Phonon limit to simultaneous near-unity efficiency and indistinguishability in semiconductor single photon sources

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Semiconductor quantum dots have recently emerged as a leading platform to efficiently generate highly indistinguishable photons [1-4], and this work addresses the timely question of how good these solid-state sources can ultimately be. We establish the crucial role of lattice relaxation in these systems [4], which we show gives rise to trade-offs between indistinguishability and efficiency. We analyse the two source architectures most commonly employed: a quantum dot embedded in a waveguide and a quantum dot coupled to an optical cavity. For waveguides, we demonstrate that the broad-band Purcell effect [5] results in a simple inverse relationship, where indistinguishability and efficiency cannot be simultaneously increased. For cavities, the frequency selectivity of the Purcell enhancement results in a more subtle trade-off, where indistinguishability and efficiency can be simultaneously increased, though by the same mechanism not arbitrarily, limiting a source with near-unity indistinguishability (> 99%) to an efficiency of approximately 96%.

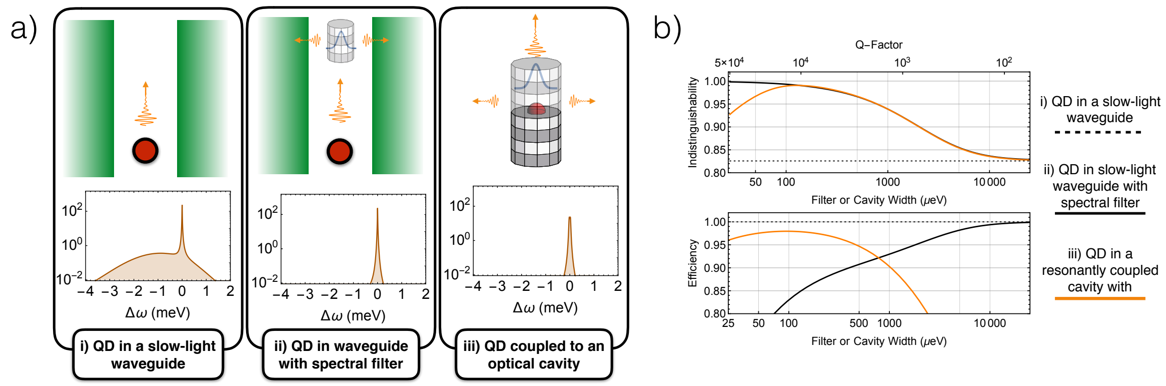

Figure 1: a) (i–iii) show the three single photon source designs we analyse and their associated emission spectra: a QD emitting into a slow-light waveguide with and without a spectral filter, and a QD in a coherently coupled optical cavity. b) Indistinguishability and efficiency of the three source architectures. The indistinguishability plot indicates that the dominant effect of a resonantly coupled cavity is to filter the QD emission, while the efficiency plot demonstrates that Purcell enhancement in a cavity can overcome efficiency losses incurred by filtration of the phonon sideband.

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