One-photon and two-photon quantum holography with bi-photon states of large spatial dimensionality

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Abstract: We report results of quantum holography (QH) where spatial informations stored in phase holograms are retrieved by measuring spatial coincidences between two images formed by spatially entangled twin photons of high-dimensionality. For the two setup configurations reported here, spatial informations are retrieved when holograms are read either with both photons or with one photon of the bi-photon states.

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1. Introduction

High-dimensionality spatial entanglement allows access to large Hilbert spaces, with applications in numerous fields of quantum optics [1]. By itself, a source of quantum light issued from spontaneous down conversion (SPDC) appears as incoherent, preventing the formation of an image of the spatial spectrum of an object (a transparency) in the Fourier plane. However, coincidence imaging of the pairs of twin photons allows this spatial spectrum to be retrieved [2–4]. All these experiments measured coincidences between two single-photon counting modules scanned on the signal and idler images. These procedures are time-consuming and use a very little part of the incident photons, leading to potential loopholes [5] if applied to the demonstration of basics properties of entanglement like the Einstein-Podolsky-Rosen (EPR) paradox [6]. Because of these drawbacks, imaging with single-photon sensitive cameras has became more and more popular and allows massively parallel coincidence counting [7]. Here we report coincidence imaging of bidimensional phase holograms using two EMCCD cameras [9]. As in [2,3], no single photon image is formed, while the cross-correlation of the twin images allows a coherent image to be retrieved in the far-field or in the near-field of the bi-photon states source. Two imaging configurations are investigated where spatial informations are retrieved when the holograms are read either with both photons or with one photon of the bi-photon states and when spatial correlations are investigated either in the far-field or in the near-field of the bi-photon states source, respectively.

2. Experimental protocol and results

The experimental set-up for two-photon QH is illustrated in Fig. 1a. Photon pairs with a dimensionality of 1790 in the two-dimensional transverse space are generated via SPDC in a type-II geometry [9]. The crystal (i.e. near field of twin photons) is imaged with a $4-f$ imaging system on a binary phase hologram and the entire flux of spontaneous down converted light illuminates the hologram. Fig. 1b shows the binary pattern engraved on a glass slide to create the phase hologram and the insert corresponds to the pattern encoded in the hologram : an array of 9 Dirac peaks. The engraving depth of the holograms is adjusted to produce a $\left(0-\frac{\pi}{2}\right)$ binary phase modulation at $710\,nm$ in order to optimize the diffraction efficiency of the hologram with the biphotons source. The cross-polarized signal and ilder beams transmitted by the hologram are then naturally separated by free space propagation thanks to the walk-off. Lastly, photons of pairs are detected and resolved spatially in the far-field on two EMCCD cameras used in photon counting mode [7]. Before detection, photons pairs emitted around the degeneracy are selected by narrow-band interference filters centered at $710\,nm$. The Fig. 1c shows the far-field mean spatial distribution of photons signal (or idler) transmitted by the hologram, we can observe that the spatial information encoded in the hologram is not retrieved, because of the incoherent nature of SPDC [3,4]. In contrast and in good agreement with the theory and stochastic simulations based on the Wigner formalism [9,10], when cross-corrrelation in momentum between twin

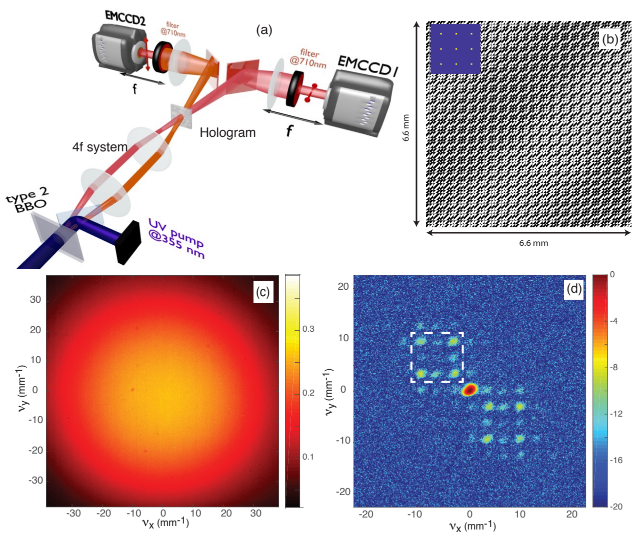

Fig. 1. (a) Experimental setup for two-photon QH. (b) Pattern of the $\left(0-\frac{\pi}{2}\right)$ binary phase hologram. The insert represents the pattern encoded in the hologram: an array of 9 Dirac peaks. (c) Average photon number in single far-field images (signal or idler) of SPDC. (d) Restored hologram formed by the normalized cross-corrrelation in momentum, given in dB, calculated over 80000 twin images. The white dotted squares indicate the location of the original pattern encoded in the hologram.

images is calculated (Fig. 1d), the spatial distribution of two-photon coincidence rate restores the original pattern encoded in the hologram at ± 1 diffraction orders because of the binary character of the hologram. In order to improve the signal-to-noise ratio (SNR) of the retrieved pattern, this cross-corrrelation image is calculated over 80000 twin images.

For one-photon QH the setup is modified such as only one of the two SPDC beams is transmitted by the hologram lying in the far-field of SPDC source and information is restored by the measurement of the near-field spatial coincidences.

3. Conclusion

We have shown that two-photon imaging potentially allows coherent manipulation of light in complex situations like holography. Unlike previous experiments [2, 3], all the light is used, preventing loopholes due to the selection of a small part of the photons and allowing full bi-dimensional manipulation of high dimensionality biphoton states, with potential applications in present hot topics, like boson sampling.

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