
Tensor Networks for Solid State Emitters: Understanding Effects of Acoustic and Optical Phonon Modes on Photon Indistinguishability

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Abstract

On-demand single photon sources with high indistinguishability are necessary for photonic quantum technologies. Indistinguishability is degraded by a highly non-Markovian vibrational environment. It has been shown that optical cavities and waveguides can enhance the indistinguishability of the bare emitter via filtering effects. To understand this, we employ tensor network techniques to exactly calculate the environmental influence and then compute two-time correlation functions of both the emitter and cavity mode.

We investigate both delocalised acoustic phonons, found in quantum dots, and localised optical phonons, present in materials with defects such as hexagonal boron nitride and diamond. These have qualitatively different effects on quantum dynamics, affecting indistinguishability differently. Notably, localised optical phonons have not been thoroughly studied. A better understanding of phonon effects in solid state emitters can aid in selecting appropriate materials for single photon sources.

Previous studies using quantum master equations, only focus on acoustic phonons and fail under certain light-matter coupling conditions. Our method makes use of time-evolving matrix product operators (TEMPO) which exactly encode the non-Markovian phonon effects of the emitter. Additionally, we employ the iTEBD algorithm to efficiently apply the MPOs to yield an infinite process tensor. This allows us to determine correlation functions of the emitter and cavity operators. Light-matter coupling can be exactly included, providing a filtering effect to the generated photons, which therefore allows indistinguishability and the power spectrum to be calculated.

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