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Efficient generation of sub-Poissonian light via coherent diffusive photonics

Matthew Thornton[1], Anton Sakovich[2], Dmitri Mogilevtsev[2] and Natalia Korolkova[1,2]

[1] University of St Andrews, St Andrews, Scotland

[2] B. I. Stepanov Institute of Physics, Minsk, Belarus

Abstract

Sub-Poissonian light, with a sharp photon-number distribution, possesses capabilities far exceeding those of classical light, and has ready applications in future Quantum Technologies such as quantum communication or quantum metrology. In this work we present numerical simulations of an integrated photonic waveguide device ("PhoG": *Photon Gun*) which is demonstrated to produce a bright sub-Poissonian output from a coherent-state input. The device is also demonstrated to deterministically produce entanglement between spatially separated waveguides. We build several theoretical models of increasing realism, and explore optimal coupling and nonlinearity parameters in preparation for an imminent first experimental demonstration of the PhoG device.

Quantum states of light possess capabilities exceeding those of classical light. Although non-classical states with well-defined photon number find many applications in quantum information processing [1, 2], methods for their deterministic and efficient generation remain elusive. In this work we numerically demonstrate the viability of non-linear coupled waveguides for deterministic generation of sub-Poissonian states - those possessing a sharp photon number distribution - and for exploration of the interplay between Hermitian and non-Hermitian (diffusive) dynamics. It is known, for example, that diffusive coupling between can lead to rich quantum properties such as entanglement generation [3], protection against decoherence [4], single-photon generation [5], or noise equalization [6]

We simulate a system of two bosonic "signal" modes in the waveguides, which are diffusively coupled via a long "tail" of evanescently coupled waveguides acting as a reservoir. All modes are subject to a strong $\chi^{(3)}$ nonlinearity. A input coherent state evolves to a sub-Poissonian output (Mandel parameter $Q < 0$) via an effective interaction mediated by the nonlinearity. The input state evolves to a sub-Poissonian output in the superposition basis of signal modes, over timescales inversely proportional to the input amplitude. We also observe entanglement generation in the original basis of signal modes.

To numerically model the system effectively, one must balance computational memory requirements against the requisite large number of tail modes and large Hilbert spaces, and a full quantum mechanical is numerically infeasible. Instead, we present a series of approximate models starting from a fully quantum single mode dissipating via a "nonlinear coherent loss" Lindblad term, $\mathcal{L}\left(\hat{a}_i^\dagger \hat{a}_i \hat{a}_i\right)\rho$, with decay rate proportional to $\chi^{(3)}$, and increasing in realism towards a many-mode model dissipating by the standard single-photon loss channels $\mathcal{L}\left(\hat{a}_i\right)\rho$. The same characteristic behaviours of intensity-dependent loss and sub-Poissonian output are observed in all models, and thus each system model is shown to reproduce the output of theory [5].

Our full system can be readily fabricated in photonic waveguides [6] and so with experiment in focus we use our simulations to explore the optimal regimes for coupling strengths and propagation length, noting that each model is in agreement over the region of optimal experimental parameters. We move soon towards a first experimental implementation, with the ultimate aim to provide a deterministic and compact source of sub-Poissonian light

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