Quantum optics in the solid state

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Due to their favourable properties, quantum dots (QDs) have attracted much recent attention from the broader quantum optics community. In particular, they have demonstrated excellent performance as sources of non-classical light for prospective optical quantum technologies. Whilst these concepts are typically based on an "ideal" quantum optics picture of an isolated two-level emitter (TLE), a QD also exhibits interactions with the local semiconductor environment which are not present in this simple picture. Whilst some problematic interactions such as those associated with fluctuating charges have been dealt with by advances in sample quality, thermal interactions with quantised vibrations of the semiconductor lattice (phonons) cannot readily be eliminated, even at ultra-low cryogenic temperatures.

In this talk I will present an overview of these electron-phonon interactions in QDs, detailing how they influence both the absorption and emission spectra of the QD in weak and strong excitation regimes. I will show how phonon interactions break the symmetry of the absorption spectrum, leading to a surprising regime where the QD TLE can reach population inversion despite the use of incoherent excitation [1]. Moving to the weak excitation regime, I will explore the influence of the phonon coupling on the emission spectrum. In particular, I will demonstrate that the fraction of light emitted into the incoherent "phonon sideband" is completely insensitive to excitation conditions [2]. I will also explain how phonon interactions lead to a strong modification of the balance of coherent and incoherent scattering processes when compared to the ideal TLE picture [2].

Harnessing this understanding of the role of electron-phonon interactions in the quantum optics of QDs, I will discuss the consequences for their applications to quantum technologies such as non-classical light sources [3]. In particular, I will focus on future possibilities for controlling and exploiting the phononic environment of QDs with a view to future applications in optical quantum technologies.

[1] J. H. Quilter, A. J. Brash et al., 'Phonon-Assisted Population Inversion of a Single InGaAs / GaAs Quantum Dot by Pulsed Laser Excitation', Phys. Rev. Lett. 114 137401 (2015).

[2] A. J. Brash et al., 'Light Scattering from Solid-State Quantum Emitters: Beyond the Atomic Picture', Phys. Rev. Lett. 123 167403 (2019).

[3] F. Liu, A. J. Brash et al., 'High Purcell factor generation of indistinguishable on-chip single photons', Nat. Nanotechnol., 13 835–840 (2018)