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IT-1-P-2710 Spiral phase plates for electron vortices

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Vortex beams have been recently developed in electron optics and generate a lot of interest due to their potential ability of retrieving magnetic information down to the atomic scale [1, 2]. Several techniques are now available to produce such beams like the holographic mask [2] or the more recent magnetic needle [3]. In this work we propose to extend the idea of Uchida & Tonomura [1] by creating a spiral phase plate with smoothly increasing thickness.
The phase plate should be composed of a light material to prevent too much absorption from the plate itself and be ideally thicker than 100 nm at its highest point to allow a smooth increase of thickness. Focused electron beam induced deposition (FEBID) is an ideal tool to realize such structures as it can deposit functional materials with high spatial resolution. In the present case, ultrathin silicon nitride (SiN) was successfully used as substrate to fabricate SiO2 spiral phase plates as shown in Fig. 1. In order to prevent unwanted scattering from the central hole in the spiral, it was filled with a small amount of platinum via FEBID.
The phase plate was then introduced into the Qu-Ant-TEM, an FEI Titan3 transmission electron microscope, operated in Lorentz mode, to achieve a large field of view with extended spatial coherence conditions. Carefully illuminating the phase plate with a uniform electron beam and looking in the far field, typical features of vortex beams were recorded. Fig. 2 displays a through focus series of the resulting beam which reveals the presence of a doughnut like intensity pattern with the destructive interference centre of the vortex beam.
In order to quantify the orbital angular momentum (OAM) carried by the outgoing beam, electron holography was performed at the edge of the phase plate. By measuring the phase shift between the thickest and thinnest area, the total OAM was estimated to be 0.6 (Fig. 3).
Further tuning of this setup provides another method for creating atomic sized electron vortex beams with the advantage of providing a single vortex beam that is easy to obtain in a standard TEM.

[1] Uchida M. & Tonomura A., Nature Letters (2010), 464, p737-739.
[2] Verbeeck J. et al., Nature Letters (2010), 467, p.301-304.
[3] Béché A. et al., Nature Physics (2014), 10, p. 26-29.

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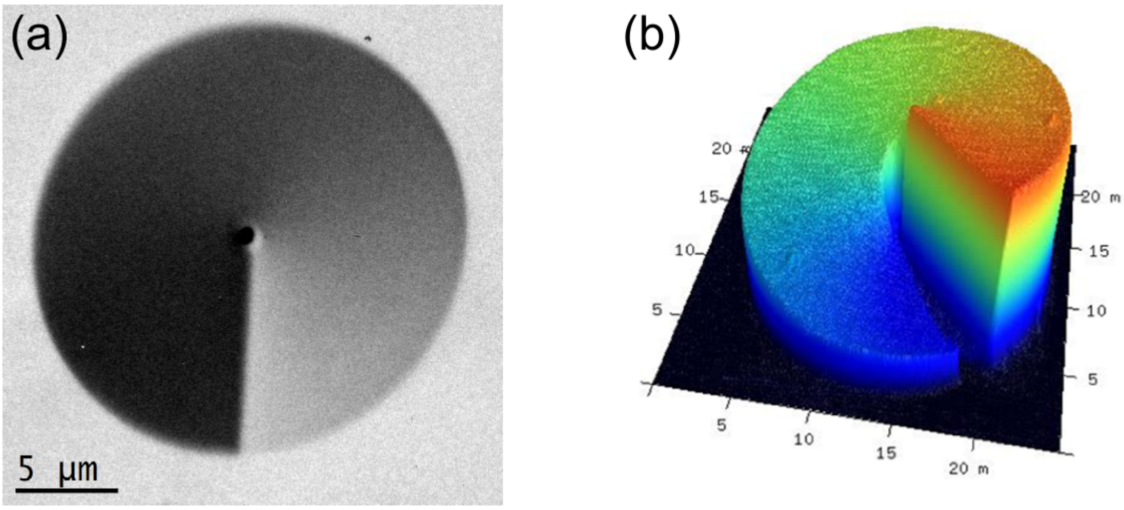

Fig. 1: (a) TEM view of the spiral phase plate with the central hole filled with platinum. (b) Atomic force microscope image revealing the thickness profile of the phase plate.

