Filtering of quantum states with plasmonic metamaterial absorber

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Abstract: We use single-photon interference on a metamaterial absorber to demonstrate quantum state filtering by dissipation, exploiting the metamaterial's ability to distinguish between symmetric and anti-symmetric superpositions of a two-path wave function.

Interference of quantum light in thin metamaterial absorbers has been recently used to implement coherent perfect absorption of single photons and NOON states. By extending this concept, we demonstrate that metamaterials can be designed to manipulate and control quantum states of light, for instance in a way that only certain parts of the wave function are transmitted, thus realizing quantum states filtering. As a proof of principle, we show that an ultrathin plasmonic absorber, embedded in a phase-tunable coherent fibre network, can be used to filter single-photon two-path superposition state.

A fibre-packaged ultrathin metamaterial absorber placed in an optical fibre interferometer was interrogated by heralded single photons from a spontaneous parametric down-conversion source (Fig. 1a). A single photon propagating in the interferometer occupies two spatial modes simultaneously, $|\psi_{in}\rangle_\varphi \sim |1\rangle_\alpha|0\rangle_\beta + e^{i\varphi}|0\rangle_\alpha|1\rangle_\beta$, where the phase retardation φ is controlled by a phase modulator. The metamaterial absorber, with optical parameters close to those of an ideal lossy beamsplitter, is completely opaque for the symmetric part ($|\psi^{(S)}\rangle \sim |1\rangle_\alpha|0\rangle_\beta + |0\rangle_\alpha|1\rangle_\beta$) of the wave function, while it is completely transparent for its anti-symmetric part ($|\psi^{(A)}\rangle \sim |1\rangle_\alpha|0\rangle_\beta - |0\rangle_\alpha|1\rangle_\beta$). Thus, any input state of the photon (or $|\psi_{in}\rangle_\varphi$ for any φ) that passes through the metamaterial, collapses to $|\psi^{(A)}\rangle$.

Anti-symmetric state filtering by post-selection was proved performing interferometric measurements of the photons after interaction with the metamaterial absorber, which show excellent agreement with the predicted photon detection probabilities at the two outputs of the double interferometer (Fig. 1b). Furthermore, since the phase retardation φ modulates the amplitudes of both symmetric and anti-symmetric parts of the input wave function ($|\psi_{in}\rangle_\varphi \sim (1 + e^{i\varphi})|\psi^{(S)}\rangle + (1 - e^{i\varphi})|\psi^{(A)}\rangle$), the probability of a single photon to pass through the metamaterial can be deterministically set between 0 and 1, as demonstrated in Fig. 1c by active phase switching.

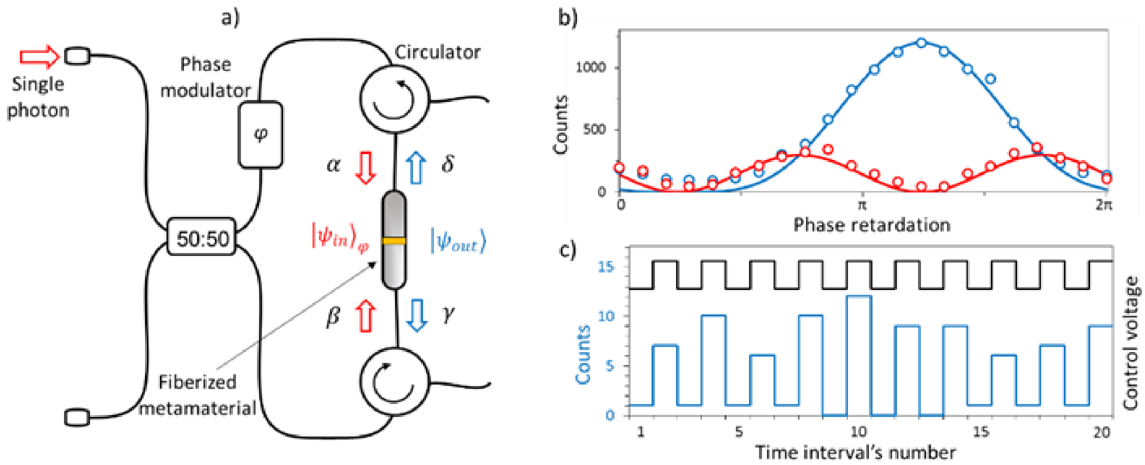

Fig. 1 a) Simplified scheme of the fibre-interferometer containing a metamaterial absorber for coherent single-photon processing. Upon dissipation of the symmetric part of the input state $|\psi_{in}\rangle_\varphi$, the output state of a single photon interfering in the fiberized metamaterial collapses to $|\psi_{out}\rangle \sim |1\rangle_\gamma|0\rangle_\delta - |0\rangle_\gamma|1\rangle_\delta$ (state filtering by post-selection). b) Interferometric measurement of the filtered photon flux at the outputs of the metamaterial-containing interferometer, showing excellent agreement with the expected behaviour of an anti-symmetric single-photon state as a function of phase retardation. c) Demonstration of active single-photon switching using the phase modulator to control the probability of single-photon coherent absorption.

Single-photon quantum state filtering may find application in quantum information protocols, for example *dual rail encoding*. More generally, dissipation engineering in designer metamaterials could become a universal processing platform for a variety of quantum states of light, including two-photon and weak coherent states.