IH1611

Semiconductor Components

Period 6 - Fall 2016

https://kth.instructure.com/courses/216

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Semiconductor Devices

Semiconductor systems are present almost everywhere in society. They are present in information and communication as well as in power electronics energy applications. Nearly all digital and analog circuits are made with silicon based semiconductor technologies such as CMOS and BJT. Today a huge amount (~one billion) of transistors can be manufactured in an integrated circuit (IC) with a size of only a few square centimeters. It is the vast amount of transistor in a single IC that enables the computing power and high functionality of today's electronic applications such as computers, mobile phones, ipads, digital cameras, displays and many more. Semiconductor devices are also used to build light emitting devices such as LED (traffic lights, solid-state lightning, indicator lights) and lasers (CD, DVD, optical communication). They can also be used to detect light and to convert light energy into electric energy (solar cells). In the energy area semiconductor devices is used to handle high currents and high voltages (several thousands of ampere and volts). Although semiconductor devices can be used in very different applications the fundamental devices used in almost all applications are the pn-diode, the Metal-Oxide-Semiconductor-Field-Effect-Transistor and the bipolar transistor. In this course you will learn the function and the device physics of these devices and how they are used in different applications.

Learning outcomes

In detail, after a successful completion of the course you will be able to:

1. Qualitatively describe the electronic energy band structure of insulators, semiconductors and metals.
2. Calculate the electron and hole concentration in the conduction and valence band using Fermi-Dirac statistics and the energy band model.
3. Describe the constituents of the current density in semiconductors and derive analytical expressions for the current density in the case of low-level injection, electron-hole recombination, externally applied voltage and external generation by light, using the drift-diffusion model.
4. Describe the function of the pn-diode, the bipolar and the long channel MOS transistor.
5. Analyse and calculate the internal electrostatics (electric charge, electric field and potential) of the pn-diode, the bipolar and the long channel MOS transistor.
6. Derive and calculate the current density in the pn-diode, the bipolar and the long channel MOS transistor using the drift-diffusion model.
7. Describe major process technologies, used to fabricate semiconductor devices and relate these to schematic cross-section drawings of devices.
8. Extract device properties from electrical measurements of devices.
9. Perform oral and written presentation of the subject Semiconductor Components.

Course main content

The overall goal of the course is that you should be able to describe the function of devices, based on the pn-junctions and MOS-structures. These devices includes the bipolar and MOS transistors, and memory cells. You should be able to describe how these devices are used in applications. You should be able to derive and calculate the currents inside these devices and be able to analyse the internal state of the charge distribution, the electric field and the current density for given terminal bias voltages. You should be familiar with the process flow, used in the fabrication of modern microelectronics.

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The overall goal of the course is that you should be able to describe the function of the pn-diode, the bipolar and the MOS transistor and how these three devices are used in applications. You should be able to derive and calculate the currents inside these devices and be able to analyse the internal state of the charge distribution, the electric field and the current density.

In detail, after a successful completion of the course you will be able to:

1. Qualitatively describe the electronic energy band structure of insulators, semiconductors and metals
2. Calculate the electron and hole concentration in the conduction and valence band using Fermi-Dirac statistics and the energy band model.
3. Describe the constituents of the current density in semiconductors and derive analytical expressions for the current density in the case of low-level injection, electron-hole recombination, externally applied voltage and external generation by light, using the drift-diffusion model.
4. Describe the function of the pn-diode, the bipolar and the long channel MOS transistor.
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6. Derive and calculate the current density in the pn-diode, the bipolar and the long channel MOS transistor using the drift-diffusion model.
7. Describe major process technologies, used to fabricate semiconductor devices and relate these to schematic cross-section drawings of devices.
8. Extract device properties from electrical measurements of devices.
9. Perform oral and written presentation of the subject Semiconductor Components.

Organization of the course

To achieve the course goals it is necessary to actively study during all weeks of the course. It is assumed that the students have followed the reading instructions before each lecture, since the lectures contains sections that require active participation from the students. In the course there are student recitations which also require preparation ahead of each class.

The course gives 7.5 credits (HEC) (200 hours of which 46 hours are in class).
There are 14 lectures (1 reserve time slot), 6 student recitations and one laboratory session with 2 associated seminars. Schedule and reading instruction are placed at the end of this course-PM.

Lectures

There are ***Reading Instructions*** at the end of this course-PM. The lectures are based on the assumption that the students have read according to Reading Instruction ***before the lecture***. During the lectures there will be sections that require ***active participation*** by the students.

