SYLLABUS

"Nanoscale Surface Physics"
PHZ 5437

Spring Semester, 2008

Instructor: Dr. Beatriz Roldán-Cuenya
Time: Tuesday and Thursday 9:00 to 10:15 am
Location: Theory: MAP 233, Laboratory: MAP 148
Office Hours: Tu/Th 10:30-12:00 pm **Office:** MAP422
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This is a three credit hour course.

Reference Textbooks:

Course material will consist of class notes, which will be distributed before each class. Additional information on the topics covered in class can be found in the following reference books.

- E. Wolf, *Nanophysics and Nanotechnology*, Wiley-VCH, (2006).
A. Zangwill, *Physics at Surfaces*, Cambridge University Press, (1988).
- Lueth, *Surface and interfaces of solids*, Springer Series in Surface Science, vol 15
- M. Prutton, *Introduction to surface Physics*, Oxford Science publication 1994
- R. J. Madix, *Surface Reactions*, (Springer Series in Surface Science, Vol. 34) (1994)
- G. A. Somojai, *Introduction to Surface Chemistry and Catalysis,* Wiley Interscience, New York (1994).
- Desjonqueres, G. Somorjai, *Concepts of surface science*, 2nd edit., Ed. Springer (1996)
- John T. Yates, *Experimental innovations in Surface Science*, Ed. Springer-Verlag, New York
- J.M. Walls, *Methods of surface analysis*, Cambridge University Press (1989)
- D. P. Woodruff and T. A, Delchar, *Modern techniques of surface science*, Cambridge Univ.(1994)
- John C. Vickerman, *Surface Analysis-The principal techniques*, Wiley publisher.
- P.K. Ghosh, *Introduction to photoelectron spectroscopy, Chemical analysis*, vol.67, Wiley Interscience 1983
- D. Briggs, M.P. Seah, *Practical surface analysis-Auger and X-ray photoelectron spectroscopy*, Wiley Interscience 1990 (2nd ed.)
- H. Windawi, F.F. Ho, *Applied electron spectroscopy for chemical analysis*, Chemical Analysis, Vol 63
- J.W. Niemantsverdriet, *Spectroscopy in catalysis*, Wiley-VCH publishers 1995
- Dawn Bonnell, *Scanning Probe Microscopy and Spectroscopy : Theory, Techniques, and Applications*, Wiley-VCH; 2nd ed., (2000).
- R. Wiesendanger, *Scanning Probe Microscopy and Spectroscopy : Methods and Applications*, Cambridge University Press, (1994)

- Sergei N. Magonov, Myung-Hwan Whangbo, *Surface Analysis with STM and AFM: Experimental and Theoretical Aspects of Image Analysis*, VCH Publishers (1996).

Course Outline:

(1) **Physics at surfaces**: overview of physical and chemical properties that change when the materials considered are a few nanometers in size.

- Surface structure and reconstructions
- Surface electron density of states, 2D electron systems
- Surface reactions: physisorption, chemisorption, energy transfer
- Size-dependent metal-semiconductor transition, reduced melting temperature, enhanced chemical reactivity, etc.

(2) Discussion of different **nanostructure fabrication** methods.

- Thermal/e-beam evaporation (UHV) → Molecular Beam Epitaxy
- Mass selected nanocluster sources (UHV)
- E-beam lithography
- Chemical synthesis (nanosphere lithography, electrophoretic deposition, di-block copolymer encapsulation, etc.)

(3) Introduction to **nanoscale** materials **imaging** techniques: physical principles and operation.

- *Scanning Tunneling Microscopy (STM)*: structural and electronic characterization: microscopy and spectroscopy.

    - <u>Fundamentals</u>: quantum tunneling, band structure effects, Coulomb blockade and single electron tunneling, elastic/inelastic/spin-polarized tunneling, surface density of states, role of tip geometry, lithography/atomic manipulation, etc.
    - <u>Information extracted</u>: real-space images with atomic resolution of conducting nanomaterials, spectroscopy at the nanoscale, electronic surface density of states.
    - <u>Instrumentation / Basic operation:</u> constant current and constant voltage modes, low temperature STM.

- *Atomic Force Microscopy (AFM)*: morphological characterization.

    - <u>Fundamentals</u>: atractive/repulsive tip-sample interactions, van der Waals/electrostatic/magnetic forces, force spectroscopy, nanotribology, etc.
    - <u>Information extracted</u>: real-space morphological images with nearly atomic resolution of conducting and non-conducting nanomaterials, charge distribution in polymer surfaces, magnetic domain formation, etc.

- Instrumentation / Basic operation: tapping and contact modes.

