Syllabus: Advance Topics in Electrooptics and Nano-Photonics

Course topic
Advance Topics in Electrooptics and Nano-Photonics
Number of credits
3 ECTS
Course responsible
Ben Gurion University of the Negev
Faculty of Engineering, Electro-Optics department
Prof. Gabby Sarusi
Mr. Amir Tal

Course lecturer
Prof. Gabby Sarusi

Prerequisites
"Electro-optics semiconductor devices" and " Fundamentals of semiconductors"

Learning outcomes

On Successful completion of this course students will be able to understand the relationship between the device structure and its functionality. In advanced stage, the student will be able to "tailor" a structure of a photonic device based on the requirements dictating. In addition the student will understand how the integration of such device can be done in a system level.

Abstract
The photon in the 21st century is considered to be with the same importance as the electron in the 20th century. The main reason is that most of the advanced systems are more and more relay on photons (internet communication, medical diagnostics and curing, military systems, etc.). In the last three decades, implementation of nano-structure in photonic devices is an obvious due to their performances tailoring capability using quantum size effect. In this course we will understand this new degree of freedom in designing new nano-scale based devices compare with the classical devices and their rolls in actual systems. We will be mainly focusing on light absorption devices such as advanced infrared detectors and solar cells and on light emitting devices such as LED, OLED and lasers. Special attention is given to topics such as plasmonic and nano-antennas as well as graphene and carbon nano-tubes and their rolls in photonics devices

Content

- Photonic semiconductors - energy bands diagram and their unique properties
- Quantum structure and the tailoring capabilities for photonics devices in nano-scales dimensions.
- Infrared physics
- Cooled and un-cooled classical infrared detectors
- Quantum wells, quantum wires and quantum dots infrared photodetectors.
- Implementation in infrared systems
- Plasmonic phenomena and nano-antennas – their practical usage in photonic devices

- LED, OLED and quantum wells lasers - quantum confinement
- Advance solid state lasers – quantum cascade lasers -
- High power lasers physics and systems
- Graphene and Carbon Nano-Tubes (CNT) and their roles in photonics devices

Teaching methods

Oral lectures combined with Power Point Presentation

Assessment

Written examination covering all material taught in the course and an oral and written presentation seminar given by each student on a pre-agreed selected topics.

Recommended Reading
S.O. Kasap "Optoelectronics and Photonics Principles and Practices" 2001
Recent published papaers

Syllabus

“Nanotechnology- Journey through time and space towards the future drugs”

Course topic
Nanotechnology and nanomedicine

Number of credits
4 ECTS
Course responsible
BGU

Course coordinateur
Dr. Tsiona Elkayam

Prerequisites
Non

Learning outcomes

On Successful completion of this course students will have knowledge on:

1. Nanotechnology in general: Definition, history and up-to-date
2. Nanotechnology implantation in array of fields like electro-optics, physics, water and more.
3. Philosophy of science in general
4. Conducting a research: from bench to off-the-shelf product.
5. Nano-medicine: needs and expectations, target drugs delivery and the word of biomaterials used for designing new carrier.
6. Analysis methods for characterisation of the nano materials and new drugs.

Abstract

This course is focusing on **Nano-Bio-Medicine**. The course audiences are high-school students in the program “Future scientist and inventors” in BGU and later on aiming to be given to all high school students. The course will be given by the leading researchers in Nano and Bio- medicine in the university and will enable us to expose those students to the nano-medicine field.

In addition to the main goal of the course, which is teaching nanotechnology in general and target drug delivery in particular, the second important goal of the course is to inspire the students and increase their curiosity to nanotechnology and science in general.

Content

1. Introduction to nanotechnology: past, present, future and vision.
2. Philosophy of science
3. Nanotechnology in different science and daily life: materials sciences, physics, security, space, water, medicine, electro optics, and daily products.
4. How research is born: Examples of a research from an idea to bench to an off-the-shelf-product.
5. Nanotechnology in the bio-medicine word: needs and vision. Introduction to target drug delivery
6. Molecular biology: introduction (from gene to proteins) and the use of target drug delivery as a treatment.
7. Biomaterials: kinds of biomaterials' designing a new carrier for drug delivery and the advantages and disadvantages of each biomaterial for this purpose.
8. Characterisation methods in the nanosciences
9. Characterisation methods used for target drug delivery.
10. Electron Microscopy: history, principle and uses for nanosciences.
11. Atomic Force Microscope: history , principle and uses for nanosciences
12. Case study: Bio-Inspired Nano-Carriers for Sub-Cellular Targeted Therapeutics.

Teaching methods

The course is present in the Moodle learning environment and includes recorded lessons and a few laboratory demonstrations.

Assessment

Knowledge test with a multiple choice questionnaire

Recommended reading

To be add later

Syllabus
"Kinetics of materials"

Course topic
Kinetics of Materials
Number of credits
4 ECTS (26 lecture hours – 2 hrs per lecture * 13 lectures)
(52 self - teaching hours – 5 hrs per lecture * 13 lectures)
Course responsible
BIU

Course lecturer
Dr. Gilbert Daniel Nessim

Prerequisites
Basic solid state chemistry, Advanced physical chemistry
Recommended but not mandatory: Introduction to X-ray diffraction (XRD)

Learning outcomes

On Successful completion of this course students will be able to:

1. Model systems using forces and fluxes
2. Solve any diffusion couple problem, including Kirkendall effect
3. Solve problems involving multi-layer diffusion
4. Solve ionic diffusion problems
5. Understand issues related to thin film diffusion

Abstract
This course, is modeled after a graduate core course taught at MIT in the Materials Science and Engineering department by Professor Samuel Allen. It is a fundamental course that presents a unified treatment of phenomenological and atomistic kinetic processes in materials. It provides the foundation for the advanced understanding of processing, microstructural evolution, and behavior for a broad spectrum of materials. The course emphasizes analysis and development of rigorous comprehension of fundamentals. Topics include are irreversible thermodynamics, diffusion, nucleation, and phase transformations. The main topic taught during the course is diffusion.
Content

1. Introduction
   Thermodynamics and Kinetics. Averaging. Fields, Variations, and Continuum Limits. Fluxes and Accumulation. Conserved and Non-conserved Quantities.
2. Principles of Irreversible Thermodynamics
   Entropy and Entropy Production. Basic Postulate of Irreversible

Thermodynamics. Linear Irreversible Thermodynamics. The Diffusion Potential. Onsager's Symmetry Hypothesis.

3. Driving Forces and Fluxes for Diffusion
   Diffusion in a concentration gradient. Reference frames for diffusion and marker velocity. Relation of diffusivity to mobility. Self-diffusion, intrinsic diffusion, and interdiffusion.
4. Interdiffusion
   Reference frames for describing diffusion. Intrinsic diffusivities. The Kirkendall effect.
5. Effects of Capillarity and Stress on Diffusion
   Surface tension and surface free energy. Mean curvature of a surface. Interface motion and changes of interfacial area. Smoothing of a rough surface. Effect of stress on diffusion potential. Equilibration of solute "atmospheres" around edge dislocations. Darcy's Flaw.
6. The Diffusion Equation
   Flux and divergence. The constant-diffusivity case. Scaling of the diffusion equation. Superposition of solutions. Error function solution. Fundamental point-source solutions.
7. Solutions to the Diffusion Equation—I
   Concentration-dependent diffusivity. Time-dependent diffusivity. Anisotropic diffusion.
8. Solution to the Diffusion Equation—II
   Steady-state solutions. Time-dependent solutions. Superposition of point sources. Method of images.
9. Solutions to the Diffusion Equation—III
   Method of separation of variables. Method of Laplace transforms.
10. Solutions to the Diffusion Equation—IV
    Numerical methods for solving differential equations. Treatment of boundary conditions. Examples.
11. Activated Jump Processes
    One-particle model. Many-body model. Computer simulations. Mean square displacement from a point source. Diffusion Resulting from Discrete Jumps Diffusion and random walks. Diffusion with correlated jumps. Relation of mean square displacement to diffusivity.
12. Diffusion in Crystals—I
    Diffusion mechanisms in crystals. Atomic models for diffusion coefficients in metals.
13. Diffusion in Crystals—II
    Atomic models for diffusion coefficients in ionic crystals. Intrinsic and extrinsic regimes of diffusion. Nonstoichiometry.
14. Short-Circuit Diffusion in Crystals
    The diffusion spectrum. Diffusion along grain boundaries. Diffusion along dislocations.

Teaching methods

The theoretical part of the course is presented in the Moodle learning environment in the form of Oral lectures combined with Power Point Presentation
Tutorials will be attached as PDF documents

Assessment

Written examination covering all material taught in the course

Recommended reading

All material needed will be provided during the course.
A complete but more complex text is:
Kinetics of Materials, Baluffi, Allen, Carter, John Wiley & Sons.
Other specific books and references to supplement the learning will be shown in class.

