Student Worksheet (Answer Guide)

CD and DVD as Diffraction Gratings

Materials

- CD(750MB,) DVD-R(4.7gB)
- Quickstick or any other packaging tape
- Meter stick
- Razor
- Tweezers
- Laser pointer
- Stand with clamps
- AFM system and/or Scion software (optional)

Caution

Do not direct the laser pointer into the eye

Use it at less than eye level so that the reflected beams are not directed into the eye

Introduction

Read the theory of diffraction gratings before you begin the experiment. CD s and DVD s can act as diffraction gratings because of the way they are made; they have grooves or spacings ranging in micrometers called tracks in which the information can be recorded. These spiral grooves in a CD act like a diffraction grating causing the colors you see when you look at a CD.

Prediction

Knowing what you know about CD and DVD make a prediction on which of the two will have the least track spacing? How do you know that? ______________________________

A DVD has much more capacity than a CD; it is partially due to the fact that the track spacing in a DVD is only about 0.740 µm while the track spacing in a CD is about 1.6 µm. This translates to about 1350 tracks per mm for a DVD and about 625 tracks per mm for a CD; this gives the DVD a two-fold gain in capacity as compared to a CD. This two-fold gain yields a seven time increase in memory capability.

Conduct an Experiment

Developed by Rama Balachandran and Karen Porter-Davis
Development and distribution partially funded by the National Science Foundation

NNIN Document: NNIN-1194
Rev: 02/2010

Purpose:

To determine the track spacing of a CD and DVD by using them as diffraction gratings.
To verify the results by analyzing the AFM images of a standard CD and DVD that have been provided.

Experimental Setup:

Step 1: To prepare CDs and DVD s to use as diffraction grating

Obtain a regular CD and DVD from your teacher.

The DVD has two polycarbonate layers which can be easily separated. Use tweezers or a knife edge to split the two layers along a portion of the edge and you can easily get the two layers apart. Discard the top polycarbonate layer. Use a piece of tape to rip off the reflective coating from the other layer and you have a clear transparent transmission diffraction grating.

A CD however has only one polycarbonate piece of plastic on which the different layers are deposited. Use the label side of the CD and use a piece of tape to rip off the protective coating and the reflecting layer. If it does not peel, off use a sharp tool to scratch off a small portion on the edge of the CD and then peel off the rest of the layer using the adhesive tape. The clear plastic can serve as a transmission grating.

Pictures

DVD

Clockwise from top left

1. Split along the edge
2. Separate into 2 layers
3. Peel off the reflecting layer with tape
4. transmission grating

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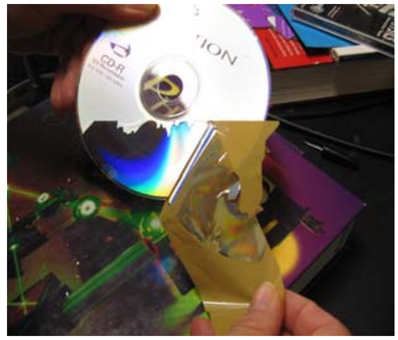
CD

Scratch the label surface



Peel off the label and reflecting layer

Transmission grating

Step 2: Diffraction pattern using the CD

Obtain a laser and fix it to a stand such that the laser is held horizontally and securely using a clamp. See picture below of experimental set up.

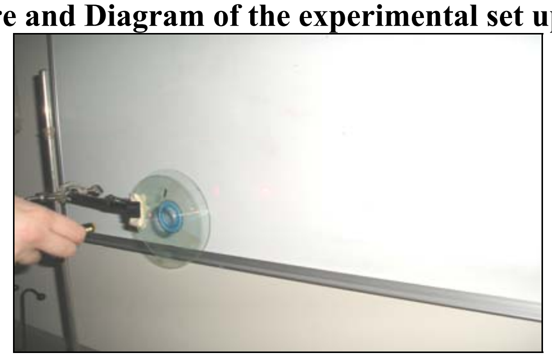
Use another stand to position the CD in front of the laser such that the light from the laser is incident normally on the CD. Place the CD as close to the laser as possible.

