Midterm Examination for
"Characterization and Manipulation at Nanometer Scale"
April 8, 2008

ID Number: ________________ Name: ________________________

Q1. Try to think and write down the possible difficulties and challenges you will face when you perform the characterization and manipulation on a single nanostructure. (10%)

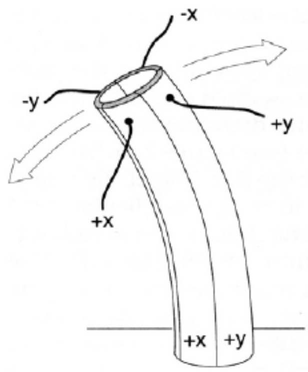
In characterizing a single nanostructure, one usually encounters the difficulties in the small size, weak signal, high reactivity, and flexible functionality. And in manipulation, the compatibilities in size and interaction force are the concern. The evolving challenges in the development of instruments and tools include: high brightness source, small probe, high sensitivity, low interference, controlled environment, low temperature, high speed, and in situ measurements.

Q2. This is a problem related to the scanning tunneling microscopy (STM).

(a) Describe how the piezoelectric tube scanner works in the STM? (5%)

(b) Write down and sketch the relation of the tunneling current with the bias voltage applied between the tip and sample. From the sketch, please show the sensitivity of the tunneling current to the distance between the tip and sample. (10%)

(c) What part of the sample's electronic structure is acquired with a positive bias applied to the tip? What about if the bias voltage is reversed? (5%)



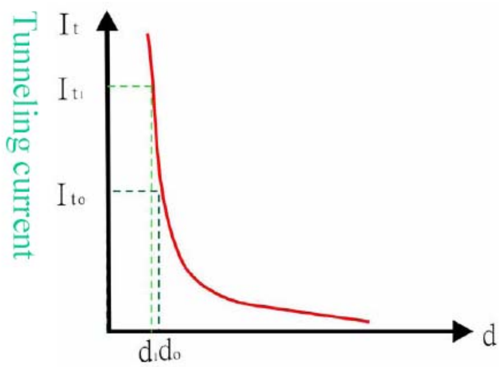
(a) The tube scanner of the STM is made of piezomaterial. This material will deform by the electric voltage applied across its two opposite faces. For a typical STM tube scanner, the outside of the tube is divided into two pairs and each pair contains the electrodes situated at the opposite side, guarding the bending motions of x and y directions, respectively (referring to the figure). An equal but opposite voltage will apply to each pair electrodes and cause one side of the tube to extend and the other side of it to contract, and the tube is thus bent toward one direction. The z-direction motion of the tube is controlled by adding a net voltage to the tally of the four outside electrodes with respect to the normally grounded inner electrode.

(b) Tunneling current $I_t \propto (V/d)exp(-A\varphi1/2d)$

A = 1.025 (eV)-1/2Å-1

φ~4 –5 eV

d decreases by 1 Å, I_t will be increased by ~10 times.



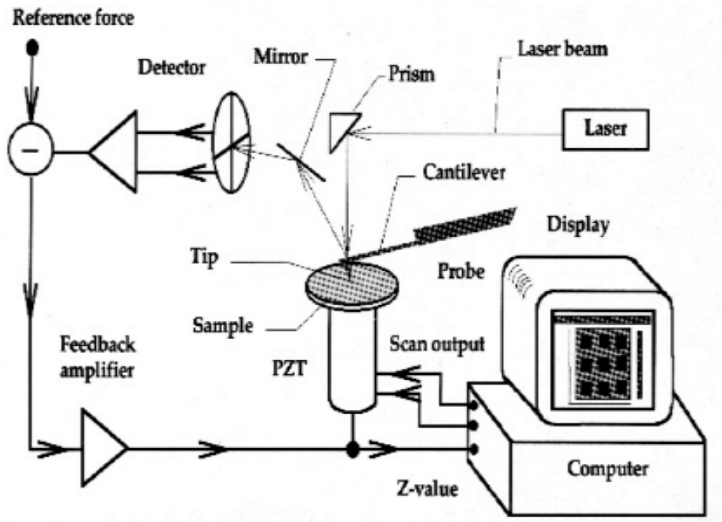
(c) With a positive bias applied to the tip, the filled density of states (DOS) of the sample's electronic structure is acquired. When the bias voltage is reversed, the empty DOS of the sample's electronic structure is probed.