Syllabus
Nano-science and nano-technology
Why is “nano” different and how is it useful?

Course topic

Nano-science and nano-technology. Why is “nano” different and how is it useful?

Number of credits

4 ECTS	(26 lecture hours	–	2 hrs per lecture * 13 lectures)
	(52 self - study hours	–	4 hrs per lecture * 13 lectures)

Course responsible

BIU

Course lecturer

Dr. Amos Sharoni & Prof. Yuval Garini

Prerequisites

Electromagnetics, waves and optics.

Learning outcomes

Broad and highly skilled knowledge of nano-fabrication and characterization methodologies and the use of nano devices and particles for biological, physical and chemical applications. More specifically:

Knowledge:

Understanding of the fundamentals of nano-science, its applications for various fields, new developments, including new optoelectronic devices, new materials and new biomedical applications

Skills:

Ability to design a solution to various technological and scientific problems using nano-fabrication, nano-characterization and nano-devices and methodologies.

Competences:

Design the principle characteristics of nano-particles for biomedical applications, nano-device for near-field optical measurements and nano-based material for surface-chemistry applications.

Learning outcomes for Project syllabus

Graduate Students of the course should know to:

1. Principle design a nano-particle to be used as an anti-cancer drug
2. Know what method and tool to use for characterizing the physical and chemical properties of nano-particles and nano-devices
3. Know the near-field optical properties of optical nano-devices

4. Know the principles of nano particles fabrication by top-bottom and bottom-top methods

Abstract

The course covers the fundamentals of nano-science and nano-technology. Students will learn the physical and chemical basics of nano-particles and nano-devices. They will learn the optical properties, electronic properties and chemical properties of these devices. They will learn the most common manufacturing methods. Finally, they will learn about application of nano science and technology for various applications in the bio-medical, physical and chemical fields.

Content

1. Introduction to nanoscience

a. What is nanoscience? brief history, nano effects on energy, machinery miniaturization, nano manipulation, nano optics.

2. Electron properties – from single atoms to bulk.
   The infinite quantum well, hydrogen atom, bulk materials, 3D, 2D, 1D structures, density of states in all dimensions, quantum dots, excitons.
3. Optical properties of nanostructures and Plasmons, photonic band gap, plasmons, near-field effect, hole-array
4. The scope of nanomaterial chemistry. Nanoscale and colloidal systems. Fundamentals of surface and interfacial chemistry, monolayers and self assembly, micelles and microemulaions (structure and properties). Supramolecular chemistry , classification of nanomaterials
5. Physical, chemical and regulatory risk aspects in nanotechnology
6. Synthesis of nanostructured materials Bottom-up vs. top-down synthesis, template-based synthesis, Sol-gel chemistry, electrochemical synthesis, sonochemistry and solvothermal synthesis solutions techniques, CVD, metal nanoparticles synthesis, Core-Shell Nanocrystals, Nanospolymers, Lithography, Layer-by-layer synthesis, Chemical functionalization
7. Specialized Techniques for Characterizing anomaterials Electron microcopy (TEM and SEM), X-ray diffraction, Infrared spectroscopy of nanoassemblies. Attenuated-total reflection (ATR) and grazing incidence angle techniques, Surface enhanced Raman spectroscopy (SERS). QCM, ellipsometry. Microcalorimetry methods (DSC and ITC) for Nanomaterials Characterization tools: Scanning methods Scanning tunneling microscope, Atomic force microscopy, Near field microscopy
8. Biological-related methods & Introduction to Biology
9. High resolution microscopy methods The diffraction limit of light, point spread function (PSF), optical transfer function (OTF), Improved methods including: confocal microscope, n-photon, structured illumination, saturation emission depletion (STED), photo activation light microscope (PALM).
10. The physics of single magnetic domains: the Stoner-Wohlfarth model. Electric properties of nanostructures

11. Chemistry applications: Solar energy harvesting, High Energy Density Batteries, High-Sensitivity Sensors, nanomaterials in catalysis
12. Application of nanoparticles in biology & medicine
13. Optical tweezers, TPM, Magnetic tweezers, Lab on a chip (LOC), Fluorescence resonance energy transfer (FRET), description of the methods, principles, capabilities and limitations

Teaching methods

The course is presented in the Moodle learning environment in the form of Oral lectures combined with Power Point Presentation

Assessment

The course grade consists of these components:
50% - Knowledge test with multiple choice questionnaire
50% - Final Project

Syllabus (English):

1. Course/Module name - **Advanced Materials and Nanotechnologies for Electrochemical Energy Storage Systems**
2. Course/Module code - **NA**
3. ECTS credits - **NA**
4. University credits - **NA**
5. Cycle - **NA**
6. Responsible department
7. Academic year **NA**
8. Semester **NA**
9. Campus – **ELBIT SYSTEMS LAND AND C4I LTD.**
10. Course/module coordinator – **Ervin Tal-Gutelmacher**
11. Coordinator E-mail – **tal.gutelmacher@elbitsystems.com**
12. Coordinator office hours **NA**
13. Teaching staff
14. Teaching language - **English**
15. Teaching arrangement and method of instruction – **Frontal Presentation and laboratory/practical lessons**
16. Attendance requirements -
17. Prerequisites
18. Course/Module description - **Overview of the fundamentals of electrochemical principles and basic thermodynamics and kinetics of electrochemical reaction, with emphasis on electro-analytical techniques and correlation to essential principles and performances of electrochemical energy storage devices (batteries, supercapacitors and fuel cells)**
19. Course/Module aims - **Design of advanced material for realization of improved electrochemical energy storage devices**
20. Learning outcomes: On successful completion of this module, students should be able to:
    a. ***Knowledge:*** **overview of the fundamentals of electrochemical principles and basic thermodynamics and kinetics of electrochemical reaction, with emphasis on electro-analytical techniques and correlation to essential principles and performances of electrochemical energy storage devices (batteries, supercapacitors and fuel cells)**
    b. ***Skills and Competences:*** **applications of theoretical electrochemical concepts to the design and implementation of novel energy storage devices. Design of advanced material for realization of improved electrochemical energy storage devices**
21. Course/Module content
    - **Fundamental Electrochemistry including:**
        - **Equivalent circuits**

        - **Thermodynamics**
        - **Reaction kinetics**
        - **Transport phenomena electrostatics**
        - **Porous media/electrodes**
    - **Electro-analytical techniques**
    - **Application of electrochemical concepts and materials selection to real-world electrochemical energy storage devices, such as:**
        - **Batteries**
        - **Supercapacitors**
        - **Fuel cells**

22. Required reading
23. Recommended reading –

    Advanced Batteries: Materials Science Aspects, by Robert A. Huggins. Call #: TK2896.H84 2009eb Online

    Other sources:
    Solid State Electrochemistry, Bruce
    Electrochemical Methods, Bard & Faulkner
    Semiconductor electrodes and photoelectrochemistry, Licht
    The CRC Handbook of Solid State Electrochemistry, Gellings & Bouwmeester

    New Carbon Based Materials for Electrochemical Energy Storage Systems – Edited by I.V. Barsukov, C.S. Johnsohn, J.E. Doninger., Springer 2006

24. Course/Module assessment:
    - End of year written examination/oral examination __

25. Additional information

Syllabus on Macroscopic Quantum Coherence in Engineered Nano-Systems

Course topic
Syllabus on Macroscopic quantum coherence in engineered nano-systems

Course code **(HUJI code 77982)**

Number of credits
4 ECTS

Cycle -MSc and Ph D

Course responsible
HUJI Jerusalem
Racah Institute of Chemistry

Academic year -NA

Semester -1st

Course coordinator
Prof. Nadav Katz

Course lecturer
Prof. Nadav Katz

Coordinator E-mail - katzn@phys.huji.ac.il

Coordinator office hours NA

Teaching language - English

Attendance requirements -None

Teaching methods

Lectures by the teacher (including recording).

Prerequisites
Undergraduate quantum mechanics (chemistry/physics majors are fine)
Linear algebra at undergraduate level
Calculus at undergraduate level

Concepts:

Advanced knowledge of the field of quantum coherence, communication and computing. Specifically we will focus on nano-engineered systems for quantum information applications.

