Dynamic electron wavefront shaping by structured electrostatic fields: Twisted electrons with tunable orbital angular momentum

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Since the first experimental demonstration of electron vortex beams in 2010 [1, 2], structured electron waves have been generated successfully using different approaches and have led to a variety of applications in electron microscopy and spectroscopy, as well as studies of other exotic quantum effects [3]. Either diffractive holograms [2, 4] or refractive phase masks [1, 3 ,5] are normally used for such experiments, as a result of their high fidelity and universal applicability. However, since they are both based on the sculpting of thin films, their use always results in intensity reduction due to absorption and scattering. Moreover, they are only able to impart static phase modulations to electrons of given energy, in contrast to the capabilities of adaptive electron optics, aberration correctors and spatial light modulators.

As electrons are charged particles, electron vortices can also be generated upon propagation through the field surrounding the end of a magnetic dipole, according to the magnetic Aharonov-Bohm effect [6, 7]. Although this approach is highly efficient and independent of electron energy, it is not straightforward to vary the magnetization of a tiny rod inside the electron microscope. This drawback can be overcome by using the electrostatic analogue of the Aharonov-Bohm effect and, specifically, by using the structured electrostatic field at the end of a line dipole (Figure 1a) [8]. We have developed a versatile device, which consists of two parallel metallic wires, whose width and separation are both approximately 200 nm (Figure 1b). The wires are patterned on a Si/SiN substrate using electron beam lithography and connected to an external power supply. A potential difference can be applied between them and varied at will, limited only by the possibility of an electrical discharge at an extremely high potential difference. Phase images were measured experimentally using off-axis electron holography from the vacuum region close to the device. Figure 2 shows the result of applying a series of different potential differences between the two wires, in order to generate the spiral phase profile of a tunable vortex beam.

This new design of a tunable, near-obstruction-free electron vortex generator can be fabricated practically on a chip and inserted into any plane in a transmission electron microscope in an aperture holder, paving the way for the introduction of adaptive electron singular optics and its applications.

References

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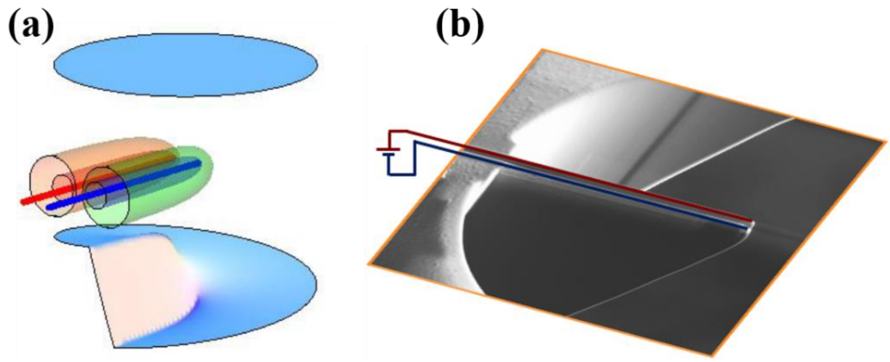

Figure 1. (a) Schematic diagram and (b) experimental realization of the electrostatic monopole vortex generator.

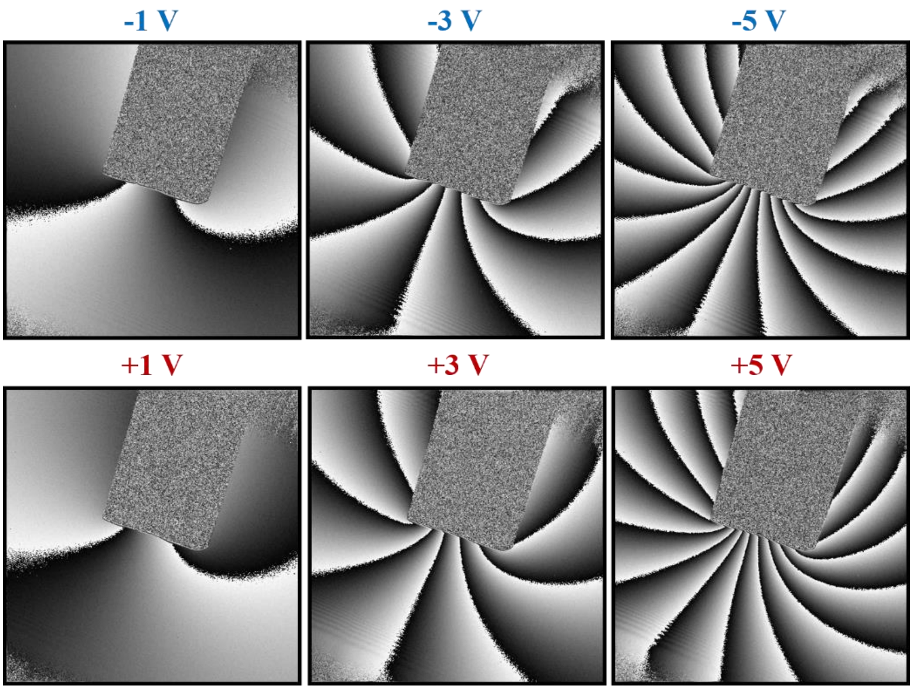

Figure 2. Experimental phase images measured using off-axis electron holography from the vacuum region close to the device, shown with different values of potential difference applied between the wires, demonstrating a tuneable spiral phase distribution.