Q3. This is a problem related to the atomic force microscopy (AFM).

(a) Sketch the core components of an atomic force microscope including the cantilever probe, sample, scanner, laser, photodiode detector, computer and feedback controller, and briefly describe how the beam deflection mechanism works. (10%)

(b) Describe how to obtain the surface topography by operating the AFM in the tapping mode? (5%)

(a)



When the sample is scanned against the cantilever probe, the surface morphology will cause the cantilever beam to move up and down. The laser spot reflected from the backside of the cantilever will be shifted in the position-sensitive diode (PSD) accordingly. The difference in photocurrents from the upper and lower parts of PSD can be measured and fed back to the control electronics in order to readjust the sample position.

(b) In the tapping mode, the cantilever is driven close to its resonance freq. with a large amplitude (> 20nm). When this vibrating cantilever is brought near the sample surface, the amplitude will change due to the force exerted to the probe by the surface. A set value is chosen for the amplitude change, thus the force between the probe and sample is fixed, and subsequent scan across the sample surface will obtain the information about the surface topography.

Q4. This is a problem related to the magnetic force microscopy (MFM).

(a) In mapping out the surface magnetic properties, inevitably, the geometrical factor will interfere. Please describe how to decouple these two signals in both principle and operation. (10%)

(b) Describe what type of magnetic information of the sample you can obtain with the conventional MFM. (5%)

(a) To obtain pure magnetic information of the sample, the geometric factor of the sample surface has to be eliminated. This can be done with scanning the sample twice at each line scan. One is taken at a close range of the sample to acquire the topographic information of the sample surface, e.g. using the tapping mode, and the data is recorded in the computer. Since the magnetic force is a long range force, the second scan is performed at a distance from the sample (normally > 50nm) following the trajectory recorded in the first scan. In a normal operation, both the AFM and MFM images are displayed side by side for comparison.

(b) Since the MFM requires a magnetic tip, it is often made from a magnetic wire or a conventional AFM probe coated with a magnetic film. Due to the slender tip shape, the magnetization direction usually lies along the tip shape. The force sensed by this kind of tip can discern the magnetization direction of the sample domain either parallel or anti-parallel to this direction. If the magnetic domains of the sample all have magnetization lying parallel to the sample surface, only the stray field originated from the domain boundaries can be detected. The determination of in-plane magnetization direction of the sample is not straightforward.

Q5. This is a problem related to the transmission electron microscopy (TEM).

(a) Name and sketch five of the many signals emitted from a solid specimen when it is bombarded with a high energy electron beam. (10%)

(b) Draw ray diagrams according to Abbe's principle and explain the procedures of obtaining the bright field (BF) and the dark field (DF) images in an electron microscope. (10%)

(c) Use diagrams and statement to explain how electrostatic lens and electromagnetic lens work. (10%)

(a)Transmitted electrons, elastically scattered electrons (diffracted electrons, for crystalline material), inelastically scattered electrons, back scattered electrons, secondary electrons, X-rays (characteristic and Bremsstrahlung), photons (for some semiconductors, minerals, and ceramics), phonons, heat, etc.

Q6. Please list the advantages and disadvantages of applying the X-ray microscopy in bio-imaging comparing with either TEM or SPM. (10%)

Advantages:

1. Higher penetration power
2. Less sample preparation treatment
3. Samples can be in their natural states
4. Easier to develop 3D tomography of the sample

Disadvantages:

1. Bright light source required
2. Less light focusing devices
3. Poor resolution comparing with TEM and SPM