Design for a 10keV Multi-Pass Transmission Electron Microscope

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Electron microscopes are unable to image many important samples (like proteins, polymers, and battery materials) at atomic resolution due to their extreme sensitivity to high-energy electron radiation. Multi-pass transmission electron microscopy (MPTEM) has recently been proposed as a way to significantly increase contrast in thin samples, causing an order of magnitude lower radiation damage at constant signal-to-noise[1].

We will present the design for a proof of concept 10keV MPTEM currently being built by Delong Instruments. Our design implements the multi-pass protocol by temporarily trapping electrons from a laser-triggered Schottky gun in a linear, self-imaging resonator. The trapping is accomplished using two fast-switching gated electron mirrors. The gated mirrors are reflective, aberration-correcting elements until a 100V pulse temporarily converts them to strong lenses. Electrons trapped in the resonator pass through the sample m times before they are released and projected onto a detector. The reduction in damage at constant signal-to-noise is proportional to m.

We will discuss the design of the gated mirrors and the organization of the resonator optics, which were optimized using Munroe Electron Beam Software (MEBS). We will also introduce a theory of the multi-pass contrast transfer function to explain how the resolution scales with m and show simulations of the expected performance on reference targets. We expect the microscope to achieve 5nm resolution.

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[1] Juffmann, Multi-Pass Transmission Electron Microscopy

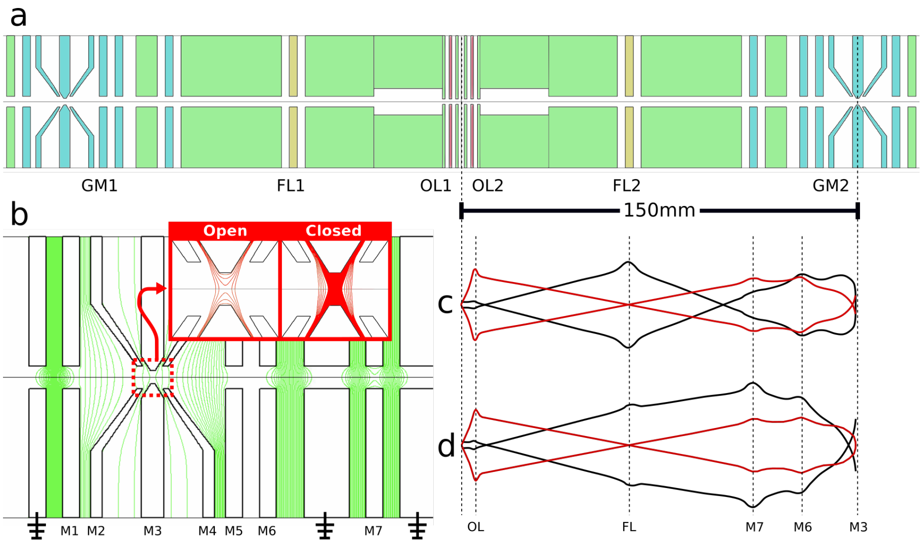

Figure 1: multi-pass optics geometry. a) Full electrode structure with gated mirrors (blue), field lenses (yellow), and objective lenses (red). b) Enlarged view of a gated mirror with equipotential lines spaced by 200V. The inset shows equipotential lines spaced 20 V from 0 V to 100 V for open and closed conditions. c) Paraxial image and field rays traced through half of the multi-pass optics. There is a diffraction plane at the turning point, so the image returns to the sample plane inverted. d) With an image plane at the turning point, the sample is properly re-imaged but spherical aberration cannot be corrected.

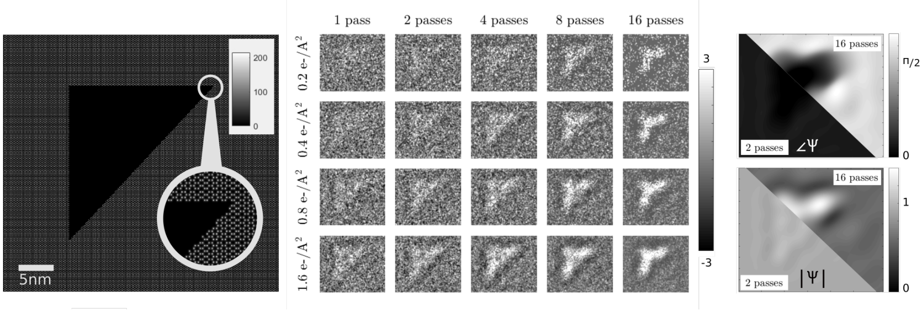

Figure 2: Simulation of a triangular hole in single-layer graphene imaged with a 10 keV MPTEM. Left: sample potential. The color bar shows the projected potential in volt-angstroms. Center: simulated micrographs with various doses and numbers of passes. The number of in-coupled electrons is adjusted along each row so that the total dose (the number of sample-electron interactions) remains constant. The simulation includes 2.8% inelastic loss and 160mm spherical aberration per roundtrip. Phase contrast is generated using 15nm defocus. The color scale is normalized to the standard deviation of the intensity at the detector. Right: exit phase (top) and amplitude (bottom) of the electron wavefunction after 2 and 16 passes.