

LASER AND ELECTRON DIFFRACTION

Introduction

One of the properties of waves is diffraction, the ability to bend around the edge of an obstacle in their path. If these obstacles are properly spaced then the individual diffracted waves, as they spread, may interact to either reinforce, partially reinforce or cancel each other. If the spacing of obstacles is known then we can predict the directions of the reinforced beams. This is summed up in Bragg's law

$$n\lambda = 2d\sin(\theta)$$

where λ is the wavelength, d is the spacing between the obstacles, θ is the angle of diffraction and n is the order of diffraction and is always an integer. (Its value is 0 in the original direction of the wave.)

Figure 1 illustrates the geometry of diffraction which is represented by Bragg's law. The straight blue lines on the left represent the incident beam while the red lines on the right the diffracted beams radiating from the openings. The arrows indicate the direction of the diffracted rays which are at right angles to the diffracted wave fronts which are in phase. (Figure 2 illustrates the concept of phase and constructive and destructive interference of waves.) The diffraction angle θ is the angle between the original beam direction ($n=0$) and the diffracted ray ($n>0$), λ is the distance between the wave fronts and d is the distance between the slits.

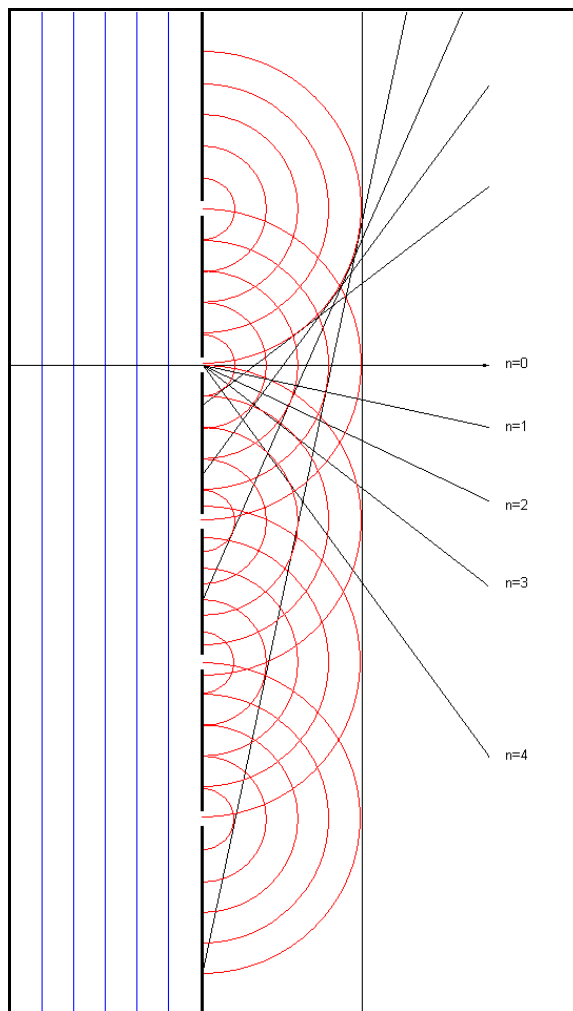


Figure 1 Diffraction through a series of evenly spaced slits.

The uses of diffraction include determining the crystal structure of materials, measuring the coefficient of thermal expansion, residual stress, crystallite size, thickness of and stress in thin films, types and amounts of phases present in a specimen and many other things where the spacing of the obstacles, in this case the atoms, is on the scale of the wavelength of the x-rays, typically 1 to 3 nm. If a longer wavelength is used then one can use diffraction to investigate the structures where the spacing between the obstacles is larger, for instance, in this experiment we use visible laser light ($\lambda=640 - 680 \text{ nm}$) to measure obstacle spacings in the neighborhood of thousandths of an inch. Not only are the spacings measured but also the symmetry of the obstacles is determined.

