Teacher's Guide

Seeing Nano II: Using atomic force microscopy to view nano-size objects

Grade Level: Middle and high school

Subject area(s): Physical science and physics

Time required: 50 – 100 minutes

Learning Objectives: Through observation and interaction students will: 1. learn how nanosize objects can be visualized; 2. enhance measurement skills; 3. learn about advanced instrumentation (how an AFM works); and 4. explore disc technology.

Summary: Students will explore the storage capacities of CDs, DVDs, and Blu-ray discs using an Atomic Force Microscope (AFM). The AFM allows us to image objects that are extremely small in size, often on the nanoscale (10^{-9}m). Students will access an AFM via Remotely Accessible Instruments for Nanotechnology (RAIN). RAIN is a free service to educators that allows students to access and control microscopes (http://nano4me.org/remoteaccess). Students control the tools over the Internet in real-time and with the assistance of an experienced engineer at the microscope advising over video conferencing software.

Pre-requisite knowledge: Students should know the size of a nanometer particularly in comparison to other micro and macro size objects. They should also understand the structure and properties of matter as well as forces exerted by matter.

Lesson Background: Nanoscale science and engineering is the study of objects that are 1-100 nm in size. Nano means one billionth (10^{-9}) and one 1 nm is equal to 10^{-9} meters. Nanotechnology has many applications that range from consumer products to pharmaceuticals. According to Lux Research, (https://members.luxresearchinc.com/research/report/13748) nano-enabled products exceeded $1 trillion in 2013. Where is nanotechnology found? -- advanced materials and textiles, information technology, energy and environment, aerospace, medicine and health, food and agriculture, national security and defense, transportation and mechanical engineering, and robotics. Advances in nanotechnology would not be possible without the advent of specialized equipment that allows us to visualize and manipulate materials at the nanoscale. The Atomic Force Microscope is one such instrument.

Nano-size objects are smaller than the wavelength of visible light (390 – 700nm) and due to their size cannot be seen with a light microscope. One instrument that is used to visualize nano-size objects is the AFM. The AFM shown in Figure 1A uses a vibrating cantilever tip to measure the surface characteristics of an object that are used to generate an image. To image the sample, a laser beam is focused on the cantilever, shown in Figure 1B, and as the cantilever scans the object's surface, sensors measure the deflection of the beam as a result of forces between the surface and the tip. The beam deflection is converted into an image of the object's

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surface. Since light is not used for the AFM, the pictures that are produced are grey scale. An AFM's probe tip is on the order of 15-40nm and its vertical resolution is ~0.1nm and lateral resolution is ~30nm. See Fundamental Theory of AFM to learn about resolution (http://www.nanoscience.gatech.edu/research/Fundamental%20AFM.php).

Compact discs, DVDs, and Blu-ray discs are some of the most commonly imaged objects for educational purposes. Have you ever noticed that these dics are the same size, but have different capacities? How can this be? If you examine the discs using the atomic force microscope, you will notice there is a structural difference between the discs. In this lesson, the AFM will be used to explore these differences.

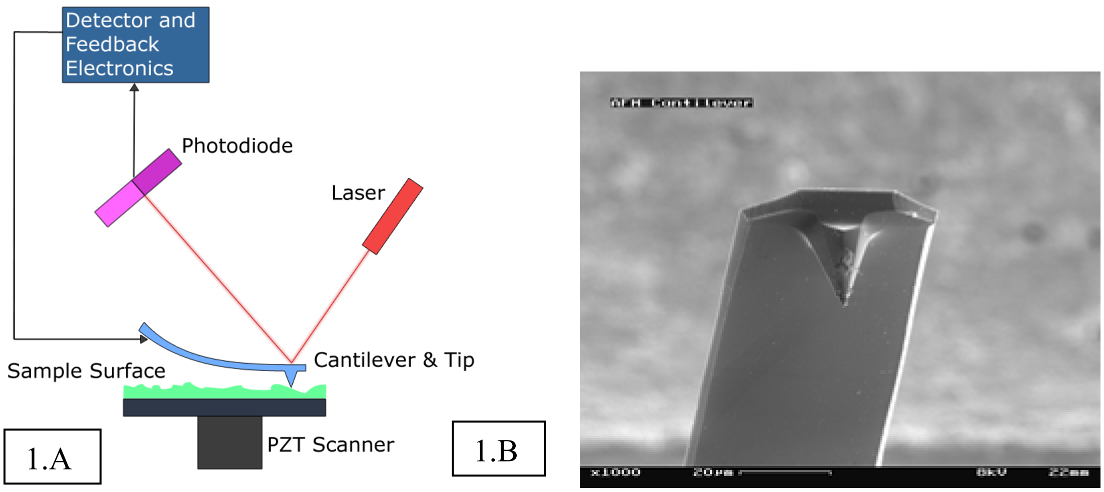

Figure 1: A is a diagram of the AFM and B is the cantilever tip [1,2]. Image A has been released into the public domain by its author, OverlordQ at the Wikipedia project and image B at Wikipedia - Attribution-ShareAlike 3.0 Unported (CC BY-SA 3.0)

