Experimental observation of multi-spatial-mode quantum correlations in four-wave mixing with a conical pump and a conical probe

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Abstract: We have experimentally demonstrated a scheme for generating a multi-spatial-mode quantum light source by a non-degenerated four-wave mixing (FWM) process with a conical pump and a conical probe in a hot atomic vapor cell. The degree of the intensity-difference squeezing between the generated twin beams is about -4.1 dB. We have also experimentally verified the multi-spatial-mode nature of the generated quantum correlation by comparing the noise levels' variation tendencies of global attenuation and local cutting attenuations.

Introduction

Multimode quantum states, due to their fundamental nature, are essential resources in quantum optics and quantum information technology. Various schemes have been proposed for generating multimode quantum states, such as multipartite-entangled or quantum-correlated states using photonic structures. Here we experimentally demonstrate a scheme for generating a multi-spatial-mode quantum light source by a non-degenerated four-wave mixing (FWM) process with a conical pump and a conical probe in a hot atomic vapor cell [1-2].

Experiment

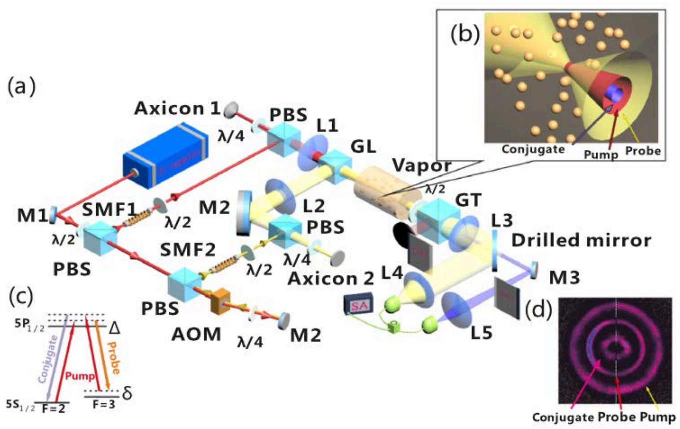

FIG. 1. The scheme and experimental layout for generating multi-spatial-mode quantum states of light via FWM process using conical probe and pump beams.

The detail of our experimental layout is shown in Fig. 1(a). Along the axial direction, a strong conical pump beam and a weak conical probe beam are crossed in the cell containing hot ^{85}Rb vapor, as shown in Fig. 1(b). As shown in Fig. 1(c), the conical pump light beam is blue tuned about 1 GHz from the D1 line of ^{85}Rb. The probe beam is blue detuned by about 8 MHz from the ground state hyperfine splitting of 3.036GHz. Fig. 1(d) shows the two-dimensional beam pattern captured by a laser beam profiler after the cell. The divergence angles of the probe and conjugate beams are 15 mrad and 5 mrad, respectively.

Result

As shown in the Fig. 2(a), the normalized noise power spectra of the conical probe beam, the conical conjugate beam, and their intensity difference are indicated as traces A, B, and C, respectively, while trace D shows the normalized SNL of all above traces. The noise levels of the two individual beams (traces A and B) are 5 dB above the SNL, while their intensity-difference noise power (trace C) is 4.1dB below the SNL at 1.5 MHz. As we can see, due

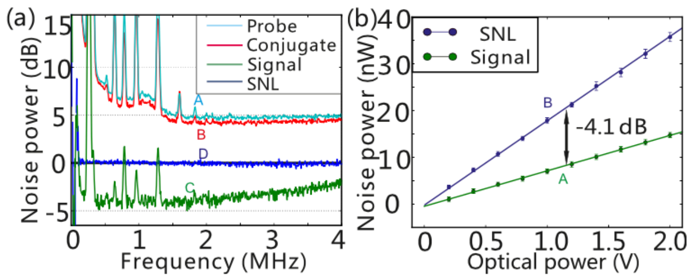

Fig. 2. Experimental results of quantum correlations between the conical probe and the conical conjugate beams: (a) Normalized noise powers of (A) probe beam, (B) conjugate beam, (C) intensity difference between the probes and the conjugate beams, and (D) the corresponding SNLs of trace A~C. (b) Intensity-difference noise versus total optical power indicated by volts (V) at 1.5MHz. Green dots: Intensity-different-noise (trace A), blue dots: SNL (trace B). The ratio between two slopes of trace A and trace B is 0.39, corresponding to –4.1 dB of quantum correlations.

to the FWM process, the conical probe beam is amplified with the generation of conical conjugate beam, whereas the quantum correlation exists between the two conical beams. Then, as shown in Fig. 2(b), we study the intensity-difference noise power (trace A) and SNL (trace B) at 1.5 MHz as a function of total optical power. The ratio between two slopes of trace A and trace B is 0.39, corresponding to -4.1 dB of intensity-difference squeezing. This result is consistent with the result given by the spectra data in Fig. 2(a).

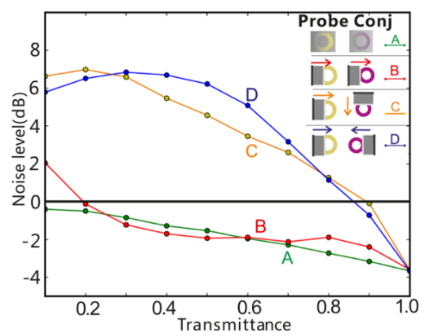

Fig. 3. The normalized intensity difference noise levels as a function of the transmittance as the two beams are attenuated equally. Probe: Probe; Conj: Conjugate. (A) The two beams are globally attenuated with a variable beamsplitter. The two beams are attenuated with razor blades cutting from (B) the same direction, (C) the perpendicular direction, and (D) the opposite direction.

In order to show the multi-spatial-mode nature, we compared the noise levels' variation tendencies for different attenuation ways. If the generated quantum correlated beams (probe and conjugate) are single mode beams, it is clear that no matter how you equally attenuate the beams, there should be no difference in measuring the intensity-difference noise level. In other words, if we could show some clear differences, then we can draw a conclusion that the quantum correlation is in multi- spatial-mode. Along this line, we measure the intensity-difference noise level in various ways of attenuation, such as global attenuation with whole beams, razor blade cutting with a few different ways as shown in Fig. 3. The similarity of the variation tendencies between local cutting attenuation from the same direction (trace B) and global attenuation (trace A) shows that such cutting attenuation roughly gives the corresponding quantum correlated parts in our current scheme, and the difference between the tendencies of local cutting attenuations from the perpendicular and opposite directions (traces C and D) and the tendency of global attenuation (trace A) indicates that we have experimentally shown the multi-spatial-mode nature for the generated quantum correlated beams.

Reference

[1] L. Cao, et al., "Experimental observation of quantum correlations in four-wave mixing with a conical pump", Opt. Lett. 41, 1201 (2017).

[2] J. Du, et al., "Experimental observation of multi-spatial-mode quantum correlationsin four-wave mixing with a conical pump and a conical probe", Appl. Phys. Lett. 110, 241103 (2017).