# Course Package

# Characterization and Fabrication of Nanostructures – 1A + 1B

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| Name module | Characterization and Fabrication of Nanostructures – 1A + 1B |
| Educational programme | MSc Nanotechnology |
| Period | First semester (block 1A and 1B) |
| Study load | 30 ECTS |
| Coordinator | B. Schouwstra |

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***Interesting for:*** BSc students of Chemical Engineering, Chemistry, Applied Physics, Electrical Engineering, and Nanotechnology.

Required preliminary knowledge: Basics of Physical Chemistry; Organic, and Inorganic Chemistry; Material Science; Molecular Biology; Solid State Physics; Quantum Mechanics (Quantum Physics, Level B2); Material Science; Nanoscience.

## Block 1A

**201600043 Characterization of Nanostructures**

This module includes a lecture part (5 EC) and an additional project part (2.5 EC).

*Lecture Part (5 EC)*
In this module, a palette of state-of-the-art characterization techniques to investigate the structure and properties of nanostructures will be introduced and applied. The module consists of 3 courses: Surface characterization (35 %), X-ray diffraction (30 %) and Microscopy and Spectroscopy (35 %). Recent publications on metal halide perovskite photovoltaics will be used as a case study to illustrate the potential and complementarity of all techniques discussed in this module.

*Project Part (2.5 EC)*
In this project, you are going to study how biological nanostructures can be characterized. To this end, you will, in a small team of students, perform a detailed analysis of a peer-reviewed scientific paper that describes research related to the characterization of biological systems at the nanoscale.

**193400050** - **Nanoscience**

Fundamentals of nanoscopic physics. Introduction to Nanoelectronics (top-down vs bottom-up approach, relevant length scales). Wave/particle duality, wave functions, wave packets, and Heisenberg uncertainty relations. Free and confined electrons, free electron model, the density of states, band theory (periodic potential), tunnel junctions/resonant tunneling, single-electron tunneling. Electronic structure of quantum dots, quantum wires, and quantum wells and their transport properties. Coulomb blockade and single electron transistor.

***Electives (1 of the 2):***

**202000662 - Optics**

In this part, we address the basic concepts of both geometrical optics (light as a ray) and physical optics (light as a wave). The course consists of a few lectures and a larger experimental assignment. In the lectures the theoretical concepts will be discussed, while in the experimental assignment the student will apply these concepts to design, construct and characterize an optical instrument (e.g. microscope and/or photo-spectrometer). The instrument is then used to carry out experiments that relate to the microscopic/spectroscopic characterization of materials.

**202000663 - Molecular Structure & Spectroscopy**

This part extends the knowledge introduced in the first year quantum mechanics course and discusses the theory behind chemical bonding, as well as spectroscopic characterization. Topics being addressed involve the valence bond theory, hybridization of orbitals, molecular orbital theory, bonding and antibonding orbitals, electronic structures of molecules, introduction spectroscopy, vibrational transitions, rotational transitions and nuclear magnetic resonance.

# Block 1B

**191210730** - **Fabrication of Nanostructures -Technology**

The course provides a general introduction to the field of manufacturing technology of microsystems. The emphasis is put on the fabrication steps. The most commonly applied steps (techniques) are treated. The techniques having the same main goal are compared, their advantages and disadvantages are discussed, and the choices of suitable techniques for the particular application/device are questioned. The important criteria (e.g. film properties, uniformity, costs, efficiency, reproducibility and reliability), to compare the different techniques, are demonstrated. It is shown how fabrication steps can be combined in a process flow to fabricate a functional microsystem. Several examples are given where the integration processes to fabricate microsystems are treated in an introductory manner, including realization of microprocessors, microfluidic systems, lab-on-a-chip, MEMS and nanoelectronic (spintronic) devices.

Two main blocks are given. Block 1 considers the basics (main building blocks) of microtechnology and includes introduction and history, substrates and wafers, modification of materials, lithography, film deposition, wet and dry etching, wafer bonding and packaging. Block 2 consists of guest lectures and covers different application areas of the main building blocks to realize microsystems in the field of integrated circuits, biochips, nanoelectronics, sensors, and micro-reactors. At the end of the course, students make short presentations about theoretically developed process flows for making a variety of structures of choice.

***Electives (2 of the 3):***

**193400141 - Nano-electronics**

Nanoelectronics comprises the study of the electronic and magnetic properties of systems with critical dimensions in the nanoregime. Quantum electronics, spin electronics, organic electronics, and neuromorphic electronics form important subfields of nanoelectronics and are being discussed in this course. Quantum electronics and neuromorphic electronics will be treated in-depth. For those who want to get a thorough introduction into the new exciting directions that will contribute to future electronics, this course is indispensable. Recommended for MSc students Nanotechnology. Applied Physics and Electrical Engineering. The course consists of lectures, assessments, and a project. In the project, a small research proposal is written on a theme related to the course. The proposal is presented in written and oral form and graded by the lecturers.

**201600046** - **Lab on a Chip**

The Lab on a Chip course will take the student to the world of miniaturized systems used in various fields of chemistry and life sciences. A "Lab-on-a-Chip" consists of electrical, fluidic, and optical functions integrated in a microsystem, and has applications in (bio)chemical and medical fields.

The core of the lab-on-a-chip system is a microfluidic channel structure, through which nanoliter amounts of liquids with dissolved molecules are propelled by hydraulic, electrokinetic, or surface forces. The fluidic structures are machined in materials like fused silica, borofloat glass, or polymers.

The course will treat all relevant aspects of such microsystems in a number of problem-based learning sessions. Microfluidic theoretical principles are treated with emphasis on the transport of liquid and dissolved molecules in microsystems and molecular separation. This is followed by an introduction in aspects of microfabrication. Electrochemical and optical detection methods are subsequently treated. Then the manipulation of cells in microfluidic systems is considered. The course finishes with a written exam and a written case study. The course is aimed at MSc students of Biomedical Engineering, Electrical Engineering, Nanotechnology, Chemical Engineering, Mechanical Engineering, or Applied Physics.

**202100083 - Quantum Optics**

In this course, we study the quantum properties of light and matter-light interaction, with some examples from modern quantum technologies, such as laser cooling and trapping, Bose-Einstein condensation, and quantum sensing. After an introduction to the formalism of quantum optics, we dive into light-matter interaction. We start with the quantization of the electromagnetic field, which leads to the introduction of the photon as the quantum of light. Then, we look at various interesting quantum states of the light field and their statistical properties, including the seminal Hanbury-Brown Twiss and Hong-Ou-Mandel experiments. Next, we introduce the machinery of multi-particle quantum optics, which will be needed in the rest of the course.

In the second part, we take a look at light-matter interaction, treating the Bloch sphere, Cavity QED and the Jaynes Cummings model, with applications to atom clocks, and quantum memories.

Finally, we turn to laser cooling and trapping and Bose-Einstein condensation. Here, we encounter some of the groundbreaking experiments from the last 25 years, showing, e.g. quantum phase transitions and the condensation of gases (or light!) to a macroscopic quantum ground state.