Student Activity

Coffee Cup Atomic Force Microscopy: Seeing the Unseen

How can you see the structure of objects that are at least 10,000 times smaller than the width of a human hair? A regular (light) microscope will not work due to the small (nanoscale) sized objects nanotechnology deals with. In this activity, pairs of students will build and manipulate an atomic force microscope Model (AFM) to visualize the dimensions of some common objects. Sample objects can be related to molecular dimensions, noting that the diameter of a DNA molecule is about 2 nm and 10 carbon atoms linked together in a line is 1 nm in length.

Background

Nanotechnology represents a new field in the investigation of matter. At the nanometer scale (one-billionth of a meter), light waves and nanoparticles are similar in size. They can be investigated only through indirect methods using very sensitive and sophisticated instruments. One of these instruments is the Atomic Force Microscope (AFM). An AFM uses deflected laser light to measure the dimensions of nanomaterials, producing a map of the object being examined. Different types of images can be produced by different types of instruments such as a transmission electron microscope (TEM), scanning electron microscope (SEM) and an AFM. A TEM image shows a very high magnification image, but only in two dimensions. However, it is often important to know the three dimensional shape of nanomaterials, and the AFM is one of the primary tools used for that task. The AFM moves a cantilever with a very sharp tip across a surface. When an elevated feature is encountered, the cantilever is bent upward. The magnitude of this deflection is measured by reflecting a laser beam off the cantilever and monitoring the beam with a position-sensitive detector. By moving the cantilever over the entire surface, a complete topographic image can be generated using the signal from the position sensitive detector. Besides higher resolution, another advantage that the AFM has over other microscopy techniques is its ability to precisely probe the three-dimensional structure of an object. For example, when using a light microscope, it is very difficult to quantitatively determine the height of features in the field of view. Using an AFM, object heights can be easily calculated based on the amount of cantilever deflection measured by the detector.

In this activity, you will assemble a model AFM from a coffee cup. Part of the model uses a laser pointer and a (round) glass cover slip, attached to the end of the flat, pointed cantilever. Movement of the model AFM over the various objects provides information about the height/width (if a sphere or cylinder) of the objects.

Constructing the AFM

While constructing the AFM, refer to Figure 1 (page 4) for guidance.

Materials:

- 8-12 oz. paper coffee cups
- Laser pointer

- Coverslip
- 2 wood pencils
- Scissors
- Tape
- Pen
- Graph paper
- Ruler

1. Turn the coffee cup upside-down so that the opening is now at the bottom. Starting from the opening of the cup, cut out a rectangular section measuring approximately 1.5 inches by 3 inches. The long dimension of the rectangle should be along the length of the cup. Leave approximately one inch between the top of the rectangular opening and the top rim of the cup.

2. To make the cantilever, cut a ½ inch wide strip by cutting > 1 inch from the top rim of the cup, on the side opposite the rectangular cutout, and making vertical cuts to ½ inch from the bottom.

3. Cut the end of the strip to a triangular point. Fold the strip into the cup so it meets the inside of the cup. Tape this part (the hinge) and then bend ½" of the pointed end of the strip so that it points down towards the open end of the cup at about a 110 degree angle.

4. Tape a cover slip or other reflective material as close to the pointed end (tip) of the cantilever as possible. Cut a star shaped hole in the top of the cup directly over the cantilever tip that can hold the laser pointer. Insert the laser pointer into the star-shaped hole, and align it so that it hits the reflective surface

on the end of the cantilever and the deflected beam can be seen on the target. A second disc can be cut from the bottom of another coffee cup, a star opening cut

