SK2901 Quantum materials and devices, 7,5hp – autumn 2020, period 2

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. These parts are examined by a written exam. Two laboratory exercises are included, where students work in groups of 2 students and submit individual reports. ‘Mini-project’, which involve studying a specific research area or application within nanoelectronics and presenting results in a short talk can be optionally chosen (bonus points to the exam).

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: Ilya Sychugov, Associate Prof. ilyas@kth.se, 08 790 4167

Assistants: Sara Cavallaro, saracav@kth.se (Tutorials)
Adil Baitenov, baitenov@kth.se (PL lab)
Fredrik Stridfeldt, fsjost@kth.se (Quantized Conductance 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 photoluminescence and conductance measurement 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 60 min on the beginning of two tutorials, see schedule below. Books may be used and both theory and calculation tasks will be included.

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 Albano, Hus3. Lab schedule is shown below and sign up lists will be distributed later.

Seminar/mini-project

An option of presenting a mini-project possibly giving 3 bonus units for the exam is available. 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.

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
2D materials	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 (in grey) schedule

Lecture *Tutorial*	*Date* *Room*	*Time*	*Subject*	*Chapter*	*Comments*
V44					
1	26-oct M31	13-15	Introduction Refresh – quantum mechanics	1	Ilya
2	28-oct Q22	10-12	Refresh - quantum mechanics	1	Ilya
1	29-oct E53	10-12	Quantum mechanics	1	Sara
3	30-oct D32	13-15	Refresh – solid state physics	2	Ilya
V45					
4	2-nov M35	15-17	Refresh – solid state physics	2	Ilya
2	3-nov D42	10-12	Solid state physics	2	Sara
5	4-nov D32	10-12	Heterostructures	3	Ilya
6	6-nov E33	13-15	Heterostructures	3	Ilya
V46					
3	9-nov E33	13-15	Heterostructures *+ Control exam, ch 1-2*	3	Sara
7	10-nov D32	10-12	Quantum wells, finite/infinite barrier	4	Ilya
8	11-nov E53	10-12	Quantum wells, different potentials	4	Ilya
4	13-nov E36	13-15	Heterostructures, Quantum wells, low-dim systems	3,4	Sara
V47					
9	16-nov Q26	13-15	Quantum dots	X	Ilya
5	18-nov E53	10-12	Quantum wells, low-dim systems	4	Sara
V48					
10	23-nov D32	13-15	Electrical transport, square barrier	5	Ilya
6	25-nov Online	10-12	Electrical transport *+ Control exam, ch 3-4*	5	Sara
11	26-nov D34	10-12	Electrical transport Quantized conductance	5	Ilya
V49					
12	1-dec D32	10-12	Electric and magnetic fields	6	Ilya
13	2-dec D32	10-12	Coulomb blockade, single electron devices	X	Jan Linnros
7	4-dec Online	13-15	Electric and magnetic fields	6	Sara
V50					
14	7-dec Online	13-15	Biosensing with nanoelectronics devices	X	Apurba Dev
8	8-dec Online	10-12	Repetition, exam tasks	All	Sara
15	9-dec Online	13-15	Mini-projects	X	Students
16	11-dec Online	13-15	Mini-projects	X	Students
V2					
Exam	11-jan Online	14-19	Exam		

X: Additional materials or review article

Lab schedule, all in Albano, Hus3 (Hannes Alfvens väg, 12)

Note that labs start at the hour: either 9:00 or 13:30!

Thursday	November 26	13:30 – 17:00		PL-lab
Friday	November 27	13:30 – 17:00		PL-lab
Monday	November 30	09:00 – 12:30	QC-Lab	PL-lab
Monday	November 30	13:30 – 17:00	QC-Lab	PL-lab
Tuesday	December 1	09:00 – 12:30	QC-Lab	PL-lab
Tuesday	December 1	13:30 – 17:00	QC-Lab	PL-lab
Wednesday	December 2	09:00 – 12:30	QC-Lab	PL-lab
Wednesday	December 2	13:30 – 17:00	QC-Lab	(PL-lab)
Thursday	December 3	09:00 – 12:30	QC-Lab	
Thursday	December 3	13:30 – 17:00	(QC-Lab)	

(in parenthesis – reserve)