Student recitations

There are 6 student recitations in the course.

At the *first lectures 6 sheets containing 6 problems* (totally 36 problems) are distributed. The sheets are numbered as S1, S2, S3, S4, S5 and S6. Before each student recitations the student should try to solve the 6 problems on the sheet related to the student recitation in question. The *student* should also *prepare* to present the *solution on the board* for the class.

The level of difficulty of the problems on the student recitation corresponds to the written exam.

In detail a student recitation is organized as follows:

1. At the beginning of the student recitation each student will put a cross on a list to indicate which of the 6 problems he/she is prepared to present to the class
2. One student is randomly picked to present each problem.
3. After the solution has been presented there is a discussion, in which all students are expected to participate. Students are expected to give feedback on the presented solution and possibly provide alternative solutions.
4. When the discussion is finished a new student presents a solution to the next problem
5. When all 6 problems have been presented and discussed the student recitation ends.

The number of crosses a student has on the list indicates how many problem the student has solved. The total number of problems is 36. To *be allowed* to attend *the written exam* the student has to acquire a *minimum of 20 crosses* after the 6 student recitations.

The scheduled time for each problem is 15 minutes but it would be appreciated if the student could present his/her solution faster to allow for discussion with the class.

The requirement for an acceptable presentation is that it should be clear to the teacher and the class that the student has made an *honest attempt to solve* the problem, but not necessarily getting the correct answer.

It is of course allowed (and encouraged) that students collaborate in order to prepare for the student recitations. For solving the problems any aid is allowed, but remember that on the written exam the only allowed aid is “IH1611 Material Properties and formulas” and a calculator.

If it is obvious that the student has NOT made an honest attempt to solve the problem (but has still crossed it on the list) all the crosses for the student from that student recitation is removed.

Laboratory work, seminars and report

Course lab includes a laboratory exercise in groups of four students. The place of the lab is in the Electrum building, KISTA CAMPUS, elevator C, level 4. Labs will be scheduled by signup online. During two hours measurement ***data are collected*** under the guidance of a lab assistant. After the lab***, each student independently determines device parameters*** from measurements. Each student receives an individual assignment and will write an individual lab report that presents the measurements, the extraction procedure and the results. Method, results and conclusions must be clearly outlined. Results should be commented on regarding accuracy and students are expected to reflect on the relationship between measurements and theory. Results should be reported with well-structured diagrams, graphs and tables. A good lab report should be clear, as well as linguistically well-written. The ***first seminar deals*** with ***extraction procedure*** and with ***report writing***.

The ***laboratory report*** should be submitted under the ASSIGNMENTS menu https://kth.instructure.com/courses/216/assignments

Please use PDF only, no WORD or OPEN OFFICE files

The ***first deadline*** is stated in the schedule at the end of this course-PM.

The laboratory report will be tested for ***plagiarism*** of the course responsible. All students will receive an email with ***three laboratory reports.*** These should be read and about half a page ***constructive feedback*** must be ***prepared before the feedback seminar***. The written feedback should be brought in two copies (one to their peers and one to the course responsible) to the ***feedback seminar*** (date and time is given in the schedule at the end of this course-PM). At the feedback seminar each student will give (to their peers) and receive (from their peers) feedback on their reports. After the seminar students can ***improve*** their reports and the ***final report*** should be sent in to the course responsible before the ***second deadline*** stated in the schedule at the end of this course-PM.

Examination

The course has three examinations that examine the course goals.

1. Laboratory report (1.5 credits Pass/Fail))
2. Student recitations
3. Written examination. (6 credits and A-F grades)

Laboratory report

The Laboratory work is awarded 1.5 credits. The grade on the Laboratory work is Pass/Fail. To be awarded the grade pass the student needs to participate in the laboratory session, the feedback seminar and file an individual laboratory report before the deadline.

Student recitations

To be allowed to attend the written exam the student has to acquire at least 20 crosses during the 6 student recitations.

Written exam

The written exam consists of 6 problems which are similar to the problems dealt with on the student recitations. There are also two questions that deal with the theory of semiconductor components which require a texted answer. Each problem/question gives a maximum of 5 points. To get the grade E a total of 20 points is required. The allowed time on the written exam is 5 hours. The students are only allowed to bring "IH1611 Material Properties and formulas" and a calculator to the written exam. Date and time for the written exam is given in the schedule at the end of this course-PM. Sign-up is mandatory and will be open online.

