Properties of squeezed light generated in ring microresonators

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Abstract

We report on the new theory approach to describe the correlation properties of photon pairs generated in high-Q on-chip microresonators in the four wave mixing process. The degree of two-mode squeezing and photon entanglement are investigated in dependence on different parameters of the pump or microresonator and the optimal regime for maximum squeezing is found. A special case of the quantum pump is discussed.

Recently, a new class of high-Q micro resonators has been developed, which are extremely promising for the generation of entangled photon pairs. Before that, the most well known devices are nonlinear bulk crystals based on the processes of spontaneous parametric down-conversion (SPDC) and spontaneous four wave mixing (SFWM). Such sources can create radiation with unique properties for different tasks, and for quantum optics problems. For many applications it is necessary to create photon pairs with a very high degree of two-mode squeezing or high correlation between photons. That was achieved using large length crystals, which allow to increase the interaction time inside the nonlinear medium [1]. However, for the problems of creating quantum devices on chip, increasing the length of the crystal is a big problem. In such a case, to use on-chip microresonators is a very good solution [2] that already demonstrates perspectives for quantum optics tasks [3], allows to achieve a high efficiency of light generation and moreover can be used to store and process quantum information [4].

The goal of our investigation is a theoretical analysis of correlation properties in generated photon pairs. Though there are some theoretical works describing nonlinear generation in resonators [5], here we extend the known theoretical approach to describe the SFWM specifically in high-Q on-chip resonators and focus on the searching the optimal regimes and parameters for greatest possible squeezing.

We analyze the generation of entangled photons in the ring resonator which $\chi^{(3)}$ nonlinearity in Heisenberg picture. The simplified Hamiltonian of the problem without losses is the following.

$$\hat{H} = \hbar\omega\hat{a}^\dagger\hat{a} - \frac{1}{2}\hbar g\hat{a}^\dagger\hat{a}^\dagger\hat{a}\hat{a} + \hbar\omega_+\hat{b}_+^\dagger\hat{b}_+ + \hbar\omega_-\hat{b}_-^\dagger\hat{b}_- - 2\hbar g\hat{a}^\dagger(\hat{b}_+^\dagger\hat{b}_+ + \hat{b}_-^\dagger\hat{b}_-)\hat{a} - \hbar g(\hat{b}_-^\dagger\hat{b}_+^\dagger\hat{a}\hat{a} + \hat{a}^\dagger\hat{a}^\dagger\hat{b}_-\hat{b}_+). \tag{1}$$

Here $\hat{a}, \hat{a}^\dagger$ stand for the photon operators in the pump mode, while $\hat{b}_\pm, \hat{b}_\pm^\dagger$ - in the correlated modes.

Because of the complexity of the system the degree of entanglement depends on many parameters such as a such as a versatile analysis is needed. It was found that the most important parameters are losses due to the connection with the external wave-guide, the amplitude of the pump field inside the resonator and the frequency detuning of the pump wave from the mode of the resonator. It was demonstrated that the degree of correlations and the purity of non-classical light increases with the loading of the resonator. Also the mapping of the squeezing degree versus many parameters is carried out and the optimal regimes are determined.

As a significant extension of our approach, the influence of quantum properties of the pump on the quality of the entanglement of generated photons is discussed.

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