Unconventional Temperature-dependence of the Zero-phonon Linewidth in Nanowire Quantum Dots

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The coherence properties of two-level systems are of crucial importance for their application in future quantum information technologies. For two-level systems in the solid-state, such as semiconductor quantum dots, the presence of charge carriers and phonons can give rise to decoherence channels that may limit their application in these technologies. Here we investigate the role of phonon-mediated dephasing using temperature-dependent high-resolution spectral linewidth measurements of photons emitted from the radiative decay of excitonic complexes in InAs/InP nanowire quantum dots [1]. These devices are fabricated using a bottom-up vapour-liquid-solid epitaxy technique that eliminates several linewidth broadening mechanisms associated with dry-etched semiconductor surfaces, 2D wetting layers and other quantum dots.

Zero-phonon linewidths of both neutral and charged excitonic complexes were a few hundred MHz at 1.8K, corresponding to approximately two times the lifetime limit, measured using incoherent excitation into the InP host material. For temperatures up to approximately 16K, we observed a non-linear increase in the linewidths consistent with a description based on the independent Boson model [2]. For higher temperatures, however, linewidths of all complexes were observed to oscillate with a period of approximately 7K. This anomalous temperature dependence was robust against large variations in the nanowire quantum dot geometry and persisted in magnetic fields of up to 9T directed along the nanowire growth direction. To account for this unconventional temperature dependence, we hypothesize a mechanism based on a phonon-mediated spin-orbit interaction specific to cylindrical geometries.

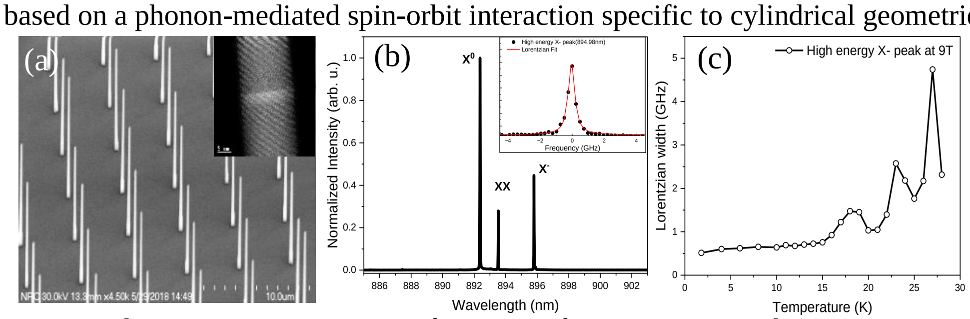

Fig. 1: (a) Scanning electron microscopy image of an array of nanowires. Inset shows a transmission electron microscopy image of an InAs/InP quantum dot. Each nanowire has a single such dot embedded within. (b) Photoluminescence spectrum of the s-shell emission from a dot measured at 1.8K and zero magnetic field showing both neutral (X^0 and XX) and charged (X^-) exitonic complexes. Inset shows the high-resolution spectrum of one of the Zeeman-split X^- states measured at 9T with the magnetic field directed along the nanowire growth direction. (c) Temperature-dependent linewidth of the X^- peak measured at 9T.

References

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[2] P. Laferrière, *et al.* Approaching transform-limited photons from nanowire quantum dots using excitation above the band gap, *Phys. Rev. B* **107**, 155422 (2023).