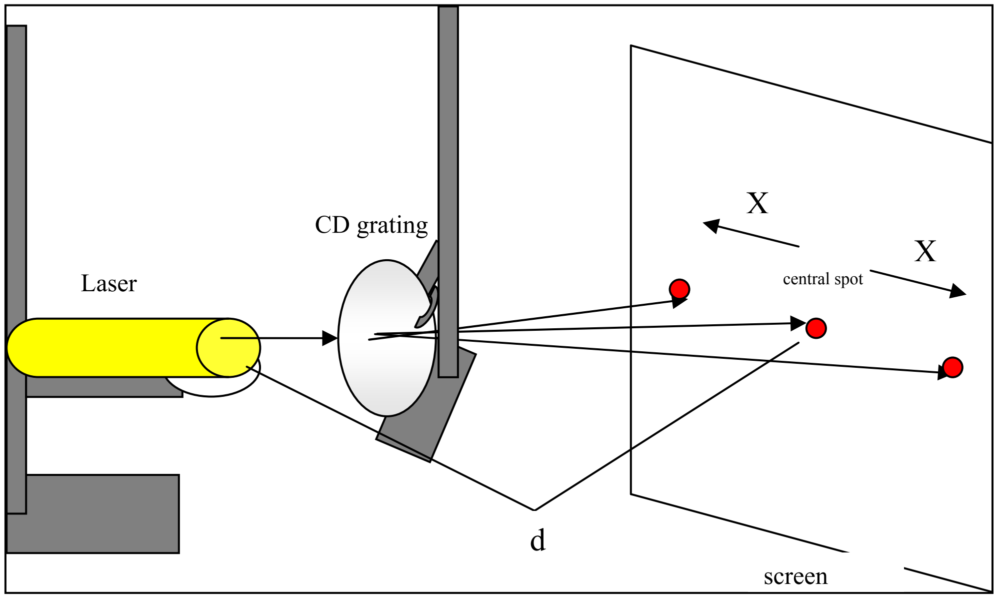
Use a blank wall or a white board as your screen so that the diffraction pattern can be observed clearly. It is preferable that the room be dark so that it is easy to observe the diffraction pattern. The laser should be positioned about a meter (or less) away from the screen.

Switch on the laser and look for the central non-diffracted beam spot on the screen. The first order maxima should be visible on either side of the central spot. The second and third order can also be observed but may not be as bright as the first order image. If the images are not on a horizontal to the screen, rotate the CD and change its orientation until you get the images on a horizontal line.

> Note that the tracks are spiral in a CD or DVD and so the spacings are not exactly parallel. The treatment for a plane transmission grating can be applied to a CD or DVD grating to a good approximation. This is also why the first and second order images may not be exact spot images of the laser beam.

Picture and Diagram of the experimental set up





Step 3: Measurement and Analysis

Measure the distance of the first order maxima from the central spot on either side and calculate its average. (X) Sample measurements are shown on the following data tables.

Measure the distance of the laser to the screen. (D)

Use the label on the laser to identify the wavelength of the laser beam that is used
Use the diffraction equation for the first order image and calculate the grating spacing;
Repeat the above procedure for the second and third order images if they are clearly visible.

Determine the average track spacing (**pitch**) of the CD grating.

Since the angle of diffraction for the first order is not really small (about 22 °), the approximation that $\sin\theta = \tan\theta$ is not valid. Evaluate $\tan\theta$ using the equation given in Step 3; if the first order image is too spread out on the screen on either side try reducing the distance of the screen to the laser setup.

