Exploring the limits of super-oscillatory imaging

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Abstract: An investigation of the resolution limits of super-oscillatory imaging shows that, for objects of limited size, resolution of λ/14 can be obtained in the far-field without the use of evanescent waves or fluorescence.

Super-oscillatory lenses have recently been demonstrated experimentally to allow far-field imaging with resolution better than λ/6 [1]. It is known that super-oscillation can be used to create arbitrarily small features in the optical field, but this is at the expense of increasingly intense sidebands. Until now it has not been known whether these very small spots could be used to achieve imaging with an equivalent resolution. We demonstrate numerically that a super-oscillatory optical field can generate a spot with a size of λ/20 in the presence of intense sidebands and that this spot can be used for imaging with a resolution of λ/14. This discovery confirms that super-oscillation can offer far-field imaging with unlimited resolution.

The key to this work is using a super-oscillatory spot with large field-of-view, that is, where the sidebands are separated from the spot by a considerable distance; in this case about 7 times larger than the spot FWHM. This allows imaging of objects which fall within the field of view and gives a resolution determined by the spot size. While this places some limits on the specimens that can be examined in this regime, far-field imaging and metrology of nanoscale structures is an extremely valuable technological development.

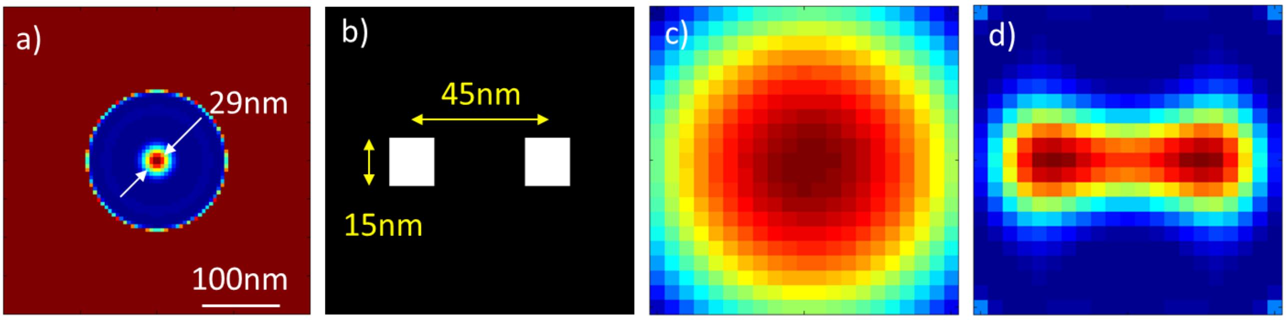

***Fig 1. Superoscillatory imaging with resolution* λ/14**. *a) Super-oscillatory spot with FWHM 29nm surrounded by intense sidebands. b) Object: pair of 15nm square holes separated by 45nm (centre-to-centre). c) Simulated confocal image of the object (*λ=640nm*), showing no resolution of the holes. d) Simulated image using super-oscillatory confocal imaging showing the clearly resolved holes.*

In the simulation, we use a similar confocal imaging arrangement to that described in [1], with the focusing lens of the confocal microscope replaced by a super-oscillatory lens. The super-oscillatory spot in this case was designed by shifting the first 5 zeros of the (band-limited) Airy spot. This mathematical process allows shaping of the spot and its field-of-view, without removing the band-limit. Such a spot could be potentially produced by the combination of a spatial light modulator with a high NA objective. This super-oscillatory spot was scanned across the sample and the light scattered from the central spot was recorded using a high NA objective and a pinhole (as in a confocal microscope).

The object chosen to demonstrate the imaging resolution is pair of 15nm square holes in an opaque film, with a centre-to-centre separation of 45nm. Imaging is carried out at a wavelength of 640nm. As seen in Fig. 1, a diffraction limited confocal microscope does not come close to resolving the two holes. However, the super-oscillatory microscope clearly resolves the holes, demonstrating λ/14 resolution in a far-field optical microscope, without any restriction on the sample other than the overall size.

Reference:

1. “A super-oscillatory lens optical microscope for subwavelength imaging”, Edward T. F. Rogers, Jari Lindberg, Tapashree Roy, Salvatore Savo, John E. Chad, Mark R. Dennis & Nikolay I. Zheludev, *Nature Materials*, 11, 432–435 (2012)