Teacher's Preparatory Guide

CDs and DVDs as Diffraction Gratings

Purpose

The objective of this lab is to observe the diffraction behavior of light waves between a CD and DVD. Using commercial electronic storage devices like CDs and DVDs as gratings rather than commercially produced plan transmission gratings enhances student interest in the activity and also opens up a discussion on the trend of improving storage capacity with the invention of Blu-ray and layered DVDs. By conducting this experiment the students should be able to calculate the spacing distance between tracks of a CD and DVD. This lab also incorporates nanotechnology by including AFM (Atomic Force Microscope) images of a CD and DVD for the students to compare with their macro-scale data.
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Time required: Two 45 minute periods

Level: High School Physics

Teacher Background

Interesting information on CDs and DVDs

CDs and DVDs have pits or grooves that spiral from the inner edge of the disc to the outer edge. These tracks are basically used to codify the information recorded on a disc. The spacing between tracks, width of tracks, their depth and reflectance vary according to the type of disc.
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 for a DVD allowing it 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.

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, which is also used for HD recording, is the Blu-ray DVD. This uses a blue laser of a much smaller wavelength which allows for a much smaller track pitch size and average pit length thus allowing more data to be compacted in the same space. Information on CDs and DVDs can be found at: http://electronics.howstuffworks.com/cd.htm and

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http//electronics.howstuffworks.com/dvd2.htm

CDs and DVDs as DIFFRACTION GRATINGS

CDs and DVDs show a display of colors when white light falls on them. This is due to the digital information (alternating pits and smooth reflecting surfaces) on the discs forming closely spaced rows acting like a reflecting diffraction grating. These rows are spaced 1.6 micrometers from one another on a CD and 0.74 micrometers on a DVD. These rows do not reflect nearly as much light as the portions of the disc that separate them. In these portions the light reflected undergoes constructive interference in certain directions. Therefore, when white light is reflected from the disc each wavelength of light can be seen at a particular angle with respect to the disc's surface producing a light spectra.

CDs and DVDs have a protective polycarbonate coating which does not interfere in the reflective diffraction grating, but to create a transmission grating the metal layer must be removed and the physical diffraction grating retrieved. This is a crucial step if Atomic Force Microscope (AFM) images are to be produced (See AFM below). DVDs are usually two layered which are fairly easy to separate. CDs are one layer and cannot be separated so other techniques must be applied. (See ADVANCED PREPARATIONS)

To listen to a CD, the laser light in the CD player is reflected consecutively from the thread of binary bits etched on the disc (alternating pits and smooth, reflecting surfaces).When the light reflects from the smooth surface it reaches the detector. However, when the light reflects from the pits it is out of phase and the intensity of the beam hitting the sensor is less (the depth for the pits is roughly about one quarter of the wavelength of the laser). Any change in the intensity of the reflected beam as it transitions from a pit to land or land to pit is converted to an electrical signal and coded as a binary 1. Electronic circuits connected to the detector translate the binary data into an electrical signal. The signal is then amplified and results in a reconstruction of the original recorded sample. A DVD player works on the same principle, but uses a smaller wavelength laser and therefore can detect information that is coded in much smaller pits and smooth, reflecting surfaces. DVDs can hold more than seven times as much data as a CD.

THE IMPORTANCE OF NANOTECHNOLOGY

Nanotechnology, in the most basic sense, is the development of usable systems at the molecular level. It does not belong to one discipline, but encompasses all of science, technology, and engineering. More and more research is being done on this level and improvements and new discoveries have been made in electronics, pharmaceuticals, textiles, etc. This will lead to more jobs in the future that will need to be filled by the students being taught in schools today. It is also important to give students a sense of perspective and to acknowledge responsible research and use of nanotechnology. Our knowledge is very limited on how nano-scaled materials affect living organisms. It is important to encourage students to move forward and to get excited about the new advances in science and engineering, but not let them travel blindly through the future.

CDs are made using processes of the semiconductor industry which has seen a dramatic reduction in the size of electronics and is now working with materials in the nanoscale range. DVDs are an example of the miniaturization of devices in terms of smaller (smaller track pitch and pit length) which leads to

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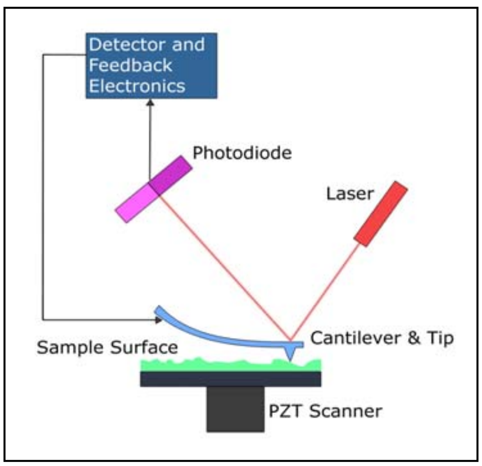
greater data storage. Blue Rays are a further extension of this as they use blue light (rays) with a wavelength of 405nm which allows even more data storage.

