Electronic Circuits	**6**	
a) Circuit View of Leakage		1
b) Power in Interconnects		3
c) Thermal Breakdown, Electromigration, Fuses		2
VII. Power in Electronic Systems	**9**	
a) Package Thermal Resistance		1.5
b) Thermal Interface Materials		1.5
c) Heat Sink Design		1.5
d) Liquid Cooling Solutions		1.5
e) Solid Cooling Solutions (Peltier)		1.5
f) System Thermometry		1.5
VIII. Power and Architecture (guest: Prof. Rakesh Kumar, ECE)	**1.5**	

IX. FINAL In-Class Presentations   __1.5__

Total: 45