Scalable squeezed light source for continuous variable quantum sampling

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Abstract

We propose a novel squeezed light source meeting the stringent requirements of continuous variable quantum sampling. Using the time-dependent effective second-order nonlinear interaction induced by a strong driving beam in the presence of the χ_3 response in a microresonator, our approach is compatible with established nanophotonic platforms. With typical realistic parameters, squeezed states with mean photon number of 10 or higher can be generated in a single consistent temporal mode at repetition rates of over 100MHz. Over 15dB of squeezing is expected in existing ultra-low loss platforms.

No degenerate squeezed light source has yet been proposed which satisfies all the requirements for practically useful quantum sampling. These stringent requirements are: (i) Scalability. (ii) Single-mode operation (iii) Sufficient squeezing levels (iv) Compatibility with single photon and photon number-resolving detection. The requirements (ii) and (iii) can be succinctly stated in mathematical terms: an ideal source provides an output quantum state of the form $e^{(r/2)A^2-\mathrm{H.c.}}|\mathrm{vac}\rangle$, with squeezing factor r reliably tunable, and in which $A = \int d\omega f(\omega)a(\omega)$ is the annihilation operator for a single well-defined spatiotemporal mode, the characteristics of which do not vary over the tuning range of r. We propose a scalable squeezed light source that comprehensively satisfies these requirements by using the time-dependent effective second-order nonlinear interaction induced by a strong driving beam in the presence of the χ_3 response in a microresonator. This allows us to write an effective squeezing Hamiltonian for 3 resonator modes, driving (D), pump (P) and squeezer (S) as $H_{\mathrm{sq}} \sim \chi_3 b_D b_P b_S^\dagger b_S^\dagger = (\chi_3\beta_D)\beta_P b_S^\dagger b_S^\dagger = \chi_2^{\mathrm{eff}}\beta_P b_S^\dagger b_S^\dagger$, where the classical amplitudes satisfy $\beta_D \gg \beta_P$ and β_D is quasi continuous-wave. This operation regime allows us to suppress spurious effects such as dynamical detunings induced by self- and cross-phase modulation of the pumps since, for our proposal, the largest contribution of these effects is a static detuning proportional to $|\beta_D|^2$. We consider a device optimized for a CW drive input power of 200 mW and include the effects of time-dependent self-phase modulation and cross-phase modulation from the pump pulse. In Fig. 1 (a) we show the squeezing performance for a structure with 400 μm round-trip length, $\omega_S = 2\pi \times 193$ THz, nonlinear parameter $\gamma_{\mathrm{NL}} = 1\ (\mathrm{Wm})^{-1}$, group velocity $v_g = c/1.7$, and intrinsic quality factor of 2×10^6 for all three resonances with escape efficiencies of 0.5 (critically coupled) for the drive mode D, 0.9 for the S mode, and 0.98 for the pump mode P; the corresponding loaded quality factors are then respectively 1×10^6, 2×10^5, and 4×10^4. In Fig. 1 (b) We show the mean photon-number occupation of the first ten Schmidt modes the dominant mode lies about 100x above the next largest mode. These results show that our design satisfy desiderata (ii) and (iii) of our list and together with appropriate fabrication and pump suppression techniques can also be made to satisfy desiderata (i) and (iv).

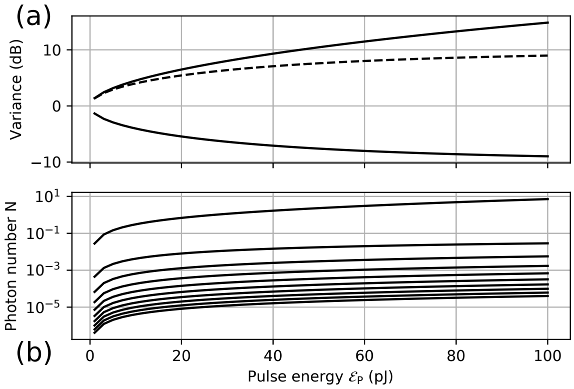

Fig. 1: System performance for a device with realistic parameters (details in text): (a) Variance relative to vacuum of the squeezed quadrature (bottom solid curve) and anti-squeezed quadrature (top solid curve) for the dominant mode. Dashed curve shows variance of anti-squeezed quadrature for an ideal pure state; Some excess anti-squeezing is evident from the finite escape efficiency. (b) Mean photon number of the first ten Schmidt modes as a function of pulse energy; the dominant mode (top curve) consistently lies about 100x above the next largest mode.

[1] Z. Vernon et al., *Scalable squeezed light source for continuous variable quantum sampling*, arXiv:1807.00044.