Learning outcomes: ***On successful completion of this module, students should be able to:***

- *Classify the advantages and disadvantages of different engineered quantum nano-systems.*
- *Calculate basic properties of different quantized nano-systems and estimate sensitivity to noise and measurement.*
- *Critically read and review current literature of nanosystems applied to quantum information processing systems - single photon sources and quantum computing architectures.*
- *Solve analytically and numerical simulations of diverse electronic and optical nano-engineered systems for quantum information.*

Course Description (Abstract)

Quantum information processing is a remarkably broad and interdisciplinary field, where internal coherence of isolated systems is utilized for communication, sensing and ultimately computation. Nano-engineered systems are the critical next step in this field – leading to single photon sources, interaction and detection at new levels. More fundamentally, the question of macroscopic quantum coherence in such systems emerges – where is the quantum information stored in the many-body state? We will focus on superconducting devices and learn how to quantize electrical circuits. Advanced topics will deal with esoteric states such as topological insulators and quantum biology.

Content

1. Single electron physics
    a. Band structure
    b. Quantum confinement and quantum dots
    c. Optical properties of heterostructures
2. Fundamentals of quantum optics
    a. Quantum coherence - Rabi oscillations, density matrices and decay mechnanisms
    b. Coupling systems – Jaynes-Cummings, Purcell effect
3. Vacancies and doping physics – Magnetic and optical properties of rare-earth doped crystals as an example.
4. Superconductivity
    a. Second quantization and BCS theory
    b. Josephson tunnelling and the AC and DC Josephson effects
    c. Semi-classical Josephson devices – amplifiers and SQUIDS
5. Interface physics

    a. Andreev bound states
    b. Interface states and coherence
6. Quantum superconducting electronics
    a. Quantizing the circuit
    b. Dealing with noise – fluctuation/dissipation
7. Advanced topics
    a. Topological insulators and their coherence
    b. The quantum-biology controversy

Assessment
Problem sets as homework during the semester and a final exam at the end of the semester.

Recommended Readings

Yuli Nazarov and Yaroslav M. Blanter, Quantum Transport, Cambridge , 2009, ISBN 978-0-521-83246-5

Bhushan, B. (Ed.), Springer Handbook of Nanotechnology, Springer, 2010, ISBN 978-3642025259

Wiliams A.,Semiconductor Nanomaterials for Flexible Technologies, Sun&Rogers, 2012, ISBN: 978-1437778236

Baldo M., Introduction to Nanoelectronics, MIT course materials, http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-701-introduction-to-nanoelectronics-spring-2010/download-course-materials/

Syllabus on Nanotechnology in the Service of Humanity

Course topic
Nanotechnology in the Service of humanity

Course code **(HUJI code 69199)**

Number of credits
5 ECTS

Cycle -All degrees

Course responsible
HUJI Jerusalem
Institute of Chemistry and The Harvey M. Kreuger Family Center for Nanoscience and Nanotechnology

Academic year -NA

Semester -2nd

Course coordinator
Prof. Danny Porath

Course lecturer
Prof. Danny Porath and guest lecturers

Coordinator E-mail - danny.porath@mail.huji.ac.il

Coordinator office hours NA

Teaching language - English

Attendance requirements -None

Teaching methods

The course will presented in the Moodle learning environment in the form of videotaped and PDF/PPT Lectures. It will include guest lectures.

Prerequisites
None.

Course description *(Abstract)*
Nanoscience and Nanotechnology originally referred to materials with at least one dimension in the size range of 1-100 nanometres (roughly 100,000 smaller than the width of human hair) that gave it a new functionality. The field emerged from the convergence of newly developed abilities in various scientific, technological and engineering fields at the dawn of the 20th century that merged together to a joint

discipline by scientists that yields a new promise for humanity. The course is aimed at the general academic audience. It will describe the new world of Nanoscience and Nanotechnology and will shed light on selected methods and research topics within this field with an emphasis on the multidisciplinary nature of this field and its contribution to the development of technology and Industry.

Course aims: to introduce the new world of Nanoscience and Nanotechnology to the general academic audience, to shed light on selected methods and research topics of this field, and explain the importance of Nanoscience and its contribution to humanity and industry.

Learning outcomes: *Upon successful completion of this module, students should be able to:*

- *Define Nanoscience as multidisciplinary new field and its characteristics;*
- *Present Nanoscience central research fields* and general applications.
- Explain the central messages of the each one of the lectures and address questions regarding them.
- *Explain the importance of Nanoscience and its contribution to humanity and industry.*
- *Communicate with people in the field of Nanoscience and Nanotechnology for the purpose of collaboration using comprehended central terms, methods and research directions.*

Content

1) Introduction to Nanotechnology:
    - What is nano? General description of Nanotechnology and general tools used in Nano
2) Nanoelectronics with molecules
    - A molecule as an electronic device
    - Top down versus bottom-up and the concept of Self-assembly
    - Examples of molecules used as electronic conduits and their unique properties
3) Nano for Energy:
    - Solar cells
    - Surfaces for energy collection
    - Catalysis
    - Energy storage
4) Nano for detection and sensing:
    -Sensors
    - Bio-sensors
    - Nano detectors
5) Drug delivery
    - Methods for targeted drug delivery
    - Encapsulation of drugs in nano-trucks
    Examples of drug delivery
6) Computation
    - Computation with molecules and DNA
    -Computation with diamonds
    -New horizons for computation using nanotechnology methods

7) Polymers as Nanomaterials
8) The story of Carbone as a nanomaterial: (Alternative: the connection between architecture and carbon nanomaterials)

- Buckyballs: e.g., C_{60}
- Nanotubes: Carbon nanotubes
- Nano-surfaces: e.g., Graphene

9) DNA as a nanomaterial

- DNA based nanostructures
- The quest for DNA as a conductive material for electronics

10) Nano in Industry:

- Examples of people and companies (e.g., Oded Shoseyov as a case study)

Required reading-None

Recommended Readings

Bhushan, B. (Ed.), Springer Handbook of Nanotechnology, Springer, 2010, ISBN 978-3642025259

Vajtai, R. (Ed.), Springer Handbook of Nanomaterials, Springer, 2013, ISBN 978-3642205958

Waser R., Nanoelectronics and Information Technology - Advanced Electronic Materials and Novel Devices, Wiley VCH, 2003, ISBN: 3-527-40363-9

Timp G., Nanotechnology, 1999, Springer, ISBN: 0-387-98334-1

Ratner M. & Ratner D., Nanotechnology - A Gentle Introduction to the Next Big Idea, Prentice Hall, 2003, ISBN: 0-13-101400-5

Baldo M., Introduction to Nanoelectronics, MIT course materials, http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-701-introduction-to-nanoelectronics-spring-2010/download-course-materials/

Assessment
Knowledge test with a multiple choice questionnaire - 100%

Syllabus
"Bio-Nanoelectronic devices for biosensing"

Course topic
Techniques for analysing biomolecules at nanometric scale: basic concepts of nanoscale sensing and some practical examples of biosensors.

Number of credits
5 ECTS

Course responsible
Politecnico di Torino
Department of Electronics and Telecommunications
Prof. Danilo Demarchi

Course lecturers
Prof. Gianluca Piccinini
Prof. Danilo Dermarchi
Prof. Sandro Carrara

Prerequisites
Knowledge of basic micro/nano technologies and of sensing devices. Basic principles of bioensing techniques.

Learning outcomes
The students will acquire the basics of quantum mechanics useful for the design and use of nanodevices, in particular nano-biosensors, covering the knowledge of the possible device production techniques. One of the goals of the course is to give to the students the capability of choosing novel solutions in terms of nanodevices and nanosensors. With the acquired knowledge, the students will have the necessary information for guiding the strategic choices for the system level design of nano-biosensors too.

Abstract
The downscaling of sensing devices is giving several improvements in terms of sensor efficiency, detection limit and is opening the possibility of doing analysis at molecular level. A review of the most important solutions at the state of the art will be done then a specific research area will be put under analysis. With this goal one of the most promising structures, the nanogaps, will be studied. With nanogaps it is possible to analyse molecules at nanometric scale. Following these aims, the course will cover the basic concepts of nanoscale sensing and a practical example of nanogap production will be carried out, starting from the fabrication in a cleanroom of the structures where the nanogaps can be created, up to the study of the system useful for the production of the nanogaps themselves.

Content

1. Modelling of molecules for nano-biosensing
   1.1. Introduction to the course
   1.2. Modelling of molecules for nanosensors
   1.3. Conduction mechanisms in molecules
2. NanoBio Sensors
   2.1. Introduction
   2.2. Basic Chemistry and Conductive Solutions
   2.3. Probes-Targets
   2.4. DNA Detection
   2.5. Probes Immobilisation
   2.6. CNT Properties & ElectroChemistry of CNTs
   2.7. CMOS Building Blocks for BioDetection
3. Technology and systems
   3.1. Interfacing biomolecules with I/O CMOS structures
   3.2. Read-out architectures for biosensor arrays
   3.3. Measurements and characterization techniques for biomolecular systems
4. Laboratory: detection of proteins inside nanogap electrodes

Teaching methods

The theoretical part of the course is presented in the Moodle learning environment in the form of HTML tutorials and videos.
The laboratory will be recorded and the most important steps of the experiment will be showed and explained to the student.

