Spring 2003

ELECTRICAL AND COMPUTER ENGINEERING 340

Solid State Electronic Devices

The course director is **Prof. K.C. Hsieh**

The course structure consists of three lecture/discussion meetings per week. Final course grades are based on the distribution of total points accumulated on the final exam, two hour exams, and assigned homework problems, as described in the section on grading criteria.

The Course information listed below is included on the pages which follow:

Spring 2003: ECE 340. Solid State Electronic Devices 3 HOURS, OR 0.75 UNIT.

Prerequisite: physics 114 and credit or concurrent registration in ECE 229.
*Graduate credit not allowed toward degrees in electrical and computer engineering.
For last-semester seniors: Passing this course is critical to your graduation on time. It is important that you work very hard from day one.

Purpose of the Course

The purpose of this course is to provide the student with the essential background on semiconductor materials and a basic understanding of the following semiconductor electronic devices that will be required for a successful career in electrical engineering:

p-n Junctions
Schottky Barrier Diodes
Bipolar Junction Transistors
Field Effect Transistors
Emitters/Photodiodes

These topics are important to the professional electrical or computer engineer because these devices are utilized in almost every area of electrical or computer engineering. To be productive and remain employed throughout a 30+ year career in electrical or computer engineering, the electrical and computer engineer needs to understand the fundamentals of semiconductors and the operation and limitations of these devices. A successful engineer will be able to apply this knowledge in the different areas of electrical engineering, whether he or she works directly in circuits and system design, control systems, communications, computers, electromagnetic fields, bioengineering, power systems, directly in the semiconductor industry, or in areas yet to develop that will certainly rely heavily on semiconductor devices and/or integrated circuits.

The material in this course will provide the background that will give the student the ability to learn and understand the performance and limits of improved devices that will be required throughout your electrical or computer engineering career.

ECE 340 Instructors and TA Office Hours

Course Director: Professor   K.C. Hsieh
148 Microelectronics Lab.
244-1806
k-hsieh@uiuc.edu

ECE 340 Instructors: gtimp@uiuc.edu , leburton@ceg.uiuc.edu, k-hsieh@staff.uiuc.edu,
jrtucker@staff.uiuc.edu , kevinkim@staff.uiuc.edu

	Section	Time	Office Address	Phone #	email address
Prof. G. Timp	A	8:00	327 Micro Lab	244-9629	gtimp@uiuc.edu
Prof. K. Kim	C	10:00	45 Everitt Lab	333-7162	kevinkim@uiuc.edu
Prof. K.C. Hsieh	X	12:00	148 Micro Lab	244-1806	k-hsieh@uiuc.edu
Prof. C. Liu	E	1:00	313 Micro Lab	333-4051	Changliu@uiuc.edu
Prof. J. Tucker	G	3:00	266 ESB	333-4810	jrtucker@staff.uiuc.edu

Room 156 Everitt Laboratory is the office for registration information, section changes, lost and found, and general course information.

Section	Time	Enrollment	Room
A	8:00	50	165EL
C	10:00	40	260EL
X	12:00	40	260EL
E	1:00	46	165EL
G	3:00	40	260EL
		Total 216	

OFFICE HOURS FOR PROFESSORS AND TA

ECE 340 - INSTRUCTORS AND TA OFFICE HOUR SCHEDULE							
TIME	SATURDAY	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
8 - 9							
9 - 10			G. Timp 327 Micro Lab				
10 - 11							
11 - 12							J. Tucker 266 ESB
12 - 1							
1 - 2				K.C. Hsieh (1:30-3:00) 148 Micro Lab			
2 - 3					C. Liu 313 Micro Lab		
3 - 4						K. Kim 45 Everitt Lab	
4 - 6		C. Xu 330M Everitt Lab					

If office hours are not available at times when you are, make an individual appointment with your instructor.

ECE 340 TA: Chenyang Xu
2534 Beckman
333-7071
cxu@uiuc.edu

Office hours will be held as listed, in the offices given in the table. Note: you can make individual appointments to see your professor at times other than the scheduled office hours

Required Textbook

Solid State Electronic Devices
Ben G. Streetman and Sanjay Banerjee, **Fifth** Edition
Prentice Hall, 2000

Reference textbooks are available in Grainger Engineering Library:

Call No: 621.3817M91D1986
Author: Muller, R.S./Kamins, T.I.
Title: Device Electronics for Integrated Circuits, 2nd ed.