Step 4: Track Pitch of the DVD

Repeat the same procedure for a DVD. With the DVD, it may be difficult to observe the second and the third order images; it is also advisable to move the laser arrangement much closer to the screen so that the first order image is closer to the central non-diffracted spot. Calculate track pitch using the same procedure in Step 3.
X = distance from maximum on screen
D = distance from grating to screen
λ_{laser} = wavelength of laser
$\theta_{diffraction}$ = calculated angle of diffraction
d = grating separation (average track spacing)

Equation 1: $d(\sin\theta) = m\lambda \qquad m = 0, \pm1, \pm2, \ldots$

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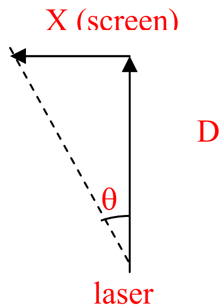
To find θ measure distance from grating to screen and the first order distance and then by using trigonometry calculate the angle.



Equation 2: $\theta = \tan^{-1}(X/D)$

Example

Data Table 1: CD

Order	X_{left}	X_{right}	X_{avg}	D	λ_{laser}	$\theta_{diffraction}$	d
m_1	0.149 m	0.13 m	0.14 m	0.295 m	650 nm	25.3 °	1.52 µm
m_2							
m_3							

Average d = 1.52 µm

Data Table 2: DVD

Order	X_{left}	X_{right}	X_{avg}	D	λ_{laser}	$\theta_{diffraction}$	d
m_1	0.34m	0.51m	0.425 m	0.20 m	650nm	64.8°	0.72 µm
m_2							
m_3							

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Average d = 0.72 µm

Track spacing of a CD is about 1.52 micrometer
Track spacing of a DVD is about 0.72 micrometer

Standard spacing of a CD is 1.6 µm.
Standard spacing of a DVD is 0.74 µm.

Step 5: Analysis of AFM Images of sample CD and DVD.
The figures 1a and 2a (on the following pages) show the AFM images of a blank CD and DVD respectively ; Figures 2a and 2b show the line scan details of the same along a cut section of the image . Measure the horizontal dimension of the image and use it to identify the scale factor (i.e., 1 cm = ? micrometer).

The AFM image is color coded to represent the depth of the different points and the color code is indicated on the bar on the right hand side.

Notice that the grooves or pits will appear darker than the lands or the flat surfaces.

Identify the tracks on the CD by using the color code; Measure the perpendicular distance between any two tracks in cm using a metric ruler; **(Note that the grating element is the combined width of the opaque and transparent lines in a regular grating; so measure the distance between tracks as including the width of the track – See arrow in scan)**
Use the scale factor to convert the measurement in micrometer. Repeat this measurement at different points on the image to get an average value of the same. This average measures the average track pitch of a CD.

Repeat the same procedure to measure the average track pitch of a DVD.

The line scans show the graphs of the z value plotted against the horizontal position of the point being scanned. This image is for a single line scan. The points with the lowest z value correspond to the grooves or tracks and the average distance between two tracks can be calculated from the line scan too. Use your values to verify the results obtained earlier from the diffraction pattern experiment.

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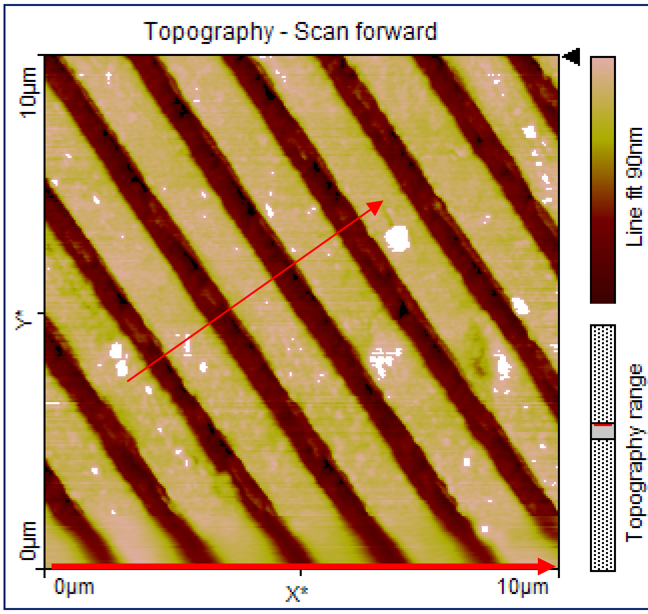
NNIN Document: NNIN-1194

