A Senior Level Lab Demonstrating the Utility of AFM

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Abstract

An experiment for our senior level laboratory course was developed to elucidate the utility of AFM in measuring the 3rd dimension. Using a laser and an interference pattern, students measure groove and bump spacing on a diffraction grating and CD, respectively, then corroborate their results using direct measurements from an AFM. The AFM reveals additional features, such as the blaze angle and bump height which exposes additional information about these devices not discernable from the initial interference pattern.

Optical Diffraction Grating

Students shine laser light onto a diffraction grating and determine the distance between the grooves on the surface by measuring the diffraction pattern. They then image the surface of the grating

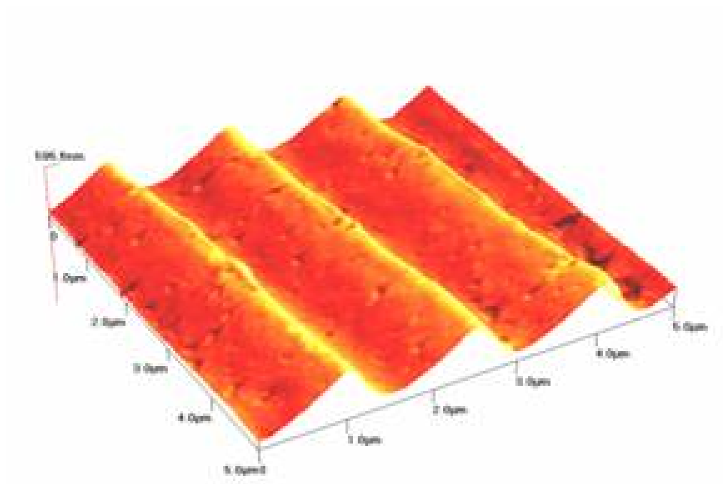

Fig 1. 5 X 5 μm^2 image of a diffraction grating.

directly using an AFM, Fig. 1, revealing an important new feature of the grating, the blaze angle, θ_B, Fig 2.

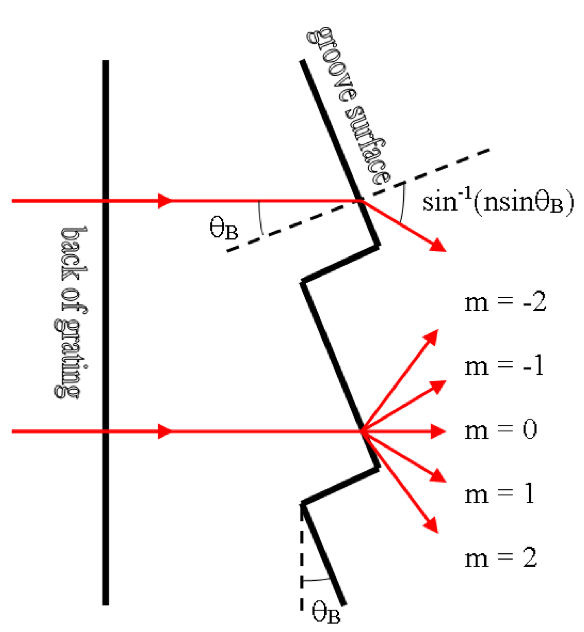

Fig. 2. The lower ray shows transmitted laser light that is diffracted into its maximum intensity peaks (m = 0, $\pm$1, $\pm$2, etc.). Without blazing, most of this light would remain undeflected along the central maximum, m = 0. Instead, with blazing, the upper ray exhibits the refraction of the central to the first order maximum, m = 1, enhancing its intensity.

Using a cross section of the AFM image, students directly measure the blaze angle and calculate the maxima angle, θ_m, of the refracted light from,

$$\sin^{-1}(n\sin\theta_B) - \theta_B = \theta_m,$$

where n is the refractive index of the grating. The gratings we use are designed to shift 500 nm light into the m = 1 maximum. Student results typically come within 10% of manufacturer specifications.

Macroscopic Diffraction Grating

In a spin-off project to the optical diffraction grating experiment, students measure the diffraction pattern of a large, blazed Plexiglas grating, Fig. 3, designed to diffract microwaves.

Fig 3. Macroscopic Plexiglas diffraction grating.

Students use standard Pasco microwave transmitters and receivers to measure the pattern of a double slit, with 6-cm slit separation, with and without the blazed grating. As shown in Fig. 4, the purpose of the blaze angle is readily apparent in the shifted diffraction pattern with the greater intensity at the m =1 maximum.