(4) Introduction to **nanostructure electronic** and **chemical** characterization using traditional surface science techniques: basic physics concepts and operation.

- *X-ray Photoelectron Spectroscopy (XPS)*
    - Fundamentals: Photoelectric effect, binding energy and chemical shift, spin-orbit splitting, initial and final state effects, charge compensation in insulators, inelastic mean free path and sampling depth, etc.
    - Information extracted: surface composition and chemical state of surface species.
    - Instrumentation / Basic operation

- *Auger Electron Spectroscopy (AES)*
    - Fundamentals: Auger process, kinetic energies of AES peaks, ionization cross section, escape depth, etc.
    - Information extracted: surface composition with high spatial resolution (few nms).
    - Instrumentation / Basic operation

- *Ultraviolet Photoelectron Spectroscopy (UPS)*
    - Fundamentals: Fermi's Golden rule, surface density of states, adsorbate-induced work function changes, etc.
    - Information extracted: band structure→ occupied band states of clean solid surfaces as well as bonding orbital states of adsorbed molecules.
    - Instrumentation / Basic operation

- *Electron Energy Loss Spectroscopy (EELS)*
    - Fundamentals: vibrational spectroscopy, excitation mechanisms: elastic or dipole scattering, inelastic or impact scattering, spatial resolution, set-up, etc.
    - Information extracted: kinetics of slow surface reactions.
    - Instrumentation / Basic operation

(5) **Chemical reactivity** characterization: functional nanostructures for gas sensing and catalysis.

- *Temperature Programmed Desorption (TPD).*
    - Fundamentals

- Information extracted: adsorbate coverage, adsorption energy, activation energy of desorption, lateral interactions between adsorbates, desorption mechanism, etc.
- Instrumentation / Basic operation

The students will have hands-on experience with the experimental techniques discussed in class.

Course Objectives and Expectations:

The students will become familiar with the novel physical and chemical properties displayed by nanoscaled materials and will learn new physical concepts that can be applied to describe the unusual behavior of low dimensional systems (nanorods, nanodots, etc.). This course will also provide fundamental theoretical and practical knowledge on how to fabricate nanostructures, how to investigate their morphological structure (AFM, STM), electronic structure (XPS, AES, UPS, STM) and chemical behavior (TPD).

Assistance to the lectures and laboratory classes is required. In addition to a midterm and a final exam, the students are expected to give a 15-minute in-class presentation on a nanoscience-related topic.

Pre-requisites: Undergraduate quantum mechanics at the level of PHY4604 or C.I.

Course Structure:

- **Laboratory**: Practical sessions will be held in the laboratory to demonstrate the operation of various structural, electronic and chemical analytical tools whose basic physical principles will be studied in class. Data analysis will be object of discussion.
- **Mid-term Exam**: There will be one written “in-class” exam (about 75 minutes).
- **Final Exam:** 6-8 problems/questions. All examinations are without books.
- **Student presentation:** Each student will present on a nanoscience related topic (see list of suggested themes) using conference format. The student will have 10-15 minutes to present his/her topic and additional 5 minutes for discussion. The presentations will take place at the end of the semester. Attendance is required.

Grades:

The final grade will be calculated according to the following scheme.

Student presentation → 25%
Laboratory → 10 %
Midterm→ 30%
Final → 35%

Grading Scale:

A	85-100
B	75-84
C	60-74
D	50-59
F	0-49

Grades are not given out in response to e-mail messages or telephone calls.
+,- grades will be given.

Course Tentative Schedule:

Topic	**Date**
Physics at surfaces-Intro	Jan 8, 10, 15, 17
Nanostructure Fabrication	Jan 22, 24, 29
Scanning Tunneling Microscopy	Feb 5, 7, 12
Atomic Force Microscopy	Feb 14, 19, 21
X-ray Photoelectron Spectr.	Feb 26, 28, March 4
Midterm	**March 6**
Auger Electron Spectr.	March 18, 20
Ultraviolet Electron Spectr.	March 25, 27
Energy Loss Spectr.	April 1
Chemical Reactivity: TPD	Apr 3, 8, 10
Student Presentations	Apr 15, 17, 21
Final Exam	To be determined

Examples of possible presentation topics

- Magnetic properties of size- and shape-selected 0D and 1D nanostructures.
- Coulomb blockade in molecular magnets .
- 2D electron gas in spin-effect transistor.
- Size dependent metal/semiconductor transition in metal clusters.
- Functional nanostructures for chemical sensing applications.
- Synthesis, characterization and applications of C-nanotubes.
- Size and shape dependent catalytic activity of metal nanoparticles supported on metal oxides.
- Scanning probe lithography.
- Growth of anisotropic structures by molecular beam epitaxy.
- Nanophotonics