Diffractive Electron Mirror in SEM

N. Abedzadeh, C-S. Kim, M. Turchetti, R. Hobbs, K.K. Berggren
Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139
navid@mit.edu

M.A.R. Krielaart, P. Kruit
Department of Imaging Physics, Delft University of Technology, Lorentzweg 1, 2628CJ Delft, The Netherlands

Electron mirrors have been used in aberration-corrected electron microscopy techniques such as low-energy electron microscopy and mirror-corrected scanning electron microscopy. More recently, a design for a quantum electron microscope, an imaging approach based on interaction-free measurement[1], was proposed.[2] This could take advantage of an electron mirror whose surface was patterned with a topographical grating (diffractive electron mirror). An electron plane wave, incident on such a diffractive electron mirror, could be diffracted as the topography imparts a modulated relative phase shift to the beam, enabling the development of a loss-less reflective electron beam splitter.

In this work, we designed and conducted proof-of-principle experiments to characterize a diffractive electron mirror integrated with a tetrode immersion lens. The electron optics, including the mirror, lens and an aligner, were optimized using ray-tracing software (*Lorentz-2E*). By constructing experiments inside a conventional field-emission SEM, we took advantage of the existing electron column and detector. Figure 1a shows a schematic of the experimental setup. In one experiment, we demonstrated electron reflection with point symmetry by simultaneous imaging of top and bottom surfaces of a micron-sized silicon cantilever (Fig. 2a). We obtained similar results by fabricating a MEMS electrostatic mirror and lens stack and observing reflection images of a holey carbon sample (Fig. 3). In a separate experiment, we replaced the flat mirror electrode with a diffraction grating fabricated using optical interference lithography and repeated the above experiment. We observed that the reflected image was comprised of partially superimposed images of the sample (Fig. 2b). This observation could be the first evidence of diffraction from a diffractive electron mirror. However, we require further investigation into these results by comparing them with estimated theoretical values for diffraction efficiency as a function of electric-field-controlled phase shift.

The separation between these superimposed images in the reflection in our experimental results is slightly larger than what a simple theory would predict for diffraction. This may be due to electron-optical effects. Diffractive electron mirrors could be used to engineer the electron wave function for applications such as nanolithography[3] and active noise suppression in electron microscopy.[4]

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[3] Grella, L. *et al*. J. *Micro/Nanolith., MEMS, and MOEMS* **12(3),** (2013).
[4] Okamoto, H. *Appl. Phys. Lett.* **92,** (2008).

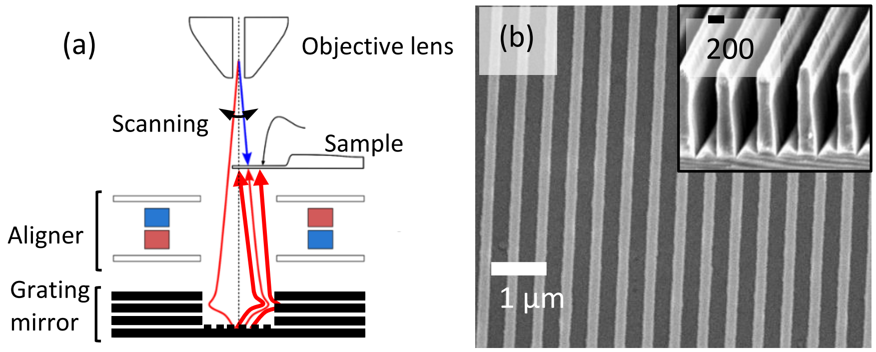

Figure 1: (a) Schematic of the experimental setup inside a conventional field emission SEM: a 2 keV focused electron beam scans the sample (blue beam), while some electrons pass by the cantilever (red beam). The tetrode diffractive mirror diffracts the incoming beam before reflecting and re-focusing the beam on the underside of the cantilever. An electrostatic octupole unit corrects misalignments sustained by the beam between the sample and the mirror. (b) Scanning electron micrograph of a silicon diffraction grating fabricated using optical interference lithography.

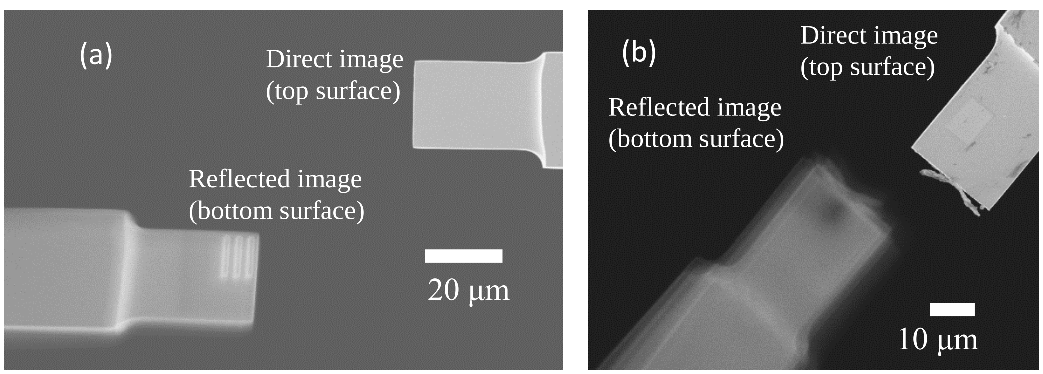

Figure 2: Simultaneous imaging of top and bottom surfaces of a thin sample: (a) using a flat tetrode mirror; (b) using a tetrode diffractive mirror: multiple partially superimposed images of the bottom surface are formed which may be an evidence for diffraction.

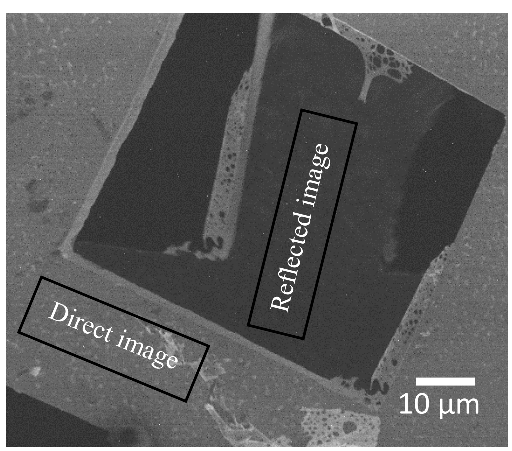

Figure 3: Simultaneous imaging of top and bottom surfaces of a holey carbon film: using an electrostatic MEMS mirror and lens stack inside a SEM.