Fabrication and characterization of a fine electron biprism on a Si-on-insulator MEMS chip

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For off-axis electron holography, an electrostatic biprism is usually located close to the selected area (SA) aperture plane of the transmission electron microscope (TEM). The application of a voltage to the biprism results in overlap of two parts of an incident electron beam and allows both the amplitude and phase of the electron wavefunction that has passed through a specimen to be recovered. The quality of the reconstructed electron wave depends directly on the information contained in the hologram. An off-axis electron hologram is characterized by its interference fringe spacing, contrast and overlap width. The interference fringe spacing and overlap width are determined by the electron optics of the TEM and by the deflection angle at the biprism. The interference fringe spacing is inversely proportional to the deflection angle, while the overlap width is influenced by the width of the biprism. In order to achieve as narrow a fringe spacing as possible with high fringe contrast, the biprism should be as narrow and stable as possible. Previous attempts to make ultra-narrow biprisms have included glass fibres coated with metal or patterned SiNx with focused ion beam. None of these attempts have provided a reproducible method of making ultra-narrow biprisms with perfect control over their dimensions.

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Here, we illustrate an approach that can be used to fabricate a biprism that has a rectangular cross-section and is located between two counter electrodes that are at the same height. We pattern the biprism in the top Si layer of a Si-on-insulator (SOI) wafer. The wafer consists of a micron-thick single-crystalline Si layer that is isolated electrically from its substrate and can be left free-standing using an etching process. When combined with microelectromechanical systems (MEMS) processes, structures can be patterned down to nm scale in three dimensions. In this way, the width of the biprism and the distance to the counter-electrodes can be chosen to have dimensions down to ~100 nm. A further advantage of using an SOI wafer to fabricate a biprism is the large Young's modulus of the single-crystalline Si biprism (170 GPa), when compared with that of a conventional biprism made from glass (~70 GPa). In addition, the two counter-electrodes can be biased independently. A schematic diagram and scanning electron microscopy (SEM) images of a biprism on an electrically-contacted MEMS chip are shown in Fig. 1, alongside a three-dimensional design drawing of a custom-made aperture rod.

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In order to test its performance, the biprism was mounted close to the SA plane in a Philips CM20 TEM. The electron deflection was measured by recording the shift of a diffraction spot as function of applied voltage. The measured deflections are compared with predicted deflections and with similar measurements made using a conventional biprism on an FEI Titan TEM in Fig. 2. The deflection is a factor two greater for the new rectangular biprism for the same applied voltage. The measured interference fringe spacing, contrast and overlap width achieved using the new biprism are also shown in Fig. 2. Here, the maximum voltage that can be applied is limited by the distance between the biprism and the counter-electrodes, which can be increased in future designs.

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In order to demonstrate the imaging capabilities of the new biprism, an off-axis electron hologram of a MoS_2 flake was recorded in a Philips CM20 TEM. The hologram and the resulting reconstructed amplitude and phase are shown in Fig. 3. In the future, the biprism will be mounted in an image-aberration-corrected FEI Titan TEM, in which the electron optics offers greater flexibility in both normal and Lorentz imaging modes.

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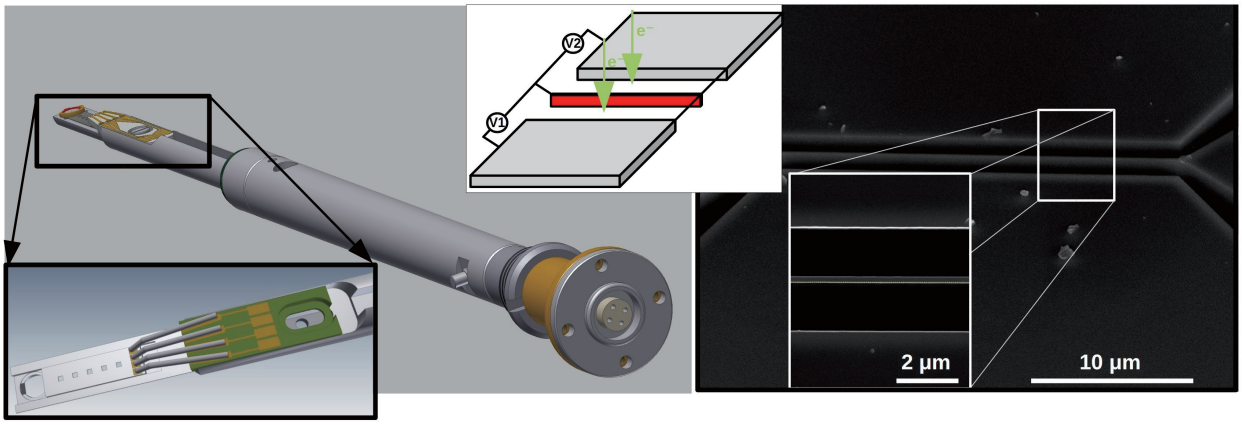

Figure 1: Design drawing of an aperture rod designed to accommodate an electrically contacted MEMS chip in the SA plane (left). Schematic drawing of a “rectangular biprism” (middle top). Scanning electron micrograph with the biprism tilted by 52 degree (right). The inset shows a magnified top view of a 120-nm-wide biprism.

