Spring 2018

University of Illinois at Urbana-Champaign

ELECTRICAL AND COMPUTER ENGINEERING 340

Semiconductor Electronics

The course coordinator is **Prof. John Dallesasse**

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-long exams, three in-class quizzes, and assigned homework, as described in the section on grading criteria.

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

Prerequisite: Physics 214 and credit or concurrent registration in ECE 329.
Graduate credit not allowed toward degrees in electrical and computer engineering.

3 HOURS.

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
Light-Emitting Diodes/Photodetectors
Bipolar Junction Transistors
Field Effect Transistors

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 40+ 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 Instructor, TAs and Office Hours

Course Coordinator: Professor John Dallesasse
2114 Micro and Nanotechnology Laboratory
333-8416
jdallesa@illinois.edu

Spring 2018 ECE 340 Instructors:

	Section	Time	Location	Office Hours Location	Tel. #	Email
Prof. L. Lee	**A**	**10:00**	**2015 ECEB**	2258 MNTL	300-4430	mllee@
Prof. K. Kim	**C**	**11:00**	**2015 ECEB**	2048 ECEB	333-7162	kevinkim@
Prof. J. Dallesasse	**X**	**12:00**	**2015 ECEB**	2114 MNTL	333-8416	jdallesa@
TA: Jingyi Chen			2255 MNTL	3034 ECEB		jingyic3@
TA: Youngseok Kim			2261 MNTL	3034 ECEB		kim505@
TA: Yu-Ting Peng			1225 MNTL	4036 ECEB		ypeng14@
TA: Wenning Fu			1225 MNTL	4036 ECEB		wfu4@

Room 2120 ECEB is the office for registration, section changes, lost & found.

TIME	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
8 – 9				Jingyi Chen	
9 - 10				Jingyi Chen	
10 - 11					
11 - 12				Youngseok Kim	
12 - 1					
1 – 2			Prof. J. Dallesasse		
2 – 3		Prof. L. Lee		Wenning Fu	
3 – 4				Yu-Ting Peng	
4 – 5				Prof. K. Kim	
5 – 6				Wenning Fu	
6 – 7					

Required Textbook:

Solid State Electronic Devices
Ben G. Streetman and Sanjay Banerjee, **Seventh** Edition
Prentice Hall, 2000/2006

Reference Textbooks are Available in Grainger Engineering Library:

Semiconductor Device Fundamentals
Pierret, Robert F.
Addison-Wesley, 1996

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

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

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

Call No: 621.38152P615s1989
Authors: Pierret, Robert F./Neudeck, G.W.
Title: Modular Series on Solid State Devices, Volumes 1-4

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

Modern Semiconductor Devices for Integrated Circuits
Chenming C. Hu
2009, First Edition, 384 pages (not yet in Grainger)

Free online textbook, see: http://ecee.colorado.edu/~bart/book/contents.htm
By Prof. Bart Van Zeghbroeck at the University of Colorado

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. NO ELECTRONIC DEVICES are allowed in class. Electronic devices can be a source of distraction to you and for the fellow students around you so please be respectful by not using them in class.

Homework: 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 be 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.

If the student has not already acquired the ability to write simple computer programs and produce computer generated graphs using Mathematica, Excel, Matlab, MathCAD, or some other program, this ability should be acquired in the first four weeks of the course.

The homework will be assigned on Friday and must be turned in at the beginning of the next Friday class, unless otherwise specified. Late homework will NOT be accepted. **Homework must be turned in to your assigned section.** Only the top 10 of the 11 assigned homework assignments will count toward the course grade, but you are encouraged to do all assignments to best prepare for the exams and final.

Homework Guidelines:
Homework must be done on 8-1/2 x 11 paper, 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) Net 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. HW done on paper ripped from a spiral-bound notebook (with rough edges) will incur a penalty.**

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 only variable symbols.
- In the final expression, numbers and units must be substituted. Note: units for each physical quantity in the equation must be *explicitly* included.

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.**

Significant Figures: 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 the professors and/or the TAs 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 page 4). ***However, the homework assignments that you turn in must be your own work and not copied from someone else's solutions.*** ***(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!