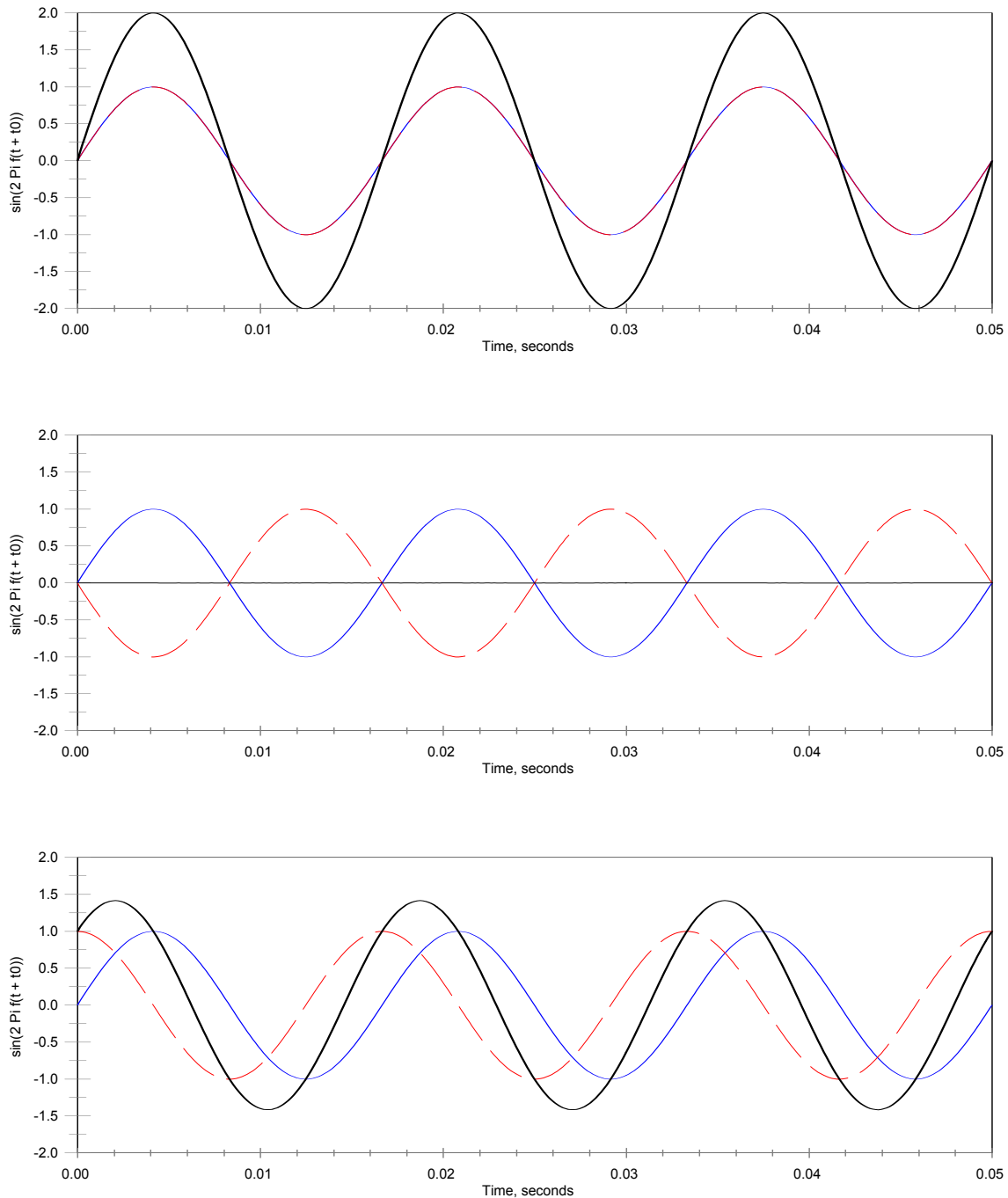


Figure 2 The two 60 Hz (wavelength=1/60 seconds) sine waves (red and blue lines) in these three graphs illustrate the effect of phase on gives rise to constructive (top), destructive (center) and partially constructive (bottom) interference. The sine waves in the top graph are perfectly in phase (the red and blue lines overlap) and their sum is a sine wave (black) having twice the amplitude of the red and blue sine waves. These sine waves reinforce each other. The sine waves in the center graph are $\frac{1}{2}$ -cycle out of phase, the sum (black) of which is equal to zero. These waves completely cancel each other out. The sine waves in the bottom graph are slightly ($\frac{1}{4}$ -cycle) out of phase and they partially reinforce each other.

Procedure

Laser Diffraction: Construct a transmission mode diffractometer similar to the one shown in figure 3. The laser source is a small 0.5 mW “lecture” laser pointer and the fixtures which hold the laser and the specimens can be as simple as a couple of standard laboratory stands with appropriate clamps plus a pair of tweezers to hold the tiny specimens. The surface on which to project the diffraction pattern can be a wall which should be about 3 meters away. An optional lens can be used to project an image of the object.

