IH2654 Nanoelectronics, 9hp – spring 2017, period 3

and FIM3003 Nanoelectronics, PhD course

For Master programs in Nanotechnology and E, F, ME and PhD students

https://www.kth.se/social/course/IH2654/
Department: SCI-School, Materials Physics

General

The course reviews the trends in low dimensional semiconductors which use quantum phenomena to realize new functions or devices and new basic building blocks. These aim at electronic, opto-electronic and new bio applications. New approaches to nanoelectronic systems will also be overviewed.

Course outline

The course comprises a series of lectures, following in large a textbook, and tutorials. Two laborations are included where students work in groups of 2 students. These parts are examined by a written exam. Finally, students should do a 'mini-project' (also in groups of 1-3 students) which involves studying a specific research area or application within nanoelectronics. These are examined and graded by a written report as well as by an oral presentation.

Course parts	*Credits*	*Hours*
Lectures		16x2 hours
Tutorials		7x2 hours
Laboration	1.5 hp (1p)	2x3 hours
Exam	4.5 hp (3p)	5 hours
Mini-project	3 hp (2p)	~40 hours
Total credits	9 hp (6p)	

Teachers

Lecturer:	Jan Linnros, prof, linnros@kth.se, 08-7904370
Assistants:	Federico Pevere, pevere@kth.se (Tutorials)
	Ilya Sychugov, ilyas@kth.se (PL lab)
	Apurba Dev, apurbad@kth.se (Quant Cond Lab)

Goals

** The student should be familiar with certain nanoelectronic systems and building blocks such as: low-dimensional semiconductors, heterostructures, carbon nanotubes, quantum dots, nanowires etc.*

** The student should be able to set up and solve the Schrödinger equation for different types of potentials in one dimension as well as in 2 or 3 dimensions for specific cases.*

** The student should be able to use matrix methods for solving transport problems such as tunneling, resonant tunneling and know the concept of quantized conductance.*

** The student should be experimentally familiarized with AFM and PL methods and know their approximate performance as well as applications.*

** Through the mini-project, students should get familiarized with searching for scientific information in their subject area, practice report writing and presenting their project in a seminar*

** Finally, a goal is to familiarize students with the present research front in Nanoelectronics and to be able to critically assess future trends.*

Syllabus

Introduction, refresh in basic quantum mechanics and solid state physics, low-dimensional semiconductors, density of states, quantum wells and heterostructures, quantum wires, quantum dots, nanocrystals, optical properties, absorption, luminescence, transport including tunneling in low-dimensional semiconductors, single-electron devices, calculation methods, fabrication methods, analyses techniques, applications, new trends in silicon VLSI-technology, physical limits in nanoelectronics, nanoelectronic systems, new approaches to replace CMOS etc.

Prerequisites

Basic understanding of the physics and chemistry of materials. Basic knowledge in solid state physics (Kittel): IM2651 or IM2601 (formerly: 2B1211 or 2B1711) and of semiconductor physics and devices: IH2651 or IH1611 (formerly 2B1252 or 2B1260). An extra lecture on the basics of semiconductors (including devices) could be given for students who feel their knowledge in this area is weak.

Examination

A written examination (TEN1; 4.5 hp) covers the lectured course. To pass the course it is necessary to do the laboratory work (LAB1; 1.5 hp) and a mini-project overviewing an application of nanoelectronics. This involves a written report and a seminar (ANN1; 3 hp). Grading of the course is based both on the written exam and the mini-project (seminar in combination with the written report). The grading scale is: A – F.

The written exam will include two parts: (i) 4 theory or descriptive tasks without books. This part is then turned in and students may then use their books for (ii) second part consisting of 4 tasks involving some calculations. The credit per task is 4 units and thus total available credit is 32. Normally 16 are required for passing. Students with credits of ~2 from passing will be given the grade “Fx” and may receive “E” after a successful oral examination. Such oral examination will be taken individually (1 h) and on a specific day to be announced.

There will also be 2 control exams which will give a maximum of 5 bonus units to the written exam. These are intended to stimulate early studies of the basics of the course. The control exams will be 30 min on the beginning of two tutorials, see schedule below. Books may be used and both theory and calculation tasks will be included.

For PhD course only Pass/Fail is registered in LADOK and a "C" or higher will be required for passing.

Laboration

The course contains 2 labs (each of ~3 hours) where students sign up 2 together:

- Lab 1: “Optical properties of nanocrystals”
- (Lab 2: “Atomic force microscope” – canceled due to AFM lab in other course)
- Lab 3: “Quantized conductance”

Each lab needs to be prepared in advance and preparation tasks should be handed in/will be questioned at the lab start. The labs are located in Electrum on floor C3. Lab schedule is shown below and sign up lists will be distributed later.

Seminar/mini-project

Students will be assigned to a mini-project. These are literature studies focusing on a specific area that will be agreed upon together with the examiner. Typically, two students will work together. The mini-project will result in a report of 4-5 pages and a seminar of ~20 min at two lectures at the end of the course. The seminar and report will be graded individually. **Full participation on all student presentations is compulsory for all students!**

Some suggestions for mini-project topics:

Quantized conductance	Single-electron devices
Tunneling devices	Self-assembled InAs quantum dots
II-VI nanocrystals	Inter-sub-band lasers
Porous silicon	QWIP – quantum well infrared detectors
Quantum dot lasers	Nanowires
Thermoelectric effect at nanoscale	

You are free to suggest other mini-projects. The book by Rainer Waser (Nanoelectronics and information technology) can be a source of ideas.