Quizzes, Exams, and Grading

Quizzes: There will be three short in-class quizzes that will not be announced in advance. Each quiz may consist of a few conceptual questions and will take about 10-15 minutes. The purpose of studying homework problems diligently is to help you keep up the pace and quizzes are designed to gauge your progress. You should use the quizzes as a diagnostic measure to identify and strengthen your possible weak points on the material. **Quizzes must be taken in your assigned section.**

Midterms & Final: In addition to quizzes, there will be two hourly exams and a comprehensive final exam. Both hourly and final exams will consist of several problems or questions. The exams will be closed book, and no calculator is allowed. An equation sheet and the physical parameters and constants that are required in the solutions will be provided with the exam, not before. The hourly exams are given in the evening at the dates and times shown in the syllabus. They will take one hour. 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.

Hour Exam I:	**Tuesday February 27th, 7:30 - 8:30 pm**
Hour Exam II:	**Thursday April 12th, 7:30 - 8:30 pm**
Final Exam:	**To Be Announced**

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

Final Score = Homework + Quizzes + Midterm + Final Exam score as follows:

Homework =	10% (top 10 of 11)
Quizzes =	15%
Hour Exam I =	20%
Hour Exam II =	20%
Final Exam =	35%
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. 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 will 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 last semesters are given below:

Spring 2016:	27% A's	37% B's	27% C's	6% D's	3% F's
Fall 2016:	28% A's	26% B's	25% C's	16% D's	5% F's
Spring 2017:	27% A's	38% B's	27% C's	4% D's	4% 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 TAs. Any questions regarding course grading should be addressed to Professor J. Dallesasse.

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, do the homework, and don't get behind. The material for this course is covered in a number of textbooks listed on page 4 that are available in the Engineering Library. If a subject is not understood clearly try another book or attend office hours. Be resourceful!

Course Policy on Absences

If you miss a quiz, exam, or homework assignment the following procedures apply:
1) Absences for job interviews or for specific university-sponsored events must be pre-arranged with the course coordinator, Prof. Dallesasse. Upon verification that the excuse is valid and complies with the UIUC Student Code, the course coordinator will issue an excused absence in the event a quiz is given. Pre-arranged excused absences will not be given for exams except in the case of specific university-related events as described in the UIUC Student Code.
2) Excused absences are not given for missed homework assignments for any reason, as only the top 9 of the 11 assigned homework assignments count towards the course grade.
3) In the event of illness, you must receive an Excused Absence Form from 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. **Note that Excused Absence Forms in the case of illness are now only given out by the office for the case of serious illness lasting more than 3 days. Excused absences are not granted for minor illness.**

For missed classes or hour exams, present the completed form in person to the course director Prof. Dallesasse and your instructor as possible after you return.

Scores on quizzes and hour exams missed due to excused absences **will not be made up.** Your grade will be determined based on the average of the grades that you have completed. Specifically, the average of your completed 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 a legitimate reason, you will automatically receive a final course grade of INCOMPLETE. In this case to complete the course, you must make arrangements through your Dean's office and with the instructor to take a makeup final exam that will be given at the scheduled time at the end of the following semester. An unexcused absence from the final will result in a grade of "0" on the final.

Students with Disabilities

Students with disabilities who may qualify for extra time while taking tests must provide a current DRES letter to the course coordinator (John Dallesasse) and their instructor immediately. Specific arrangements will be made on a case-by-case basis.

