Hybrid quantum photonics with nanodiamonds and plasmons

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Hybrid quantum photonic platforms combining different photonic elements in a single functional unit have great potential to leverage the strengths of individual subunits while avoiding their respective limitations. The desired functionality of such a hybrid integration relies on strong light-matter interaction at the single-photon level, and requires nanometre-scale fabrication precision and potentially involves a material diversity that is incompatible with standard nanotechnological processes.

In this talk, I will discuss our recent developments in realization of hybrid integrated quantum photonic circuits based on dielectric-loaded plasmonic waveguides, containing accurately positioned nanodiamonds (NDs) with colour centres. This includes a top-down fabrication technique that was developed for accurate and deterministic positioning of waveguide components to incorporate NDs containing a single (nitrogen, silicon or germanium) vacancy centre [1]. Moreover, a chip-integrated cavity was demonstrated combining resonant and plasmonic enhancement to increase the spontaneous emission rate of single photons at the zero-phonon line, with up to 42-fold Purcell enhancement at the cavity resonance [2].

We have also demonstrated on-chip remote excitation of single quantum emitters by the plasmonic modes in dielectric ridges atop colloidal silver crystals [3]. Quantum emitters were produced by incorporating single germanium-vacancy (GeV) centres in NDs, providing bright, spectrally narrow and stable single-photon sources suitable for highly integrated circuits. Cryogenic characterization of GeV-NDs indicated symmetry-protected and bright zero-phonon optical transitions with up to 6-fold enhancement in energy splitting of their ground states as compared to that found for GeV centers in bulk diamonds (i.e. up to 870 GHz in highly strained NDs vs. 150 GHz in bulk) [4]. The larger energy split in the ground state implies a potentially longer spin coherence time due to the suppressed phonon-mediated transitions between the lower and upper branches. Using electron-beam lithography with hydrogen silsesquioxane (HSQ) resist, dielectric ridges were fabricated on single crystalline silver plates to contain those of deposited NDs that were found to feature appropriate single GeV centres. The hybrid plasmonic configuration enabled the 532-nm pump laser light to propagate on-chip in the waveguide and reach an embedded ND containing a single GeV centre. The remote GeV emitter was thereby excited and coupled to spatially confined modes with an outstanding figure-of-merit of 180 due to a ∼six-fold Purcell enhancement, ∼56% coupling efficiency and ∼33 μm propagation length (at the emission wavelength), thereby opening new avenues for the implementation of nanoscale functional quantum devices.

References

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