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Semiclassical Maxwell- Bloch computational methods for superradiance and subradiance effects in quantum dot systems

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Extended Abstract

Collective constructive interference in optical ensembles gives rise to the phenomenon of superradiance [1]. In this effect, a spontaneous phase-locking of dipoles from two- or multi-level systems leads to radiation emission that is faster and stronger compared to the case of independent emitters. Theoretical descriptions of superradiance often rely on effective Hamiltonians where interaction with one or few cavity modes is assumed, the emitters are homogeneous, and the excitation is considered to be perfectly symmetric. However, to understand superradiance, it is essential to consider the role of the emitters' spatial and energy inhomogeneity. Disorder in the local distribution of the emitters strongly affects the superradiant dynamics by populating subradiant states, where emitters can remain trapped in excited states.

Here, we use a new Maxwell Bloch computational approach [2] to simulate the superradiant coupling of CuCl semiconductor quantum dot ensembles embedded in a NaCl solid matrix. These materials exhibit strong dot-dot dipolar coupling, and some superradiant effects have been experimentally observed in them [3]. Our computational approach describes the dynamics of each quantum dot, which evolves in the presence of a classical radiation field resulting from the laser, and long- and short-range dipolar field originating from all the other dots. The approach reduces the full quantum master equation dynamics to a set of coupled nonlinear Bloch equations describing each dot's excitation and polarization dynamics. In systems with a small number of multilevel dots, we compare the full master equation dynamics with our semiclassical approach to explore the role of quantum mechanical entanglement in the dynamics.

Our computations identify geometrical, density, and frequency configurations that could lead to observing new superradiant and subradiant phases in these systems. In particular, the approach could help engineer systems where entanglement-rich dark states can be exploited for quantum technology applications such as quantum memories or quantum sensing.

References

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