Measuring the gigantic wavevectors and energy backflow in super-oscillatory optical field with metasurfaces

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Abstract: Using metasurface based interferometry setup, for the first time we experimentally demonstrate that electromagnetic field near a super-oscillatory optical focus has zones with energy backflow and gigantic local wavevectors exceeding the wavevector of incident light several times over.

It is commonly believed that only the non-propagating electromagnetic field in the vicinity of nanostructures can be structured on sub-wavelength level and thus could be decomposed into plane waves with wave-vectors exceeding that of incident light creating the high spatial frequency near-field. Here we show that super-oscillatory fields in free space could feature energy backflow and gigantic local wavevectors that are several times higher than that of incident light. With the aid of an appropriately designed plasmonic metasurface, we experimentally measured phase of the super-oscillatory field and visualized fast-variation phase singular points. Unlike conventional phase measurement techniques where interference with an additional plane wave is usually required, our metasurface serves as a built-in interferometer which is capable of retrieving the phase by simply adjusting the incident polarizations and recording the corresponding intensity components.

Figure 1(a) shows the schematic of experimental arrangement. When *x*-polarized light illuminates the metasurface, the E_y component diffracting from the two set of slit-antennas orienting at ±45° has a phase difference of π which could act as a binary phase grating to create the super-oscillatory field with appropriately optimized mask (SEM image shown in Fig. 1(b)). In the meantime, the E_x component is in-phase, thus forming a plane wave considering the mask period is in subwavelength scale only creating the zero-diffraction order. Similarly, with *y*-polarization illumination, a plane wave could be generated in E_y. Futhermore, with circular polarization illumination, the E_y component is the superposition of the plane wave and the super-oscillatory field to be measured (there will be a $\pm\,\pi/2$ phase delay depending on the handedness of the circular polarization light). In this way, the phase information of the super-oscillatory field is encoded into the intensity patterns and therefore could be retrieved by measuring a set of intensities with *x*-, *y*- and circular polarization illuminations and without the necessity to build up a rather complex interferometry setup. An exampled super-oscillating retrieved phase is shown in Fig. 1(c) and 1(d) where the singular points are highlighted with green circles which coincide with the low-intensity regions. Excellent agreement is found between simulation and experiment.

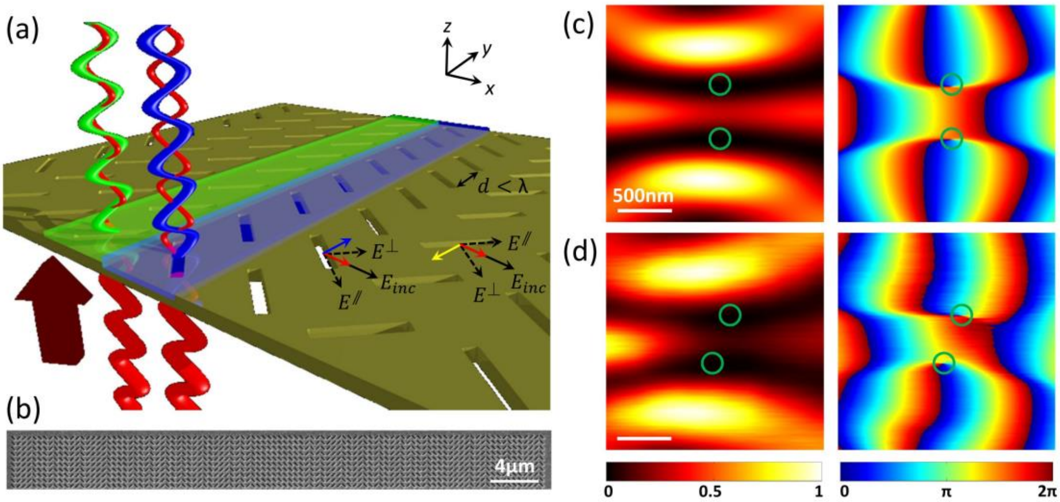

Fig. 1 (a) Schematic for the phase recovery setup. (b) SEM image of sample. (c) The calculated intensity (left) and phase (right) distributions of super-oscillatory field E_y in the propagation plane. The focus is designed at z=10 μm. (d) Experimentally measured intensity and phase distributions near the super-oscillatory hotspot. The phase singular points are highlighted with green circles where the gigantic local wavevector and energy backflow are expected.

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[2] G. H. Yuan, S. Vezzoli, C. Altuzarra, E. T. F. Rogers, C. Couteau, C. Soci, and N. I. Zheludev, "Quantum super-oscillation of a single photon," Light: Sci. & Appl. 5, e16127 (2016).