Coffee Cup Atomic Force Microscopy

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In this activity, students use a model created from a coffee cup to explore the working principle of an atomic force microscope (AFM). Students manipulate a model of an AFM, using it to examine various objects to retrieve topographic data and then graph and interpret results. The students observe that movement of the AFM cantilever can be monitored by the deflection of a laser beam. Goals for the students are to examine macroscopic objects and relate their measurement technique to the atomic- and molecular-scale measurements of an actual AFM.

Measurements on the Nanoscale

Nanoscience involves studying the properties of materials when the structural features of the materials are one hundred nanometers (one nanometer is one billionth of a meter) in size or smaller. Examining objects on the nanoscale is different from examining larger objects. Light microscopes allow scientists to see objects that are much smaller than the human eye can resolve, but they still cannot be used to examine nanoscale features. This is due to the fact that light microscopes are limited by the rules governing the behavior of light. Because of the wave nature of light, light microscopes cannot resolve features smaller than one-half the wavelength of the light being used to view the object. For example, a microscope using blue light (~400 nm) could, at best, resolve features of ~200 nm. This resolution constraint of light microscopes is called the diffraction limit.

Because physical and chemical properties of materials are size dependent, the structure of a nanoscale object determines its ultimate utility in any application. To create devices with specifically desired characteristics, scientists must be able to fabricate and characterize nanostructures with defined shapes and sizes. This process is much easier if scientists are able to visualize the objects or features of interest. The atomic force microscope (AFM), with its ability to topographically map objects on the nanoscale, is one tool that makes this research possible. The AFM overcomes the diffraction-limited resolution of conventional light microscopes by employing a flexible cantilever that scans over a three-dimensional surface and deflects when topographical features are encountered (Figure 1). The magnitude of the deflection is directly proportional to the size of the surface features and is measured by monitoring the translation of a laser beam that is reflected off the surface of the cantilever. Since its invention in the mid-1980s, the AFM has developed into one of the most useful tools in nanoscience research.

Experimental Overview

Students often have difficulty understanding how scientists visualize atoms, molecules, and other materials on a very small size scale. AFM can be used to reveal the arrangement of atoms in solids or to image nanoscale features such as cracks, grain boundaries, and roughness on a surface. This project is applicable when atomic structure and size is discussed. A discussion of the electromagnetic spectrum is also a place where nanostructures, and their light behavior dependence on size and shape, can be examined *(1, 2)*. The necessity of using instruments such as an AFM for structure examination would be an important point of interest in studying nanomaterials. Hands-on, tactile activities help students understand difficult concepts such as atomic size and molecular structure. Activities designed to illustrate measurements using a scanning probe microscope (SPM), another nanoscale measurement tool, could be a useful supplement to this activity *(3–5)*. In this activity, students construct a model AFM and use it to measure the height features of macroscale objects, in much the same way that an actual AFM measures the features of nanoscale objects.

Experimental Details

Students construct, calibrate, and use a model AFM to measure the size of small classroom objects (Figure 2). The AFM is made out of a paper coffee cup, 18 mm glass coverslip or other reflective surface, tape, and a laser pointer (for purchasing details and construction see the supporting material). The construction is simple and straightforward. A cantilever tip is fashioned from the walls of the coffee cup, and a coverslip is placed over the triangular tip of the cantilever. A laser pointer is secured perpendicular to the horizontal plane the AFM sits upon and focused onto the cantilever tip. The base of the coffee cup AFM runs on tracks made from two pencils and two rulers. Each student group needs a complete coffee cup AFM (laser pointer included) and several small classroom objects to perform this activity. Some good objects include coins, keys, erasers, or paperclips. Another possibility is to use objects that resemble nanoparticles; for example, spheres, prisms, rods, cubes, and triangles are routinely fabricated in nanoscience laboratories. A small wooden block set would have many of these shapes; alternatively, they could be made from cardboard cutouts.

Hazards

Students must take care not to shine the laser pointer toward anyone. Some wavelengths of light produce energy that is damaging to biological tissues, including the retina. Students should also handle the glass coverslips with care, as they are very fragile and if broken can produce shards that may cut or become imbedded in skin.

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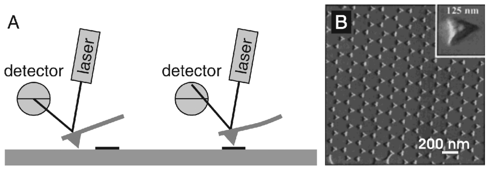

Figure 1. Schematic of cantilever deflection and AFM image: (A) An AFM cantilever before and during interaction with a surface feature. Note the position of the reflected laser spot on the position-sensitive detector. (B) An AFM image of silver nanoprisms on a glass surface fabricated by Nanosphere Lithography.

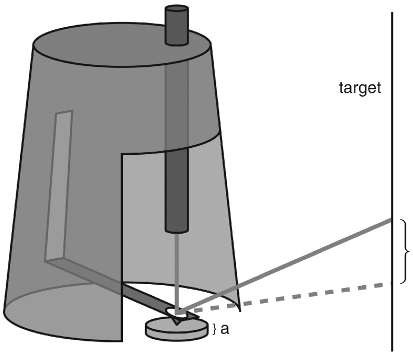

Figure 2. Schematic of an AFM model in use. Small object of height "*a*" causes a deflection in the cantilever, which causes projected beam to deflect a large distance "*A*" on the target. Because the large distance *A* can be easily measured, the size of the small object using simple, predetermined ratios can be calculated.

Results and Discussion

To accurately translate between the deflection of the reflected laser beam and object height, students first need to calibrate their model AFM by taking a series of measurements of objects of known height. The movement of the laser beam on graph paper can be plotted as a function of cantilever height. The data points can then be fit with a linear equation where the slope is equal to the magnification factor produced by the model AFM (Figure 3A).

Once the model is calibrated, it can be used to measure the dimensions of small classroom objects. Students "scan" the model AFM over an object and note the laser beam position on the graph paper (z dimension) at each specific point during the AFM scan (x dimension). The z dimension can be translated to actual object height using the magnification factor determined in the calibration step. Plotting this converted height value as a function of scan position creates a graphical picture of the small object in two dimensions (Figure 3B). Finally, students verify their model AFM measurements by measuring the object dimensions with a ruler. Comparing the "measured" and "actual" provides a good opportunity to reinforce the concept of experimental error (error and standard deviation of a model AFM tested by a high school class can be found in the supporting material). To add a level of complexity to the project, students can also scan the object in the direction orthogonal to their original scan (y dimension); this will provide x, y, and z values that can be plotted using a computer graphing program to create a three-dimensional, topographic map of the object.

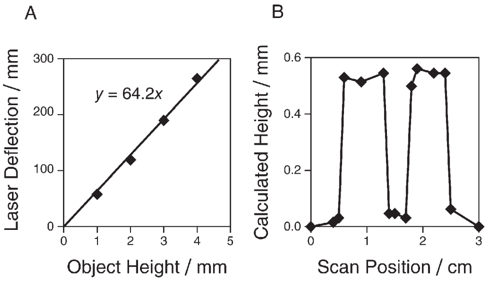

Figure 3. AFM calibration and imaging: (A) Calibration of a model AFM showing a linear fit to the experimental data points. This AFM produced a magnification factor of approximately 64.2. (B) "Image" of a washer that was mapped using the model AFM. Laser deflection was converted to calculated height using the magnification factor determined in (A).

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Supporting Information Available

Student handout; purchasing details and construction of the AFM; error and standard deviation of a model AFM tested by a high school class. This material is available via the Internet at http://pubs.acs.org.