Call No: 621.381ST8S1990
Author: Streetman, Ben G.
Title: Solid State Electronics Devices, 3rd ed.

Call No: 621.38152w184f
Author: Wang S.
Title: Fundamentals of Semiconductor Theory and Device Physics

Call No: 621.381sa19f
Author: Sah, Chih-Tang
Title: Fundamentals of Solid-State Electronics

Call No: 621.38152z1s
Author: Zambuto, Mauro
Title: Semiconductor Devices

Call No: 621.38152p966i
Author: Pulfrey, David L.; Tarr, N. Garry
Title: Introduction to Microelectronic Devices

Call No: 537.622ad5i
Author: Adler, R.B./Smith, A.C./Longini, R.L.
Title: Introduction to Semiconductor Physics, SEEC Vol. 1

Call No: TK 7872D6G7
Authors: Gray, P.E./DeWitt. D./ Boothroyd, A.R./Gibbons, J.F.
Title: Physical Electronics and Circuit Models of Transistors, SEEC Vol.

Call No: 621.381528t396c
Authors: Thornton, D./DeWitt, D./ Gray. P.E./Chenette, E.R.
Title: Characteristics and Limitations of Transistors, SEEC Vol.

Call No: 621.38152si64s
Authors: Singh, Jasprit
Title: Semiconductor Devices, An Introduction

Call No: 621.38152P615s
Authors: Pierret, Robert F./Neudeck, G.W.
Title: Modular Series on Solid State Devices Vol. 1, Semiconductor Fundamentals

Call No: 621.38152P615s1989
Authors: Pierret, Robert F./Neudeck, Gerold W.
Title: Modular Series on Solid State Devices, Vol. 1, 2nd edition, Semiconductor Fundamentals

Call No: 621.381522N393p
Authors: Pierret, Robert F./Neudeck, G.W.
Title: Modular Series on Solid State Devices Vol. 2 The PN Junction Diode

Call No: 621.3815282N393b
Authors: Neudeck, Gerold W. Pierret, Robert F.
Title: Modular Series on Solid State Devices Vol. 3 The Bipolar Junction Transistor

Call No: 621.3815284P615f
Authors: Pierret, Robert F./Neudeck, Gerold W.
Title: Moudlar Series on Solid State Devices Vol. 4, Field Effect Devices

Call No: 537.622N26S
Authors: Neamen, Donald A.
Title: Semiconductor Physics and Devices

Call No: 621.3815'2-dc20
Pierret, Robert F. (on order)
Semiconductor Device Fundamentals

Call No: 621.38152T952i
Tyagi, M.S.
Introduction to Semiconductor Materials and Devices

Requirements of the Course

Class etiquette:

Students must study the assigned material before class, attend class regularly, be attentive, ask questions, and complete the required work satisfactorily.

Required work:

Homework. There will be homework problems assigned daily. You should examine the problems prior to the class in which they are assigned so that you can ask questions as needed during the class period in order to be able to complete the solution of these problems as far as possible without further assistance. The homework is due at the beginning of the class period after they are assigned. Late homework will not be accepted.

The homework will consist of several types of problems: There will be a few simple "plug-in" problems to illustrate and reinforce the concepts covered in the assigned reading and lectures, and derivations of equations given in the textbook or in class. Another type of problem that is important in developing the understanding of semiconductor devices and their applications is the application or extension of the concepts that have been studied to new situations. Occasionally, a problem will be assigned on topics that are not studied in class. This type of problem is probably the most important because it teaches the student how to learn new material on his own, an ability that will be essential for a successful career in electrical or computer engineering. Another type of problem that will be assigned on certain topics is the design problem, where judgment must be used and there may b e a number of acceptable answers. The final type of problem is the computer based problem in which the variation of a particular quantity can be plotted as a function of some variable for different parameters. Examples are the variation of the free electron concentration in a semiconductor sample as a function of temperature for different values of the doping concentrations, N_d and N_a, and the characteristics of a field effect transistor where the drain current is plotted as a function of the drain voltage for different values of the gate voltage. These types of problems are tedious to analyze using a simple calculator, but are trivial using a computer and plotting routines. NOTE: If the student has not already acquired the ability to write simple computer programs and produce computer generated graphs using Mathematica, Excel, Matlab, Matcad, or **some** other program, this ability should be acquired in the first four weeks of the course.