Assessment

For the students who will not follow the online course only, the evaluation is based on an oral examination of the concepts acquired in the course. For all the students, an online questionnaire will have to be passed and the course is finalised with a written report.
The course evaluation consists of these components:
40% – Knowledge test with a multiple choice questionnaire (online) and/or oral discussion
60% – Final Report

Recommended readings

- Carrara, S. (2011). *Nano-Bio-Sensing*. Springer Verlag.
- Folch A. (2012). *Introduction to BioMEMS*. CRC Press
- Yoo, H.-J. (2010). *Bio-Medical CMOS ICs*. Springer Verlag.

Syllabus
"Molecular electronics for the realisation of novel nanoelectronic devices"

Course topic
Theory and design of nanodevices based on organic molecules.

Number of credits
5 ECTS

Course responsible
Politecnico di Torino
Department of Electronics and Telecommunications
Prof. Danilo Demarchi

Course lecturers
Prof. Gianluca Piccinini
Prof. Danilo Dermarchi
Prof. Mariagrazia Graziano

Prerequisites
Knowledge of basic micro/nano electronic technologies and of electronic devices. Basic principles of organic chemistry.

Learning outcomes

> **Knowledge:** basics on quantum mechanics and of the use of molecules, in particular organic ones, for the realization of electronic devices.
>
> **Skills:** applications of theoretic concepts to the design and implementation of novel electronic devices.
>
> **Competences:** design of molecular devices. Approach to the study of a not standard solution for the realisation of electronic devices.

Abstract
The course starts introducing the basic concepts of molecular conduction. Then are described the analysis, modelling and simulation approaches for molecular nanodevices. The most important families of molecules (conductive and based on charge state) are presented showing their principles and categories. The course ends with some applications examples of molecular wires, molecular FETs, molecular memories, molecular QCA.

Content

1. Molecules for nanodevices
   1.1. Introduction to the course
   1.2. Modelling of molecules for nanodevices
   1.3. Conduction mechanisms in molecules
   1.4. *LAB1*: Introduction to the molecular simulation with Gaussian
2. Molecules and Devices
   2.1. Organic Molecules for Electronics
   2.2. *LAB2*: Electronic structure (MO) of molecules with Gaussian
   2.3. *LAB3*: I-V simulation of molecular devices with VNL
3. Technology and systems
   3.1. Interfacing nanodevices with I/O CMOS structures
   3.2. Read-out architectures for sensor arrays
   3.3. Measurements and characterization techniques for molecular systems.

Teaching methods

The theoretical part of the course is presented in the Moodle learning environment in the form of HTML tutorials and videos.
The practical work is organised in different laboratories for the modelling and simulation of molecular devices using Gaussian and VNL.

Assessment

The evaluation is based on an oral examination of the concepts acquired in the course and this is associated with a practical work on one of the tools presented during the laboratories and the Hands-On sessions. All is finalised with a written report.
The course evaluation consists of these components:
60% – Knowledge test with a multiple choice questionnaire and oral discussion
40% – Final Report

Recommended reading

- Rigler, R., & Vogel, H. (2007). *Single Molecules and Nanotechnology*. Springer Ed.
- Petty, M. C. (2007). *Molecular Electronics*. John Wiley & Sons Ltd.
- Deleonibus, S. (2008). *Electronic Device Architectures for the Nano-Cmos Era From Ultimate Cmos Scaling to Beyond Cmos Devices.* Pan Stanford Publishing Pte. Ltd.

Syllabus
"Biotechnology"

Course topic
Basic concepts and applications in biotechnology
Number of credits
5 ECTS
Course responsible
Grenoble INP Phelma
Prof. Dr. Franz Bruckert
Course lecturers
Marianne Weidenhaupt, Didier Delabouglise, Catherine Picart, Didier Gasparutto, Charlotte Vendrely, Dominique Bourgeois, Valerie Stambouli, Yann Roupioz…

Prerequisites
A basic knowledge of biological macromolecules (DNA, RNA, proteins) and of genes (gene structure, promoter, transcription, translation, splicing).
A basic knowledge of prokaryote and eukaryote cell culture and of the control of gene expression (transcription factors, histones).

Learning outcomes
Upon successful completion of this course students should be able to:
- Understand the basics of protein engineering
- Use fluorescent molecules
- Know the basic properties of nanoparticles and how to functionalize, characterize and handle them
- Know how to prepare bioactive surfaces and to characterize them
- Know the basic principles of most biosensors
- Critically read the scientific literature about possible applications of nanoparticles and bioactive surfaces in biology and medicine

Abstract
Nanobiotechnology is a new and vast domain, which is intrinsically multidisciplinary, first because at this scale, chemical and physical properties combine to provide new functions, second because living cells and organisms are sensitive to molecules and molecules assemblies, from the nano- to microscale. The possibility to engineer objects with such resolution gives the opportunity to strongly influence biological phenomena, for the best and the worse. It is therefore essential to provide a good overview of the possibilities and the difficulties of these technologies, using example of ongoing research activities. In this way the student will develop his/her imagination and be ready to seize new opportunities from his own work.

Content
Introduction : how scale influences properties in chemistry, physics and biology
1. Protein and DNA modular design and supramolecular assembly
   1.1 Genetic engineering
   1.2 Protein expression caveats
   1.3 Fluorescent proteins : engineering of optical properties,
   1.4 Surface functionalization techniques, click chemistry
   1.5 Amyloid fibers and other protein polymers

1.6 Antibody structure and variability
1.7 Cooperativity and molecular dynamics
1.8 DNA origamis
2. Properties and manipulation of nanoparticles
   2.1 DLVO theory and particle stability in fluids
   2.2 Characterization of molecular assemblies and nanoparticles in solution : DLS, SAXS
   2.3 The protein corona
   2.4 Biodegradable nanoparticles
   2.5 Optical properties of nanoparticles
   2.6 Chemical properties of metal oxide nanoparticles
   2.7 Practical microfluidics
   2.8 Magnetic nanoparticles
   2.9 Nanoparticle uptake by cells; their fate in different cell compartments
   2.10 Nanoparticles in medical imaging and therapy
3. Bioactive materials
   3.1 Hydrogels and polyelectrolyte multilayer films
   3.2 Characterization of thin layer coating physical, chemical and mechanical properties
   3.3 Cell spreading and adherence on functionalized surface
   3.4 Cell patterning
   3.5 Cell mechanotransduction
   3.6 Cell differentiation on functionalized surface
   3.7 Thrombostatic surfaces
4. Biosensors
   4.1 Fluorescence detection, caveats, quenching, FRET, time-resolved fluorescence
   4.2 Luminescence detection
   4.3 Electrochemical detection, redox reactions, mediators
   4.4 Field Effect electrical detection or charged molecules
   4.5 Surface Plasmon Resonance detection and imaging
5. Nanoimaging
   5.1 AFM in liquids
   5.2 Super-resolved microscopy techniques

Conclusion: biomimetic and bio-inspired approaches

Teaching methods

The theoretical part of the course is presented in the Moodle learning environment in the form of HTML tutorials.

The practical work represents the analysis of one or several recent articles. In both cases on-line support by the tutor is provided.

Assessment

The course grade consists of these components:
40% – Knowledge test with a multiple choice questionnaire
60% – Final Project

Recommended reading

Inspired by Biology: From Molecules to Materials to Machines. National Research Council (US) Committee on Biomolecular Materials and Processes. Washington (DC): National Academies Press (US); 2008.

Syllabus
"Spintronics"

Course topic
Basic concepts and applications in spintronics
Number of credits
5 ECTS
Course responsible
Grenoble INP Phelma
Dr. Liliana Buda-Prejbeanu
Course lecturers
Mair Chshiev,Ursula Ebels

Prerequisites
Basics in solid state physics, quantum mechanics, electromagnetism and magnetism.

Learning outcomes
At the end of the courses the student should be able to:

- Understand the basics of magnetic materials and building blocks of a magnetic devices
- Know the basic properties of magnetic nanostructures
- Use the LLG equation for understanding the control of the magnetization
- Analysing rigorously the scientific literature
- Know the basic principles of various applications (sensors, memories, oscillators)

Abstract
Since the discovery of the giant magnetoresistance the research activity of spintronics evolves extremely fast and many applications have since been defined: magnetic sensors, read heads, magnetic memories, magnetic logic devices, microwave components. A major trend of spintronics devices is the continuously decreasing size of the active part combined with an increasing operation frequency (nanosecond and below). The course will cover the spintronics from the basics knowledge to working principles of various applications passing through fabrication and characterization technics. Knowing how the magnetic behaviour is affected by the device scaling and how to control the magnetization is the key issue for imaging new application or optimized the exiting one.