Teachers and additional information

Lectures & Course responsible

Professor Anders Hallén, Lectures

Associate Professor Gunnar Malm, Lectures and Course responsible

Teachers and lab assistant

Mattias Ekström and Gunnar Malm, Student recitations 1-6.

Assistant XX, laboratory sessions, 2h per group of four students

Examiner

Associate Professor Gunnar Malm

Course prerequisites

Electromagnetic theory, electric circuit theory, introductory solid state physics, introductory quantum mechanics alternatively thermodynamics with statistical physics, basic chemistry.

Course literature

Modern Semiconductor Devices for Integrated Circuits, Chenming Calvin Hu, 2010, Pearson Education , ISBN-10: 0-13-700668-3.

Schedule and Reading Instructions

The Laboratory session is not scheduled signup will be online. L=Lecture, S=Student recitation, Sem=Seminar, I=Individually meet a teacher, T=Tentamen,

Activity	Date	Time	Place	Content	Reading Instruction	Teacher
L1	Nov 2	13-15	D32	Course-PM, Bond model, Energy Band model, Fermi-Dirac distribution function	Ch. 1.1-1.9, 1.11, 2.1-2.2	**AH**
L2	Nov 4	15-17	E33	Energy Band model, n_o and p_o, Drift Current	Ch. 1.1-1.9, 1.11, 2.1-2.2	**AH**
L3	Nov 8	8-10	D32	Diffusion currents Generation/Recombination	Ch. 2.3-2.9	**AH**
S1	Nov 9	16-18	D41	Student recitation 1	Online S1	**ME**
L4	Nov 11	13-15	E34	PN-diode: Electrostatics	Ch. 4.1-4.5	**AH**
Sem	Nov 14	13-15	E32	Extraction of properties from measurement data. What is a good written report?	Online material from course round spring 2013	**GM& assistant**
L5	Nov 15	8-10	B22	PN-diode: Drift and Diffusion currents	Ch. 4.6-4.9	**AH**
L6	Nov 16	13-15	D33	PN: Schottky contacts	Ch. 4.16-4.22	**AH**
S2	Nov 18	10-12	M37	Student recitation S2	Online S2	**ME**
L7	Nov 22	8-10	D35	PN: Solar cells, LEDs and Diode Lasers	Ch. 4.12-4.15	**GM**
L8	Nov 23	13-15	D32	MOS Capacitor. Electrostatics	Ch. 5.1-5.6	**GM**
S3	Nov 25	10-12	Q13	Student recitation S3	Online S3	**ME**
L9	Nov 29	8-10	B22	MOSFET: Electrostatics and drain current	Ch. 6.1-6.2, 6.4-6.6	**GM**
L10	Nov 30	13-15	E34	MOSFET: Mobility and CMOS inverter	Ch. 6.3 and 6.7	**GM**
S4	Dec 1	10-12	B22	Student recitation S4	Online S4	**ME**
L11	Dec 2	15-17	D32	Scaling of modern CMOS circuits	Chap. 7 based on Figs. 7-2, 7-5 & 6, 7-9, 7-13 & 7-14, 7-18 & 7-19	**GM**
Deadline	*Dec 6 23.59*		***First version of lab report submitted under ASSIGNMENTS menu***			
L12	Dec 6	8-10	D32	PN: Case study Bipolar Transistor	Ch. 8.1-8.4, and 8.5	**GM**
L13	Dec 8	10-12	B22	Process Technology Guest Lecture to be decided	Ch. 3	**GM& guest**
Sem	Dec 9	10-12	Q11	Peer-review seminar on Laboratory report. Bring your feedback in two copies, one to the teacher and one to		**GM& assistant**

				your peer.		
S5	Dec 9	13-15	D35	Student recitation S5	Online S5	**ME**
Deadline	*Dec 22 23.59*		*Final version of lab report submitted under ASSIGNMENTS menu*			
L14	Dec 13	8-10	D32	Repetition	Chapters 1,2 and 4	**GM&ME**
S6	Dec 14	13-15	L41	Student recitation S6		**ME**
Reserve time	Dec 16	10-12	E53	Repetition	Chapter 5,6 and 7	**TBD**
T	**Jan 10, 2017**	**8-13**	**E2, E3**	**Written Exam** *Online signup is mandatory!*	**All**	**GM**