Optical Characterization of Single Tin-Vacancy Centers in Diamond Nanopillars

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Abstract: We characterize the optical and spin properties of tin-vacancy centers isolated in diamond nanopillars. We measure spectrometer-limited linewidths < 15 GHz, a strong polarization dependence of the emission, and Zeeman splitting behavior consistent with previous theoretical predictions.

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Color centers in diamond have emerged in recent years as attractive candidates for optically active, solid-state quantum bits (qubits). In particular, inversion-symmetric color centers based on group-IV impurities in diamond have gained interest because of their strong emission into their zero-phonon lines (ZPL) and immunity to electric field noise to first order [1]. The negatively charged tin-vacancy (SnV^-) center in diamond is of this class of emitters. The large ground-state splitting of ~ 850 GHz of SnV^- suggests it has potential for a long spin coherence time T_2 at 4 K [2]. The SnV^- has also been found to have greater quantum efficiency ($QE \sim 80\%$) than negatively charged Si- and Ge-vacancy (SiV^- and GeV^-) centers [3]. Furthermore, the ZPL wavelengths of SnV^- (~ 620 nm) are longer than those of the GeV^- and Pb-vacancy center, which facilitates future integration of SnV^- into nanophotonic devices.

Despite the promising attributes of the SnV^- center in diamond, its properties remain relatively unexplored, especially for single SnV^- in fabricated nanostructures. We have fabricated diamond nanopillars containing single SnV^- centers and characterized the photoluminescence spectrum. The SnV^- has four ZPLs around 620 nm referred to as transitions A, B, C, and D in order of decreasing energy. At temperatures below ~ 40 K, the spectrum is dominated by the C and D transitions. We characterize the linewidths, polarization, and Zeeman splitting of the C and D transitions.

We fabricate pillars that contain SnV^- by implanting electronic grade, single crystal diamond with $^{120}Sn^+$ ions at 370 keV, with a dose of 2×10^{11} cm^{-2}. After annealing the implanted diamond for 30 minutes at 800°C and 90 minutes at 1100°C, we grow 200 nm silicon nitride (Si_xN_y) by low-pressure chemical vapor deposition. The pillars are defined by electron-beam lithography and range in diameter from 140 nm to 300 nm. Using the Si_xN_y as an etch mask, we etch 500 nm into the diamond with a directional O_2 plasma etch. A scanning electron microscope (SEM) image is shown in Fig. 1(a).

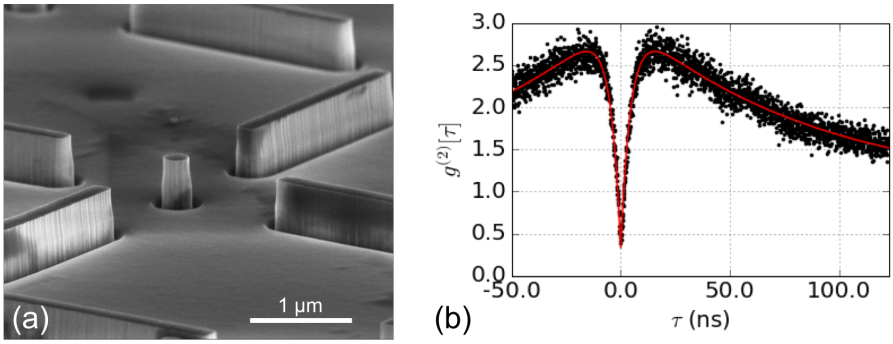

Fig. 1. Single SnV^- center in a nanopillar. (a) SEM image of a diamond nanopillar. Neighboring bars facilitate the location of pillars in 2D photoluminescence scans. (b) Second-order autocorrelation ($g^{(2)}[\tau]$) measurement of a SnV^- in a nanopillar. We find $g^{(2)}[0] = 0.31 \pm 0.02$, indicating that a single SnV^- has been isolated in the nanopillar under study.

