Modeling of phonon effects on a single quantum dot laser

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Single atom lasers [1] have been predicted to have interesting characteristics with respect to their threshold behavior and quantum properties of the emitted light. Experimental evidence of single quantum dot lasing [2] shows that this ultimate limit of miniaturization of laser devices is achievable in the solid state technology. On the other hand, carrier-phonon coupling has been demonstrated to modify the dynamical properties of a quantum dot–cavity system [3], which can be expected to affect also the quantum-dot laser properties.

In this contribution, we theoretically study the dynamics of a quantum dot–cavity system from the point of view of the phonon effects on the transient build-up of the cavity field, the lasing threshold, and the quantum properties of the field itself.

Our model is based on the Markovian Master equation for a two-level atom interacting with a single cavity mode, as described by the standard Janes–Cummings Hamiltonian, and incoherently pumped from the ground to the excited state. Cavity losses and radiative recombination to unconfined modes are also included. In addition, the quantum dot is coupled to bulk phonons via the standard coupling mechanisms typical for semiconductors. Such a model can be solved numerically exactly for the inversion dynamics and the evolution of the cavity field state.

We study the interplay between the phonon-assisted feeding of the cavity mode and the phonon-induced dephasing of optical coherence and discuss the modification of the lasing threshold and quantum field properties induced by the coupling to phonons.

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