Content

1. Introduction in magnetism
   1.1. Magnetic moment, magnetic materials
   1.2. Magnetic stable states, hysteresis
   1.3. Coherent magnetization reversal
   1.4. Magnetization dynamics (Landau-Lifshitz-Gilbert equation)
   1.5. Superparamagnetism
2. Nanofabrication and characterization of magnetic nanostructures
   2.1. Deposition technics
   2.2. Nanofabrication technics
   2.3. Technics of global characterization
   2.4. Technics of local characterization

3. Spin dependent transport

3.1. Magnetoresistive phenomena (AMR, GMR, TMR, SHE)
3.2. Spin transfer torque (STT)
3.3. Spin orbit torque (SOT)

4. Magnetic field sensors
   4.1. Movement detection
   4.2. Molecular detection
   4.3. Magnetic reading heads
5. Spin torque oscillators
   5.1. General equation of the oscillator
   5.2. Steady state precession (IPP, OPP)
   5.3. Vortex oscillator
6. Magnetic random access memories
   6.1. Field induced magnetization switching MRAMs
   6.2. Thermally assisted MRAMs
   6.3. Spin Transfer Torque MRAMs (planar and perpendicular)
7. Spin orbit torque devices
   7.1. Magnetic domain wall motion in nanostripes
   7.2. Magnetization reversal in perpendicularly magnetized nanodots
   7.3. Skyrmions in magnetic nanostructures

Teaching methods

The theoretical part of the course is presented in the Moodle learning environment in the form of HTML tutorials.
The practical work represents the analysis of one or several recent publications or datasheet product. In both cases on-line support by the tutor is provided.

Assessment

The course grade consists of:
60% – Knowledge test with a multiple choice questionnaire
40% – Final Project

Recommended reading

B. Dieny, R.C. Sousa, J. Hérault, C. Papusoi, G. Prenat, U. Ebels, D. Houssameddine, B. Rodmacq, S. Auffret, L.D. Buda-Prejbeanu, M.C. Cyrille, B. Delaët, O. Redon, C. Ducruet, J-P. Nozières, I.L. Prejbeanu, *Spin-transfer effect and its use in spintronic components* Int. J. Nanotechnol., **7**, Nos. 4/5/6/7/8, 691 (2010).

J.M.D. Coey, Magnetism and Magnetic Materials, Cambridge University Press (2010).

ATOMISTIC SIMULATION OF MATERIALS

Syllabus

Course Topic:
Atomistic Simulation of Materials

Number of Credits
5 ECTS

Course Responsible:
Tel Aviv University
Department of Materials Science and Engineering
Dr Oswaldo Diéguez

Course Lecturer:
Dr Oswaldo Diéguez

Prerequisites:
Previous exposure to a university course in general physics or general chemistry. Previous exposure to computer programming in any language.

Learning Outcomes:
Upon completion of this course the student will be able to:

- Explain the basic physical theories behind the most used models to do atomistic simulations of materials (e.g., classical semiempirical potentials and quantum-mechanical density-functional theory).
- Implement those models in a computer language of choice to produce software for numerical calculations.
- Carry out numerical experiments that rely on atomistic models for materials.
- Perform analysis of those numerical experiments in order to gain understanding about the properties of particular materials.
- Critically read the scientific literature presenting results obtained using atomistic simulation of materials.

Abstract:
All materials are made of atoms. This simple and powerful statement will serve as the scientific basis of this course. We will model the interaction between atoms or their parts using different methods. We will implement these models into computer programs for doing numerical experiments. Then, we will analyze the results of these numerical experiments to gain understanding about the macroscopic properties of materials: their structure, vibrational properties, electronic properties, and more.

Content:

1. Introduction to Atomistic Simulation of Materials: Review of Classical Mechanics, Quantum Mechanics, Statistical Mechanics, and Computers.
2. Monte Carlo Methods: The Example of a Phase Transition in a Hard Spheres System.
3. Molecular Dynamics: The Example of a Phase Transition in a Hard Spheres System.
4. Interatomic Potentials: Computing Properties of Materials using Molecular Dynamics.
5. Quantum Mechanics: The Example of the Hydrogen Molecule.
6. Tight Binding Method for Carbon: Implementation and Computation of the Properties of Diamond and Graphite.
7. First-Principles Methods: The Example of the Siesta Code to Study Molecules, Insulators, and Metals.
8. Atomistic Simulation of Materials Today.

Teaching Methods:
Each unit of the course contains explanations about the concepts to be covered, and a small research project that requires application of these concepts. The explanations will be recorded in short videos, where the instructor will describe the main physical concepts relevant to the unit. Then, the student will download a report with a description of a small computational project, where understanding of the topic will be needed to carry out some numerical experiments. This report will contain enough information so that the student can check that his/her code implementation is correct, and whether the results of the numerical experiments will make sense.

Assessment:
50% of the grade will come from practical work of the students in exercises that require writing scientific code and performing numerical experiments. 50% of the grade will come from a multiple-choice test about the concepts learned in the course.

Recommended Reading:
We will use several articles from the scientific literature of atomistic simulation of materials. In addition, the following books can be helpful in learning some of the concepts in the course:

- *Computational Physics*, by Thijssen, Cambridge University Press (1999).
- *Computer Simulation of Liquids*, by Allen and Tildesley, Oxford University Press (1989).
- *Electronic Structure: Basic Theory and Applications*, by Martin, Cambridge University Press (2008).
- *Molecular Dynamics Simulation: Elementary Methods*, by Haile, Wiley-Interscience (1997).
- *Understanding Molecular Simulation: From Algorithms to Applications*, by Frenkel, Academic Press (2001).

Syllabus
“Introduction to Surface Science"

Course topic
Introduction to Surface Science

Number of credits
3 ECTS

Course responsible
TAU

Course lecturer
Prof. Shachar Richter

Prerequisites
Basic course in College Chemistry and Physics

Learning outcomes

On Successful completion of this course students will be able to:

1. Identify basic concept in surface science including surface to volume ratio, vacuum technology and relevant calculations, surface crystallography, relaxation and reconstruction, electrical properties, and surface adsorption.
2. To choose appropriate surface science tool for given scientific problem
3. Critically read professional surface science scientific paper

Abstract
The goal of this short course is to introduce to the students the principles of surface physics and chemistry.
Selected topics will include the followings:
Surface crystallography; reconstruction and relaxation; Energetics at surfaces; Electronic properties of surfaces; Adsorption phenomena; Surface science analytical tools.

Content

1. Introduction

    Surface definitions

    Clean surfaces

    Surface/volume concept

    Vacuum technology

2. Crystal Surfaces

Introduction to crystallography

Symmetry in crystals

Surface planes

High index surfaces.

Surface relaxation and reconstruction

3. Electronic Properties

   From atoms to crystals

   Periodic functions- Bloch equations

   Band bending, Fermi-level pinning

4. Surface Thermodynamics

5. Adsorption and Interfaces

   Chemical and Physical adsorption

   Self-assembly phenomena

   Interfaces

6. Surface Science tools

Teaching methods

The course is presented in the Moodle learning environment in the form of HTML tutorials.

Assessment

Each student has to critically asses a scientific paper in surface science

Recommended Readings

Basic books in Surface science such as:

S, Roy Morrison; the Chemical Physics of Surfaces
F. Bechstedt: Principle of Surface Physics
K. Oura et al. Surface Science, An introduction

Syllabus
Fundamentals of NanoBiotechnology:
where nanotechnology, biology and medicine interface

Course number: 648011
Course topic
The fundamentals of how nanotechnology interfaces with biology

Number of credits
3.5

Course lecturer
Asst. Prof. Avi Schroeder
Department of Chemical Engineering
Technion – Israel Institute of Technology

Prerequisites
Graduate students

Learning outcomes
Upon successful completion of this course students should be able to:

- Understand the fundamental function of cells, and how nanotechnologies interact with cells.
- Describe the various applications of nanotechnology in biotechnology & medicine
- Explain the process of self-assembly – from single molecules into nanoparticles
- Describe and explain how nanoparticles are fabricated and characterized
- Describe the principles of loading small molecule drugs, proteins or nucleic acids (DNA/RNA) into nanoparticles.
- Describe and explain the scientific basis and medical benefits for using nanotechnology for treating diseases.
- Design proper delivery approaches for introducing nanoparticles into cells and to disease models in vivo.
- Demonstrate how nanotechnology-based innovation can drive better medicine and a stronger economy.

