Spring 2008 MSAE E4990y
Introduction to Scanning Tunneling Microscopy and Atomic Force Microscopy

Lecturer: C. Julian Chen
Lecture time: Mon Wed 11:00 – 12:15
Classroom: 1106B Mudd
Office time: Mon 1:00 – 4:00 pm
1336 Mudd, Tel: 212-854-8980

The scanning tunneling microscope (STM) and the atomic force microscope (AFM), both capable of visualizing and manipulating individual atoms, are the cornerstones of nanoscience and nanotechnology today. This course covers the principles of STM and AFM, as well as the instrumentation details. As illustrative applications, catalysis research, electrochemistry, as well as imaging and manipulating biological molecules will be described.

Prerequisite: Introductory quantum mechanics, for example, APPH E3100y, APPH E4100x, PHYS G4021x, PHYS G4022y , CHEM C3079x, CHEM G4221x.

Text: C. Julian Chen, Introduction to Scanning Tunneling Microscopy, Second Edition, Oxford University Press 2007. Full text is available online through the Columbia Library: E-Resources – Databases – Oxford Scholarship Online – Physics.

Goals: The Students Will…

- Understand the basic physics of the signals detected by STM and AFM: Tunneling phenomenon especially through the Bardeen theory, and various types of atomic forces including van der Waals force, ionic bond force, repulsive atomic force, and the covalent bond force especially in terms of the Herring-Landau perturbation theory.
- Understand the basic design and construction of STM and AFM: piezoelectric scanners, vibration isolation, feedback system, electronics and control, course positioners, and cantilevers for atomic force detection.
- Understand the basic operation of STM and AFM: tip preparation and conditioning, setting the tunneling condition or force detection condition, setting scanning conditions, setting spectroscopic measurements, and inelastic tunneling.
- Understand the interpretation of STM images, using the Tersoff-Hamann model and the convolution of tip states and sample states.

- Understand the interpretation of AFM images, with various modes of operation, including contact mode, tapping mode, and non-contact mode.
- Understand methods of the application of STM and AFM to various fields of research, including condensed-matter physics, chemistry, materials science, and biophysics.

Teaching Methods

The lectures include ppt presentations as well as fully detailed derivations on a blackboard. While the concepts, designs, and images are presented with ppt, the important theoretical frameworks are derived in great details, including the Landauer theory and the Bardeen theory of tunneling, the Herring-Landau perturbation theory of covalent bonds, the theory of tube scanners, and the theory of vibration isolation. The handouts of the ppt files will be posted on the webpage after each lecture.

Office Time

Monday 1:00 to 4:00 by appointment only.

Homework and Exams

Homework will be assigned at the end of each lecture, and due each Monday (25%). The midterm will be on March 10 (25%). The final exam will be on May 12 (50%). Although homework counts only 25%, it is important to do it diligently, because the exam problems will be similar to those in the homework.

Schedule

Lecture 1	Jan 23	Wed	Basics of STM
Lecture 2	Jan 28	Mon	Basics of AFM
Lecture 3	Jan 30	Wed	Catalysis research
Lecture 4	Feb 4	Mon	Electrochemical STM
Lecture 5	Feb 6	Wed	Biological Studies
Lecture 6	Feb 11	Mon	Bardeen tunneling theory (1)
Lecture 7	Feb 13	Wed	Bardeen tunneling theory (2)
Lecture 8	Feb 18	Mon	Tunneling matrix elements
Lecture9	Feb 20	Wed	Tersoff-Hamann model
Lecture 10	Feb 25	Mon	Van der Waals force, ionic force and repulsive force
Lecture 11	Feb 27	Wed	Covalent bonding force
Lecture 12	Mar 3	Mon	Relation between tunneling and covalent-bond force
Lecture 13	Mar 5	Wed	Nanomechanical effects

Mar 11, Midterm exam

Lecture 14	Mar 14	Wed	Review of Bardeen tunneling theory
Lecture 15	Mar 24	Mon	Atomic-scale imaging: concept
Lecture 16	Mar 26	Wed	Atomic-scale imaging: computations and experiments
Lecture 17	Mar 31	Mon	Piezoelectric effect, tripod and bimorph
Lecture 18	Apr 2	Wed	Tube scanners
Lecture 19	Apr 7	Mon	Vibration isolation
Lecture 20	Apr 9	Wed	Electronics and control
Lecture 21	Apr 14	Mon	Mechanical designs
Lecture 22	Apr 16	Wed	Tip treatment and characterization
Lecture 23	Apr 21	Mon	Scanning tunneling spectroscopy
Lecture 24	Apr 23	Wed	Inelastic tunneling
Lecture 25	Apr 28	Mon	AFM: the cantilevers, static mode
Lecture 26	Apr 26	Wed	AFM: tapping mode
Lecture 27	May 5	Mon	AFM: non-contact mode

May 7-9, Study days

May 12, Final exam