Shallow Diamond Silicon Vacancy Centers for Coherent Spin-Magnon Coupling

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Abstract:

We aim to develop a platform for coupling isolated silicon-vacancy (SiV) electron spins to magnetic spin waves, potentially enabling a magnon mode to act as a quantum bus. To enhance the dipolar coupling, SiV centers need to be placed near the magnetic material, and thus near the surface of the diamond. Here we report on our study of the optical properties of shallow diamond SiV centers.

Summary of Research:

Diamond SiV centers can have long spin coherence times and narrow optical transitions, enabling the realization of spin-photon entanglement [1]. These good properties make SiV a good candidate for engineering a quantum bus. We aim to develop a spin-magnon interface by coupling SiV centers to a high-quality magnon mode. A key parameter, the spin-magnon coupling rate, is maximized when the SiV spins are close to the magnetic material [2]. However, shallow defects are more susceptible to surface states that reduce coherence times and broaden optical transitions [3,4]. Here we fabricate near surface diamond SiV centers and study their properties relevant to spin-magnon transduction.

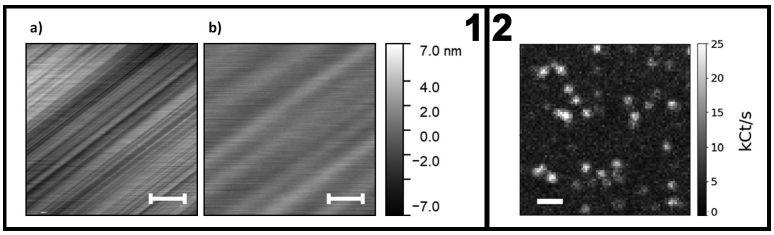

Figure 1, left: Diamond surface atomic force microscope (AFM) image before (a) and after (b) Ar/Cl2 and O2 reactive ion etch. Scale bar is 1 μm.

Figure 2, right: Photoluminescence image of SiV centers. Scale bar is 1 μm.

We start from a single crystal diamond substrate (nitrogen concentration < 5 ppb). A polished diamond sample has a highly strained surface layer. We remove the top 5 μm using reactive ion etch (RIE) with Ar/Cl_2 and O_2 plasma [5,6] using the PT 770 etcher. This process reduces surface roughness and polishing streaks (Figure 1). The diamond sample is then implanted with 45 keV ^{28}Si ion at a fluence 10^{10} ions/cm^2, resulting in an estimated implanted depth of 32 ± 9 nm [7]. The sample is vacuum annealed to mobilize vacancies enabling the formation of SiV centers. Vacuum annealing also leaves behind graphite on the diamond surface, which we remove by cleaning the diamond in through a tri-acid boil (equal volume of sulfuric, nitric and perchloric acid).

We study the optical properties of the SiV centers in a home-built confocal microscope setup. SiV centers are excited with a continuous wave green laser (532 nm) with a power density of about 50 mW/μm^2. We observed a SiV density of 0.5 SiV/μm^2, corresponds to a conversion efficiency of 0.5% (Figure 2), comparable to conversion efficiency at a higher implant energy (150 keV) [8].

SiV centers emit about 70% of light into the zero-phonon line (ZPL) near 737 nm [9], which is advantageous for single photon generation. At room temperature, this line is a few nm broad due to electron-phonon processes [10]. At low temperature (10 K), the line narrows and a four-line fine structure emerges (Figure 3a). The fluorescence wavelength distribution is shown in Figure 3b. About half of the SiV centers transition emission lines have linewidths at the spectrometer resolution limit.

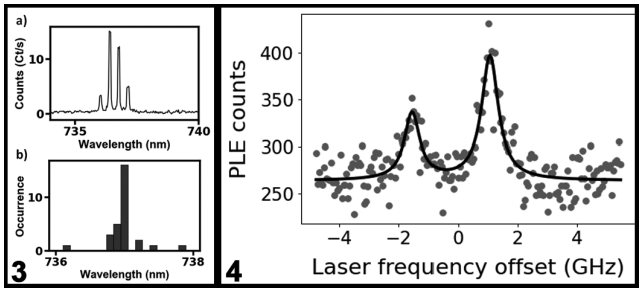

Figure 3, left: (a) Emission spectrum of a SiV center. (b) Wavelength distribution of 29 SiV centers. Figure 4, right: PLE scan of a SiV center under 400 nW/μm² resonant laser excitation. Full width half maximum (FWHM) are 630 ± 220 MHz and 680 ± 240 MHz.

To more accurately probe the linewidth, we use photoluminescence excitation (PLE) spectroscopy. We excite SiV centers with a frequency-tunable laser that we tune over the resonant optical transition while collecting emission from the phonon sidebands with wavelength larger than 750 nm. We observe narrow transition linewidths of 630 ± 220 MHz (Figure 4), which is only a few times larger than the lifetime limited linewidth (93 MHz) [8].

Conclusions and Future Steps:

We fabricated shallow diamond SiV centers with narrow optical transitions. In the future we plan to study the spin of shallow SiV centers as we work towards integration of SiV centers with magnetic material.

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