Project the diffraction pattern of each grid onto a suitable screen (white board, white paper) and mark the locations of the spots. Mark the spot for the center “transmitted” spot with an “X” and note the distance from the specimen to the screen. After recording as many spots as possible repeat this procedure for all other specimens. Using these patterns analyze them to determine the spacing between obstacles. Also, note the symmetry of each spot pattern.

Warning

Do not look directly into the laser (with remaining eye) and be careful of surfaces which may reflect the laser’s beam. While the power of this laser is quite low, less than 5 mW, it can cause eye damage.

Electron Diffraction: To see how diffraction is used to study the crystalline structure of materials perform a similar analysis on the diffraction pattern in figure 4. This diffraction pattern was obtained using a transmission electron microscope (TEM) which, instead of using laser light, uses a tightly focused beam of high-energy (20 kV-300 kV) electrons. Polaroid film records the diffraction pattern, but if an objective lens is used one can also obtain an image of the specimen. In this case, the projection distance was 530 mm and the wavelength was 0.0037 nm and the spots are a result of diffraction involving planes of atoms.

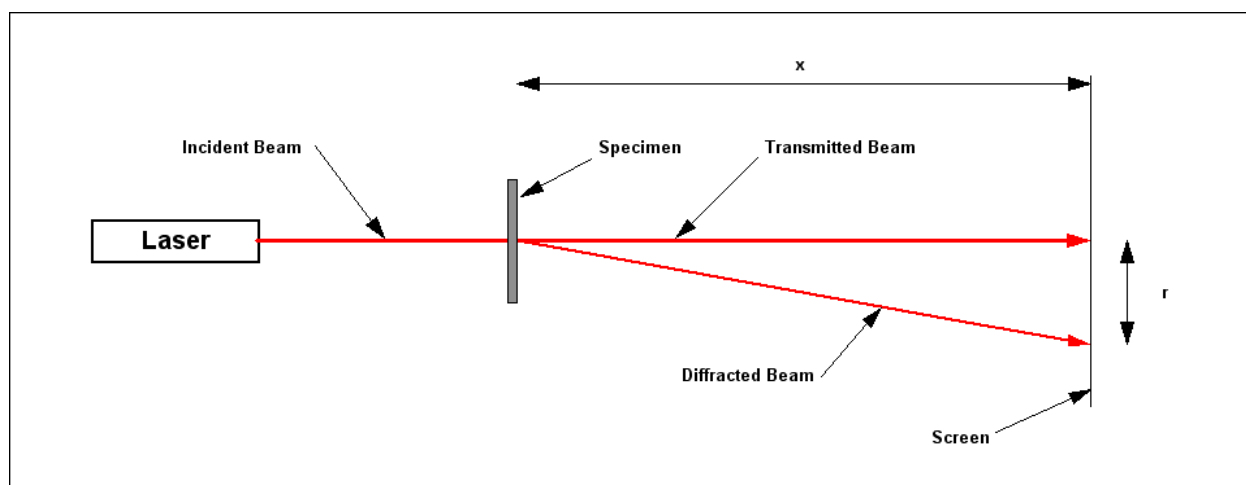


Figure 3 Schematic diagram of the laser diffractometer used in this experiment. The projection distance is x , the distance between the transmitted and diffracted beam spots on the screen is r and the angle between the transmitted and diffracted beams is 2θ .

Results

Laser Diffraction

Wavelength: _____ nm, _____ millimeters

Projection distance: _____ meters, _____ millimeters

Table 1. Results of measurements made on the laser diffraction patterns.

Specimen	Symmetry	Diffraction Spot Spacing (mm)	Diffraction Angle, 2θ (degrees)	Obstacle Spacing (mm)	Grid Mesh Size
Grid #1					
Grid #2					
Grid #3					
Grid #4					
Grid #5					

Electron Diffraction

Wavelength: _____ nm

Projection distance: _____ meters, _____ nm

Symmetry _____

Table 2. Results of measurements made on the electron diffraction pattern.

