Cavity-waveguide interplay in optical resonators and its role in optimal single-photon sources
Interfacing solid-state emitters with photonic structures is a key strategy for developing highly efficient photonic quantum technologies. Such structures are often organized into two distinct categories: nanocavities and waveguides. However, any realistic nanocavity structure simultaneously has characteristics of both a cavity and waveguide, which is particularly pronounced when the cavity is constructed using low-reflectivity mirrors in a waveguide structure with good transverse light confinement. In this regime, standard cavity quantum optics theory breaks down, as the waveguide character of the underlying dielectric is only weakly suppressed by the cavity mirrors. By consistently treating the photonic density of states of the structure, we provide a microscopic description of an emitter including the effects of phonon scattering over the full transition range from waveguide to cavity. This generalized theory lets us identify an optimal regime of operation for single-photon sources in optical nanostructures, where cavity and waveguide effects are concurrently exploited.
Fundamental cavity-waveguide interplay in cavity QED

Interfacing solid-state emitters with photonic structures is a key strategy for developing highly efficient photonic quantum technologies [1]. Such structures are often organised into two distinct categories: nanocavities and waveguides. However, any realistic nanocavity structure simultaneously has characteristics of both a cavity and waveguide, which is particularly pronounced when the cavity is constructed using low-reflectivity mirrors in a waveguide structure with good transverse light confinement. In this regime, standard cavity quantum optics theory breaks down, as the waveguide character of the underlying dielectric is only weakly suppressed by the cavity mirrors. In this work [2], we present a quantum optical model that captures the transition between a high-Q cavity and a waveguide, allowing consistent treatment of waveguides, lossy resonators, and high quality cavities. Our model constitutes a bridge between highly accurate optical simulations of nanostructures [3] and microscopic quantum dynamical calculations. This way, the quantum properties of generated light can be calculated, while fully accounting for the electromagnetic properties of the nanostructure. The generality of this theory enables us to identify an optimal regime of operation for quantum dot single-photon sources, which simultaneously harnesses the high efficiency of a waveguide and the phonon-suppressing spectral structure of a cavity [4,5].
Protocol for generating multiphoton entangled states from quantum dots in the presence of nuclear spin fluctuations

Multiphoton entangled states are a crucial resource for many applications in quantum information science. Semiconductor quantum dots offer a promising route to generate such states by mediating photon-photon correlations via a confined electron spin, but dephasing caused by the host nuclear spin environment typically limits coherence (and hence entanglement) between photons to the spin $T_2^*$ time of a few nanoseconds. We propose a protocol for the deterministic generation of multiphoton entangled states that is inherently robust against the dominating slow nuclear spin environment fluctuations, meaning that coherence and entanglement is instead limited only by the much longer spin $T_2$ time of microseconds. Unlike previous protocols, the present scheme allows for the generation of very low error probability polarization encoded three-photon GHZ states and larger entangled states, without the need for spin echo or nuclear spin calming techniques.

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Denning, E. V., PhD Student, Department of Photonics Engineering
Mørk, J., Main Supervisor, Department of Photonics Engineering
Iles-Smith, J., Supervisor, Department of Photonics Engineering
Willatzen, M., Supervisor, Department of Photonics Engineering
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