The homework assignments must be completed according to the following guidelines.

Homework guidelines

Homework must be done on 8-1/2 x 11 paper, one side only, preferably on engineer calculation sheets or engineering calculation pads.

The pages for each homework assignment must be stapled together. The pages must be numbered, and the following information must be on the first page: (1) your name, (2) ID #, (3) assignment number, date, (4) class section, and (5) instructor's name.

The homework must be neat and easily readable, in pen, dark pencil, or computer output, and **all work leading to your answer must be shown.**

Homework format

The solution to each homework or exam problem *must* include all of the following that are appropriate for the particular problem:

A diagram and/or the equations required for the problem.

Solution of the equations for the appropriate quantities, using just variable and constant symbols.

In the final expression for the quantities of interest, numbers <u>and units</u> must be substituted. (Note: <u>units for each physical quantity in the equation must be *explicitly* included</u>.)

The units of the quantity in the final answer must be converted to those desired by using unity multiplication factors. *(The units commonly used in semiconductor device work are those in the SI system of units, with the exception that it is common to use cm(10^{-2}m) or sometimes μm (10^{-6}m), instead of meters for length measurements, and cm^3 rather than m^3 for volume measurements.*

Finally, and only after all of the above have been done, use a calculator to complete the necessary numerical calculations, and then draw a box around your answer.

<u>Significant Figures:</u> In the calculation of quantities from theoretical models or from experimental measurements, it is important to be aware of in the number of significant figures that are meaningful in your final result:

(1) If an expression involves the product or quotient of several quantities, the number of significant figures retained in the answer should only be as many as the number of significant figures in the least precise quantity used in the calculation,

(2) If a calculation involves sums and differences, the number of significant figures retained should be determined by the smallest number of decimal places in any term in the expression: e.g., $12.5 + 1.3295 = 13.8$.

(3) **For calculations in this course, assume that the quantities given are sufficiently accurate to justify retaining three significant figures in your final result.** Display your results in the form of a graph whenever appropriate.

You will not receive **full** credit for a homework or exam problem unless all of these requirements are complied with. If we cannot read your work on the homework or exams, you will receive zero credit!

You are encouraged to work together and discuss the homework assignments. Please see your professor and/or the TA's during their office hours for assistance on material or homework problems that you do not understand. If you are having difficulty with a particular topic, try reading about the same topics in the books that are available for ECE 340 in the Grainger Engineering Library (See the list on pp. 5 and 6). *However, the homework assignments that you turn in <u>must be your own work and not copied from someone else's solutions.</u> (Copying someone else's solution and submitting it as your own is cheating!)*

Note!

Homework or exam problems that are illegible or difficult to read and follow, or do not include the appropriate units explicitly, will not receive full credit.

Be neat!

Exams

There will be two midterm exams and a comprehensive final exam. Each of the "hourly" exams will consist of several problems or questions. The exams will be closed book. An equation sheet and the physical parameters and constants that are required in the solutions will be provided. The hourly exams are combined exams given in the evening at the times shown in the syllabus. They will be planned to take one hour, but you will be given 2 hours to complete them in an attempt to minimize time pressure. The format of your exam solutions should be the same as that used for the homework assignments: units must be shown explicitly, your answer must be circled and

your work must be readable. Numerical answers should contain three significant figures unless more are justified by the given data. The final exam is a three hour combined exam which will be given at a time to be scheduled. You will need a scientific calculator for the homework and the exams.