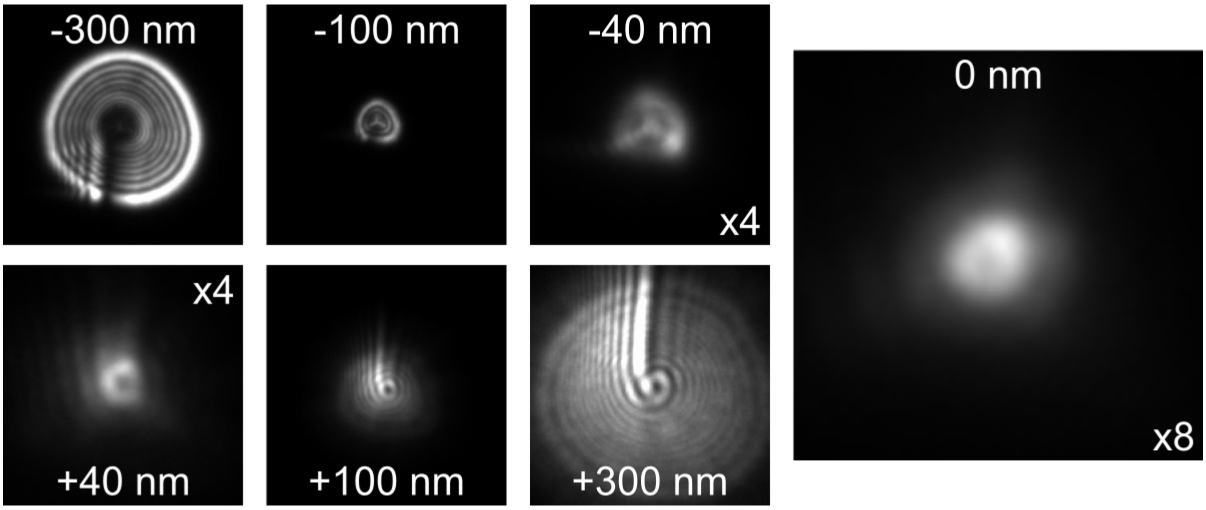

Fig. 2: Far field through focus series of an electron beam evenly illuminating the phase plate. The destructive interference area in the middle of the fully condensed beam (black hole) is typical of a vortex beam.

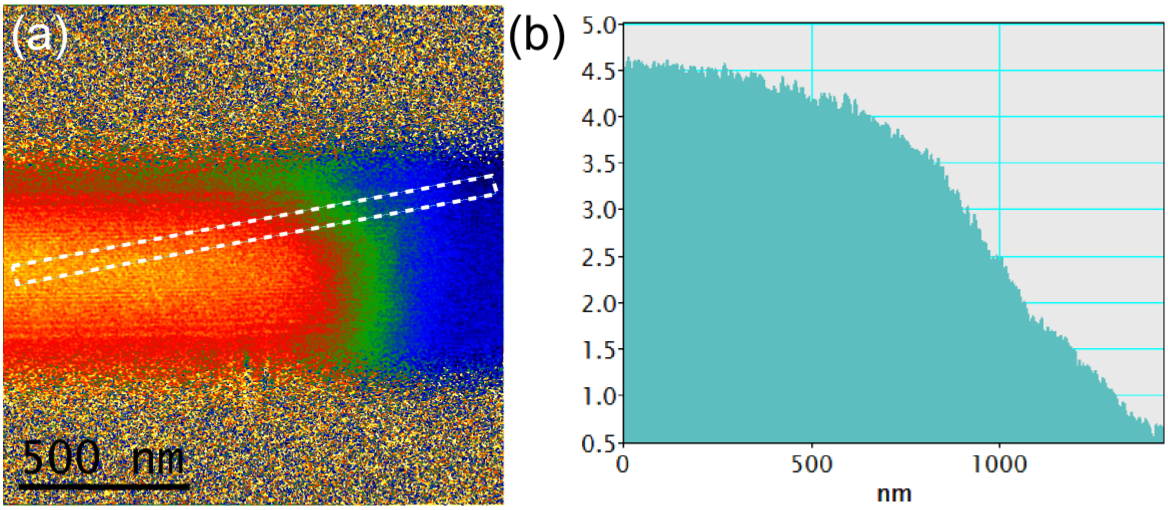

Fig. 3: (a) Phase image of the edge of the phase plate, between the thickest and thinnest area of the spiral, acquired by holography. (b) Phase profile taken along the dotted area displayed in (a) revealing a total phase shift of 4 rad corresponding to a total OAM of ~0.6.