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【8】Quantum Photonics with solid-state emitters

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Arguably, the only really useful single photon source in quantum technology is a source of close-to-perfect single photons. The demands are stringent in terms of purity (the level of anti-bunching), coherence (the level of indistinguishability) and brightness (the efficiency of the entire device). Such a source would find applications in device-independent quantum cryptography. The quantum repeater requires in addition a stationary bit at each node, for instance a coherent spin. Ideally therefore, a system is required with a coherent spin and efficient spin-photon interface.

Implementing these ideas in the solid-state is appealing as nano-technology can potentially add a lot of device functionality. However, a solid-state environment is a source of noise, phonons in the lattice, charge noise from fluctuating charges in the solid and spin noise from the fluctuating nuclear spins of the host atoms. Also, a solid-state emitter may emit not just a photon (the zero-phonon-line) but also a photon together with a phonon.

Reported here is progress on two prominent solid-state emitters, a semiconductor quantum dot [1] and the NV colour centre in diamond. The two emitters have complementary strengths and weaknesses. A semiconductor quantum dot is a source of high quality single photons but single spins dephase rather rapidly. Conversely, the NV centre hosts a highly coherent spin but the photons are of low quality.

In the case of quantum dots, the noise in high quality material is very low [2] and in the best case (resonant excitation at low temperature), transform-limited linewidths have been achieved [3]. A micro-cavity is under development with the goal of increasing the brightness [4]. A quantum dot electron spin dephases rapidly on account of the spin noise in the nuclei. A hole spin is a viable alternative and dephases much less rapidly than an electron spin in the presence of unprepared nuclear spins [5].

In principle, a resonant micro-cavity confers multiple benefits to the NV centre photons: faster recombination, preferential emission into the micro-cavity mode, and, crucially, an increase in the zero-phonon-line fraction. In practice, it has been difficult to secure these advantages, largely because nano-fabrication of diamond is very challenging. However, an increase in the zero-phonon-line fraction from 3% to close to 50% has now been achieved by embedding ultra-pure diamond membranes in a micro-cavity [6].

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