Exam I: Thursday, February 27, 2003, 7-9 p.m., Burrill Hall 124, Greg Hall 213,
                    Chem Annex 112
Exam II: Tuesday, April 10, 2003, 7-9 p.m., Everitt 151, MSEB 100
Final Exam: May 9 – 16, 2003. Exact time to be announced

Grading Criteria

Your grade in ECE 340 is based primarily on your scores on the homework assignments, the two hour exams, the final exam, and your class participation as follows:

Final Score = Homework score + Hour exam scores + Final exam score as shown below:

Homework =   20%
Hour Exam I =   20%
Hour Exam II =   20%
Final Exam =   40%

Total =   100%

Letter grades will be assigned to different ranges of the Final Scores at a meeting of the course staff at the end of the semester following the final exams. Plus and minus grades may be given to the highest and lowest 1/3 in each letter grade range.

 Study the material ahead of time, attend class, pay attention and ask questions! Your performance and contributions in class can help you learn the material.

Because of this grading procedure, **it is not possible to accurately determine your letter grade from your scores before the course is completed.** As a guide, the grade distributions for the Fall 2001 are given below:
Spring 2002
        20% A's   27% B's   31% C's   15% D's   7% F's

From this grade distribution, you can make a rough estimate how you are doing throughout the semester by obtaining your percentile ranking from the TA's. Any questions regarding course grading should be addressed to Professor Hsieh.

The topics covered in this course build on each other, so what you learn early in the course will be needed to understand later topics. Therefore, keep up with the schedule, study the daily assignments ahead of time, do the homework, and don't get behind. The material for this course is covered in a number of textbooks listed on pp. 5 and 6 that are available in the Engineering Library. If a subject is not presented clearly in the textbook or by the instructor, try another book.

Course Policy on Absences

If you miss an exam or homework assignment, the following procedures apply:

To receive an excused absence, you must either arrange your absence in advance with your instructor (i.e., prior to the absence), or complete an Excused Absence Form at the Undergraduate College Office, Room 207 Engineering Hall, indicating what work you have missed and the reason for the absence. This form must be signed by a physician or medical official for a medical excuse, or by the Office of the Dean of Students (Emergency Dean) for a personal excuse due to personal illness, family emergencies, or other uncontrollable circumstances. The office may be reached at 333-0050.

For missed classes or hour exams, present the completed form in person to your section instructor as soon as possible after you return.

Scores on quizzes, homework, and hour exams missed due to excused absences **will not be made up.** Your grade will be determined based on the average of the homework grades or exam grades that you have completed. Specifically, if you miss a homework assignment or hour exam, because of an excused absence, the average homework scores or exam scores will be used to determine the total, homework or hour exam score and the final total score.

Work missed due to an unexcused absence will be counted as a 0.

You **must** take the final exam to receive a grade for the course. If you miss the final exam for any reason (excused or not), you will automatically receive a final course grade of INCOMPLETE. To complete the course, you must make arrangements through your Dean's office and with the instructor to take a makeup final exam which will be given at the scheduled time at the end of the following semester.

