Control and Manipulation of Spatial and Spectral Properties of Bright Squeezed Vacuum States of Light

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Nowadays different types of non-classical states of electromagnetic field are possible to be generated. Among them squeezed states of light appears to be the most attractive due to their unique properties that are very perspective for many important and interesting practical applications in modern quantum optics including storage and transfer of quantum information. Such non-classical states of light can be produced in a parametric down conversion process and are known to be characterized by strong correlations between photons. In addition such light can carry non-zero optical angular momentum and is referred to as twisted light. To control the mode content and properties of such non-classical squeezed twisted light both in the spectral and spatial domain is a very important problem.

It is possible to generate squeezed states of light with huge mean number of photons per mode. To describe theoretically the spatial and frequency properties of such bright squeezed light appears to be a rather difficult problem since in this case the perturbation theory is no more valid. For this reason to develop new theoretical approaches valid in this regime appears to be of great importance. In this work a new theoretical approach is presented that describes the features of bright squeezed vacuum light both in the spectral and spatial domain beyond the perturbation regime. Our generalized fully analytical approach is based on the concept of independent collective (Schmidt) modes and can be used for the cases of both weak and strong nonlinear interaction. In the frame of the Heisenberg representation we obtain a fully analytical solution for the evolution of the photon-creation operators for each Schmidt mode and calculate different characteristics measured in experiment.

In our work we investigate both theoretically and experimentally the spectral and spatial properties of bright squeezed vacuum light and suggest methods to control and manipulate its characteristic features, photon correlations and mode content using a developed SU(1,1) nonlinear interferometer scheme based on two nonlinear crystals separated by a certain medium. The scheme has turned out to be a versatile source of OAM modes populated by large numbers of photons. Variation of the number of OAM modes is demonstrated by changing the distance between the crystals or the pump power. The reconstruction of the spatial Schmidt modes shapes and weights from the covariance measurement on single-shot spectra is reported. Methods of selective amplification of different radial modes are developed. If between the crystals a medium with high group velocity dispersion is placed it is possible to play with the spectral properties of the squeezed light by changing the time delay between the pump pulse and the nonlinear signal amplified in the second crystal. The possibility of dramatic spectral narrowing and enhancement of the generated squeezed light in a certain frequency range is demonstrated. Methods of production of mostly single frequency mode radiation or selective generation of extremely narrow two-color squeezed vacuum light are suggested theoretically and demonstrated experimentally. A very good agreement between our theoretical results and experimental data is demonstrated. In addition the interplay between spatial and spectral degrees of freedom is analyzed and its experimental observation is discussed.