Improving Squeezing purity from a $KNbO_3$ crystal by temperature tuning

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Abstract: We show a method to increase the purity of a squeezed state generated by a femtosecond laser and down-conversion crystal. The method relies on temperature tuning the down- and up-converting crystals, which changes the spatial and spectral output mode of the down-converter to match the local oscillator.

OCIS codes: (270.6570) Squeezed States; (270.1670) Coherent optical effects

1. Introduction

Pure Vacuum Squeezing is desired for the generation of optical Cat States, which are a superposition of two coherent states with opposite phase. Recent work [1] showed that one can use a squeezed vacuum state and photon subtraction to generate an optical Schrödinger Cat. The fidelity of the cat state, however, is limited by the purity of the squeezed state. Generally the purity of the squeezed vacuum degrades by loss. Those losses are generally loss in optical elements and temporal and spatial mode-mismatch of the squeezed vacuum mode with the local oscillator mode. However, by using a femtosecond laser source, an additional source of degradation originates from the parametric down-converter itself: Some non-degenerate photon pairs are generated, of which only one photon occupies the same spectral, spatial and temporal mode as the local oscillator. This photon acts as a noise source and can be considered as excess noise from the parametric down-converter. These non-degenerate photon pairs are generated because of the broad bandwidth of the second harmonic pump and the crystal's phase matching conditions. By temperature tuning a $KNbO_3$ crystal, i.e. changing the phasematching conditions, we produce squeezed states with higher purity, which should allow for higher fidelity Cat States.

2. Phase matching and output modes

Our down- and up-converting crystals are 100 μm and 150 μm thick $KNbO_3$ crystals, cut for a fundamental wavelength of 862 nm. To achieve the phasematching condition, the crystals are temperature tuned. For vacuum squeezing, the signal and idler photons are desired to be degenerate at half the pump frequency. Also, these photons have to match the local oscillator spatial mode, i.e. they must be generated collinear with the pump. If the pump is a single frequency, this requirement is satisfied. However, by pumping with femtosecond pulses, the bandwidth of the pump is broad and non-degenerate collinear photons are generated of which only one photon will match the local oscillator modes. In order to suppress the generation of these photon pairs, the parametric up-conversion and down-conversion crystal can be temperature tuned to achieve the lowest possible number of excess noise photons.

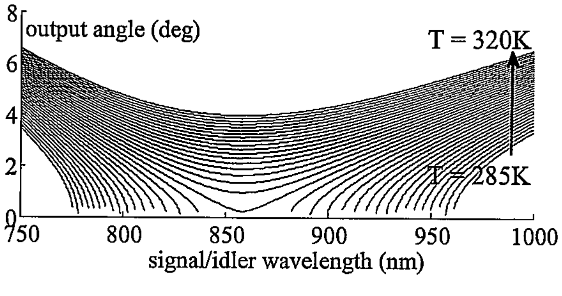

Fig. 1. Parametric downconversion from a KNbO3 crystal.

Figure 1 shows a calculation of the signal and idler output angles as a function of wavelength and crystal temperature. At the optimal phase matching temperature of 301K the down-conversion process produces signal and idler photons with equal wavelength (~862 nm) at an output angle of 0 degrees relative to the pump beam. At lower temperatures signal and idler photons of different wavelengths are both produced at an angle of 0 degrees, and at higher temperatures signal and idler photons of equal wavelength are produced at angles greater than 0.

3. Measurement and Results

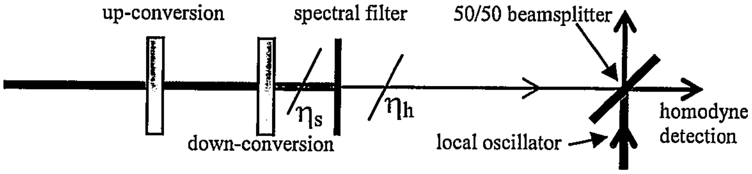

Fig. 2. Schematic experimental setup.