Spring 2017 ECE 340 COURSE SCHEDULE AND OUTLINE			
Class #	**Date**	**Topic**	**Assigned §'s - Study from Streetman**
1	W 01/17	**Introduction to the course and general introduction to semiconductor electronics**	**Read Info Packet**
2	F 01/19	**General introduction to semiconductor electronics (cont'd)**	
3	M 01/22	**Semiconductors, crystal structure** *1.1Solid-State Materials* *1.2 Crystal Lattices*	§'s 1.1, 1.2, Read §'s 1.3.1, 1.4
4	W 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. 214) §'s 3.1, 3.1.1, 3.1.2
5	F 01/26	**Energy bands (cont'd) and charge carriers in semi-conductors** *3.1.3 Metals, Semiconductors, and Insulators* *3.2.1 Electrons and Holes*	§'s 3.1.3, 3.2.1 **HW1 Due**
6	M 01/29	**Intrinsic material, extrinsic material** *3.2.3 Intrinsic Material* *3.2.4 Extrinsic Material*	§'s 3.2.3, 3.2.4
7	W 01/31	**Distribution functions, Fermi-Dirac statistics, Max-well-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
8	F 02/02	**Distribution functions, Fermi-Dirac statistics, Max-well-Boltzmann statistics, and carrier concentrations (cont'd)** *3.3.1 The Fermi level* *3.3.2 Electron and Hole Concentrations at Equilibrium*	§'s 3.3.1, 3.3.2 **HW2 Due**
9	M 02/05	**Carrier concentrations (cont'd) and temperature de-pendence** *3.3.3 Temperature Dependence of Carrier Concentrations* *3.3.4 Compensation and Space Charge Neutrality*	§'s 3.3.3, 3.3.4
10	W 02/07	**Drift of carriers in electric fields** *3.4.1 Conductivity and Mobility*	§'s 3.4.1
11	F 02/09	**Resistance, temperature, impurity concentration,** *3.4.2 Drift and Resistance* *3.4.3 Effects of Temperature and Doping on Mobility*	§'s 3.4.2, 3.4.3, **HW3 Due**
12	M 02/12	**Invariance of the Fermi level at equilibrium** *3.5 Invariance of the Fermi Level at Equilibrium*	§'s 3.5
13	W 02/14	**Optical absorption and luminescence / carrier genera-tion and recombination** *4.1 Optical Absorption* *4.3.1 Direct Recombination of Electrons and Holes*	§'s 4.1, 4.3.1

14	F 02/16	**Carrier generation and recombination (cont'd)** *4.3.1 Direct Recombination of Electrons and Holes* *4.3.3 Steady State Carrier Generation; Quasi-Fermi Level*	§'s 4.3.1, 4.3.3 **HW4 Due**
15	M 02/19	**Carrier generation and recombination (cont'd) and photo-conductivity** *4.3.3 Steady State Carrier Generation; Quasi-Fermi Level* *4.3.4 Photoconductive Devices*	§'s 4.3.3, 4.3.4
16	W 02/21	**Diffusion of carriers** *4.4.1 Diffusion Processes* *4.4.2 Diffusion and Drift of Carriers*	§'s 4.4, 4.4.1, 4.4.2
17	F 02/23	**Diffusion of carriers (cont'd)** *4.4.2 Diffusion and Drift of Carriers; Built-in Fields* *4.4.3 Diffusion and Recombination;*	§'s 4.4.2, 4.4.3 **HW5 Due**
18	M 02/26	**Review, discussion and problem solving**	
	Tu 02/27	**HOUR EXAM** (Chaps. 1, 3, & 4, up to 4.4.2 included) **7:30 - 8:30 P.M.** combined sections	
19	W 02/28	**Steady state carrier injection; diffusion length** *4.4.4 Steady State Carrier Injection; Diffusion Length*	§'s 4.4.4
20	F 03/02	**p-n junctions in equilibrium, contact potential** *5.1 Fabrication of p-n Junctions,(short intro)* *5.2 Equilibrium Condition* *5.2.1 The Contact Potential*	Read § 5.1 Study §'s 5.2, 5.2.1, 5.2.2
21	M 03/05	**p-n junctions in equilibrium, space charge** *5.2.2 Equilibrium Fermi Levels* *5.2.3 Space Charge at a Junction*	Study §'s 5.2, 5.2.1, 5.2.2, 5.2.3
22	W 03/07	**Space charge at a junction** *5.2.3 Space Charge at a Junction*	§ 5.2.3
	F 03/09	**No Class: Engineering Open House**	**HW6 Due Mon 3/13**
23	M 03/12	**Current flow in a P-N junction** *5.3. Forward- and Reverse-Biased Junctions; Steady State Conditions* *5.3.1 Qualitative Description of Junction Current Flow*	§ 5.2.3, 5.3, 5.3.1 **HW6 Due**
24	W 03/14	**Carrier injection, the diode equation** *5.3.2 Carrier Injection*	§ 5.3.2
25	F 03/16	**Minority and majority carrier currents** *5.3.2 Carrier Injection* *5.3.3 Reverse Bias*	§'s 5.3.2, 5.3.3 **HW7 Due**
	03/19-03/23	**Spring Break**	
26	M 03/26	**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
27	W 03/28	**Stored charge, diffusion capacitance, and junction capacitance** *5.5.4 Capacitance of p-n Junctions*	§'s 5.5.4

