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Holographic Generation of Highly Twisted Electron Beams

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Free electrons can possess an intrinsic orbital angular momentum upon free-space propagation [1][2]. Beams with a high number of twists are of particular interest because they carry a high magnetic moment about the propagation axis. Using electron holographic plates obtained by FIB patterning of SiN membranes we generated a beam with an orbital angular momentum up to 200ħ in the first order of diffraction: the biggest ever demonstrated so far [3].
Using EFTEM mapping in a JEOL 2200 FEG TEM microscope operated at 200keV we carried on a detailed experimental analysis of the thickness pattern in the holographic plate in order to evaluate the introduced phase effect and therefore the wavefunction right at the exit of the hologram. By simple propagation we were able to know the wavefunction at different planes: The intensity pattern was found to be in agreement with the experiments at different focal planes.
Fig 1a shows indeed the comparison of the intensity pattern as calculated by propagation and the experiment at Fraunhofer, it is evident a very good agreement.
The knowledge of the wavefunction permits to decompose it in different values of Orbital angular momentum (OAM). The OAM spectrum is evaluated by transforming the calculated electron wave function into polar coordinates and performing the Fourier transform in the azimuth coordinates.

It is easy to verify that when the OAM is written with respect to the geometric center of one of the vortexes the correct average OAM number of about L=200ħ is recovered. The broadening of the distribution is due to the loss of intensity at very high frequencies induced by hologram imperfections. In fact an eigenvalue of OAM should have no azimuthal localisation.

We were also able to locate the positions of the each singularity: in fig 1c we highlighted in red the singularity centres and superimposed them to the intensity. Singularities are mainly located on the periphery of the dark region and spatially decomposed probably as an effect of the interference of the 0th order beam that cannot be completely spatially separated.

An in depth analysis of the radial profile also reveals a large number of ripples outside the main ring, suggesting that the generated beam has a large spectrum decomposition in terms of Laguerre-Gauss Eigenfunctions, especially with respect to the radial number p. These characteristic can be tight down to the hard aperture used to limit the hologram. In fig 1d we fitted for sake of example the wavefunction at a given plane using a "minimal" set of Laguerre Gauss states about L=200 ħ and p=0-50 but it is worth recalling that the actual radial decomposition depends sensibly on the actual electron optics, on the hologram details and on hologram illumination conditions.

We expect to apply these beams to interact with magnetic field and to couple with Landau states in the microscope but it is important to take into account the above limitations to plan future experiments.

References:

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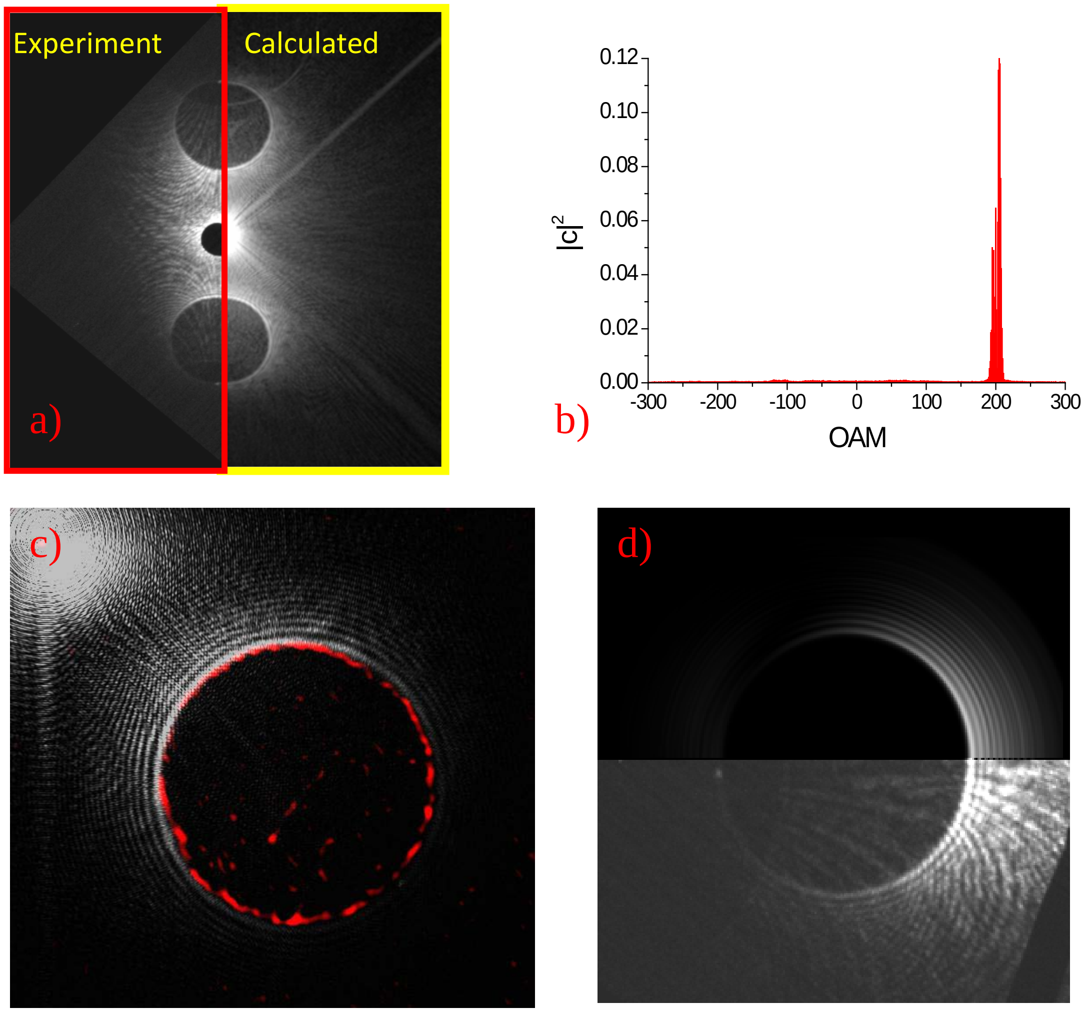

Figure 1. a) Comparison of the experimental and calculated intensity of the hologram diffraction: the +/-1 and 0th order diffraction are visible. b) spectrum of the OAM of one of the generated vortexes. c) phase singularities (red) superimposed to the diffracted intensity: almost all singularities are located to the perifery of the dark region. d) example of possible fitting of the actual wavefunction to a limited set of Laguerre Gauss state. The fitting (above) and the experiment (below) are compared. Even under simplified assumptions on the hologram illumination a minimum set states of a few L (see b) and radial number p=0-50 are necessary to provide a qualitatively reasonable decomposition of the vortex state.