Specimen	Distance to the Diffraction Spot (mm)	Diffraction Angle, 2θ (degrees)	Interplanar Spacing (mm)
Spot #1			
Spot #2			
Spot #3			
Spot #4			
Spot #5			
Spot #6			
Spot #7			
Spot #8			

Analysis

1. Are all the grids of the same type (symmetry)?
2. What was the highest order of diffraction in each pattern?
3. The mesh size of a grid is given in “holes” per square inch. What is the mesh size for each of the grids examined?
4. Did you notice differences in the diffraction patterns for the copper and nickel grids which had the same mesh size and symmetry?
5. How would the diffraction patterns be different if the grids had been stretched in the horizontal direction? Vertical direction?
6. What is the symmetry and the interplanar spacings for the TEM diffraction pattern in figure 4? Compare the interplanar spacings you measured to typical interatomic distances listed in the periodic table.
7. The wavelength of the x-ray widely used in crystallography is 0.15406 nm. Is this wavelength small enough to get diffraction from an array of atoms (a crystal).
8. An image can be formed by using a lens to collect some or all of the diffracted rays. This implies that each ray contains some of the information about the sample. How would the image change if the high-angle rays were excluded? The low-angle rays? All but one ray?

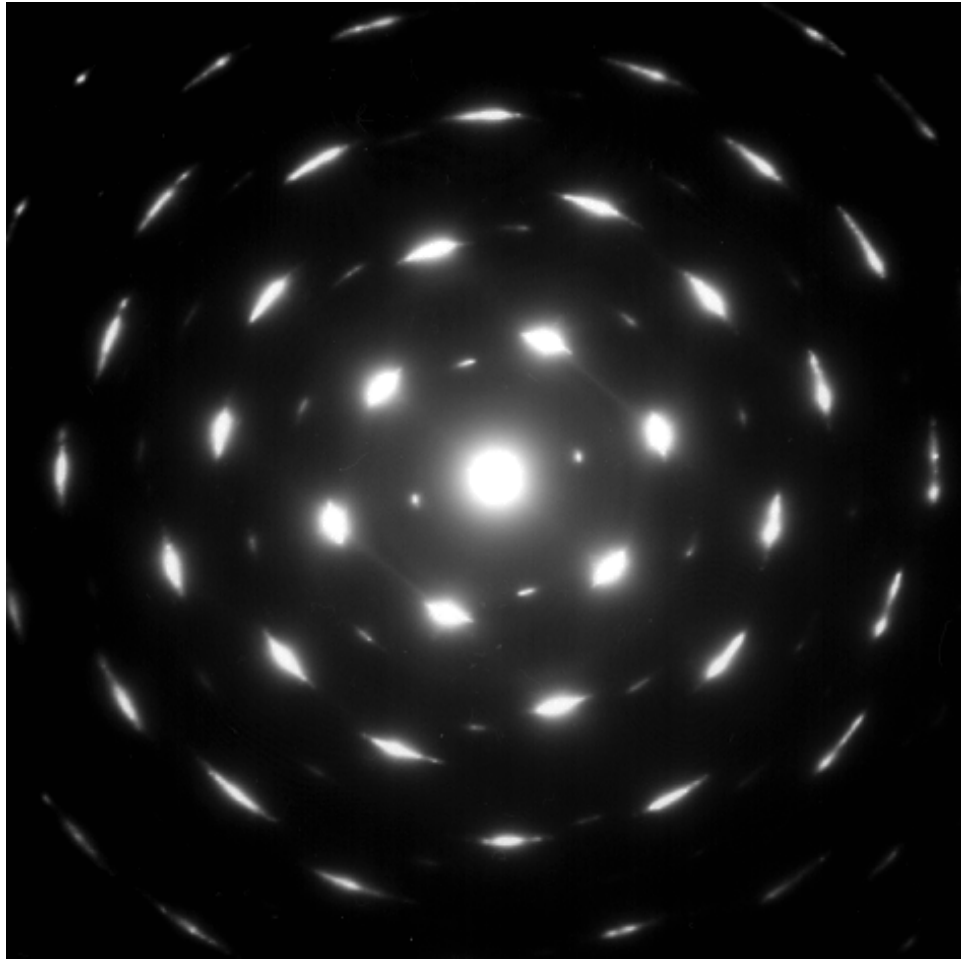


Figure 4 TEM diffraction pattern of nanocrystalline nickel aluminide (Ni₃Al). The streaking of the brighter spots is due to the extreme deformation of this specimen and the fainter set of spots are due to the superlattice aspect of this material's crystal structure. The image shown here has been magnified by a factor of 2.11 over that of the original film image. (Courtesy of Sam McFadden, Ph.D. dissertation, U.C. Davis, 2001)

