Quantum Correlations in Nanolaser: Lasing and Squezing

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We report the first identification of a non-classical regime of squeezed light emission in a single-mode quantum dot laser model that fully accounts for two-particle quantum correlations between photons and charge carriers. This phenomenon, previously unassociated with lasers, paves the way for novel applications of nanolasers in continuous-variable quantum technologies.

Moreover, lasing occurs in the presence of quantum bistability between a non-lasing state and a non-classical coherent state. The coherent state, defined by a distinct central frequency and finite linewidth, emerges from a saddle-node bifurcation with finite amplitude, accompanied by an unstable coherent state. As a result, coherent emission in nanolasers stems from a mixing of lasing and non-lasing states.

Importantly, we verify that these effects persist even when the nanolaser includes non-identical quantum dots with a distribution of transition frequencies, reinforcing their relevance for experimental realization.

We further find that the population inversion at threshold changes monotonically with cavity losses and the light-matter coupling strength. In contrast, the pump rate at threshold exhibits non-monotonic behavior, with minima caused by rapid depletion of the upper level at strong coupling or low cavity losses.

In the limit of a macroscopic laser—comprising many emitters and multiple non-resonant modes—the threshold approaches the semi-classical prediction. However, a crucial distinction remains: lasing in this regime requires finite-size perturbations to initiate.