The Super-oscillating Superlens

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Abstract: We demonstrate a lens that creates a sub-wavelength focal spot beyond the near-field by exploiting the phenomenon of super-oscillation.

The recently discovered phenomenon of super-oscillation predicts that a properly tailored interference can create sub-wavelength localisations of light that propagate beyond the near-field of the structure creating the diffraction [1, 2]. This leads to the possibility of a new class of far-field optical imaging devices with better than diffraction limited resolution and provides an alternative to the well known Pendry-Vesselago negative index super-lens. Here we show that a binary mask of concentric metal rings can act as a high-throughput super-oscillating sub-wavelength focusing device.

The principle of superoscillation is that a band-limited function can oscillate arbitrarily fast in a small region, at the expense of a loss of energy into sidebands around that region. In the domain of optics, this means that a properly constructed optical field may have an arbitrarily small focal spot, much smaller than the classical diffraction limit, in the presence of high intensity sidebands elsewhere in the field. We have demonstrated that nanohole arrays can be used to create these super-oscillating optical fields [2], but the throughput of these arrays is low and the properties of the focal spot cannot be easily controlled. Here we use designed arrays of concentric rings as a binary mask. The ring masks have a throughput of ~50%; a factor of 10 greater than the nanohole arrays, and the masks can be optimised to produce focal spot tailored to specific requirements.

Below we show the results from a binary ring mask super-oscillatory lens. The lens is manufactured with focussed ion beam milling of concentric rings into a 100nm aluminium film. The lens is illuminated with a plane wave of wavelength λ=660nm, and the focal spot produced is imaged with a high NA microscope. The mask is designed with an optimisation algorithm to minimise the central spot size within a given field of view. Here we experimentally form a 0.4λ focal spot, 1.25 times smaller than the classical diffraction limit.

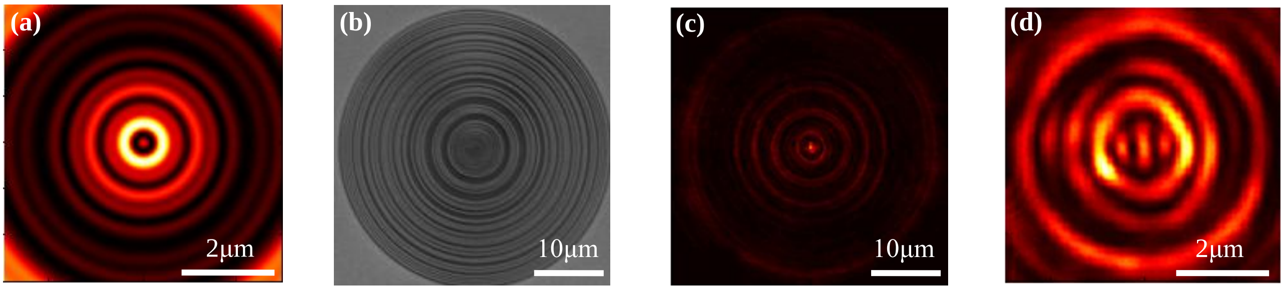

Fig.1: **(a)** Sample simulated focal spot from a concentric ring mask showing a central spot of 0.25λ. **(b)** SEM image of a superoscillating superlens. A pattern of concentric rings is milled through a 100nm aluminium film using focused ion beam milling. **(b)** Experimental isolated focal spot, FWHM 0.5λ, formed 12μm from the lens in **(b). (c)** Experimental focal spot formed 11μm from the lens with FWHM spot size of 0.38λ in the x direction.

[1] M. V. Berry and S. Popescu, Evolution of quantum superoscillations and optical superresolution without evanescent waves, Journal of Physics A: Mathematical and General, vol. 75, pp. 6965-6977, 2006.
[2] F. M. Huang, Y. Chen, F. J. Garcia de Abajo, and N. I. Zheludev, Optical super-resolution through superoscillations, Journal of Optics A: Pure and Applied optics, vol. 9, pp. S285-S288, 2007.