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Research paper

Creation of negatively charged GeV and SnV centers in nanodiamonds via ion implantation

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ABSTRACT

Solid-state quantum emitters, in particular group-IV vacancy centers in diamond, are at the forefront of research in quantum technologies due to their unique optical and spin properties. Reduction of the diamond host size to the nanoscale enables new opportunities in terms of integration and scalability. However, creating optically coherent quantum emitters in nanodiamonds remains a major challenge. Here, we present the fabrication of germanium- and tin-vacancy centers by means of ion implantation. We describe the fabrication process and present the optical properties of the created color centers. We achieve high-purity single-photon emission via resonant excitation and strong coherent drive of a SnV^- center. The successful integration of heavier group-IV vacancy centers in nanodiamonds paves the way for further advances in fields such as hybrid quantum photonics or sensing on the nanoscale.

1. Introduction

Coherent quantum emitters are key building blocks on the way to establishing quantum-based networks [1–4] or quantum repeaters [5–7]. Ideally, the interface would be modular, functionally scalable and mass-producible. Integrating solid-state quantum emitters with photonic devices is an appealing approach to solve the challenge of implementing such an interface [8,9]. One alternative approach is to employ a hybrid system [10,11] comprising of a nanodiamond (ND) as the color center host, which is then selectively positioned within, for instance, silicon-based photonic devices [12], micro-cavities [13–15], or bullseye structures [16]. NDs hosting color centers, are not only essential for application in quantum optics, but they have attracted remarkable attention for bioimaging [17,18] and quantum sensing on the nanoscale [19,20]. It is therefore of great interest to reliably incorporate color centers into NDs maintaining their good optical properties. As a coherent photon source, inversion-symmetric negatively charged group-IV vacancy (G4V) centers, in particular silicon vacancy (SiV^-), germanium vacancy (GeV^-), and tin vacancy (SnV^-) centers, are emerging candidates [21–23]. These emitters offer a high Debye–Waller factor, which results in a predominant emission into the zero-phonon line (ZPL) (Fig. 1(a)), crucial for spin-photon entanglement [24–26]. The ZPL wavelengths for the SiV^-, GeV^- and the SnV^- centers are 737 nm, 602 nm and 620 nm respectively [27–29]. Additionally, their atomic structure, consisting of a group-IV element bonded to two adjacent missing carbon atoms, results in a D_{3D} symmetry (Fig. 1(b)) which makes them robust against disturbances from external electrical fields [30–32]. The electronic structure of G4 V centers is a spin 1/2 system, which results in an electronic energy level scheme as shown in Fig. 1(c). Spin–orbit coupling leads to the formation of four orbital levels, two arising from the splitting of the ground state (GS) and two from the excited state (ES) [33]. The resulting optically active transitions are labeled as A, B, C, D in Fig. 1(c) and can be observed only at cryogenic temperatures. Depending on the impurity atom, the transition energies vary as well as the energy splitting of the GS and ES. The respective GS splittings for SiV^-, GeV^- and SnV^-, at zero strain, are 50 GHz, 150 GHz and 850 GHz and the ES splittings are 250 GHz, 980 GHz and 3000 GHz (Fig. 1(c)) [29,30,34].

Among G4V centers, the SiV^- is the most studied [35–38] and lot of previous work has been done to optimize the fabrication process both via ingrowth synthesis [39–41] and ion implantation [42–44]. In contrast, the deterministic creation of heavier G4V centers remains challenging. It is nevertheless desirable due to the good coherence properties of SnV^- and GeV^- centers at liquid helium temperature [45,46].

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