Nanolaser Model Including Quantum Correlations and Collective Effects

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We present a model for a single-mode nanolaser that incorporates all two-particle quantum correlations between photons and electrons. Our findings indicate that the onset of lasing necessitates finite amplitude fluctuations of stimulated emission. Furthermore, we demonstrate that lasing and non-lasing regimes coexist, which is consistent with the quantization of light and contrary to semi-classical predictions. The laser solution with continuous stimulated emission is characterised by a central frequency, which is determined by a universal formula, and a finite linewidth, which can be experimentally verified to identify the emission process. Electron-electron correlations, which are responsible for collective effects such as superradiance, increase the threshold for continuous stimulated emission; however, this effect is significantly mitigated by weak phonon scattering. As the number of intracavity emitters increases, the quantum model with phonon-induced dephasing increasingly aligns with the semiclassical model, except in the immediate vicinity of the laser threshold. The effects of two-particle quantum correlations on the resulting nanolaser model are examined, allowing for the identification of a bistable region between a laser solution with constant amplitude stimulated emission and a non-laser solution with low coherence. In contrast to semi-classical theories, our findings align with light quantization and reveal a bistability region in systems that are far from the semi-classical limit.