Abstract
Nanobiotechnology is an arm of nanotechnology that studies, and makes use of the advantages of nanomaterials at the interface with biological systems. There are numerous potential applications, e.g. in medicine (drug delivery, tissue engineering), in bio-nanosensors (using cells, or biological components, like antibodies, nucleic acids etc.) as part of sensitive nano sensors.
In this course, following an introduction to cell biology, and several examples of the various applications of bionanotechnology, we will focus on one important application in nanomedicine. We will study why nanotechnology grants major advantages over conventional treatment approaches, for treating different diseases, including cancer.
The course will describe various types of nanoparticles, including liposomes – lipid based vesicles.
This course will deal with the fundamental aspects of constructing medicinal nanoparticles: from the molecular building blocks to the formation of drug carriers.
The thermodynamic basis and practical approaches for fabricating nanoparticles will be studied.

The course will deal with approaches for loading and delivering drugs and genes to disease sites using nanotechnology.
Approaches for targeting drugs to specific organs and to diseased tissues will be described.
The application of nanobiotechnology, and specifically, nanomedicine, will be studied.

Keywords:
Nanotechnology, biology, medicine, cancer

Content

1) Fundamentals of cell biology
    a. Cell types
    b. Organelles
    c. The main processes in the life of a cell
    d. From cells to tissue
2) An introduction to nanobiotechnology, how does nanotechnology interfaces with biology[1,2]
    a. How nanosize affects properties
    b. Building blocks: lipids, polymers, carbon nanotubes, proteins and DNA
    c. Self-assembly and the packing parameter[4,5]
    d. Types of nanoparticles
3) Applications of Nanobiotechnology & nanomedicine:
    a. Nanobiosensors
    b. Nano-functionalization of surfaces with biomolecules for various applications such as selective recovery of compounds produced in biotechnological processes, and in microfluidic devices
    c. Tissue engineering with biocompatible nanostructures, soft lithography
    d. Diagnostic imaging and drug delivery (detailed further on).
4) Mechanism of nanoparticle fabrication[6,7]
    a. Extrusion[8]
    b. Sonication
    c. Electrospinning
5) Characterizing nanoparticles:
    a. Electron microscopy
    b. Dynamic light scattering
    c. Chromatography
6) Introduction to nanomedicine
    a. Paul Ehrlich's magic bullet
    b. Targeting diseased tissue and specific organs in the body: highlighting cancer.9,10
    c. The EPR effect
    d. Evading the immune system: Stealth (PEGylation)
    e. Stimulating the immune system
    f. Inside the cell: escaping from the endosome
7) Loading drugs into nanoparticles
    a. Selecting the proper building blocks for constructing your nanoparticle
    b. Small molecule drugs
    c. Nucleic acids (DNA, RNA)
8) Controlled release of drugs from liposomes in disease sites[11]

a. pH-sensitive nanoparticles
b. reduction sensitive nanoparticles
c. enzyme-induced activation/release
d. using external stimuli to release drugs from nanoparticles.

9) Nanotechnology in the clinic: pro's and con's

Teaching methods

The course will combine theoretical studies, together with highlighted case studies, that exemplify the fundamental principles.
We will take advantage of the filmed nature of the course to add to the course live filming from the lab – to help familiarize the students with the translation of theory into practice. Where necessary, experts from the world will explain their perspective on nanomedicine.

The theoretical part of the course is presented in the Moodle learning environment in the form of HTML tutorials.
The practical work will include reading materials the students will be expected to deal with for answering questions online, as a basis for continuing to the following lectures.
At the completion of the course, the students will be requested to submit an original project in which they design a drug delivery system. A peer review approach for evaluating the projects will be introduced.

Assessment

The course grade consists of these components:
40% – Knowledge tests with a multiple choice questionnaire
60% – Final Project

Recommended reading

Biology: Life: The Science of Biology, 7th Edition - W. Purves, D. Sadava, G. Orians, C. Heller

NanoBioTechnolgy: Nanobiotechnology: Concepts, Applications and Perspectives

Christof M. Niemeyer (Editor), Chad A. Mirkin (Editor)

ISBN: 978-3-527-30658-9

1 Torchilin, V. P. Recent advances with liposomes as pharmaceutical carriers. *Nat Rev Drug Discov* **4**, 145-160 (2005).
2 Duncan, R. & Gaspar, R. Nanomedicine(s) under the microscope. *Mol Pharm* **8**, 2101-2141, doi:10.1021/mp200394t (2011).
3 Mouritsen, O. G. *Life As a Matter of Fat. The Emerging Science of Lipidomics*. (Springer-Verlag, 2005).
4 Israelachvili, J. N. *Intermolecular and Surface Forces*. 2 edn, (Academic Press, 1992).
5 Kumar, V. V. Complementary molecular shapes and additivity of the packing parameter of lipids. *PNAS* **88**, 444-448 (1991).

6 Barenholz, Y., Bolotin, E., Cohen, R. & Gabizon, A. Sterically stabilized doxorubicin loaded liposomes (DOXIL): From basics to the clinics. *Phosphorus Sulfur and Silicon and the Related Elements* **109**, 293-296 (1996).

7 Drummond, D. C., Meyer, O., Hong, K., Kirpotin, D. B. & Papahadjopoulos, D. Optimizing liposomes for delivery of chemotherapeutic agents to solid tumors. *Pharmacological reviews* **51**, 691-743 (1999).

8 Clerc, S. G. & Thompson, T. E. A possible mechanism for vesicle formation by extrusion. *Biophys J* **67**, 475-476 (1994).

9 Maeda, H., Wu, J., Sawa, T., Matsumura, Y. & Hori, K. Tumor vascular permeability and the EPR effect in macromolecular therapeutics: a review. *J Control Release* **65**, 271-284 (2000).

10 Torchilin, V. P. & Papisov, M. I. Why do polyethylene glycol-coated liposomes circulate so long? *J. Liposome Res.* **4**, 725-739 (1994).

11 Schroeder, A., Kost, J. & Barenholz, Y. Ultrasound, liposomes, and drug delivery: principles for using ultrasound to control the release of drugs from liposomes. *Chem Phys Lipids* **162**, 1-16 (2009).

Syllabus

Quantum Mechanics for the Nano Program

Course topic

Introduction to quantum mechanics and its applications in nano-science

Number of credits

2.5 points (26 lecture hours – 2 hrs per lecture * 13 lectures)
(13 exercise hours – 1 hrs per exercise * 13 exercises)
(56 self learning hours – 2 hrs per exercise * 13 exercises)

Course responsible

Technion – Israel Institute of Technology

Course lecturer

Prof. Uri Peskin

Prerequisites

Physics 2, Hedva 2, Linear Algebra, General Chemistry.

Learning outcomes

<u>Knowledge</u>: The mathematical structure of quantum mechanics: The meaning of energy quantization, uncertainty of measurements, superposition of states, pure and mixed ensembles. Familiarity with the energy spectrum of simple systems. Familiarity with approximation methods for complex systems. Familiarity with quantum phenomena on the nano-scale: the quantum size effect in nanoparticles, nuclear vibrations and zero point energy, the Pauli exclusion principle in many electron systems, bands formation in periodic lattices.

<u>Skills</u>: Analyse a given phenomenon according to the principles of quantum mechanics. Implement the acquired mathematical tools in order to obtain quantitative results for measurable quantities for simple models. Provide qualitative explanations for phenomena using the acquired conceptual understanding of quantum mechanics on the nano-scale. Get access to textbooks or articles, dealing with quantum mechanical phenomena.

<u>Competences</u>: Propose explanations to newly encountered nano-scale phenomenon, or experimental result, in terms of underlying quantum mechanical principles. Predict and design experimental test for novel phenomena/effects on the basis of quantum mechanical analysis.

Abstract

The course introduces quantum mechanical principles and their usage in describing and interpreting nano-scale systems. Emphasis is made on the development of concepts and methodologies. Examples relating to particular applications in nano-science are given in

each topic. The topics covered are: Quantum states and observables. The stationary Schroedinger equation and its solution for bound systems. The variational approach. The orbital approximation in many-electron systems. Discrete models and semi-empirical methods. The superposition principle and quantum dynamics. Measurements on pure and mixed ensembles. The density operator, quantum thermodynamics, quantum kinetics, Fermi's Golden rule.

Content

Chap 1: Introduction to quantum mechanics

1. Interference of matter and wave-particle duality. De Broglie formula and "two slits" experiments. The probabilistic postulate. Classical trajectories vs the Schroedinger picture.
2. The state of a system as a wave function. Probability and Normalization.
3. Observables as operators: position, momentum, angular momentum, the Hamiltonian.
4. The Schroedinger equation in 1D and 3D, The Schroedinger equation for a general atom/molecule.
5. The stationary Schroedinger equation and the standing waves as Hamiltonian eigenstates.