28	F 03/30	**Optoelectronic devices (photodiodes)** *8.1.1 Current and Voltage in an Illuminated Junction* *8.1.2 Solar Cells* *8.1.3 Photodetectors*	§'s 8.1.1, 8.1.2, 8.1.3 **HW8 Due**
29	M 04/02	**Optoelectronic devices (cont'd)** *8.2 Light-Emitting Diodes* *8.4 Semiconductor Lasers*	§'s 8.2.1, 8.2.2, 8.3, 8.4.1, 8.4.2, 8.4.3, 8.4.4, 8.4.5
30	W 04/04	**Metal semiconductor junctions** *5.7.1 Schottky Barrier* *5.7.2 Rectifying Contacts* *5.7.3 Ohmic Contacts*	§'s 5.7.1, 5.7.2, 5.7.3
31	F 04/06	**Metal-insulator-semiconductor FET** *6.4.1 Basic Operation* **Metal-insulator-semiconductor FET (Cont'd)** *6.4.2 The Ideal MOS Capacitor*	§'s 6.4.1, 6.4.2 **HW9 Due**
32	M 04/09	**MOS capacitor** *6.4.3 Flatband Voltage* *6.4.4 Threshold Voltage*	§'s 6.4.3, 6.4.4
33	W 04/11	**Review, discussion and problem solving**	
	Th 04/12	**HOUR EXAM** (Chaps. 4.4, 5 & 8) **7:30 - 8:30 P.M.** combined sections	
34	F 04/13	**MOS capacitor (Cont'd)** *6.4.5 MOS Capacitance-Voltage Analysis*	§'s 6.4.5
35	M 04/16	**MOS field-effect transistor** *6.5.1 Output Characteristics* *6.5.2 Transfer Characteristics*	§'s 6.5.1, 6.5.2
36	W 04/18	**MOSFET (Cont'd):** *Small-signal analysis* *Resistive load-NMOSFET-common-source amplifier* *CMOS inverter (Integrated Circuits)*	§'s 6.5.8, 9.3.1, 9.5.1
37	F 04/20	**Narrow-base diode** Handout on narrow-base diode	§'s handout on BJT **HW10 Due**
38	M 04/23	**Introduction to bipolar junction transistor** *BJT Fundamentals* *Relationship between narrow-based diode and BJT*	§'s 6.1.1, 6.1.2, 7.1, 7.2, 7.3 and handout
39	W 04/25	**Introduction to bipolar junction transistor** *BJT specifics*	§'s 7.3, 7.4.1, 7.4.2, 7.4.3, 7.4.4 and handout
40	F 04/27	**Introduction to bipolar junction transistor (cont'd)** *Normal mode operation*	§'s 7.3, 7.4.1, 7.4.2, 7.4.3, 7.4.4 and handout **HW11 Due**
41	M 04/30	**Bipolar junction transistor (Cont'd),** *Common-emitter amplifier and small-signal current gain*	§'s 7.4.1, 7.4.2, 7.4.3, 7.4.4 and handout
42	W 05/02	**Review, discussion and problem solving**	
		FINAL EXAM, (Chaps. 1, 3, 4, 5, 6, 7, 8, & 9) **To be announced**	

This is for the 1986 2nd edition, Device Electronics for Integrated Circuits, ISBN: 0471887587. I have not looked at the recent 3ed. The fundamentals in this "1980's vintage" 2ed. text haven't changed, and therefore it is still relevant.Â Finally, as a warmup before tackling M&K, you might consider "Intuitive Ic Electronics: A Sophisticated Primer for Engineers and Technicians" by Thomas M. Fredericksen. Good luck. Read more. An integrated circuit or monolithic integrated circuit is a set of electronic circuits on one small flat piece of semiconductor material that is normally silicon. The integration of large numbers of tiny transistors into a small chip.Â Integrated circuit from an EPROM memory microchip showing the memory blocks, the supporting circuitry and the fine silver wires which connect the integrated circuit die to the legs of the packaging. Virtual detail of an integrated circuit through four layers of planarized copper interconnect, down to the polysilicon (pink), wells (greyish), and substrate (green). An integrated circuit or monolithic integrated circuit (also referred to as an IC, a chip, or a microchip) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material that is normally silico