A CD is an optical disc used to store data and was originally developed to store and playback music. This purpose has changed over time and CDs now are used for photos, videos, graphics, etc. DVDs are also optical storage discs but were developed to store video and due to their convenience and sturdiness ended the era of VHS tapes. DVDs are also used for a variety of data storage. Blu-rays are optical discs that have higher storage capacity, quality, image resolution, etc.
All three discs have pits or grooves that spiral from the inner edge to outer edge which are called tracks. These tracks are what codifies the data on a disc. The spacing between tracks, width of tracks and their depth is what controls the amount of data that can be stored.

Knowing the physical characteristics of the disc can help calculate the storage capacity of the disc. Not only does a DVD have more tracks per mm relative to a CD, but the average pit length is also less allowing a DVD to accommodate more data (7X more data than a CD). The process of error correction on a DVD is much more efficient allowing it to have more free space for data storage. CDs and DVDs use red lasers to read the binary encoded data.

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The storage capacity of a DVD can be increased further by having a two-sided DVD or by adding more layers. In a double-layered DVD there are two layers of information. The top information layer is below a semi-reflective coating and the bottom layer is affixed to a fully reflective coating. The two layers are separated by a transparent coating.

The newest technology in improving storage capacity is the Blu-ray disc. This optical disc uses a blue laser (actually blue-voilet) which has smaller wavelength that allows for a much smaller track pitch size and average pit length. These features allow more data to be compacted into the same space. Links to further information on CDs and DVDs can be found in the Resource section. You may want to explore the NNCI lesson *CDs and DVDs as Diffraction Gratings* found at: https://www.nnci.net/node/5375.

When viewing the discs with the AFM, the groves/pits appear darker than the lands/flats. The pits on a disc are sometimes called bumps because they appear as depressions or pits on the aluminum side, but on the side the laser reads they are bumps. The AFM will provide you with 3-D images so that you can observe the individual pits and lands.

References:

1. Atomic Force Microscope diagram. https://commons.wikimedia.org/wiki/File:Atomic_force_microscope_block_diagram.svg
2. AFM cantilever. https://en.wikipedia.org/wiki/File:AFM_(used)_cantilever_in_Scanning_Electron_Microscope,_magnification_1000x.JPG

Materials:

- Access to an Atomic Force microscope via RAIN http://nano4me.org/remoteaccess). You could also check with a local university to see if they offer educators free access to an AFM.
- Samples of CD, DVD and Blu-ray discs. The remote access provider will inform you of the size of the material needed for analysis. Parents or friends may have damaged versions that they would be willing to donate.

Safety Information: There are no safety concerns for this lesson.

Advance Preparation: Schedule a time to use one of the AFMs on RAIN. Ensure that the materials to be scanned are sent to the RAIN site in advance. The instructor should review the function of the AFM with students at least a day before the activity. In addition to the RAIN videos, additional explanations regarding AFMs are listed in Additional Resources section In addition, there are numerous videos on YouTube that offer explanations on the operating principles. Students could view these during class time or assign viewing as homework.

Suggested Teaching Strategies or Troubleshooting Tips: Coordination with the RAIN site is very important. Prior your RAIN session, watch the remote access videos at: http://nano4me.org/remoteaccess. It is recommended to do a test run to ensure that the

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remote software works at your school. **Make sure that the magnification is the same for each of the scans.**

Directions for the Activity:

Part I. Pre-activity questions

1. CD vs DVD Ask students if they have ever wondered or know why a CD and DVD look identical, but have different capacities, functions, and players? Have them make sense of this phenomenon by developing explanations. Much of the differences are the capacities of the two types of discs. Have the students brainstorm on comparing and contrasting a CD and DVD and develop at least 3 examples for each.

<u>Example answers:</u>

> Similarities: - same size, both can store data, use lasers to read the information on the disc, both are optical storage devices, made of similar materials, low cost.
>
> Differences - DVD has greater storage capacity: it holds almost 7 times more data than a CD (CD capacity is 700MB; DVD capacity is 4.7GB), a DVD player can play a CD but a CD player cannot play a DVD, DVD has better optical resolution, DVD uses digital optical disc data storage.