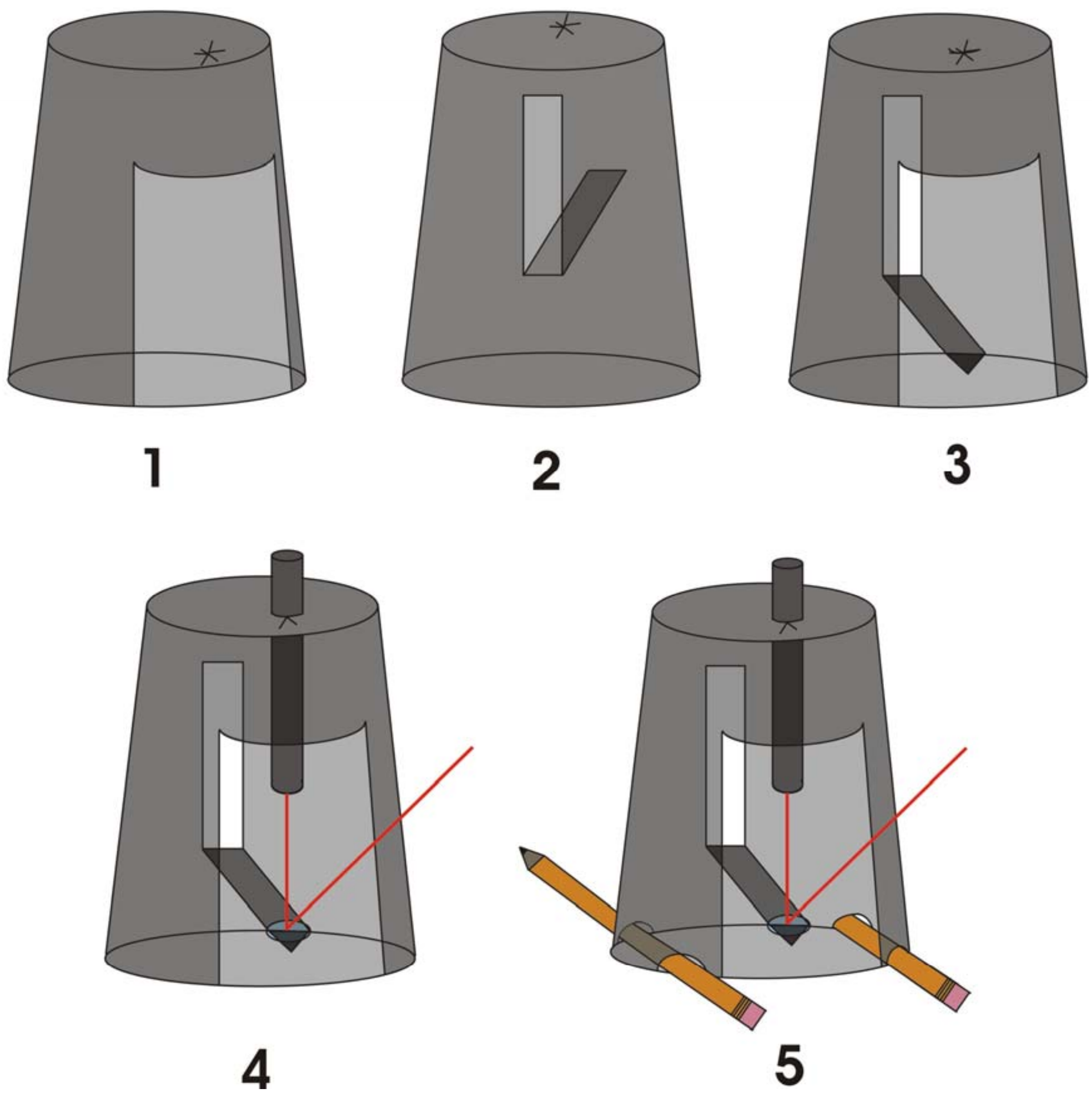

Figure 1. Instructions for Assembling the Coffee Cup Atomic Force Microscope. (1) Invert the coffee cup, and then cut a rectangular strip from the side of the cup. (2) Cut a strip on the opposite side from top to 1/2 inch from bottom and fold flat to inside of cup. (3) Cut a triangular point on to the cantilever, and point down to opening about 110 degrees. (4) Tape a reflective surface to the cantilever, and orient the laser pointer so that the beam reflects off the cantilever and onto the ruler or graph paper. (5) Cut slots in the bottom of the coffee cup just large enough to fit over the pencil rails.

into it, and inserted into the body of the AFM (star cuts aligned) to hold the laser pointer more securely in place, if desired. Secure the laser with a rubber band placed over the protruding end on top, through the rectangular opening and over the exposed end of the laser inside.

5. Make two aligned slots on either side of the coffee cup (at the bottom or opening of the cup) for the pencil rails. Secure the two pencils onto a flat surface using tape and place the cup over the rails so that they fit into the slots. You may wish to secure a ruler next to the pencils as well in order to keep track of the cantilever position as you scan over the object. You are now ready to use the AFM!

Try This

Once the AFM model is constructed, various objects will be available for your examination, and each group (2 students) will examine a sphere representing a gold or silver nanoparticle and two or more other objects. ***DO NOT SHINE THE LASER POINTER TOWARDS ANYONE! THIS WAVELENGTH OF LIGHT PRODUCES ENERGY THAT IS DAMAGING TO BIOLOGICAL TISSUES, ESPECIALLY OCULAR TISSUES, INCLUDING THE RETINA. BE VERY CAREFUL HANDLING GLASS COVER SLIPS WHICH MAY CRACK, PRODUCING SHARP-EDGED PIECES THAT CAN CUT OR BECOME IMBEDED IN SKIN.*** Each group will have graph paper, a metric ruler, a cover slip, and a laser pointer.

1. Set up your target (paper or ruler) about 12 – 24 inches from where you'll be measuring your objects. It is important to keep the distance between the AFM and the laser target as constant as possible throughout your measurements. Varying this distance will change the magnification factor you determine in the calibration step! Slip a small piece of paper around the laser pointer button and secure, tightly, with tape, so the laser is on all the time.