Class Meeting	Date	Topic	Assigned §'s - Study from Streetman 5th Edition
1	W 01/22	**Introduction to the course, semiconductors, crystal structure** *1.1 Semiconductor Materials* *1.2 Crystal Lattices*	§'s 1.1, 1.2, Read §'s 1.3.1, 1.4 **Read Information Packet**
2	F 01/24	**Bonding forces and energy bands in solids** *3.1.1 Bonding Forces in Solids* *3.1.2 Energy Bands*	(Review topics in Chap. 2 from Phys. 114 as required) §'s 3.1, 3.1.1, 3.1.2
3	M 01/27	**Bonding forces and energy bands in solids (cont'd)** *3.1.3 Metals, Semiconductors, and Insulators* *3.1.4 Direct and Indirect Semiconductors*	§'s 3.1.3, 3.1.4
4	W 01/29	**Energy bands (cont'd) and charge carriers in semiconductors** *3.2.1 Electrons and Holes* *3.2.2 Effective Mass*	§'s 3.2.1, 3.2.2
5	F 01/31	**Intrinsic material, extrinsic material** *3.2.3 Intrinsic Material* *3.2.4 Extrinsic Material*	§'s 3.2.3, 3.2.4
6	M 02/03	**Distribution functions, Fermi-Dirac statistics, Maxwell-Boltzmann statistics, and carrier concentrations** *3.3.1 The Fermi level* *3.3.2 Electron and Hole Concentrations at Equilibrium*	§'s 3.3.1, 3.3.2
7	W 02/05	**Carrier concentrations (Cont'd) and the Temperature dependence**- *3.3.2 Electron and Hole Concentrations at Equilibrium* *3.3.3 Temperature Dependence of Carrier Concentrations* *3.3.4 Compensation and Space Charge Neutrality*	§'s 3.3.2, 3.3.3, 3.3.4
8	F 02/07	**Optical absorption and luminescence / Carrier Generation and Recombination** *4.1 Optical Absorption* *4.2 Luminescence* *4.3.1 Direct Recombination of Electrons and Holes*	§'s 4.1, 4.2, 4.3.1
9	M 02/10	**Carrier Generation and Recombination (Cont'd) and photo-conductivity** *4.3.2 Indirect Recombination: Trapping* *4.3.3 Steady State Carrier Generation; Quasi-Fermi Levels*	§'s 4.3.2, 4.3.3
10	W 02/12	**Drift of carriers in electric fields**	§'s 3.4.1, 3.4.2, 4.3.4

		3.4.1 Conductivity and Mobility	
		3.4.2 Drift and Resistance	
		4.3.4 Photoconductive Devices	
11	F 02/14	**Temperature, impurity concentration, and** **high electric field effects on mobility, Hall effect** *3.4.3 Effects of Temperature and Doping on Mobility* *3.4.4 High-Field Effects* *3.4.5 The Hall Effect*	§'s 3.4.3, 3.4.4, 3.4.5
12	M 02/17	**Hall effect (Con'd) / Diffusion of carriers** *3.4.5 Hall effect* *4.4.1 Diffusion Processes* *4.4.2 Diffusion and Drift of Carriers; Built-in Fields*	§'s 4.4, 4.4.1, 4.4.2
13	W 02/19	**Diffusion of carriers (Cont'd),** **the continuity equation** *4.4.2 Diffusion and Drift of Carriers, Built-in Fields* *4.4.3 Diffusion and Recombination;* *The Continuity Equation*	§'s 4.4.2, 4.4.3
14	F 02/21	**Steady state carrier injection; diffusion length** *4.4.4 Steady State Carrier Injection; Diffusion Length*	§ 4.4.4
15	M 02/24	**Haynes-Shockley experiment (Discussion and Movie)** *4.4.5 The Haynes-Shockley Experiment*	§ 4.4.5
16	W 02/26	**REVIEW**	
	Th 02/27	**HOUR EXAM #1** (Chaps. 1, 3 & 4) combined sections, **7:00 - 9:00 PM** **Burrill 124, Greg Hall 213 & Chem Annex 112**	
17	F 02/28	**No class**	
18	M 03/03	**P-N junctions in equilibrium, contact** **potential** *5.1 Fabrication of p-n Junctions,* *5.2 Equilibrium Condition,* *5.2.1 The Contact Potential*	Read § 5.1 Study §'s 5.2, 5.2.1
19	W 03/05	**Space charge at a junction** *5.2.2 Equilibrium Fermi Levels* *5.2.3 Space Charge at a Junction*	§'s 5.2.2, 5.2.3

20	F 03/07	**Current flow in a P-N junction**
		 5.3. Forward- and Reverse-Biased Junctions;
		     Steady State Conditions
		 5.3.1 Qualitative Description of Current Flow at a
		     Junction
			§'s 5.3, 5.3.1

21	M 03/10	**Carrier injection, the diode equation** *5.3.2 Carrier Injection*	§ 5.3.2
22	W 03/12	**Minority and majority carrier currents** *5.3.2 Carrier Injection* *5.3.3 Reverse Bias*	§ 5.3.3