We verify that the SnV^- in the pillars are single emitters by measuring the second-order autocorrelation ($g^{(2)}[\tau]$). An example data set with a fit to the data is shown in Fig. 1(b). For that pillar the $g^{(2)}[0]$ is found to be 0.31 ± 0.02, indicating that the SnV^- in the pillar is indeed a single emitter.

We measure the photoluminescence spectrum and find the optical transition linewidths for C and D to be spectrometer-limited. A Lorentzian fit to the peaks, shown in Fig. 2(a) finds the upper estimates on the linewidths to be 10.6 GHz and 11.7 GHz for C and D respectively. We find the emission to have strong polarization dependence (Fig. 2(b)) reminiscent of that measured for SiV^- [4].

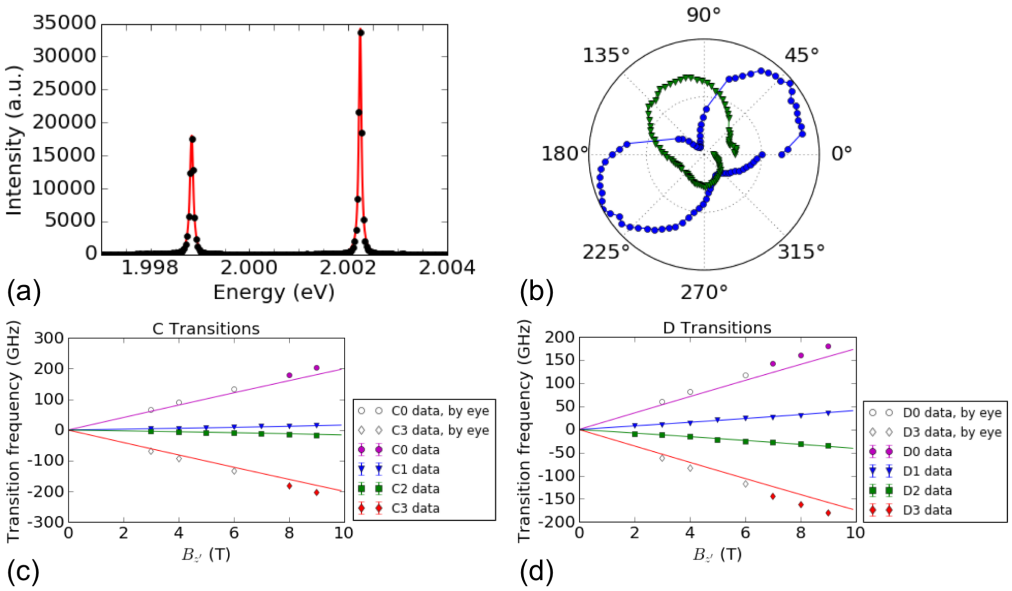

Fig. 2. Photoluminescence of single SnV^-. (a) Photoluminescence spectrum of a SnV^- in a diamond nanopillar. Lorentzian fits (red curves) to the data (black dots) have linewidths 10.6 GHz and 11.7 GHz for C and D transitions respectively. (b) Polarization dependence of the emission. C transition data are represented with blue dots, and D transition data with green triangles. (c) Locations of the optical transitions C under a magnetic field applied along [001] ($B_{z'}$). The C transition splits into four distinct transitions. Experimental data of the transition frequencies are presented as points. Solid lines are derived from the theory presented in Ref. 2. (d) Same as (c) for D transitions. Plots for (c) and (d) from Ref. 5.

Lastly we characterize the spin response of SnV^- to an external magnetic field applied along the [001] axis. From spectra taken at different magnetic field strengths, we extract the central frequencies for each of the peaks that appear. The results can be found in Figs. 2 (c) and (d). We find the experimental data to be in good agreement with theoretical predictions from Ref. 2.

In summary, we isolate single SnV^- in diamond nanopillars and characterize the optical and spin properties. The single SnV^- is found to have spectrometer-limited linewidths < 15 GHz and a strong polarization dependence of both optical transitions. Furthermore, the Zeeman splitting behavior of the SnV^- is in good agreement with the theoretical model proposed by Ref. 2.

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