Semiconductor quantum optical nanosystems

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In this talk I will give an overview of several research themes pursued in my group in which optically active quantum dots or molecules are embedded within electrically tunable structures and / or tailored photonic environments. For example, we have used multicolour ultrafast pump-probe spectroscopy to investigate charge and spin dynamics in individual, electrically tunable InGaAs quantum dots and molecules. Results show how the polarization state of light can be faithfully mapped onto the exciton spin wavefunction, manipulated via geometric phase control and read out via spin-selective stimulated exciton emission or conditional biexciton absorption. Similar experiments performed on QD-molecules elucidate the comparative roles of elastic and inelastic *intra*-molecular electron tunneling and allow us to directly probe coupling of the molecular exciton to acoustic phonons, one of the principle sources of decoherence. We achieve precise hole spin initialization and monitor the real time coherent evolution of the hole spin wavefunction in an externally applied magnetic field. Dephasing of the exciton and single hole spin wavefunctions is entirely negligible over typical manipulation times (<4ps), facilitating very high fidelity (>97%) state control.

Whilst light can be used to control and manipulate to such isolated matter qubits, photons also provide the most attractive route to couple spatially separated quantum systems. Here, technologies based on two-dimensional photonic crystals are attractive since they allow for control of coherent light-matter interactions using defect *nanocavities*, the efficient routing of single photons “on-chip” using *waveguides* that exploit slow light phenomena and photon state characterisation using *beam splitters*. The additional development of integrated single photon detection would open up attractive paradigms for integrated *quantum optical circuits*. With this motivation I will also discuss the use of slow light phenomena in GaAs photonic crystal waveguides to efficiently route single photons and detect them using *integrated* NbN superconducting single photon detectors (SSPDs) on GaAs substrates. Studies of optimised samples reveal that up to 96% of the photons emitted by single dot couple to the waveguide mode and, furthermore, NbN SSPDs on GaAs exhibit remarkable single photon detection efficiencies >20% at 950nm with a timing resolution <90ps. First attempts to realize waveguide coupled SSPDs on GaAs will also be discussed.