Rev: 02/2010



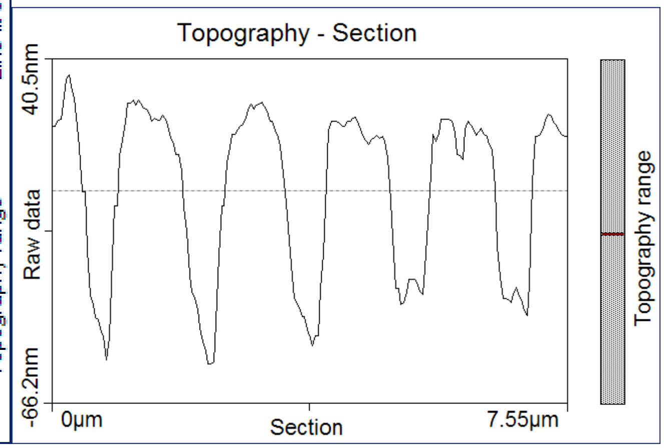


Fig1a. AFM image : Sample : Memorex CD 750 MB; blank; scan size 10 micrometer

1b. Line scan of the image

Calculations for the CD image:
Scale factor: 7.2 cm = 10 micrometers; 1 cm = 1.39 micrometers
4 x track pitch = 4.4 cm = 6.12 micrometers
track pitch = 1.53 micrometers
(Note that the grating element is the combined width of the opaque and transparent lines in a regular grating; so measure the distance between tracks as including the width of the track – See arrow in scan)

AFM average track pitch of a CD: 1.53 micrometers

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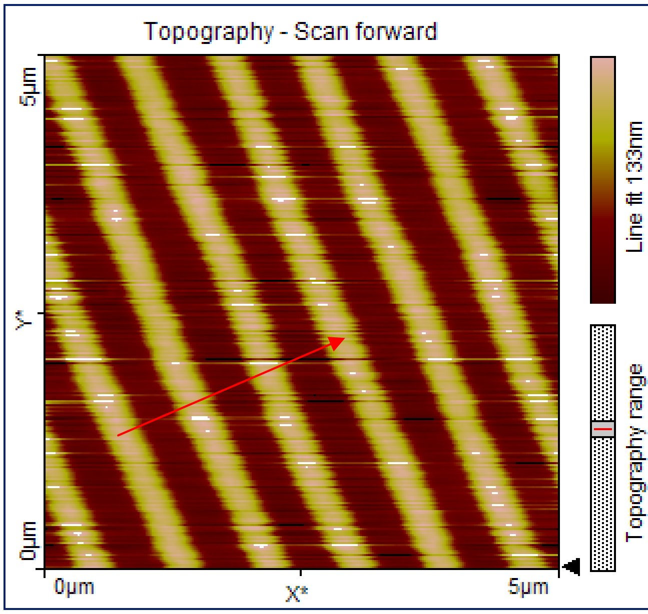

