UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

# SYLLABUS DEL CORSO

## Surfaces and Interfaces

**2223-1-F5302Q012**

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### Aims

The course has two targets. On the one hand, to complete the knowledge acquired during a Course in Solid State Physics, answering the fundamental question: what happens to the properties of a perfect and infinite solid when the lattice periodicity ends at a surface? On the other hand, it is intended to provide the basis for all applications of Semiconductor Physics, Physics of Electronic Devices and Nanotechnologies, inevitably involving surfaces, interfaces and epitaxial depositions. The approach is both theoretical and experimental.

### Contents

The science of free surfaces in 26 Lessons: experimental techniques and theoretical models for the study of composition, structure, electronic states, thermodynamics, and vibrational properties.
The phenomena of adsorption, diffusion and desorption of atoms and molecules on a free surface, in 6 Lessons.
The epitaxial deposition of a thin film on a substrate, techniques and models in 7 Lessons.
The structures of interfaces and the alignment of the electronic bands in the two materials, as the basis of electronic devices, in 4 Lessons.
The course ends with 5 Lessons of advanced surface topics, concerning the pattering of substrates by etching, the rate equations describing the epitaxial growth and the three-dimensional epitaxy of quantum dots and nanowires.

### Detailed program

Lesson 1: Introduction to the Course

Lesson 2: Ultra High Vacuum and the preparation of clean surfaces

Lesson 3: Experimental methods for the analysis of surface composition

Lesson 4: Surface Bravais lattices and 2D reciprocal lattices

Lesson 5: The LEED scattering technique for surface structure

Lesson 6: The ion scattering technique for surface composition and structure

Lesson 7: Structural analysis by Rutheford Back Scattering (RBS) techniques

Lesson 8: Microscopy at the atomic resolution

Lesson 9: The electronic charge density at metal surfaces

Lesson 10: Shockley surface states in metals

Lesson 11: The tight binding approach to surface states and the local DOS

Lesson 12: The angle-resolved photoemission spectroscopy for band dispersion

Lesson 13: The electronic bands at notable metal surfaces

Lesson 14: The hybrid-orbital approach to the electronic states in semiconductors

Lesson 15: Surface states in tetrahedral semiconductors for the «as cut» configuration

Lesson 16: The intriguing reconstructions of the Si (111) surface

Lesson 17: Dimer-pair reconstructions at Si (100), Si (110), and GaAs (110) surfaces

Lesson 18: Reconstructions and charge transfer at polar surfaces

Lesson 19: Thermodynamics at surfaces, the surface energy and the surface tension

Lesson 20: Surface energies of different facets and the equilibrium morphology of crystals

Lesson 21: The larger mean square displacement for vibrations at the surface (theory)

Lesson 22: The larger mean square displacements at surfaces (LEED data) and the surface melting

Lesson 23: The surface vibrations in the elastic medium and in the diatomic linear chain

Lesson 24: Kinematics of the inelastic scattering at surfaces and the EELS technique

Lesson 25: Measurement of 3-D phonon dispersion relations by He scattering

Lesson 26: Calculation of surface phonon dispersions and comparison to He TOF data for notable cases

Lesson 27: The physisorption of atoms and molecules at metal surfaces

Lesson 28: Chemisorption and reactive chemisorption at surfaces

Lesson 29: Surface diffusion of adsorbate species

Lesson 30: Two-dimensional phase transitions in adsorbate layers

Lesson 31: Adsorption and desorption kinetics in a microscopic picture

Lesson 32: Adsorption kinetics in and out of equilibrium, elements of deposition

Lesson 33: Growth: Physical Vapour Deposition and Molecular Beam Epitaxy

Lesson 34: Growth: epitaxy by means of chemical reactions

Lesson 35: Modalities of film growth ( layers, islands, islands plus layers )

Lesson 36: The capillarity model of 2- and 3-dimensional island nucleation

Lesson 37: Elements of dislocation theory and the formation energy of dislocations

Lesson 38: Critical thickness for plastic relaxation in heteroepitaxial films

Lesson 39: Film-growth studies: experimental methods and some notable results

Lesson 40: Structural models of solid/solid interfaces and the notable Si/SiO2 interface

Lesson 41: Principles governing the electronic band lineup at solid interfaces

Lesson 42: Metal induced gap states and band lineup at metal/semiconductor interfaces

Lesson 43: The band lineup at semiconductor heterointerfaces

Lesson 44: The etching techniques and the substrate paterning for heteroepitaxy (Adv)

Lesson 45: Rate equation models for kinetics and thermodynamics of epitaxy (Adv.)

Lesson 46: Thermodynamics of epitaxial quantum dots, morphology versus size (Adv.)

Lesson 47: Oswald ripening of quantum dots and the role of substrate patterning (Adv.)

Lesson 48: Kinetics and thermodynamics in the epitaxy of nanowires and fins (Adv.)

## Prerequisites

Advanced Course in Solid State Physics

## Teaching form

Frontal lessons.

## Textbook and teaching resource

MAIN TEXT
H. Luth, Solid Surfaces.., Sixth Edition, Springer Verlag, 2015;

ADDITIONAL TEXTS (all the material which is strictly necessary is uploaded in the e-learning platform)

A. Zangwill, Physics at Surfaces, Cambridge 1990;

M. C. Desjonquères and D. Despanjaard, Concepts in Surface Physics, Springer Verlag, 1998;

J.E. Ayres, Heteroepitaxy of Semiconductors, CRC Press, 2007;

M. Prutton, Introduction to Surface Physics, Oxford Un. Press, 1994;

J.A. Venables, Introduction to Surface and Thin Film Processes, Cambridge Un.Press, 2000;

J.B. Hudson Surface Science, Wiley Interscience Publications, 1998.

### Semester

Second semester

### Assessment method

Oral examination, consisting in two, or three questions on different parts of the course, where the illustration of the topic is requested to be accompanied by sketches, equations, or numerical data, depending on the case. The final mark is given di a numerical scale, from 18 to 30 cum laude.

### Office hours

By appointment after e-mail request to leo.miglio@unimib.it. It will be also possible to have a remote colloquium via the Webex meeting tool.

### Sustainable Development Goals

AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE