Quantum polarization tomography with all-dielectric metasurfaces

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Measurements of quantum states of photons are conventionally performed with series of optical elements in bulk setups [1] or optical chips incorporating multiple tunable beam splitters. Here, we suggest and develop experimentally, for the first time to our knowledge, a new concept of quantum-polarization measurements with a single all-dielectric resonant metasurface [2]. The operating principle is presented in Fig. 1(a): A metasurface spatially splits different components of photon polarization states, which then enables full reconstruction of the photon state based on the photon correlations with simple polarization-insensitive single-photon detectors or EMCCD cameras. The subwavelength thin structure provides an ultimate miniaturization, and can facilitate quantum tomography by spatially-resolved imaging without a need for reconfiguration. Such parallel-detection approach promises not only better robustness and scalability, but also the possibility to study the dynamics of quantum states in real-time.

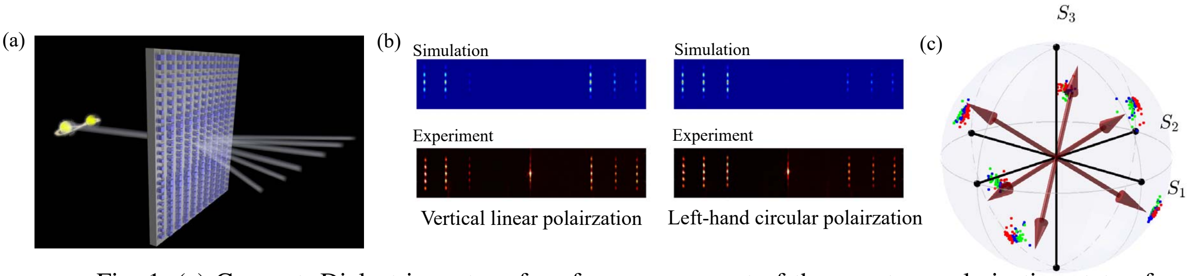

Fig. 1. (a) Concept: Dielectric metasurface for measurement of the quantum-polarization state of light. (b) Experimentally measured and numerically simulated representative transmission patterns in *k*-space for different input polarizations. (c) Measured (dots) and designed (arrows) polarization projective bases on a Poincaré sphere.

We perform optical characterizations of the fabricated metasurface. As we probe the metasurface with differently polarized laser beams, the observed far-field patterns are in agreement with our simulations [see examples for two polarizations in Fig. 1(b)], whereas additional central spots originating from fabrication imperfections only slightly lower the diffraction efficiency. Furthermore, we process the sets of images to fully characterize the polarization projective bases on a Poincaré sphere and find them to be in excellent agreement to our design [Fig. 1(c)], which are chosen to be in the optimal frame for the reconstruction of multi-photon polarization states. The metasurface has a very high average diffraction efficiency of 85%, while both the efficiency and projective bases are sustained across a broad bandwidth of over 100 nm. The metasurface can be easily extended to measuring multi-photon states by taking multi-fold correlations. Our metasurface with six output beams can measure up to four-photon polarization states using simple on-off single-photon detectors, whereas multi-photon states can be fully characterized by imaging on an EMCCD camera.

We anticipate that our approach will find applications in free-space quantum communication, cryptography, and computation, where metasurface can serve as a robust and accurate device for quantum imaging, replacing multiple bulk elements. Our metasurface may be extended to imaging spatially-varying quantum-polarization states, e.g. higher order multi-photon Stokes parameters.

The authors acknowledge financial support from the Australian Research Council. A portion of this research was conducted at the Center for Nanophase Materials Sciences, which is a DOE Office of Science User Facility.

References

1. D. F. V. James, P. G. Kwiat, W. J. Munro, and A. G. White, Phys. Rev. A **64**, 52312 (2001).
2. A. I. Kuznetsov, A. E. Miroshnichenko, M. L. Brongersma, Y. S. Kivshar, and B. Lukyanchuk, Science **354**, aag2472 (2016).