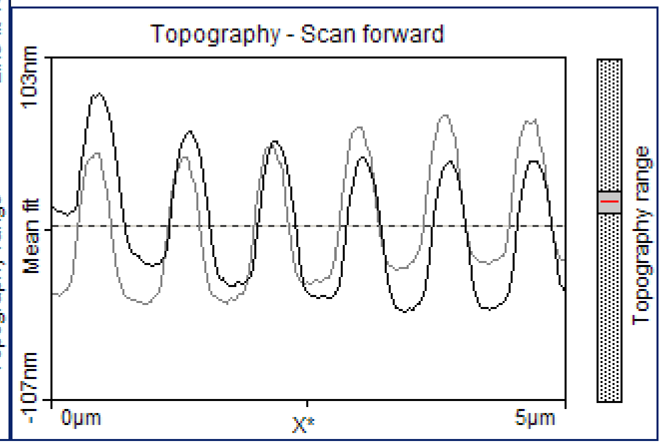

2a. AFM image Sample : Sony DVD-R 4.7 GB; Blank, scan size 5.0 micrometer

Fig 2b- Line scan of the sample

Calculations for the DVD image :
Scale factor: 7.2 cm = 5 micrometers; 1 cm = 0.694 micrometer
3x track pitch = 3.4 cm = 2.36 micrometers
track pitch = 1.13 cm = 0.787 micrometer

AFM average track pitch of a DVD: 0.79 micrometer

Analyze the Results

1. **Explain why the CD or the DVD acts like a transmission grating?**
   The CDs and DVDs have spiral grooves cut on the disk space running from the inner edge to the outer edge. There is also a reflective metal coating on top of this groove pattern. The combination of the two makes the CD or DVD a reflective grating. When white light falls on a CD, constructive interference takes place between the reflected beams and this happens at different angles for different wavelengths and so the colors of the spectrum become visible.

2. **Is the CD grating any different from the plane transmission grating you use to study the spectrum of different elements? If so, in what ways is it different?**

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The spacing between lines in a CD is usually in the order of 1.6 micrometers and commercial transmission gratings have spacings in the order of about 4.5 micrometers. The lines of a plane transmission grating are parallel, while the tracks of a CD are not exactly parallel in a given region because they are actually spiraling outward from the center.

3. **How did the experimental result agree with your prediction?**
   The track spacing of a DVD is about one half of that of a CD. The students should be able to confirm this both from the AFM images and the diffraction experiment.

4. **How did the experimental results agree with your calculated values of the track spacing from the AFM pictures of the sample CD and DVD?**
   Answers vary depending on the experimental results. There should not be any difficulty getting good agreement between the two values and the error is usually under 10 %.

Draw Conclusions

5. **A DVD can store 7 times as much data as a CD. Given the results of your experiment about the track pitch on a CD and DVD , is the above statement justified ? If not, what other factors should be considered to explain why a DVD has 7 times more capacity than a CD.**
   The track pitch of a DVD is half as that of a CD making twice as many tracks possible on a DVD relative to a CD and this gives it a 2x gain in capacity.
   Additional to this, the average pit length of a DVD is half as that of a CD giving it twice as much storage capacity and the use of less sector overhead for error correction on a DVD frees up more space for data.

6. **What physical limitations arise in trying to reduce the track pitch to even smaller values for increasing the capacity? How else can the capacity be improved?**
   The size of the pit cannot be smaller than the wavelength of the laser beam itself; Blu-ray DVDs therefore operate with blue light with a wavelength of 405 nm which means more information can be compacted into the same storage space as a regular DVD.

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Cleanup

Have students separate the DVDs and CDs so they can be used again.

Have students return all materials used in the experiment reminding them to be cautious with the lasers and razor blades.

Have students check around their area to make sure they have not left any equipment, supplies, or trash.

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Assessment

Answer the analysis and conclusion sections. The optional section may also be assessed.

Resources

To learn more about nanotechnology and this lab, here are some web sites with educational resources:

How CDs work: http://electronics.howstuffworks.com/cd.htm
How DVDs work: http://electronics.howstuffworks.com/dvd.htm
How Nanotechnology works: http://science.howstuffworks.com/nanotechnology1.htm
Integrating Nanotechnology into the classroom: http://www.bowlesphysics.com/nano/
Nanotech Education Programs: http://www.nanotech.ucsb.edu/NanotechNew/highschool.html
AFM: http://stm2.nrl.navy.mil/how-afm/how-afm.html
AFM: http://virlab.virginia.edu/VL/easyScan_AFM.htm
NNIN: http://www.education.nnin.org
Georgia Tech: http://www.mirc.gatech.edu/education.php

