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Noiseless, Quasi-Phase-Matched Parametric Amplifier in Bulk Lithium Niobate

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Although noiseless optical amplification has been demonstrated in bulk KTP crystals, and is well understood, there have been no observations of noiseless optical amplification in bulk quasi-phase-matched (QPM) systems. That such an amplifier is possible was predicted recently and indeed squeezing has already been observed in QPM waveguides (using KTP and $LiNbO_3$). QPM materials are attractive for use in quantum-optical devices because they give access to certain (large) components of the nonlinear susceptibility tensor that cannot be used in conventional birefringent phase-matching schemes. They also extend the range of materials accessible for use in parametric amplifiers to include some low-birefringence crystals exhibiting large nonlinearities.

Even with the technological advantages offered by certain QPM crystals, efforts to find practical applications for optical parametric amplifiers are hampered by the need for enormous pump-field strengths. The obvious solution to the problem of the pump-field requirement is to confine the incident energy to a narrow interaction region thereby increasing the energy density. However, this approach can only be realised at the expense of sacrificing the homogeneity of the parametric interaction between pump and signal waves. This in turn causes vacuum field fluctuations from parasitic modes to be mixed into the signal mode thereby degrading the signal to noise ratio and negating the advantage of using an optical parametric amplifier.

In the experiments presented here, optical signals have been amplified with up to 9dB of gain, yet with a noise figure (NF) of only 1.09, as compared to the minimum possible NF of a classical amplifier with the same gain which would equal 1.86. Furthermore, the interaction is achieved with tightly focused incident fields in a sample of bulk QPM lithium niobate. The entire interaction region is only 200μm thick and 2.8mm long. This performance was achieved with the aid of a theoretical model in which the effect of wavefront curvature and mode distortion are treated within a quantised mode framework using a spatial mode basis. Such a simulation permits the fundamental origin of the excess quantum noise to be easily traced to zero-point fluctuations of high-order spatial modes which couple to the signal mode *via* the parametric interaction. Furthermore the simulation enabled an experimental geometry to be selected in which an optimal compromise is made between wavefront matching (pump beam smaller than signal) and pump-homogeneity (pump larger than signal), so that the overall noise figure remains well into the quantum-performance region.

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