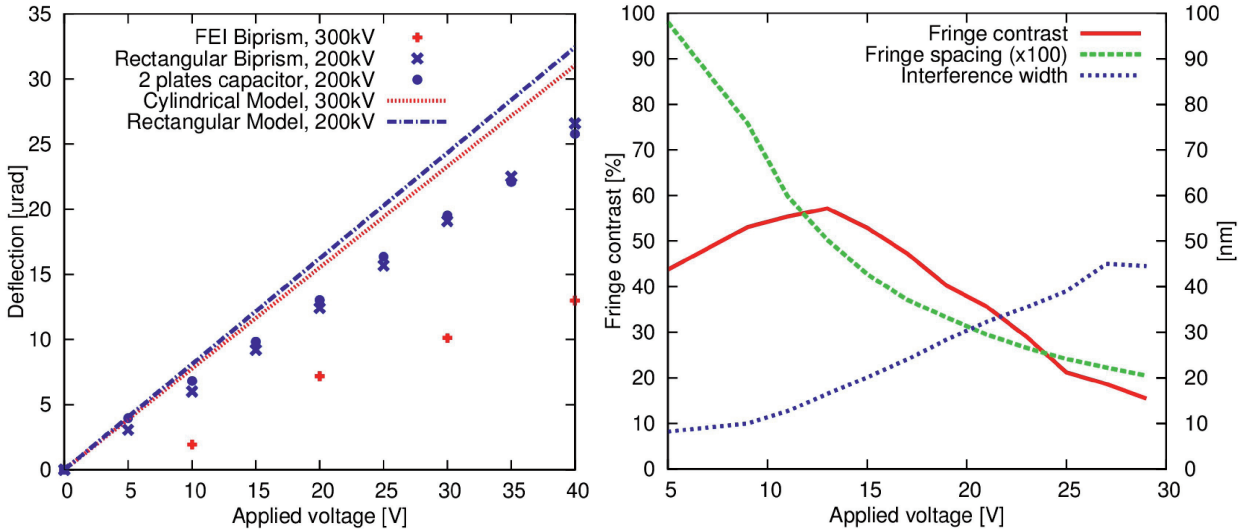

Figure 2: Deflection of a relativistic electron beam for standard and rectangular biprism geometries. The lines show the predicted deflections (left). Interference fringe contrast, spacing and overlap width plotted as a function of voltage applied to the rectangular biprism recorded on a Philips CM20 TEM (right).

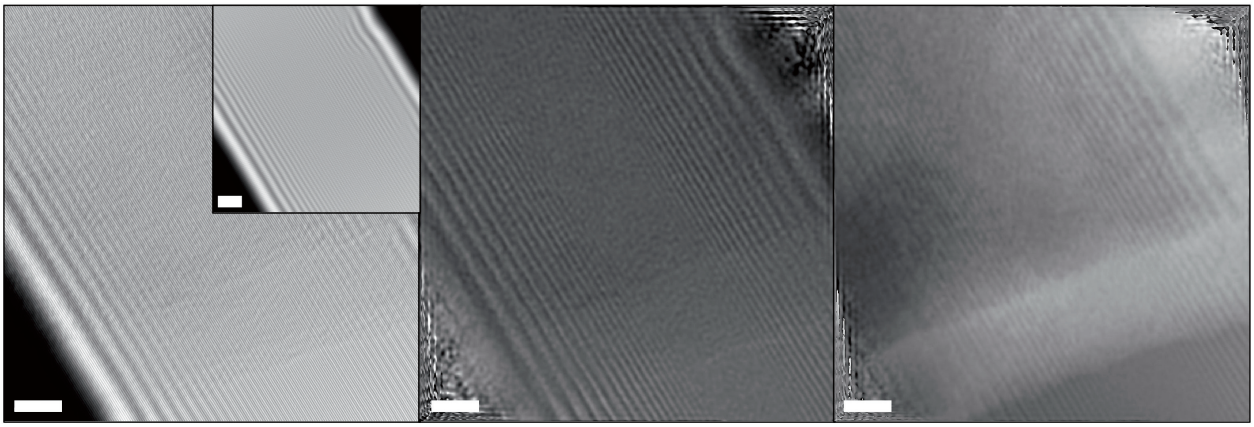

Figure 3: Electron hologram of a MoS2 multilayer flake recorded in a Philips CM20 TEM with 27 V applied to the rectangular biprism under standard imaging conditions, with a reference hologram shown in the inset (left). Reconstructed amplitude (middle) and phase (right). The scale bar is 5 nm.