National Science Education Standards

Science and Technology

- Understandings about science and technology

Abilities Necessary to do Scientific Inquiry

- Design and Conduct Scientific Investigations
- Use Technology and Mathematics to Improve Investigations and Communications

Interactions of Energy and Matter

- Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

Georgia Performance Standards

SCSh1. Students will evaluate the importance of curiosity, honesty, openness, and skepticism in science.

a. Exhibit the above traits in their own scientific activities.
b. Recognize that different explanations often can be given for the same evidence.
c. Explain that further understanding of scientific problems relies on the design and execution of new experiments which may reinforce or weaken opposing explanations.

SCSh2. Students will use standard safety practices for all classroom laboratory and field investigations.

a. Follow correct procedures for use of scientific apparatus.
b. Demonstrate appropriate technique in all laboratory situations.
c. Follow correct protocol for identifying and reporting safety problems and violations.

SCSh3. Students will identify and investigate problems scientifically.

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a. Suggest reasonable hypotheses for identified problems.
b. Develop procedures for solving scientific problems.
c. Collect, organize and record appropriate data.
d. Graphically compare and analyze data points and/or summary statistics.
e. Develop reasonable conclusions based on data collected.
f. Evaluate whether conclusions are reasonable by reviewing the process and checking against other available information.

SCSh4. Students will use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.

a. Develop and use systematic procedures for recording and organizing information.
b. Use technology to produce tables and graphs.
c. Use technology to develop, test, and revise experimental or mathematical models.

SCSh5. Students will demonstrate the computation and estimation skills necessary for analyzing data and developing reasonable scientific explanations.

a. Trace the source on any large disparity between estimated and calculated answers to problems.
b. Consider possible effects of measurement errors on calculations.
c. Recognize the relationship between accuracy and precision.
d. Express appropriate numbers of significant figures for calculated data, using scientific notation where appropriate.
e. Solve scientific problems by substituting quantitative values, using dimensional analysis and/or simple algebraic formulas as appropriate.

SCSh6. Students will communicate scientific investigations and information clearly.

a. Write clear, coherent laboratory reports related to scientific investigations.
b. Write clear, coherent accounts of current scientific issues, including possible alternative interpretations of the data
c. Use data as evidence to support scientific arguments and claims in written or oral presentations.
d. Participate in group discussions of scientific investigation and current scientific issues.

SCSh7. Students will analyze how scientific knowledge is developed. Students will recognize that:

a. The universe is a vast single system in which the basic principles are the same everywhere.
b. Universal principles are discovered through observation and experimental verification.
c. From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Major shifts in scientific views typically occur after the observation of a new phenomenon or an insightful interpretation of existing data by an individual or research group.
d. Hypotheses often cause scientists to develop new experiments that produce additional data.
e. Testing, revising, and occasionally rejecting new and old theories never ends.

SCSh8. Students will understand important features of the process of scientific inquiry. Students will apply the following to inquiry learning practices:

a. Scientific investigators control the conditions of their experiments in order to produce valuable data.
b. Scientific researchers are expected to critically assess the quality of data including possible sources of bias in their investigations' hypotheses, observations, data analyses, and interpretations.
c. Scientists use practices such as peer review and publication to reinforce the integrity of scientific activity and reporting.
d. The merit of a new theory is judged by how well scientific data are explained by the new theory.

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e. The ultimate goal of science is to develop an understanding of the natural universe which is free of biases.
f. Science disciplines and traditions differ from one another in what is studied, techniques used, and outcomes sought.

SP4. Students will analyze the properties and applications of waves.

a. Explain the processes that results in the production and energy transfer of electromagnetic waves.
b. Experimentally determine the behavior of waves in various media in terms of reflection, refraction, and diffraction of waves.
c. Explain the relationship between the phenomena of interference and the principle of superposition.

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