Figure 2 shows a schematic drawing of our experimental setup. A femtosecond laser pulse is sent into a 150 μm thick $KNbO_3$ crystal to create the second harmonic up-conversion for pumping the down-conversion crystal, which is a similar, 100 μm thick, $KNbO_3$ crystal. The down-conversion process creates a squeezed vacuum state. This state is then sent to a 50/50 beamsplitter, where it is combined with the local oscillator. The squeezed vacuum is measured by homodyne detection. The homodyne detection utilizes a charge integration system with a field effect transistor reset switch to allow for maximum signal-to-noise performance. Measurement of the whole squeezing phase space reveals the squeezing (minimum noise variance) and anti-squeezing (maximum noise variance) variances. We model a noisy squeezed state as a pure squeezed state that has passed through a beamsplitter with transmissivity η_s, which we call the 'purity' of the squeezed state. We can infer η_s from the observed squeezing and anti-squeezing noise levels and correcting for the homodyne detection efficiency (η_h = 80%) and electrical noise background (4%).

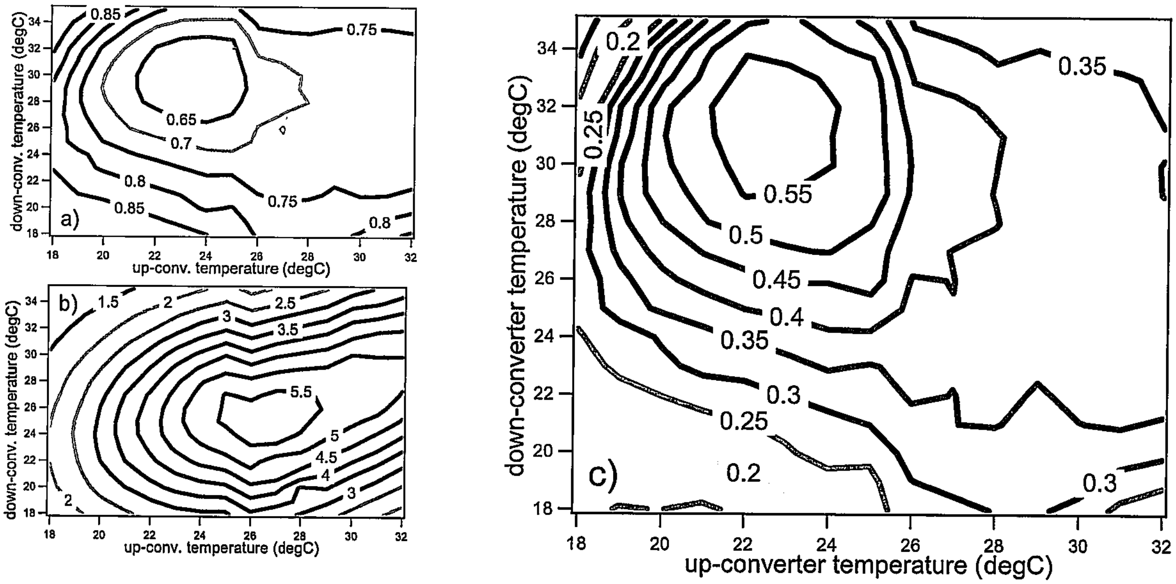

Fig. 3. Experimental Results. Figure 3c shows a contour plot of the squeezing purity η_s as calculated from the squeezing-to-anti-squeezing ratio. Figure 3a and 3b show the acquired squeezing and anti-squeezing values, respectively.

Figure 3 shows the results. Figure 3a and 3b show contour plots of the acquired squeezing and anti-squeezing variances as a function of up-converting and down-converting crystal temperatures. In both crystals optimum phasematching was achieved at 28°C. However, at this temperature the purity of the squeezed vacuum is only 40% (Fig. 3c), whereas for a lower up-conversion temperature (22°C) and higher a down-conversion temperature (32°C), the purity increases to 59%. This is a 47% increase compared to the optimum phasematching temperature.

4. Conclusion

The data clearly indicates an improvement of the squeezing purity with crystal temperature tuning. For higher down-converter temperatures and lower up-converter temperature, the purity increases. This method can potentially be useful for the generation of high fidelity cat states where high purity and high amplitude squeezing is desired.

5. References

[1] Alexei Ourjoumtsev, Rosa Tualle-Brouri, Julien Laurat, Philippe Grangier, "Generating Optical Schrödinger Kittens for Quantum Information Processing", Science **312,** 83-86 (2006)