Diffractive Electron Mirrors as Lossless Beam Splitters

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Thin monocrystals[1], electron biprisms[2], and fabricated transmission gratings[3] have long been used to coherently split electrons. Recently, Agarwal *et al.* reported the use of thin crystals as electron beam splitters and couplers in the construction of a micron-sized Mach-Zehnder interferometer for demonstration of Elitzur-Vaidman type interaction-free measurements[4]. All these methods could potentially suffer from inelastic scattering and absorption and are therefore lossy to some extent. This becomes a major issue for applications such as quantum electron microscopy (QEM) which requires that single electrons complete many round trips inside a resonant cavity, effectively multiplying the loss probability by the number of round trips. Thus, in one of the designs for QEM, the use of reflective diffraction gratings as lossless electron beam splitters is proposed[5].

In this work, we present a proof-of-principle experiment to demonstrate the working of a diffractive electron mirror (DEM) in an SEM. We constructed a DEM by mounting a fabricated topographical grating on the mirror electrode of a tetrode immersion lens (Fig. 1a-b). Applying a negative bias to the mirror electrode produced sinusoidal equipotential surfaces above the grating which could impart a modulated phase shift onto an incident electron plane wave resulting in electron diffraction in the far-field. To verify electron diffraction, we designed an experiment inside a conventional SEM (Fig. 1c). By placing a sample on the back-focal plane of the tetrode immersion lens, the focused diffracted/reflected beams could strike the bottom surface producing multiple images.

The result is shown in Fig. 2a, where the top and bottom surfaces of a micron-sized Si cantilever were imaged using the setup shown in Fig. 1c. Multiple side-images appear on either side of the central reflected image. This result suggests that a DEM could split an electron beam through diffraction. Fig. 2b-c compares an experimental SEM image with a processed image, the result of convolution between a single reflection image and an expected point spread function. Although there is a strong resemblance between the two, further investigation into discrepancies between diffraction spot separation and orientation in the experimental results, and those predicted by theory, is required.

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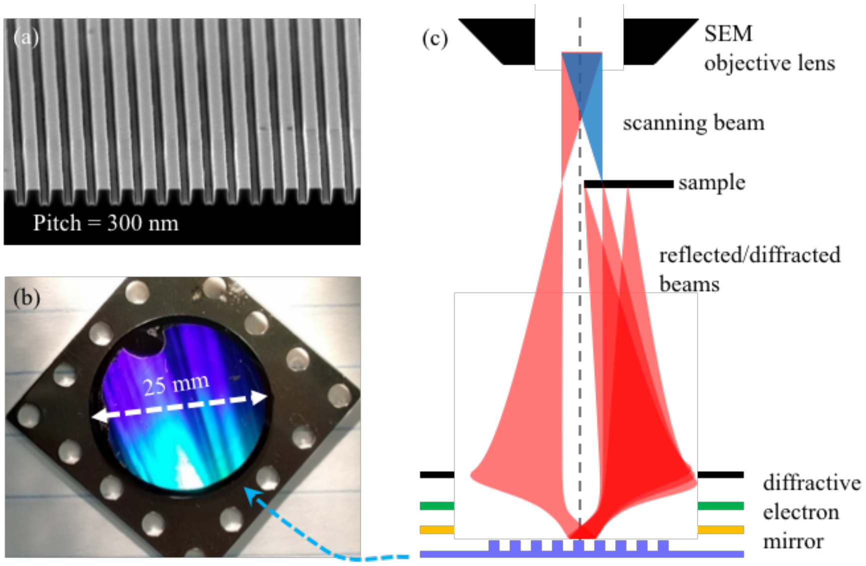

Figure 1. Diffractive electron mirror as an electron beam splitter. (a) SEM micrograph of a Si one-dimensional grating fabricated through optical interference lithography followed by reactive ion etching. (b) Large-are diffraction grating mounted on the mirror electrode of a tetrode immersion lens. (c) Schematic of a proof-of-principle experiment to demonstrate electron diffraction using a diffractive electron mirror in an SEM. A focused beam scans the top surface of the sample, producing an image. As the beam scans away from the sample, it continues its trajectory towards the diffractive mirror which could diffract and reflect the beam. Multiple focused beams strike the bottom surface to produce multiple images. Diffracted beam separation in this schematic is exaggerated.

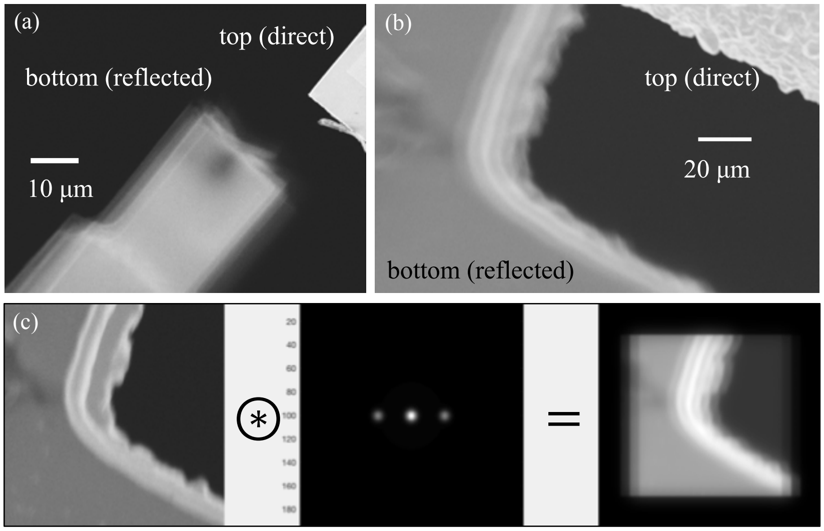

Figure 2. Evidence for electron diffraction. (a) Simultaneous imaging of top and bottom surfaces of a Si cantilever in SEM, obtained by placing a diffractive mirror below the sample as in shown Fig. 1c. The side-images on either side of the reflected image are evidence for diffraction. (b) Experimental results with a TEM Cu grid used as the sample. (c) The result of convolution between a single reflected image (left) and a three-pronged Gaussian point spread function (PSF) (middle) resembles the experimental result, (b). The orientation of the PSF was chosen arbitrarily to make the resemblance stronger. The reason why the PSF corresponding to the expected diffraction orientation did not produce the strongest resemblance to the experiment is under investigation.