2. DVD vs Blu-ray Ask if students think that all DVD discs are created equal. DVDs and Blu-ray discs have the same function, but Blu-ray discs do not play in normal DVD players and also have superior video quality compared to DVDs. Have the students brainstorm on comparing and contrasting DVD and Blu-ray discs and develop at least 3 examples for each.

<u>Example answers:</u>

> Similarities: both are optical discs, both store data, both appear similar in appearance, both are commonly used for videos and games.
>
> Differences: Blu-ray discs are more expensive, DVD players cannot be used to play Blu-ray discs, Blu-ray disc can store more information than a DVD (25GB for a single layer or 50 GB for a dual layer Blu-ray), DVD uses red laser to read data while Blu-ray uses blue laser.

Part 2. Using the AFM

The AFM scans will allow the determination of any difference between a CD, DVD, and Blu-ray discs.

1. Scan your CD and DVD pieces at the same magnification and ask the AFM operator to save each image to send to the class. In general, sketch the image for each and label the lands/flats (mounds) and pits/groves (spaces). Remember that the groves/pits appear darker than the lands/flats. You can either determine the number of pits while viewing the materials during the scan or you can wait until you receive the images from the RAIN site. Students should also measure the size of the pits and lands to compare to the standard measurements reported for each disc.

The very small dimensions of the pits/bumps make the spiral track on a CD extremely long. If you could lift the data track off a CD and stretch it out into a straight line, it would be 0.5

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microns wide and 5 km long (4.3 miles). Each pit is 850nm to 3.5µm (3500nm) long, 0.5 mm (500nm) wide and 100nm deep. The track spacing is 1.6µm (1600nm).

DVD tracks consist of pits that are 400nm long, 320nm wide, and 120nm deep. If the DVD's data were stretched out into a straight line, it would measure 12km (7.5 miles) in length. The track spacing is 740nm.

2. Examine the Blu-ray with the AFM and compare to the DVD image. Determine the number of pits during the scan or wait until you receive the images from the RAIN site. Students should also measure the size of the pits and lands to compare to the standard measurements reported for the Blu-ray disc.

Blu-ray discs have pits that are 150nm in length, 130nm wide and 320nm deep. The smaller the pit size the higher the resolution. If the Blu-ray data could be stretched out it would be 64km (39.8 miles) in length.

A final discussion would be to ask the students what they think the lands and pits represent and how the laser interacts with these. The lands and pits are the 1's and 0's of binary computing (lands = 1; pits=0) which forms the basis of encoding data.

Assessment:
Assessment will be dependent upon the approach used in this activity whether class based or group work. If you assign the answers and measurements to individuals or groups then a simple assessment of correct answers will suffice such as determination of the number of pits and approximate size. Further evidence of understanding would be a discussion of resolution quality as a result of pit size.

Additional Resources:
How an AFM works:
http://virtual.itg.uiuc.edu/training/AFM_tutorial/ and
https://www.wecanfigurethisout.org/VL/easyScan_AFM.htm.
https://www.youtube.com/watch?v=0jP7baCqFLw
https://www.nanosurf.com/en/how-afm-works/afm-operating-principle
https://pubweb.eng.utah.edu/~lzang/images/Lecture_10_AFM.pdf
http://www.nanoscience.gatech.edu/zlwang/research/afm.html
https://www.parksystems.com/index.php/medias/nano-academy/how-afm-works
https://en.wikipedia.org/wiki/Atomic_force_microscopy
CD, DVD, and Blu-ray discs: https://wiki.metropolia.fi/display/Physics/CD%2C+DVD+and+Blu-ray+Disc
How Stuff Works: CD - https://electronics.howstuffworks.com/cd.htm;
DVD - https://electronics.howstuffworks.com/dvd.htm;
Blu-ray - https://electronics.howstuffworks.com/blu-ray.htm.

Standards:
- Waves and Electromagnetic Radiation

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- PS4.B Electromagnetic radiation
    a. Crosscutting Concepts: Structure and function
    b. Connection of Engineering: Influence of Science, Engineering, and Technology on Society and the natural world.
- Structure and Properties of Matter
    a. Crosscutting Concepts: Structure and function and Cause ad effect

Optional Activity: You could also have a class discussion or have students research the types of lasers used by each disc and the differences of these lasers in terms of wavelength and resolution. It would be a good way for them to look at the visible light spectrum and develop an understanding of practical applications in current technology.

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