Toward a programmable phase plates for electrons

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Electron beam shaping provides microscopists with a new way to see the electron microscope column as an optical bench for electrons [1, 2], with opportunities to perform new electron experiments and to measure new observables such as magnetic dichroism and vertical magnetic fields. This development relies on the creation of synthetic holograms, which allows arbitrary amplitude and phase profiles to be imparted to the electron beam. Such holograms are generated computationally by interfering a structured wave with a reference wave. The resulting patterns are transferred to electron-transparent SiN membranes using nanofabrication. Unfortunately, this approach is inefficient, as the materials themselves scatter electrons.

In comparison, beam shaping in light optics permits patterns to be changed easily at the touch of a computer button. The technology of spatial light modulators based on liquid crystals offers the possibility of controlling the refractive index of a large matrix. An analogue for electrons has recently been proposed through the control of electrostatic fields [3]. Unfortunately, if one removes all material from the electron beam path, then electrostatic fields must be characterized by a function of the form $\nabla_{x,y}^{2} = 0$(where x,y are the in-plane coordinates). Although harmonic functions of this kind have interesting applications ranging from vortex generation [4] to detection [5], they do not provide full flexibility for all possible phase modulations. In the context of the Q-SORT project (www.qsort.eu), we are developing programmable phase plates. In contrast to the recently published design [3], we use a small number of miniature control electrodes and a substantially free space solution, which provides higher efficiency while keeping the project affordable in terms of the current technology. Figure 1(a) shows an image of a custom-made chip with multiple electrodes, allowing for quasi-harmonic potential generation. Figure 1(b) shows the end of a compatible holder with electrical biasing contacts.

The mathematical approach that is required to calculate the electrode voltage for a desired beam shape requires solution of the inverse Dirichlet problem in three dimensions. Such solutions can be obtained using finite element calculations or semi-analytical inversion methods. Figure 2 shows a calculated solution for a programmable phase plate that produces a Bessel beam of the form $\varphi = k\rho$, where $\rho$is a radial in-plane coordinate and k is a constant.

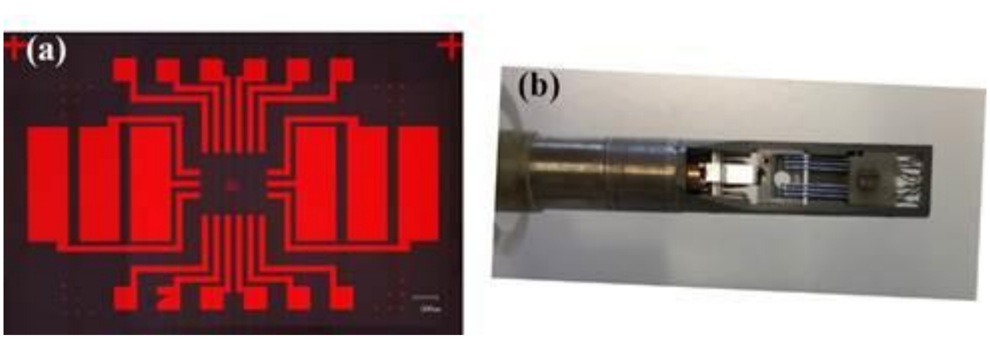

Figure 1. (a) Optical image of a custom-made chip with multiple electrodes for a programmable phase modulator. (b) End of a compatible holder with electrical biasing contacts.

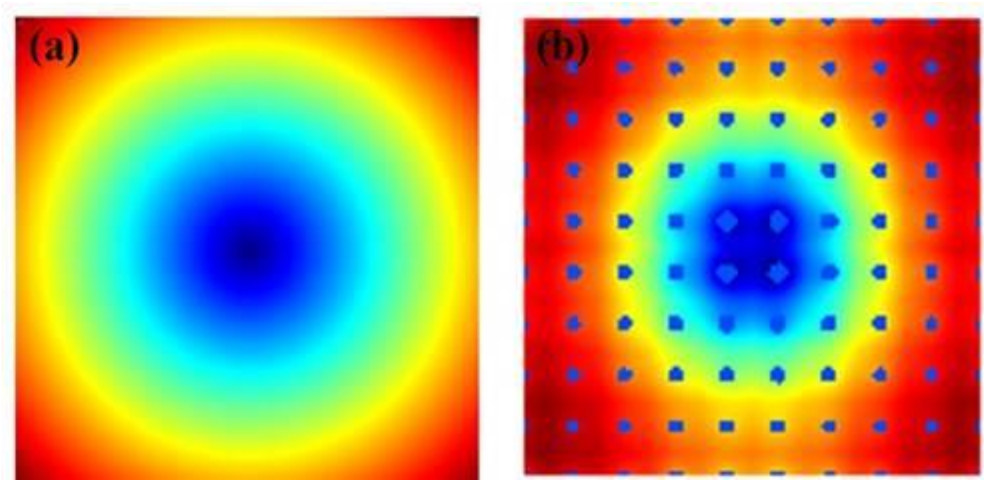

Figure 2. (a) Target Bessel beam phase. (b) Actual phase obtained using a discrete charge distribution.

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