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Quantum nanophotonics with group IV defects in diamond

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Diamond photonics is an ever-growing field of research driven by the prospects of harnessing diamond and its colour centres as suitable hardware for solid-state quantum applications. The last two decades have seen the field shaped by the nitrogen-vacancy (NV) centre with both breakthrough fundamental physics demonstrations and practical realizations. Recently however, an entire suite of other diamond defects has emerged—group IV colour centres—namely the Si-, Ge-, Sn- and Pb-vacancies. In this perspective, we highlight the leading techniques for engineering and characterizing these diamond defects, discuss the current state-of-the-art group IV-based devices and provide an outlook of the future directions the field is taking towards the realisation of solid-state quantum photonics with diamond.

The field of diamond photonics is marching into its third decade—its birth arguably marked by the 1997 discovery of room temperature optically detected magnetic resonance from a single diamond nitrogen-vacancy (NV) centre.[1] The unique ability of the NV's spin to be initialized, manipulated and optically read out at room temperature gave substance to the aspiration of realizing solid-state quantum bits operating in ambient conditions.[2,3] Tremendous efforts followed, driven by the goal to engineer high-quality NV centres with long spin coherence times, and ameliorate the fabrication of diamond nanostructures for efficient light extraction.[4–7] The remarkable progress made in pursuit of this endeavour resulted in landmark realizations both in fundamental and applied science including on-demand entanglement,[3] nanoscale nuclear magnetic resonance[8,9] and quantum memories.[10]

Nonetheless, these realizations revealed how advanced quantum applications require specific characteristics for the single-photon emitter candidate. For quantum communication, it is desirable for the emitter to have high quantum efficiency, high Debye–Waller factor, short lifetime and negligible spectral diffusion. Additionally, for quantum sensing and quantum computing the source should have an addressable spin state to encode the information, which can be initialized, manipulated and read out, and with a coherence time that is a few-order-of-magnitude longer than the time required to perform a fundamental operation on the state itself. Consequently, for some applications that require better photon throughput, for example, quantum repeaters, the NV centre is not ideal. Its long fluorescent lifetime (~11 ns) and weak emission into the zero-phonon line (ZPL) (only ~4% at room temperature) put an upper bound to the maximum photon rates achievable when employing NV centres in basic quantum

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