Course literature

- The course will be based on the following text book: *The physics of low-dimensional semiconductors*, by John Davies (1998), ISBN 0-521-48491-X. The book provides an introduction and the foundations of the field of semiconductor nanostructures. It requires basic knowledge in quantum mechanics and solid state physics. The book can be bought at KTH book store (~570 SEK) or Bokus (565 SEK) & AdLibris (~500 SEK) or Amazon ($72). The book is now also available as an e-book via KTH library (go to www.kth.se/en/kthb -> search "the physics of…" -> click on "Fulltext / Links" -> click on "Cambridge University Press Online Books", download selected chapters in pdf format).
- A new textbook "Fundamentals of nanoelectronics" by George W. Hanson, ISBN 978-0-13-158883-7 can be a useful second book to read.
- Lab manual: "Optical properties of nanocrystals"
- Lab manual: "Quantized conductance"
- Hand-outs and review articles

Reading list

The physics of low-dim semiconductors, John. H. Davies

Chapter 1	Should be known as basics of quantum mechanics	1
Chapter 2	2.1 – 2.7	1
	2.8	2
Chapter 3	3.1 – 3.9 (descriptive but all concepts should be known)	1
	3.10 concept of "effective mass approximation" important	2
Chapter 4	4.1 – 4.8	1
	4.9	2
Chapter 5	5.1 – 5.2, 5.4 – 5.5	1
	5.3, 5.6, 5.7 – 5.7.1 (Figs 5.22-23 important), 5.9	2
	5.7.2 – 5.8	-
Chapter 6	6.1 – 6.4.7	1
	6.4.8 – 6.6.2	2
Chapter 7-10	Some parts may be included (given later)	2

Additional reading (may be updated later):

• 'Semiconductor clusters…' A.P. Alivisatos, Science 1996	2
• 'Quantum dots and nanoparticles' from the book "Fundamentals of nanoelectronics" by George W. Hanson	2
• 'Quantum Point Contacts' by H. v. Houten & C. Beenakker	2
• 'Coulomb blockade and single electron transistors' by T.J. Thornton	2
• 'The emergence of spin electronics in data storage' by C. Chappert, A. Fert and F. Nguyen Van Dau, Nature Materials 2007	2
• 'Spintronics' by Stefano Bonetti, lecture notes	2

Ratings (at right):

1	Deep knowledge, for exam: theory & calculation tasks
2	Read through, overview knowledge, for exam: descriptive tasks
-	Not included

Lecture & tutorial schedule (in grey), all at central campus

Lecture *Tutorial*	*Date* *Room*	*Time*	*Subject*	*Chapter*	*Comments*
V3					
1	18-jan D4448	10-12	Introduction Refresh - quantum mechanics	1	
2	18-jan D4448	13-15	Refresh - quantum mechanics	1	
3	20-jan D4448	13-15	Refresh – solid state physics	2	
1	20-jan D4448	15-17	Quantum mechanics	1	
V4					
4	23-jan D4448	13-15	Heterostructures	3	
5	25-jan D4448	10-12	Heterostructures	3	
V5					
6	30-jan D4448	13-15	Quantum wells, low-dim systems	4	
2	30-jan D4448	15-17	Solid state physics	2	
3	3-feb D4448	14-16	Heterostructures *+ Control exam, ch 1-2*	3	
V6					
7	6-feb D4448	13-15	Quantum wells, low-dim systems	4	
8	8-feb D4448	10-12	Quantum dots, nanowires	X	
9	10-feb D4448	10-12	Electrical transport	5	
V7					
10	13-feb D4448	13-15	Electrical transport Quantized conductance	5	
4	13-feb D4448	15-17	Quantum wells, low-dim systems	4	
11	15-feb D4448	10-12	Extra	-	
5	17-feb D33	14-16	Tunneling transport *+ Control exam, ch 3-4*	5	
V8					
12	20-feb D4448	13-15	Electric and magnetic fields	6	Last project sign-up!
13	22-feb D4448	10-12	Electric and magnetic fields Aharanov-Bohm, Quant. Hall	6	
14	24-feb D4448	10-12	Guest lecture? (Spin transport/not confirmed)	X	
V9					
15	27-feb	13-15	Single electron devices	X	

	D4448				
6	27-feb D4448	15-17	Electric and magnetic fields	6	
16	3-mar D4448	10-12	Repetition		
V10					
17	6-mar D4448	13-15	Extra		
7	6-mar D4448	15-17	Repetition, exam		
V11					
Exam	15-mar E51	14-19	Exam		
V14?					
18	?	?	Student presentations		

x: Additional materials or review article

Lab schedule, all in Electrum, Kista

Photoluminescence Lab – week 7

Monday	February 13	09 – 12
Tuesday	February 14	09 - 12
Wednesday	February 15	14 – 17
Thursday	February 16	09 – 12
Friday	February 17	09 - 12

Quantized conductance Lab – week 8

Monday	February 20	09 – 12
Tuesday	February 21	09 - 12
Thursday	February 23	09 – 12
Friday	February 24	14 – 17
Monday	February 27	09 – 12