ATOMIC FORCE MICROSCOPES

Atomic Force Microscopes (AFMs) are devices that are able to measure the surface topography of a sample on a nanometer/micrometer scale and turn those measurements into an image of the sample. On this scale optical microscopes are out of the question because the light waves are larger than the nanoparticles themselves. There are other types of microscopes that are able to "view" at nano-levels, but an advantage of AFMs is that they do not require the sample to be in a vacuum, so biological specimens can be investigated. Another advantage is since there is no electron transport involved in the AFM method insulated samples can also be seen.

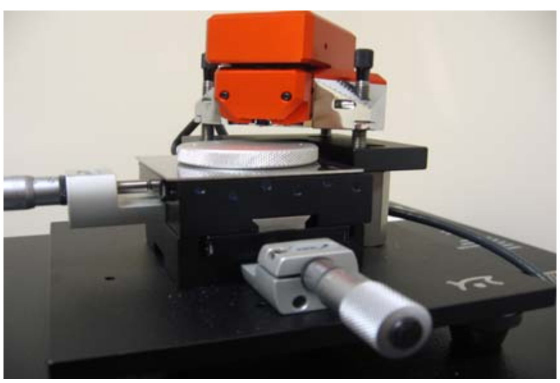
The basic principle behind how the AFM works is based on the interaction between a probe (a sharp tip attached to a cantilever) and the atomic surface of the sample. The forces on the tip can be attractive or repulsive and cause the tip to deflect due to a change in these forces. The deflection is detected by the reflection of a laser beam shone on the reflective, back surface of the cantilever. There are two main modes for the AFM: contact mode and tapping mode. In contact mode the tip is dragged across the surface, whereas in tapping mode (oscillating mode) the tip is oscillated on a vertical axis as it scans the sample. The benefit to this mode is that there is usually less damage to the surface and to the tip due to the weaker force interactions during contact.



http://wills-nanotech.blogspot.com/2006_04_01_archive.html

Fig. 5

Fig. 6a and 6b: Nanosurf easyScan AFM



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Materials

- CDs
- DVDs
- Laser source
- White screen (or wall)
- Tape (clear packing works best)
- Metric rulers and meter sticks
- Clamps
- Stands
- Razor blades
- Tweezers
- AFM images of a CD and DVD gratings (provided)
- Optional
    - AFM software (Scion) to read images
    - AFM unit to scan and read images

ADVANCED PREPARATIONS

RETRIEVAL OF PHYSICAL DIFFRACTION GRATINGS FROM CDs AND DVDs
(Pictures included in the Student Worksheet with answer guide below)
DVDs

1) Identify the two layers and take a razor blade and carefully slice between them. They should separate fairly easily.
2) Discard the protective polycarbonate coating.
3) Take large pieces of tape (packing tape works well) and gently press the tape onto the reflective surface and then rip the tape off. Continue this until the majority of the metal coating is removed. (Sometimes small pieces of metal are difficult to remove – this is not a problem just use a portion that is clear for the large scale experiment or for imaging purposes).

CDs

1) A unpainted CD is required (CD-R's and CD-RW's work well)
2) Take large pieces of tape (packing tape works well) and gently press the tape onto the top surface (the side that can be written on) and then rip the tape off. Continue this until the majority of the metal coating is removed. (There are two layers of metal – the top layer is the one that can be written on, the lower layer is the reflective layer – both must be removed).

SAFETY INFORMATION

LASERS

Most lasers used in high school laboratories are the continuous wave, low power (0.5 - 3.0 mW.) lasers. The main danger is possible damage to the retina if a student looks directly into the beam or non-diffused reflection. Remind the students of this and direct them to be very careful when using the lasers.

RAZOR BLADES

The blades are quite sharp and could cut or puncture a student. The teacher may want to handle the process of opening the DVDs prior to the student's lab.

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DIRECTIONS FOR THE ACTIVITY

1) Discuss interference, diffraction, and diffraction gratings.
2) Demonstrate diffraction with different types of gratings.
3) Divide the class into groups of two to three students.
4) Review the general procedures of the lab and remind the students about the safety concerns when using lasers.
5) After the data is collected from the CD and DVD gratings, discuss the size of these gratings and how small a distance the grooves are from one another. Ask the students if they are able to measure the grooves with a ruler or able to see them under an optical microscope (if an optical microscope is available demonstrate this for the class).
6) Explain to the students that objects on the micro and nanoscale must have special equipment to be viewed. Discuss the basic concept of the AFM (make sure the students understand that the images that they see are not photographs but digital interpretations of the topography of the object).
7) Depending on time and equipment restraints there are three options for the second part of the lab:
    a) If the use of an AFM is possible, actually make new samples of the CD and DVD for imaging. Then perform the calculations to determine the distance between tracks and compare to the other data obtained. (This activity was developed using the Nanosurf® easyScan 2 AFM System by NanoScience)
    b) If the use of imaging software is available download the images (from the NNIN website) provided to evaluate. Then perform the calculations to determine the distance between tracks and compare to the other data obtained. Directions in the appendix details use of the Scion software http://www.scioncorp.com/.
    c) If options a and b are not possible, take the hard copies of the images provided and use a metric ruler to measure the distance between tracks. Then perform the calculations to determine the distance between tracks and compare to the other data obtained.

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