Single-mode bright squeezed vacuum

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Abstract. We perform the selection of a single mode from a bright squeezed vacuum state generated via high-gain parametric down-conversion. Since the first mode of the Schmidt expansion of the state available in experiment is approximately Gaussian, the selection is performed by means of a projection scheme based on a single-mode fiber. The selection strategy requires measuring the dependence of the intensity of the signal after the fiber vs. the waist of the Gaussian mode coupled into this fiber. The first Schmidt mode corresponds to the Gaussian mode at which this dependence peaks allowing for it to be isolated.

Keywords: squeezed vacuum, bright squeezed vacuum, Schmidt decomposition, narrowband filtering, parametric down-conversion.

1 Introduction

Squeezed vacuum (SV) is a quantum state of light, essentially multimode, generated at the output of an optical parametric amplifier (OPA) with the quantum vacuum state at the input. Bright squeezed vacuum (BSV) is obtained when the OPA is strongly pumped. In this work we address the experimental problem of extracting a single mode out of BSV and making it available for further use as a novel *macroscopic* quantum source, that is, a source with a large mean number of photons per mode that still preserves quantum correlations.

The usage of BSV can be beneficial in many applications. For instance, it promises to push forward the resolution capability of quantum lithography by beating the Rayleigh limit. The ability to exploit its high-order photon number correlations would work even better for the advancement of this field of research [1]. In the same direction, quantum interferometry with BSV may increase the precision of phase and displacement measurements, as it is expected to be the case for gravitational-wave detectors.

The enhancement of light-matter interactions by using conditionally prepared large Fock states is also foreseen as a beneficial application of BSV. It could be used in various emerging quantum technologies, for instance for quantum computing with ions, atoms or alike. While the opportunities of practical usage of BSV are far from being fully understood, it is clear that its impact in the field of quantum information and computation will be related not only with its brightness *per se*, but with the large dimensionality of its Hilbert space, which is a consequence of its multimodeness. However, this feature can only be properly exploited if it is possible to isolate and control individually a single mode of this radiation and thus to have access to multiple channels. Moreover, the possibility to study BSV itself, observing its statistics and using it as playground for fundamental research in quantum optics also depends on its availability in a single mode.

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2 Experiment

Our approach to the problem of filtering a single mode of BSV relies on the concept of the Schmidt decomposition. Previous work in this direction has shown that under certain conditions, faint SV can be expanded in orthonormal modes that preserve quantum correlations [3] and can be filtered out by implementing an appropriate projection scheme [2]. We performed an experiment aiming to detect and extract the first mode in the Schmidt expansion of a given BSV state. As a first approximation, our estimates are based on the similarities between faint SV and BSV. We deal only with angular variables and use the fact that the first spatial Schmidt mode is very close to a Gaussian. As a consequence, the experimental projection scheme needed for this task relies mainly on a single mode fiber (SMF), which acts as a lossless filter projecting the BSV field on the first Schmidt mode (Fig. 1).

3 Results

This situation has been modeled by taking into account the transfer function of the fiber. In experiment, by measuring the dependence of the intensity of the signal after the fiber vs. the waist of the Gaussian mode coupled into the fiber, the Schmidt mode can be targeted. Because the statistics of a single BSV mode are thermal, the measurement of the normalized second-order intensity correlation function $g^{(2)}$ before the fiber provides the information on the number of modes present in the system in the absence of filtering. However, after the fiber the information of the number of modes obtained through this quantity is erased due to the effect of the fiber itself and the properties of thermal light. This behavior agrees well with our calculations.

Radiation with single-mode statistics, in principle, can be retrieved by performing its narrowband filtering. This

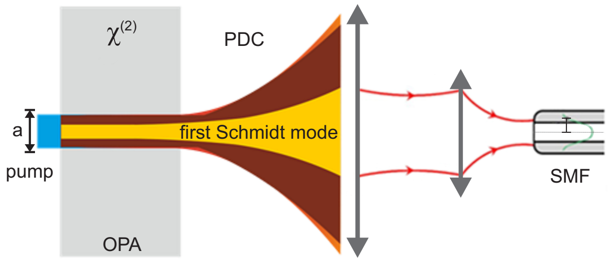

Figure 1: Experimental scheme showing the selection of the first Schmidt mode of the parametric down-conversion (PDC) radiation by a SMF. In the near field (crystal output plane) the diameter of the generated PDC beam is given by the size of the pump a and it considerably exceeds the coherence radius r, since the beam is not diffraction-limited. The waist of the first Schmidt mode is given by the geometric mean of these two parameters, a and r. Similarly, the PDC divergence is much larger than the divergence of the first Schmidt mode. The first Schmidt mode is a Gaussian (diffraction-limited) beam and it can be filtered optimally by a SMF.

is done by using a pinhole restricting the angular distribution of the radiation and a monochromator restricting its frequency bandwidth. As a result, the detection volume is much smaller than the coherence volume [4]. Using this method we have filtered a single mode of BSV with a very large mean number of photons, which already makes this system useful in applications. However the disadvantage of this procedure are the high losses introduced, which also demonstrates the importance of performing an appropriate Schmidt mode selection on BSV.

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