2. Along the tracks, slowly move your AFM to the base of a taped down object, and mark the laser spot on your graph paper target. Pulling the AFM backward over the object, move to the top of the object (highest point) and mark the laser hit. Now, move to the bottom of the object and mark the hit, again. This measurement will give you the height (H) of the object. To get the width (or length), travel across the diameter (if object is circular) or along the length (if cylindrical). Mark the laser hits.

3. To calibrate your AFM, measure the dimensions of an object and compare with the laser deflections (e.g. a 2 mm tall object shows laser deflections of 40 mm). Repeat a total of three times with a range of object heights, and plot the laser deflections as a function of object height. The resulting plot should be fit with a linear equation through the origin ($y = m*x$) where the slope, m, is equal to the magnification factor.

4. Measure the following objects: small (~6mm) sphere, and then two more objects. For example, a cylinder (cut from a coffee stirrer), a quarter and a washer or o-ring.

5. Construct graphs representing the dimensions of the objects examined. This will be accomplished by measuring the change in deflection of the laser hits seen on the (graph) target, and converting this difference to object height using your magnification factor. Graphs will have axes of Y = H and X = W.

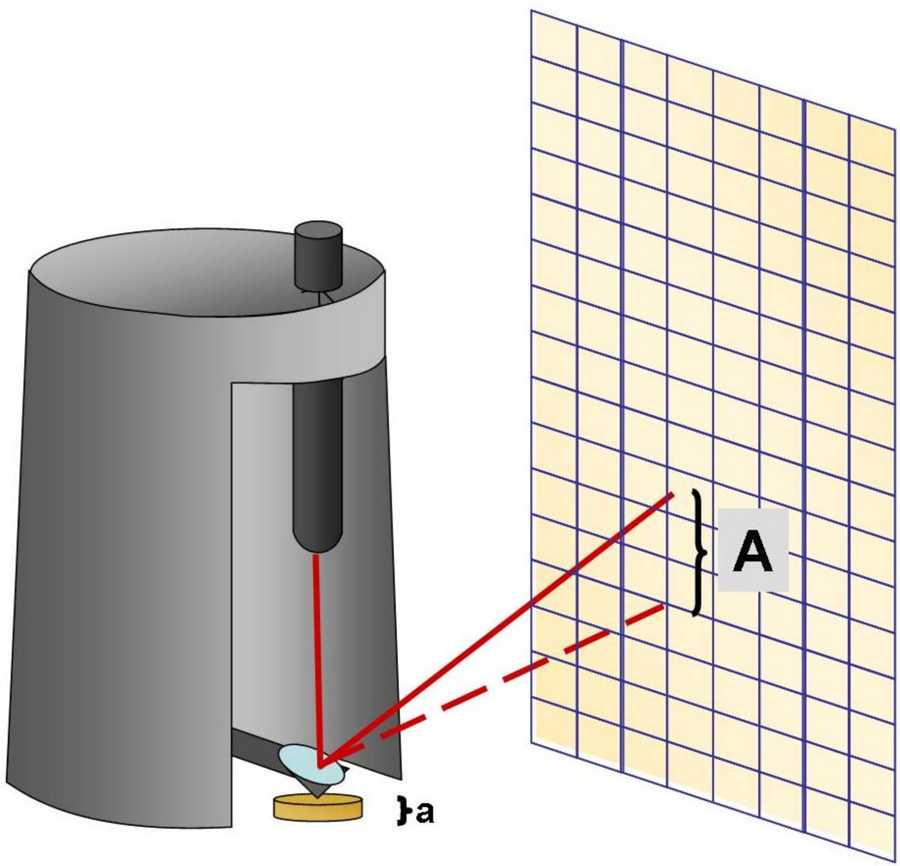

Figure 2. Picture of AFM Model in Use. Small object of height "a" causes a deflection in the cantilever, which causes projected beam to deflect a large distance "A" on the target. Because we can easily measure the large distance A, we can calculate the size of the small object using simple, predetermined ratios.

Questions

____1. How can a three-dimensional image of a surface be created based on measurements similar to that performed in the activity?

____2. What happens if different shapes were used for the tip of the cantilever? For example, what differences might be expected when using a large, blunt tip instead of a small, sharp tip?

____3. The technique used in this activity relies on deflection due to the physical contact between the surface and the cantilever tip. What other ways could the cantilever be deflected? (Hint: Think about attractive-repulsive forces in nature.)

____4. What is the principle involved that allows you to construct your graphs? Do you think an actual AFM uses this same principle? How?

Information from the World Wide Web

1. Northwestern University's DiscoverNano education site for students and teachers; www.discovernano.northwestern.edu.
2. Scanning Probe Microscopy at Bristol; http://spm.phy.bris.ac.uk/techniques/AFM/
3. Veeco NanoTheater; http://www.veeco.com/nanotheatre/default.asp
4. National nanotechnology initiative; for students K-12; http://www.nano.gov/html/edu/eduk12.html