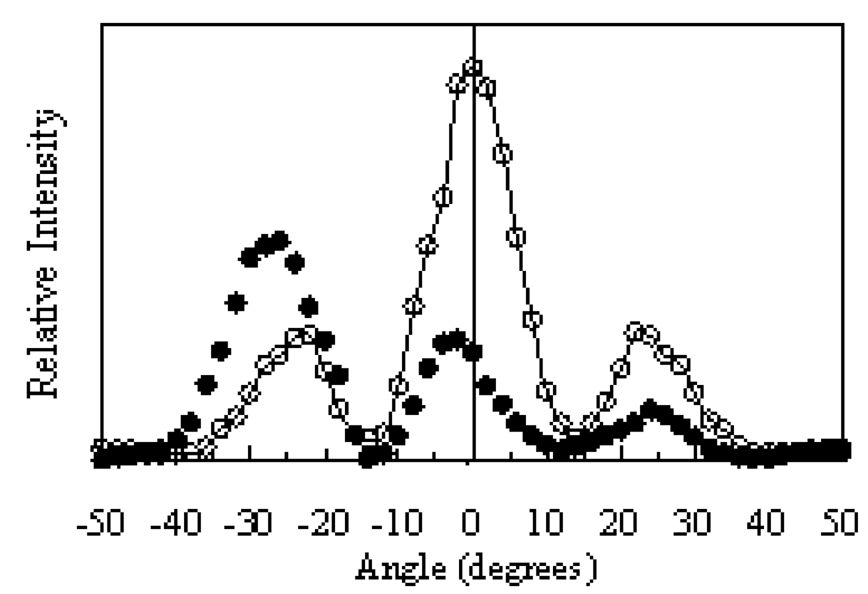

Fig 4. Data for the two-slit interference experiment with (solid circles) and without (open circles) the blazed grating.

References

K. G. Vandervoort, S. L. Adams, and A. M. Hyder, Am. J. Phys. 74, 649 (2006).

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Compact Discs

Students shine laser light onto a CD surface and use the diffraction pattern to determine the distance between the grooved features on the surface. Using AFM, they reveal the surface features to be rows of bumps, as shown in Fig. 5. Extrapolating the number of bumps in the image to the total surface area of the CD gives them the rough storage capacity of a CD, 700 MB.

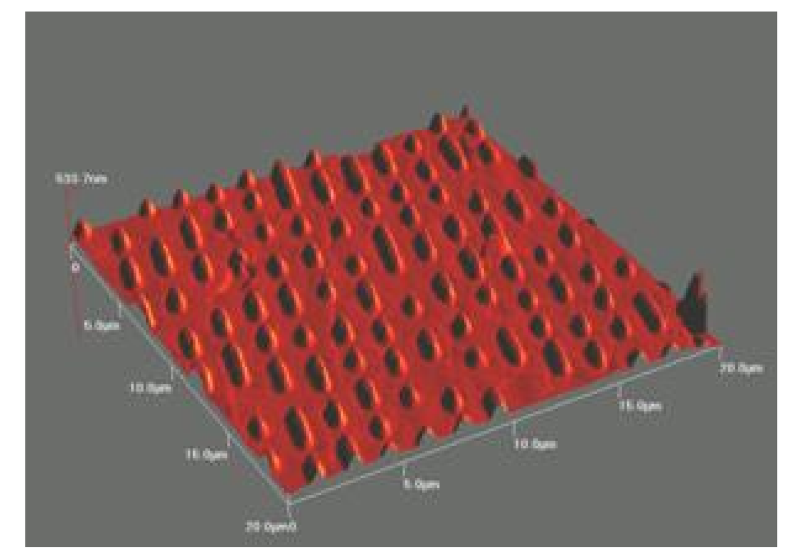

Fig 5. 20 X 20 μm^2 image of a non-recordable CD.

In addition to the bump surface spacing, the AFM measures the height of the bumps, carefully engineered to be ¼ the wavelength of the laser light used in a CD player. Shown in Fig. 6, this design produces destructive interference, yielding a data bit of zero.

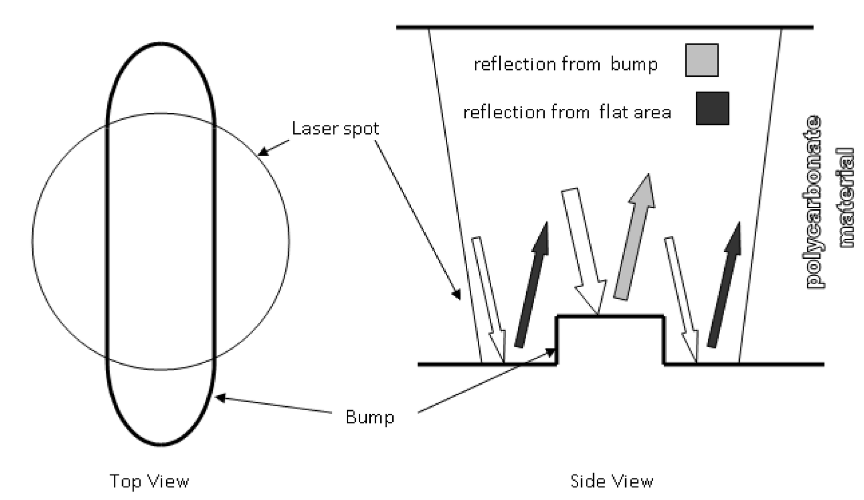

Fig. 6. Light beam reflected from a bump and its surrounding area destructively interferes with itself .

To compare the measured bump height (~125 nm) to the CD infrared laser wavelength of 780 nm, students must first determine the reduction of the wavelength in the polycarbonate coating of the CD by,

$$\lambda_{coating} = \frac{\lambda_{air}}{n},$$

where n is the coating refractive index (1.55).