Focused X-ray vortices with high topological charge

D. Cojoc [1], M. Prasciolu[1], A. Carpentiero[1], L. Businaro[1], B. Kaulich[2], E. Di Fabrizio[3], ***S.Cabrini***[4]

1 – CNR-INFM National Laboratori TASC, LILIT beamline, Trieste, Italy
2- ELETTRA Synchrotron, TWINMIC, Trieste, Italy
3- University Magana Grascia Catanzaro, BIONAM Laboratori, Italy
4 - Molecular Foundry – LBNL, Nanofabrication Facility, Berkley, USA

Vortices are characterized by a true zero in the intensity distribution that is stable under propagation; the phase at these points is therefore undefined. These structures have a “doughnut” like transversal intensity distribution and carry an orbital angular momentum, proportional to *l* [1]. Vortices are obtained for visible wavelengths using proper designed diffractive optical elements (DOEs) which convert the Gaussian beam generated by normal laser sources [2] and are used for optical particle manipulation. Same techniques used to design DOEs for visible light can be generalized for shaping X-ray beams [3].

Theoretical fundamentation and experimental observation of x-ray vortices at 9 keV were reported recently using phase plate fabricated in polymide as a spiral staircase structure approximating a spiral ramp [4]. Nevertheless, this phase plate is a non focusing element which generates a vortex beam observable only far away from it. Due to the limited thickness of the material, only vortices with low TC can be generated with phase plates. Moreover, phase plates can not be fabricated for soft x-ray since the material thickness is too small to be controlled.

We designed and fabricated amplitude DOEs to generate x-ray vortices with high TC and tested them at TWINMIC station at Elettra Syncrotron, in scanning [5] and full field microscope setup configurations. DOE function is calculated summing a helical wave with a desired TC to a spherical wave. In the scanning setup we used a the DOE as microscope objective and demonstrated the doughnut intensity pattern characteristic to the vortex but we could not characterize the phase distribution. In the full field X-ray experiment we used larger DOEs that generate a high focused TC vortex ($l=32$). The vortex DOE, fabricated at TASC-LILIT beamline, has the following characteristics: 220 nm gold on 100 nm silicon nitrade membrane, 300 nm resolution, 614 um diameter, 111 mm focal length at 720 eV. The DOE, placed in the condenser position converts the X-ray input beam into a helical beam focused in the sample plane where the intensity pattern is a doughnut with radius proportional to the square root of the topological charge. In order to characterize also the phase distribution characteristic to the vortex field we used the interference between the zero order beam and the vortex. The obtained interference pattern demonstrates the phase distribution characteristic to the optical vortex with the topological charge l=32. Possible applications of the interaction of these beams with the matter [6] are also discussed.

References

[1] A.T. O’Neil, I. MacVicar, L. Allen, and M.J. Padgett, Phys. Rev. Lett., 88 (2002) 053601-1.
[2] N.R. Hackenberg, R. McDuff, C.P. Smith, and A.G. White, Optics Lett., 17 (1992) 221.
[3] Di Fabrizio E., Cojoc D., Cabrini S., Kaulich B., Susini J., Facci P., Wilhein T., Optics Express, 11, 2278-2288, (2003)
[4] A.G. Peele, K.A. Nugent, A.P. Mancuso, D. Paterson, I. McNulty, J.P. Hayes, J. Opt. Soc. Am. A, 21 (2004) 1575.
[5] D. Cojoc, B. Kaulich, A. Carpentiero, S. Cabrini, L. Businaro, E Di Fabrizio, Microeleectronic Engineering 83 (2006) 1360.
[6] A. Alexandrescu, D. Cojoc, and E. Di Fabrizio, Phys.Rev. Lett. 96, 243001 (2006).