Chap 2: The solution of the Schroedinger equation for simple models

6. The particle in a box – energy quantization and the quantum size effect.
7. The Harmonic oscillator and second quantization – nuclear vibrations
8. The wave functions for an electron in the hydrogen atom and the central potential problem.

Chap 3: Approximation methods

9. Many electrons systems and the orbital approximation
10. The electron spin and the Pauli exclusion principle.
11. The linear variation principle
12. Tight binding models – bands formation in solids.

Chap 4: Quantum measurements

13. Quantum dynamics: Non stationary solutions, the superposition principle and wave packets.
14. Quantum Measurements: The eigenvalues and eigenfunctions of Hermitian operators.
15. The orthonormal basis. Probability distributions, expectation values and the Heisenberg uncertainty relation.
16. State vectors and Dirac's notations.
17. Mixed quantum states – the density operator.

18. Quantum Thermodynamics: The Liouville equation and the equilibrium density.
19. Quantum kinetics: Master equations and Fermi's Golden rule.

Teaching methods

The theoretical part of the course would be presented in the Moodle learning environment in terms of oral lectures, including animations and simulations for demonstration. Exercises will be presented as written assignments, partially solved in the designated tutorial lectures, and mostly left for the student as written assignments.

Assessment

A combination of a written examination covering all material taught in the course, and the students assignments (including, in part, peer assessment).

Recommended reading

All material needed, will be provided during the course.
Supporting text book is: J. J. Sakurai, Modern Quantum Mechanics (Addison-Wesley, Boston, 1994)

Syllabus
"Design of Nanoscale MOS ICs"

Course topic
Design of Nanoscale MOS ICs
Number of credits
5 ECTS
Course responsible
TUS Sofia
Department of Micrtoelectronics
Prof. Dr. Marin Hristov
Course lecturer
Prof. Dr. Marin Hristov

Prerequisites
Microelectronics technology and design rules, solid state physics, computer added design in electronics.

Learning outcomes
Upon successful completion of this course students should be able to:
- Compare the CMOS technologies for nanotransistors as FDSOI and Tri-Gate;
- Explain the steps in IC design and the different design rules;
- Design the schematics of CMOS integrated circuits end perform the simulations;
- Solve the problems with modelling and simulating short channel transistor circuits;
- Design the layout of CMOS ICs;
- Perform the extraction of the schematics from the layout and verification of the design and analyse the cause for the errors.
- Demonstrate innovation, autonomy, and sustained commitment to the development of new modelling and design rules through performing a full design of nanoscale ICs

Abstract
Problems related to the design and investigation of submicron and nanoscale MOS integrated circuits are covered by this course. Currently there are some nanotechnologies in the means of 14 nm design kits, which are available via the EUROPRACTICE organization. The main attention is drawn to the theoretical and practical usage of state-of-the-art industrial CAD systems, e.g. CADENCE, SYNOPSYS and others. The designers who use those systems can implement nanoscale elements from the relevant standard cell libraries. The specific parameters, related to the nanoscale effects are represented in the embedded system models of the elements.

Content
Introduction

The design in the 'More than Moore' era:

The effect 'digital becomes analogue' (subtreshold, gate leakage – pure digital circuits to be simulated with consideration of analogue effects), voltage headroom shrinks and makes analogue and RF design complicated, etc.

1. CAD tools for design of analogue and mixed-signal integrated circuits (CADENCE)

1.1. Schematics.

Getting Started, Understanding Connectivity and Naming Conventions, Creating Schematics, Creating a Multisheet Schematic, Creating Symbols, Automatically Creating Cellviews, Editing Objects, Editing Properties, Traversing the Design Hierarchy and Creating a Design Configuration

View, Checking Designs, Plotting Designs, Setting Schematic Composer Options, Customizing the Schematic Composer

1.2. Simulation

1.2.1. Spice

Introduction, Built-In Variables and Arrays, Expressions and Functions, Commands, Circuit Analysis, Components, Command and Model Files, Device Models, Subcircuits, Examples, Analysis, Node Referencing

1.2.2. Spectre

Getting Started with Spectre, SPICE Compatibility, Spectre Netlists, Parameter Specification and Modeling Features, Analyses, Control Statements, Specifying Output Options, Running a Simulation, Time-Saving Techniques, Managing Files, Identifying Problems and Troubleshooting, Example Circuits, Dynamic Loading

1.2.3. Verilog XL

About the Verilog-XL Integration Environment, Setting Up the Simulation Environment, Working with the Stimulus, Running and Controlling a Interactive Simulation, Viewing Simulation Results Interactively, Debugging Your Design, Running Batch Simulations, Comparing Simulation Results, Netlisting

1.3. Layout

1.3.1. Envisia Silicon Ensemble

Introduction, The Basics, Timing-Driven Design Flow, Environment Variables, Error Messages

1.3.2. IC Chip Assembly

Chip Assembly Overview, Preparing, Translating, and Checking Data, Setting Routing Rules, Analyzing and Preparing the Design for Routing, Routing Your Design, Design File Syntax Example, Questions and Answers, Trouble Shooting, Via Naming Conventions

2. CAD tools for design of digital circuits (SYNOPSYS)

2.1. Methodologies

Introduction, The Design Process, Detailed Design, FPGA's and ASIC's, FPGA Design Flow, ASIC Design Flow

2.2. Synopsys Environment

CoCentric, Physical Synthesis, Synthesis Tools, DesignWare, Library Compiler, Simulation Tools, Static Timing and Formal Verification

2.3. VHDL and Verilog

3. Design of deep-submicron devices (subtreshold, gate leakage etc.)

4. System design, future trends (multiphysics simulation, error propagation, multi-technology, multi-scale: device (nm) to board (dm), analogue and digital design for deep-submicron technologies).

Teaching methods

The theoretical part of the course is presented in the Moodle learning environment in the form of HTML tutorials.

The practical work represents a project for design of submicron integrated circuit with a remote access to SYNOPSIS and CADENCE which run on the server of ECAD laboratory at TU-Sofia. In both cases on-line support by the tutor is provided.

Assessment

The course grade consists of these components:

40% – Knowledge test with a multiple choice questionnaire

60% – Final Project

Recommended reading

Deleonibus S., Intelligent Integrated Systems: Devices, Technologies, and Architectures, Pan Stanford Publishing, 2014, ISBN-13: 978-9814411424.

Collaert N., CMOS Nanoelectronics: Innovative Devices, Architectures, and Applications, CRC Press, 2012, ISBN-13: 978-9814364027.

Deleonibus S., Electronic Device Architectures for the Nano-CMOS Era. From Ultimate CMOS Scaling to Beyond CMOS Devices, Pan Stanford Publishing, 2008, ISBN-13: 978-9814241281.

Lee P., Introduction to Place and Route Design in VLSIs, 2006, ISBN 978-1-4303-0492-0,

Scheffer L., Lavagno L. and Martin G. (ed), Electronic Design Automation for Integrated Circuits Handbook, Volume 1, EDA for IC System Design, Verification and Testing, Taylor & Francis, 2006, ISBN 0-8493-7923-7

Scheffer L., Lavagno L. and Martin G. (ed), Electronic Design Automation for Integrated Circuits Handbook, Volume 2, EDA for IC Implementation, Circuits Design and Process Technology, Taylor & Francis, 2006, ISBN 0-8493-7924-5

Syllabus on Nanomaterials

Course topic
Nanomaterials
Number of credits
5 ECTS
Course responsible
TUS Sofia
Department of Micrtoelectronics
Prof. Dr. Slavka Tzanova
Course lecturer
Ass. Prof. Dr. Elitsa Gieva

Prerequisites
Microelectronics technology and design rules, solid state physics, computer added design in electronics.

Learning outcomes
Upon successful completion of this course students should be able to:

- Compare the properties of materials for deep-submicron and nanometre CMOS IC, HEMT, single electron transistors and resonant tunnelling devices;
- Discuss the advantages of devices on carbon nanotubes and graphene;
- Explain the physical principles of spintronic devices and choose appropriate materials for them;
- Select a method and plan the procedures for characterisation of molecular systems;
- Plan the fabrication procedure for deep-submicron and nanometre CMOS IC with the proper technological process for the materials of the substrate, implanted areas, isolation, metallisation.

Abstract
This course will take an in-depth look at nanomaterials used in nanoelectronics. Theory and concepts of nanomaterials will be covered, including the chemistry and physics of nanomaterials. The course will also focus on major classes of nanomaterials, including carbon nanotubes, nanostructured materials, nanowires, nanoparticles, nanoclays, and other nanomaterials. Applications of nanomaterials to technology areas in nanoelectronics will also be discussed.