23	F 03/14	**No class (EOH)**	
24	M 03/17	**Reverse-bias breakdown** *5.4 Reverse-Bias Breakdown* *5.4.1 Zener Breakdown* *5.4.2 Avalanche Breakdown*	§' s 5.4, 5.4.1, 5.4.2
25	W 03/19	**Stored charges, diffusion capacitance and junction capacitance** *5.5.4 Capacitance of p-n Junctions*	§ 5.5.4
26	F 03/21	**Metal semiconductor junctions** *5.7.1 Schottky Barrier* *5.7.2 Rectifying Contacts* *5.7.3 Ohmic Contacts* *5.7.4 Typical Schottky Barriers*	§'s 5.7, 5.7.1, 5.7.2, 5.7.3, 5.7.4
	M 03/31	**No Classes (Spring Break)**	
27	03/24 --- 03/28	**Narrow-base Diode** *Handout on narrow-base diode*	Review §' s 5.3, 5.3.1, 5.3.2
28	W 04/02	**Introduction to bipolar junction transistor** *Handout on BJT Fundamentals*	§' s 6.1.1, 6.1.2, 7.1, 7.2, 7.3 and handout
29	F 04/04	**Bipolar junction transistor (Cont'd), definitions terminal currents –-- straight-line approximation** *Handout on BJT specifics*	§' s 7.4.1, 7.4.2 and handout
30	M 04/07	**Bipolar junction transistor (Cont'd),** *Handout on common-emitter amplifier and small-signal circuit*	§' s 7.4.2, 7.4.3, 7.4.4 and handout
31	W 04/09	**Review**	
	Th 04/10	**HOUR EXAM #2** (Chaps. 1, 3, 4, 5 & 7) combined sections **7:00 - 9:00 PM, Everitt 151 & MSEB 100**	
32	F 04/11	**No class**	
33	M 04/14	**Metal-insulator-semiconductor FET** *6.4.1 Basic Operation* *6.4.2 The Ideal MOS Capacitor*	§' s 6.4.1, 6.4.2
34	W 04/16	**Ideal MOS capacitor (Cont'd)** *6.4.2 The Ideal MOS Capacitor*	§ 6.4.2
35	F 04/18	**MOS Capacitor (Cont'd)** *6.4.2 The Ideal MOS Capacitor* *6.4.3 Effects of Real Surfaces (Flatband voltage)*	§' s 6.4.2, 6.4.3
36	M 04/21	**MOS Capacitor (Cont'd)** *6.4.4 Threshold Voltage* *6.4.5 MOS Capacitance-Voltage Analysis*	§' s 6.4.4, 6.4.5
37	W 04/23	**MOS field-effect transistor** *6.5.1 Output Characteristics* *6.5.2 Transfer Characterisitics*	§' s 6.5.1, 6.5.2, 6.5.3,

		6.5.3 Mobility Model	
38	F 04/25	**MOSFET (Cont'd)** *6.5.4 Short Channel MOSFET I-V Characteristics* *6.5.5 Control of Threshold Voltage*	§'s 6.5.4, 6.5.5
39	M 04/28	**Integrated Circuits (CMOS, Inverter, logic devices)**	§'s 9.3.1, 9.5.1
40	W 04/30	**Metal-semiconductor field-effect transistor** *6.3.1 Structure Current-Voltage Charateristics* *(Linearly Region and Saturation Region)*	§'s 6.2.1, 6.2.2, 6.3.1
41	F 05/02	**Optoelectronic Devices (Photodiodes)** *3.1.5 Variation of Energy Bands with Alloy* *Composition* *5.8 Heterojunctions* *8.1.1 Current and Voltage in an Illuminated Junction*	§'s §'s 3.1.5, 5.8, 8.1.1
42	M 05/05	**Optoelectronic devices (cont'd)** *8.1.2 Solar Cells* *8.1.3 Photodetectors*	§'s 8.1.2, 8.1.3, 8.1.4
43	W 05/07	**Optoelectronic devices (cont'd)** *8.2 Light-Emitting Diodes* *8.4 Semiconductor Lasers*	§'s 8.2.1, 8.2.2, 8.2.3, 8.4.1, 8.4.2, 8.4.3, 8.4.4, 8.4.5
44	F 05/09 F 05/16	**FINAL EXAM,** (Chaps. 1, 3, 4, 5, 6, 7&8) **To be announced**	