Cascaded up-conversion of bright squeezed vacuum

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Parametric down-conversion (PDC) is a second-order nonlinear optical process where a pump photon splits into two ones with lower energy, which are called signal and idler photons. Depending on the pump intensity, two PDC regimes are distinguished, namely spontaneous (SPDC) and high-gain PDC, both of them producing nonclassical states of light. SPDC generates biphoton field, because the intensity of the generated light is low and the number of photons per mode is much smaller than one. In the high-gain regime, which requires a strong pump wave, at the output of crystal we get a nonclassical state of light with large number of photons per mode, known as bright squeezed vacuum (BSV) [1]. The efficiency of PDC depends on the value of the quadratic susceptibility, the pump intensity and the fulfilment of phase matching conditions, which are equivalent to the energy and momentum conservation laws [2].

Due to its unique statistical properties and large number of photons per mode, BSV can be an efficient pump source for nonlinear optical processes, e.g. optical harmonic generation [3]. Indeed, as the BSV intensity increases exponentially during propagation through a nonlinear crystal, the efficiency of cascaded nonlinear optical processes increases. One of them, the cascaded up-conversion of the signal wave due to its interaction with the pump wave, was considered e.g. in Refs. [4, 5]. It was shown that the temporal behavior of the output signals depends on whether the down-conversion or the up-conversion process dominates. In contrast to the temporal behavior of the output signals, the nature of the photon statistics is the same regardless of which process dominates.

In our work we present the results of experimental and theoretical studies of cascaded nonlinear processes induced by high-gain parametric down conversion.

In the experiment, a 10 mm BBO crystal was used for type-I PDC generation with the Ti:Sapphire laser (800 nm, 5 kHz repetition rate, 1.6 ps pulse duration and 220 μJ pulse energy) as a pump. Cascaded up-converted BSV signal with the central wavelength of 533 nm was observed for the degenerate and non-degenerate PDC regimes. The angular-frequency spectrum of up-converted BSV was measured. It should be noted that cascaded up-conversion occurs without the fulfillment of the phase-matching condition, which should be taken into account for the numerical description of the process.

For the theoretical description of broadband cascaded up-conversion of BSV the quantum momentum operator approach [6] was used. The evolution of the annihilation operators was found in the Heisenberg picture for the coupled BSV and up-converted modes. In comparison with the existing approaches [4, 5], our method allows one to take into account a non-zero phase-mismatch for different spectral components of the radiation. Using this solution, the angular-frequency spectra and the correlation functions of PDC and up-converted BSV were calculated. The main advantage of the proposed theoretical description is the ability to consider cascaded up-conversion as the losses for the BSV. In spite of the low efficiency of non-phase-matched up-conversion we show that such losses significantly decrease the value of quadrature squeezing of BSV.

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