Content
1. Current trends in nanoelectronics
The course will cover the materials for:
- Deep-submicron and nanometre CMOS IC (under 50 μm);
- HEMT (high electron mobility transistor);
- Devices on carbon nanotubes and graphene;
- Resonant tunnelling devices and circuits;
- Single electron transistors;

- Spintronics;
- Quantum electronics;
- Bioelectronics and molecular electronic devices.

2. Materials for deep-submicron and nanometer CMOS IC:
   - Materials for the substrate – tight Si;
   - Alternative materials for the gate insulator: high K gate insulators;
   - Gate electrode materials (n+ polysilicon, mid-gap, metals);
   - SOI;
   - Double-Gate Transistor Structures and Multi-Gate Transistor Structures.

3. Materials for HEMT:
   - Heterostructures on A3B5 (GaAs/ AlGaAs, InGaAs/InAlAs etc.).

4. Materials for devices on carbon nanotubes and graphene:
   - CNT – Carbon nanotubes – physical characteristics.
   - CNT devices: CNT Transistor, CNT –Based Field Emission Devices, Junctions, Heterojunctions and Quantium Confined Structures Based on Carbon Nanotubes, Microwave Devices Based on Carbon Nanotubes, CNT Based Electrical Sensors;
   - Graphene.

5. Materials for resonant tunnelling devices:
   - Structures of resonant tunnelling devices and circuits: AlAs/GaAs/AlAs, AlSb/InAs/AlSb.

6. Materials for single electron transistors:
   - Single Electron Transistors structure and materials: Si, GaAS.

7. Spintronics:
   - Physical principles and materials for spintronic devices;
   - Spintronic structures: Spin Valves, Spin Pumps, Spin Diodes, Spin Transistors, Spin Based Optoelectronics Devices, Spintronic Computation.

8. Quantum electronics:
   - Quantum electronic devices (QED) – physical principles and materials;
   - Short-Channel MOS Transistor, Split-Gate Transistor,Electron-Wave Transistor, Electron-Spin Transistor, Quantium Cellular Automata (QCA).

9. Materials for bioelectronics and molecular electronic devices:
   - Characterisation of molecular systems: electrical properties of molecules;
   - Molecular electronic devices, polymer electronics, self-assembling circuits, optical molecular memories;
   - Molecular processor, DNA analyzer as biochip.

Teaching methods

The course is presented in the Moodle learning environment in the form of HTML tutorials.

On-line support by the tutor is provided.

There is optional practical work (mandatory of rthe students at TUS) in the laboratory of vacuum layer deposition of the Dep. of Microelectronics at TU-Sofia.

Assessment
Knowledge test with a multiple choice questionnaire

Recommended Readings

Vajtai, R. (Ed.), Springer Handbook of Nanomaterials, Springer, 2013, ISBN 978-3642205958

Bhushan, B. (Ed.), Springer Handbook of Nanotechnology, Springer, 2010, ISBN 978-3642025259

Wiliams A.,Semiconductor Nanomaterials for Flexible Technologies, Sun&Rogers, 2012, ISBN: 978-1437778236

Kumar V., Nanosilicon, 2013, Elsevier Science, ISBN: 9780080445281

Baldo M., Introduction to Nanoelectronics, MIT course materials, http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-701-introduction-to-nanoelectronics-spring-2010/download-course-materials/

Syllabus: Scanning Probe Microscopy

Course topic
Scanning Probe Microscopy
Number of credits
5 ECTS
Course responsible
Weizmann Institute of Science
Faculty of Chemistry
Dr. Sidney R. Cohen

Course lecturer
Dr. Sidney R. Cohen

Prerequisites
Background knowledge in Physical Chemistry

Learning outcomes
Upon successful completion of this course students should be able to:
(1) Describe the fundamental components of any scanning probe microscope – *detection* of physical quantity measured; meaning of *setpoint*; *operation of control system* acting to reduce error signal by feedback; *transducing* voltage signal so motion
(2) Predict the effect of various scanning parameters – feedback gain, scan speed, setpoint, on the image obtained.
(3) Know how to choose an appropriate probe for a specific sample and scientific problem.
(4) Decide which of the various modalities of scanning probe microscopy are appropriate for a specific sample/scientific question.
(5) Know the advantages and disadvantages of the technique relative to other microscopies.
(6) Critically read and review current literature which is based on scanning probe microscopy
(6) Identify artifacts in their work and that of others
(7) Be familiar with realized and potential applications of SPM in practical and industrial environments.
(8) Propose standard SPM experiments for solving a specific scientific problem.
(9) Perform basic image manipulation and analysis procedures (levelling, filtering, histogram adjustment, statistical and grain analysis)

Abstract
Scanning Probe Microscopy has revolutionized our view of materials and our power to investigate their fundamental properties. This course will cover the fundamental physical principles behind the technique, considerations in the operation of the instrument, aspects of data acquisition and analysis, and applications. Subjects will largely be discussed through referral to current scientific literature.

Content

Background Physical Effects: Surface Forces; Surface Free energy; Capillary effects; Tunneling; Quantum size effects on electronic levels and electron transport; Surface Potentials; Near Field phenomena

Principles of SPM Instrumental design and operation: Feedback, vibration isolation, signal and noise considerations, **comparison with other microscopies**, common artifacts.

Data Analysis and image processing

Use and misuse of different filtering in data presentation, handling of varying dynamic range, statistical and spectral analyses

Applications:

Realtime atomic and molecular imaging: Applications in molecular structure and catalysis

Nanomechanics – Measurements of local adhesion, stiffness and hardness; comparison to other techniques; size-related effects.

Electronic phenomena- Quantum size effects on electronic levels and electron transport; Molecular Electronics; Solar Cells, Influence and exploitation of electrostatic forces.

Optics : Optical interactions on the nanometer scale, near field optics for sub micron resolution, tip-enhanced optical effects

Life Sciences: Molecular force Spectroscopy, in-vitro imaging; realtime video AFM, cellular mechanics.

Nanotechnology: Lithography; Data Storage; NEMS and MEMS

Teaching methods

The course is presented in the Moodle learning environment in the form of HTML tutorials.

On-line support by the tutor is provided.

A few laboratory demonstrations will be employed to facilitate understanding of certain techniques.

Assessment

Knowledge test with a multiple choice questionnaire

Recommended Reading

Books:

Scanning Tunneling Microscopy and Spectroscopy Theory, Techniques, and Applications ed. Dawn Bonnel (1993)

Atomic Force Microscopy, Peter Eaton and Paul West 2010

Scanning force microscopy of polymers Vancso, G., Schonherr, H. 2010

Amplitude Modulation Atomic Force Microscopy Ricardo García 2010.

Web references:

http://wws.weizmann.ac.il/ChemicalResearchSupport/afm/instruction-manuals

Syllabus: Introduction to materials and nanotechnology

Course topic
Nanotechnology for teachers

Number of credits
5 ECTS

Course responsible
Weizmann Institute of Science
Department of Science Teaching
Dr. Ron Blonder

Course lecturer
Dr. Ron Blonder

Prerequisites
High school science teachers

Learning outcomes

Upon successful completion of this course students should be able to:

(1) Summarize the historical developmentof quantum mechanics

(2) Explain atomic spectra and chemical bonding using qualitative quantum mechanics

(3) rationalize the use and understand results of selected characterization methods: AFM, STM, TEM, SEM, XRD, XPS.

(4) Identify and discuss ethical issues regarding nanotechnology research and application

(5) Critically read and review current research literature in nanotechnology

(6) Build a presentation of a chosen area in nanotechnology based on synthesis of several research papers

(7) Identify the advantages, disadvantages and the potential of a chosen research.

(8) Evaluate peer presentations of different areas in nanotechnology

Abstract
Nanoscience is an important new scientific field. Nanotechnology is the ability to create materials, devices, and systems having fundamentally new properties and functions by working at the atomic, molecular, and supramolecular levels. These new properties are used as the basis for the development of new technology in electronics, magnetics, optoelectronics, medical diagnostics, alternative energy, and more.This

course will cover the essential concepts of nanotechnology applying them in contemporary studies in nanotechnology. Subjects will largely be discussed through referral to current scientific literature.

Content

(1) qualitative quantum mechanics
(2) size and scale
(3) size-dependent properties
(4) characterization methods
(5) fabrication approaches to nanomaterials
(6) the making of nanotechnology
(7) dimensionality
(8) classification of nanomaterials
(9) innovation and application of nanotechnology
(10) functionality

Teaching methods

The course is presented in the Moodle learning environment in the form of HTML tutorials and includes:

- Recorded lessons
- Reading assignments
- Peer-review of course assignments.

Assessment

Final project – A scientific report of a selected nanotechnology research applying the essential concepts that were learned in the course.

Recommended Reading

Contemporary research papers that will be selected according the participating interests.