Sub-wavelength Localization of a Single Photon

Guanghui Yuan[1], Stefano Vezzoli[1], Charles Altuzarra[1], Edward T. F. Rogers[2], Christophe Couteau[1], Cesare Soci[1], Zexiang Shen[1], and Nikolay I. Zheludev[1,2]

[1]*Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore 637371, Singapore, ghyuan@ntu.edu.sg*
[2]*Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, Southampton SO17 1BJ, United Kingdom*

We report the first experimental demonstration of super-oscillatory behaviors in single photon regime, where the quantum wave-function of a single photon can be localized into length scale much smaller than the smallest wave length contained in its Fourier spectrum.

Super-oscillations are phenomena that a band-limited function can oscillate much faster than its highest Fourier component over arbitrarily large intervals [1]. As a result of delicate near-destructive interference, super-oscillations feature particularly intriguing characteristics that they occur in relatively low-intensity regions accompanying with rapid phase variations. The super-oscillation idea is surprising and counterintuitive since it gives the illusion that the Fourier component is 'super-shifted' to be outside the spectrum of the function.

Super-oscillations are of particular interest in quantum physics. The original insights which eventually led to super-oscillations started with the observation by Aharonov that the usual measurement procedure for preselected and postselected ensembles of quantum systems can give unusual results [2]. As a result of the uncertainty principle, the initial boundary condition of a quantum mechanical system can be selected independently of the final boundary conditions. Interestingly, the weak measurement of quantum system can have values much higher than the spectrum of the operator. Although quantum weak-measurement of single photon and super-oscillations of classical fields have been verified in previous works, direct evidence on sub-wavelength localization of single photon due to super-oscillation has not been provided thus far.

Both classical and quantum measurements are carried out, where we use either a continuous laser or a single photon source from a pair of correlated photons generated by spontaneous parametric down-conversion in nonlinear crystal. We direct one channel onto a specially designed one-dimensional meta-lens consisting of multiple parallel slits, which serves as a binary mask to diffract the incoming light causing it to interfere behind the mask. In the focal plane of the lens, a hot-spot with FWHM of ~0.4λ was achieved in the super-oscillation region, undoubtedly revealing sub-wavelength localization of quantum wavefunctions of single photon.

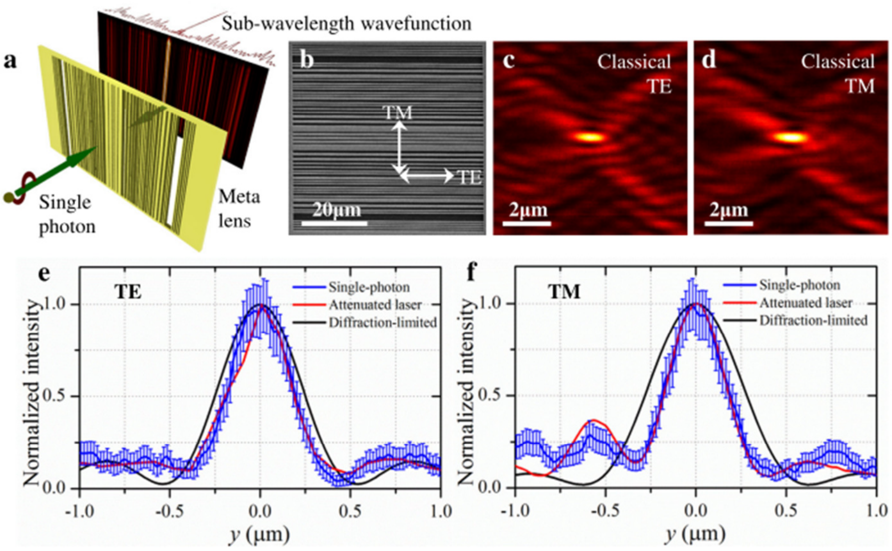

Fig. 1 (a) Schematic configuration of single photon super-oscillation; (b) SEM image of the 1D meta-lens; Classical measurement of the sub-wavelength hotspots using sCMOS camera for (c) TE and (d) TM polarizations; Normalized probability of the super-oscillatory wavefunctions for (e) TE and (f) TM, which are experimentally recorded by a single-photon detector in the experiment. The error bar is determined by the square root of coincidence counts.

References

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