

## Very Low Energy TEM Diffraction of Nanostructures

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We have built a very low energy (500 eV to 5 keV) TEM to analyze nanoscale gratings. These ‘artificial crystals’ are large arrays of closely-spaced slits etched all the way through material membranes. Using this technique, we find that low energy electrons are coherently transmitted through the slits, but there is a non-uniform refractive index *within the free space of each slit*. This refractive index is mediated by the self-induced image potential of the electrons as they pass through the slits. Here we discuss the microscope and the two imaging modes used to analyze these structures.

The gratings we have analyzed (see Figure 1) have a lattice spacing of 100 nm in one direction and 1.5  $\mu\text{m}$  in the other. They are made at the MIT NanoMechanical Technology Laboratory [1], and consist of an array of 50 nm slits etched all the way through a 150 nm thick silicon nitride membrane. They are coated with approximately 5 nm of Au/Pd or Pt.

The TEM (Figure 2) is a customized ISI WB-6 SEM, with the scanning mode disabled. The vacuum chamber has been extended to enable the wave transmitted through the sample to propagate 75 cm to the detector. We use two imaging modes in this device (diffraction and Fourier self-images) to obtain high-resolution information about the gratings, despite the fact that their characteristic length scales ( $<100\text{ nm}$ ) are  $1/100^{\text{th}}$  the minimum probe size achievable in our system (10  $\mu\text{m}$ ).

Diffraction images are obtained by focusing the beam down near the detector (see Figure 3). Under this condition the beam is nearly collimated and spatially extended at the grating, enabling coherent electron diffraction. As described in [2], we find that the diffraction images contain important information about the phase of the exit wave. The diffraction images can be quite asymmetric about the zeroth order (unscattered beam), which can only be attributed to elastic scattering in the free space of the grating slits. These results can be modeled by considering an image potential interaction between the electron and its image charges induced within the surfaces of the grating.

Images of the gratings themselves are obtained using two consecutive gratings, with the beam focused near them to provide incoherent illumination as described in [4]. This is a Lau interferometer configuration, and it is a Fourier self-imaging technique borrowed from optics [3]. This can be thought of as a form of point projection holography, except that the slits in the first grating serve as an array of mutually incoherent point sources. When two identical gratings of period  $d$  are separated by a half integer multiple of the Talbot distance ( $=2d^2/\lambda$ ) the resulting far field diffraction intensities line up, forming an image of the grating. The advantage of this technique is that images can be obtained using very incoherent, low brightness illumination.

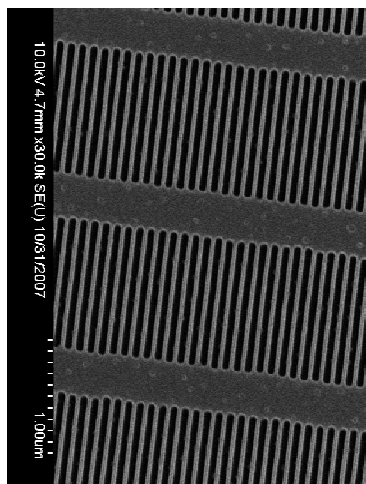
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[1] T. A. Savas *et al.*, J. Vac. Sci. Technol. B 13 (1995) 2732.

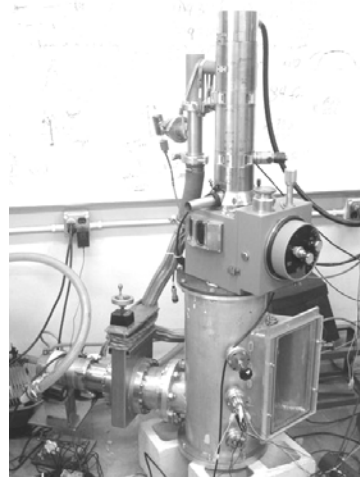
[2] B. McMorran, J. Perreault, T.A. Savas, and A. Cronin *et al.*, Ultramicroscopy 106 (2006) 356.

[3] K. Patorski, Progress in Optics 27 (1989) 3

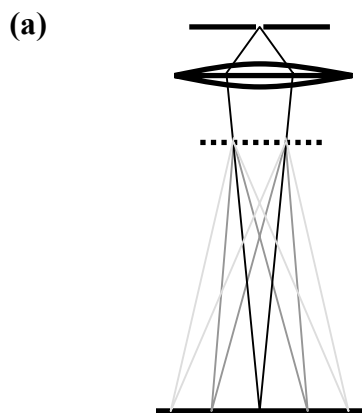
[4] A. Cronin and B. McMorran, Phys. Rev. A 74 (2006) 061602R.



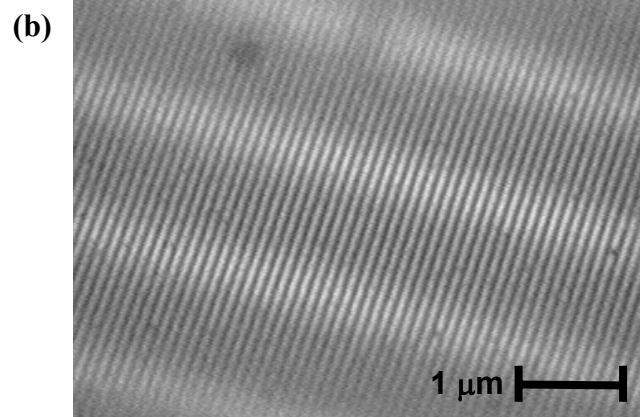
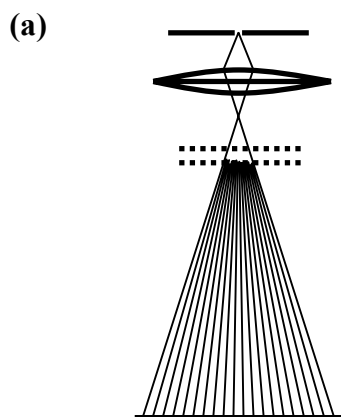
**Figure 1.** Nanoscale slit array, imaged using a Hitachi S-4800 FE-SEM.



**Figure 2.** Our very low energy TEM.



**Figure 3.** (a) Setup for free space diffraction imaging in a low voltage TEM, and (b) the resulting diffraction pattern.



**Figure 4.** (a) Setup for Lau-assisted TEM, and (b) the resulting self-images of a nanoscale slit array.