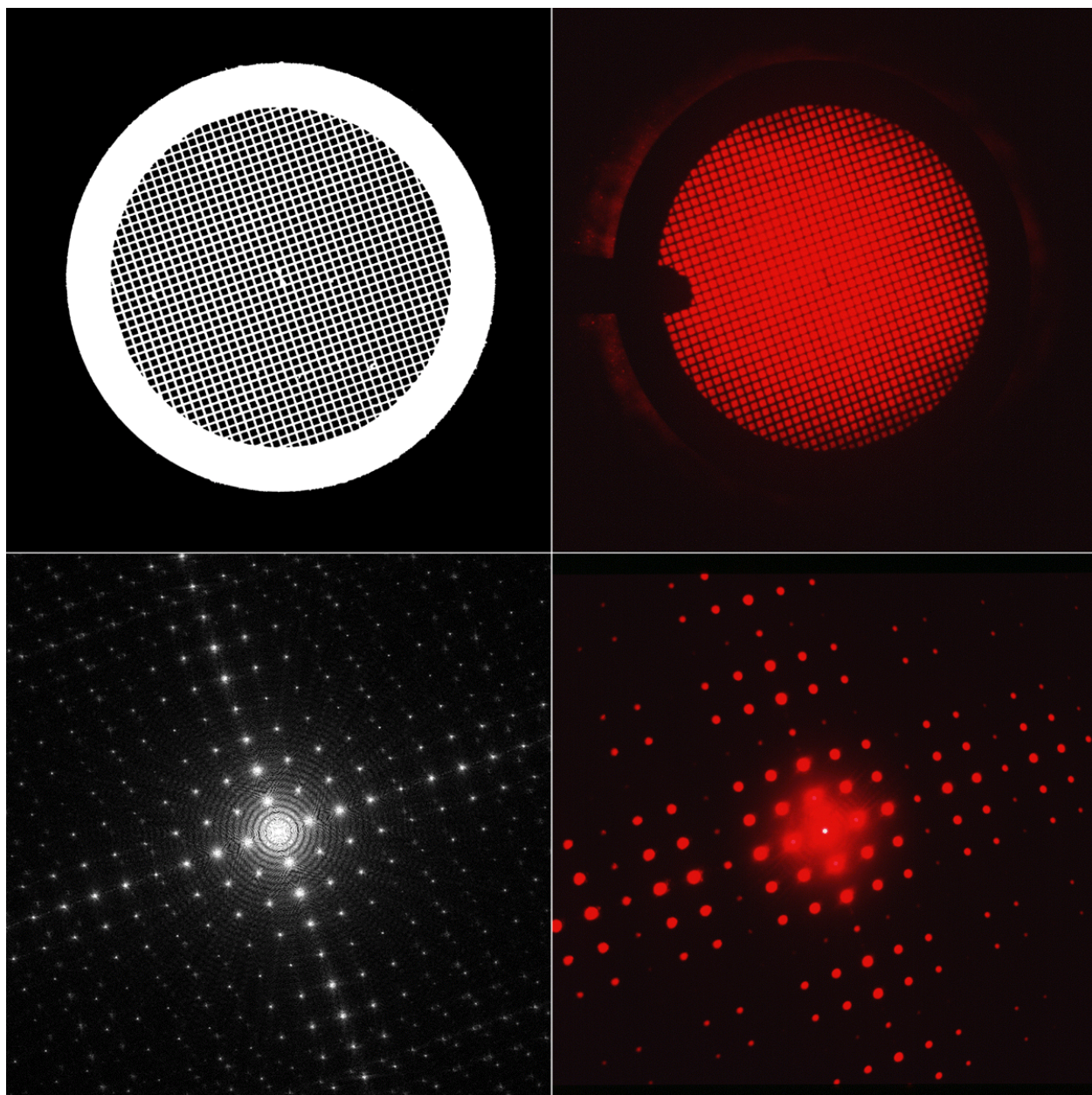


Figure 5 This figure shows results typical of those obtained in this experiment (right) along side an image of the same TEM grid obtained using an optical microscope (top left) and the Fourier transform of this image (bottom left). One can clearly see that the diffraction pattern and the Fourier transform are practically identical. This should tell you something about diffraction patterns.