UAB Universitat Autònoma de Barcelona	Imaging and Spectroscopy at the Atomic Scale Code: 45735 Credits: 3 2026/2027

Degree programme	Type	Course
Applied Nanoscience: From Materials to Devices	OP	1

Contact lecturer

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Teaching staff (external to UAB)

Marc Gonzàlez Cuxart

Deniel Martín Jiménez

Belén Ballesteros Pérez

Group languages

You can consult this information at the end of the document.

Prerequisites

Background in physics and chemistry of condensed matter, including atomic structure, chemical bonding, crystallography, band structure, electronic, optical, and magnetic properties of materials. Also, knowledge of quantum mechanics concepts such as wave-particle duality, quantum states, and electron tunnelling, as well as familiarity with surface science and atomic-scale interactions, relevant for scanning probe and electron microscopy techniques.

Objectives

The course aims at introducing how concepts of condensed matter physics and chemistry can be investigated using modern experimental techniques, namely scanning probe and electron microscopies. These enable direct visualization and spectroscopic probing of matter at the nanometre and sub-nanometre scales, the relevant length scales at which physical and chemical phenomena governed by quantum mechanics emerge.

By the end of the course, the students will be able to:

- Understand and identify the fundamental operating principles behind key atomic-scale microscopy techniques, including scanning probe microscopy methods and transmission electron microscopy.
- Interpret and relate different types of local spectroscopic measurements to the physical and/or chemical information they provide about materials at the nanoscale.
- Become familiar with the basic operating principles of scanning probe microscopy and transmission

electron microscopy.
- Analyse and interpret topographic and spectroscopic datasets, correlating their main features to extract meaningful physical and chemical information.
- Connect local structural, electronic, and chemical properties of materials to their atomic-scale environment.
- Distinguish between purely topographic contributions and spectroscopic information in complex, coupled measurement signals.
- Integrate information from multiple spectroscopic and imaging techniques to build a comprehensive understanding of the properties of nanomaterials.

Learning outcomes

- CA11 (Relate local physical and chemical properties to the atomic environment.) Relate local physical and chemical properties to the atomic environment.
- CA12 (Differentiate purely topographic information from spectroscopic information in convoluted techniques.) Differentiate purely topographic information from spectroscopic information in convoluted techniques.
- CA13 (Combining different spectroscopies to obtain comprehensive information on specific properties of nanomaterials.) Combining different spectroscopies to obtain comprehensive information on specific properties of nanomaterials.
- KA11 (Identify the operating principles of two atomic-scale microscopy techniques: the scanning probe microscopy family and transmission electron microscopy.) Identify the operating principles of two atomic-scale microscopy techniques: the scanning probe microscopy family and transmission electron microscopy.
- KA12 (Relate the type of local spectroscopy to the physical/chemical information that can be obtained with it.) Relate the type of local spectroscopy to the physical/chemical information that can be obtained with it.
- SA13 (Make basic use of a probe microscope.) Make basic use of a probe microscope.
- SA14 (Make basic use of a transmission electron microscope.) Make basic use of a transmission electron microscope.
- SA15 (Analyse topographic and spectroscopic maps correlating their main characteristics.) Analyse topographic and spectroscopic maps correlating their main characteristics.

Contents

MODULE 1: Atomic Force Microscopy (AFM) - 7 h (Daniel Martín)

- History of Atomic Force Microscopy.
- Basic Concepts of Surface Science.
- Surface Forces.
- AFM Operation.
- AFM Sensor Parameters.
- AFM in Different Environments.
- AFM Measuring Modes.
- Force-Distance Curves.
- Imaging Artefacts.
- Nanotribology and Friction Force Microscopy (FFM).
- Nanoscale Electrical Characterization.
- AFM Applications.
- Electrostatic Force Microscopy (EFM) and Kelvin Probe Force Microscopy (KPFM).
- Frequency-Modulation AFM in Ultra-High Vacuum (FM-AFM-UHV).
- Latest Advances in AFM.
- Software for Image Analysis.
- Requirement: Students must bring their own computers and install the required software.
- Nanomechanical Properties.

MODULE 2: Scanning Tunnelling Microscopy (STM) - 6 h (Marc González Cuxart)

- Background and History.
- Electron Tunnelling.
- Electronic Concepts.
- STM Operation.
- Imaging and Topography.
- Instrumentation.
- STM and Scanning Tunnelling Spectroscopy (STS).
- STM and Inelastic Electron Tunnelling Spectroscopy (IETS).
- Atomic manipulation.
- Advanced STM techniques.

MODULE 3: Transmission Electron Microscopy (TEM) - 6 h (Belén Ballesteros)

- Background and History of electron microscopy.
- Fundamentals of electron microscopy.
- TEM core technology and aberrations.
- TEM instrumentation and function of the different parts.
- Principles of contrast formation in TEM.
- Electron diffraction techniques.
- Scanning Transmission Electron Microscopy.
- Spectroscopies in the TEM at the atomic scale.
- Advanced TEM techniques.
- Strategies for TEM sample preparation.

Learning activities and methodology

Title	Hours	ECTS	Learning outcomes
Autonomous work	48	1.92	
Practicum	2	0.08	CA11, CA12, CA13, KA11, KA12, SA13, SA14, SA15
Tutorial sessions	8	0.32	CA11, CA12, CA13, KA11, KA12, SA15
Lectures	17	0.68	CA11, CA12, CA13, KA11, KA12, SA13, SA14, SA15

The course will consist of theoretical lectures, supervised practical sessions, and tutorials. Visits to scientific facilities will be organized, where the various types of microscopes studied in the course can be seen in operation.

Annotation: within the schedule set by the centre or degree programme, 15 minutes of one class will be reserved for students to evaluate their lecturers and their courses or modules through questionnaires.

Assessment

Continuous assessment activities

Title	Weight	Hours	ECTS	Learning outcomes
Written exams (x3)	60%	0	0	CA11, CA12, CA13, KA11, KA12, SA13, SA14, SA15

Oral presentation	40%	0	0	CA11, CA12, CA13, KA11, KA12, SA15

Three written assessments to be delivered during the course (20% each).

Oral presentation at the end of the course (40%).

Bibliography

R García. Amplitude modulation atomic force microscopy. Wiley-VCH, 2010. 373, 2010

Garcıa, R., & Perez, R. (2002). Dynamic atomic force microscopy methods. *Surface science reports*, *47*(6-8), 197-301.

Cappella, B., & Dietler, G. (1999). Force-distance curves by atomic force microscopy. *Surface science reports*, *34*(1-3), 1-104.

Axt, A., Hermes, I. M., Bergmann, V. W., Tausendpfund, N., & Weber, S. A. (2018). Know your full potential: Quantitative Kelvin probe force microscopy on nanoscale electrical devices. *Beilstein journal of nanotechnology*, *9*(1), 1809-1819.

R. Wiesendanger, *Scanning Probe Microscopy and Spectroscopy: Methods and Applications*, Cambridge University Press, (1994).

Williams, D. B., & Carter, C. B. *Transmission Electron Microscopy: A Textbook for Materials Science* (2nd ed.). Springer (2009).

Software

Nanonis STM Simulator V5e (https://www.specs-group.com/nanonis/products/mimea/).

Gwyddion (https://gwyddion.net/).

Course groups and languages

The information provided is provisional until November 30. After this date, you will be able to consult the language of each group through this link. To access the information, you will need to enter the course CODE

Type of teaching	Group	Language	Semester	Shift
(TEm) Theory (master)	1	English	first semester	afternoon