Characterizing and bypassing decoherence in semiconductor quantum dot-based light-matter interfaces

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Semiconductor quantum dots (QDs) have been demonstrated to be versatile candidates to study the principles of light-matter interaction [1]. In contrast to fundamental atom-photon interfaces, a key factor to the understanding of observed phenomena in semiconductor quantum electrodynamics is the interaction of electrons with the semiconductor QD host material, cf. Fig. 1(a). The inherent many-body properties of a solid-state, in particular the electron-phonon interaction, lead to often undesired decoherence, where the superposition of otherwise distinct quantum states becomes lost and information about the system is carried away into the surrounding of the embedded QD.

For example, the Wigner delay of QD light emission is limited not only by twice the radiative lifetime as in the case for isolated atoms but also by the phonon-scattering induced decoherence time to approximately the lifetime of the exciton, cf. Fig. 1(b). This decoherence is, however, intrinsically non-Markovian with a memory effect of the host material and the detuning dependence clearly shows an interplay between incoherent and coherent electron-phonon processes, not captured with Lindblad-based dephasing models. A successful approach to model non-Markovian scattering processes relies on the semiconductor Bloch equation approach, employing Born-factorization but including non-secular and non-Markovian effects self-consistently within this microscopic-based approach [2]. In Fig. 1(b), the non-Markovian theory reproduces the experimental data while Markovian models are of limited accuracy either for small or large detunings.

A microscopic theory at hand to characterize and identify the source of decoherence, proposals to counteract decoherence become possible. Here, we propose to take the strongly entangled and non-Markovian properties of the system-environment dynamics into account. By solving the dissipative dynamics exactly beyond the Born-factorization approach, we theoretically demonstrate how reservoir engineering allows to stabilize initial coherence in a QD system up to room temperature via quantum feedback or Pyragas-based control protocols. In Fig. 1(c), we plot the coherence $\langle \eta(t) \rangle$ at 200 ps for different temperatures and feedback delay times. At certain values for the delay ($\alpha_0 \tau/(2\pi) = 1.0$), the initial coherence is almost fully recovered even at elevated temperatures.

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References