SK2901 Quantum materials and devices, 7,5 hp – autumn 2019, period 2

(and SK3894 Nanoelectronics, PhD course)

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

Department: SCI-School, Department of Applied Physics, Photonics unit

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. The course was previously IH2653 with name "Nanoelectronics".

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. Previous years (at 9hp) the course also included a 'mini-project' (3hp) which involved studying a specific research area or application within nanoelectronics. This year it is left as a free option.

Course parts	*Credits*	*Hours*
Lectures		16x2 hours
Tutorials		8x2 hours
Laboration	1.5 hp	2x3 hours
Exam	6 hp	5 hours
Total credits	7,5 hp	

Teachers

Lecturers: Jan Linnros, prof, linnros@kth.se, 08 790 4370
Ilya Sychugov, associate prof. ilyas@kth.se, 08 790 4167

Assistants: Sara Cavallaro, saracav@kth.se (Tutorials)
Adil Baitenov, baitenov@kth.se (PL lab)
Rinat Yapparov, yapparov@kth.se (Quant Cond Lab), 08 790 6368

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.*

** 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): SK2758 or IM2601 and of semiconductor physics and devices: IH2651 or IH1611. 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; 6 hp) covers the lectured course. To pass the course it is necessary to do the laboratory work (LAB1; 1.5 hp). 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 (SK3894) only Pass/Fail is registered in LADOK and a "C" or higher will be required for passing. PhD course not active at present)

Laboration

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

- Lab 1: “Optical properties of nanocrystals”
- Lab 2: “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

Previous years when the course had 9 hp a mini-project was included. This year this will still be available as an option possibly giving 3 bonus units for the exam. 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 seminar of ~20 min to be presented at the end of the course. No written report.

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/carbon nanotubes
Thermoelectric effect at nanoscale	Graphene/2D materials
Perovskite solar cells	Grätzel solar cells
Phase change memories	Nanoscale biosensors

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. The book can be bought at KTH book store (~710 SEK) or Bokus (598 SEK) or Amazon ($63). 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).
- Two alternative books to read: (i) “Fundamentals of nanoelectronics” George W. Hanson, ISBN 978-0-13-158883-7; (ii) “Semiconductor nanostructures” by Thomas Ihn, ISBN 978-0-19-953443-2
- 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

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*
V44					
1	31-oct V22	10-12	Introduction Refresh - quantum mechanics	1	Ilya (Jan)
2	1-nov Q31	13-15	Refresh - quantum mechanics	1	Ilya
V45					
3	4-nov E53	13-15	Refresh – solid state physics	2	Ilya
1	5-nov E33	10-12	Quantum mechanics	1	Sara
4	6-nov V11	10-12	Refresh – solid state physics	2	Ilya
5	8-nov E53	13-15	Heterostructures	3	Ilya
V46					
2	11-nov D34	13-15	Solid state physics	2	Sara
6	12-nov E33	10-12	Heterostructures	3	Ilya
7	13-nov D34	10-12	Quantum wells, low-dim systems	4	Jan
3	15-nov Q24	13-15	Heterostructures + *Control exam, ch 1-2*	3	Sara
V47					
8	18-nov D32	13-15	Quantum wells, low-dim systems	4	Jan
9	19-nov D32	10-12	Quantum dots, nanowires	X	Jan
4	20-nov D42	10-12	Heterostructures, Quantum wells, low-dim systems	3,4	Sara
10	22-nov L52	13-15	Electrical transport	5	Jan
V48					
11	25-nov D33	13-15	Electrical transport Quantized conductance	5	Jan
12	26-nov E53	10-12	Electric and magnetic fields	6	Jan
5	27-nov D42	10-12	Quantum wells, low-dim syst. + *Control exam, ch 3-4*	4	Sara
V49					
13	3-dec D33	10-12	Guest lecture: Biosensing	X	Apurba Dev
14	4-dec D33	10-12	Electric and magnetic fields Aharanov-Bohm, Quant. Hall	6	Jan
6	6-dec V11	13-15	Tunneling transport	5	Sara
V50					
15	9-dec D32	13-15	Single electron devices	X	Jan

7	9-dec D32	15-17	Electric and magnetic fields	6	Sara
16	10-dec D32	10-12	Repetition		Jan
8	13-dec D32	13-15	Repetition, exam tasks	6	Sara
17	?	??	Student presentations		Jan/Ilya
V2					
Exam	13-jan E34,E53	8-13	Exam		

x: Additional materials or review article

Lab schedule, all in Electrum, Kista

Note that labs start at the hour: either 9:00 or 13:00 !
Wait for lab assistant at main hall in Electrum at staircase C

Wednesday	November 27	13 – 16	PL-Lab	QC-lab
Thursday	November 28	09 – 12	PL-Lab	QC-lab
Thursday	November 28	13 – 16	PL-Lab	QC-lab
Friday	November 29	09 – 12	PL-Lab	QC-lab
Friday	November 29	13 – 16	PL-Lab	QC-lab
Tuesday	December 3	13 - 16	PL-Lab	QC-lab
Wednesday	December 4	13 - 16	PL-Lab	QC-lab
Thursday	December 5	09 - 12	PL-Lab	QC-lab
Thursday	December 5	13 - 16	PL-Lab	QC-lab