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Quantum Control and Waveguide Integration of Diamond Tin-Vacancy Spin Qubits

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Abstract: We show coupling of an SnV center to a diamond waveguide of 20% with almost transform-limited optical transitions. Besides, we show control over the SnV spin qubit and extend its coherence to over a millisecond.

1. Introduction

Nodes of a quantum network require an efficient spin-photon interface, coherent spin qubits and high-fidelity spin qubit control. Color centers in diamond have shown to be promising candidates for this role [1,2]. The tin-vacancy (SnV) has emerged as an interesting candidate of this family as it can be integrated in nanophotonic devices with preservation of optical properties due to its robustness against charge noise while allowing operation temperatures above 1 K. Moreover, it has a high quantum efficiency and Debye-Waller factor, both around 0.8 [3]. Therefore it is compatible with nanophotonic waveguides with a broadband nature and lower fabrication and tuning requirements than nanophotonic cavities. The microwave control of tin-vacancy requires strain to be allowed. Here we show that this does not hold back quantum control and dynamical decoupling, consistent with recent reports [4, 5], establishing microwave as a feasible control mechanism.

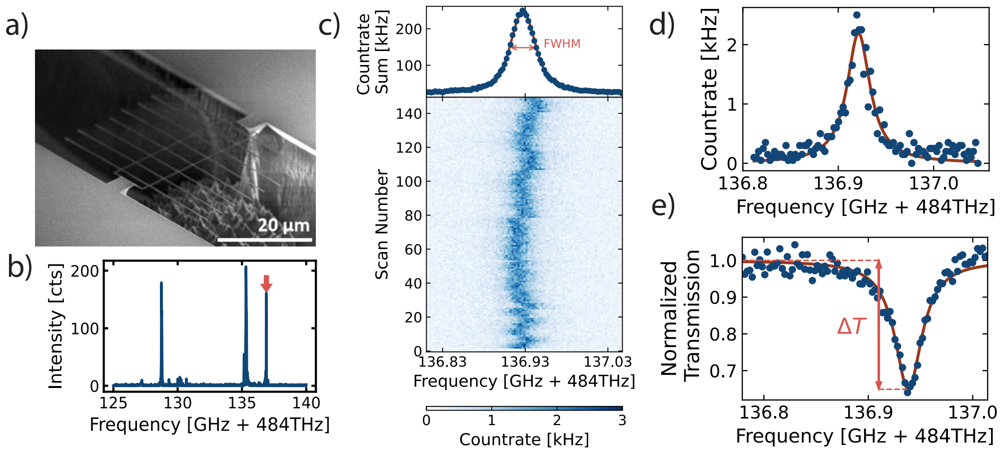

Fig. 1. Waveguide integration of SnV (a) Scanning electron microscope image of the suspended diamond waveguides. (b) Photoluminescence excitation (PLE) scan showing several SnVs coupled to the waveguide. (c) Repeated PLE on a single SnV (red arrow in (b)). In this scan, no charge initialization pulse is applied. The plot on top shows the sum of all scans. (d) Single line scan showing narrow, almost transform-limited linewidth. (e) Transmission extinction due to coherent interaction between the low-power input laser and the SnV.

2. Waveguide integration

The SnVs were created by implantation of Sn ions and subsequent annealing. The single mode diamond waveguides were fabricated using quasi-isotropic diamond etching, placed in a 4K closed cycle cryostat and coupled on both sides to a lensed fiber [6]. In a photoluminescent excitation (PLE) measurement (fig. 1(b) multiple SnVs show up. In fig. 1(c) the PLE is repeated 150 times on one of the peaks. The summed signal has a FWHM of 35.8(2) MHz compared to an individual linewidth of 29(1) MHz (fig. 1(d)), indicating limited spectral diffusion.

The individual linewidth is close the lifetime limited, hence the optical transition is coherent and dephasing is limited. Lastly, we measure the transmission through the waveguide, using the second fiber to collect the light. When we use a low power input laser an transmission dip (fig. 1(e)) is observed. The depth of the dip of 35(1) % indicates a clear nonlinear effect and corresponds to a coupling of the SnV to the waveguide of 20%, close to the theoretical maximum for this waveguide.

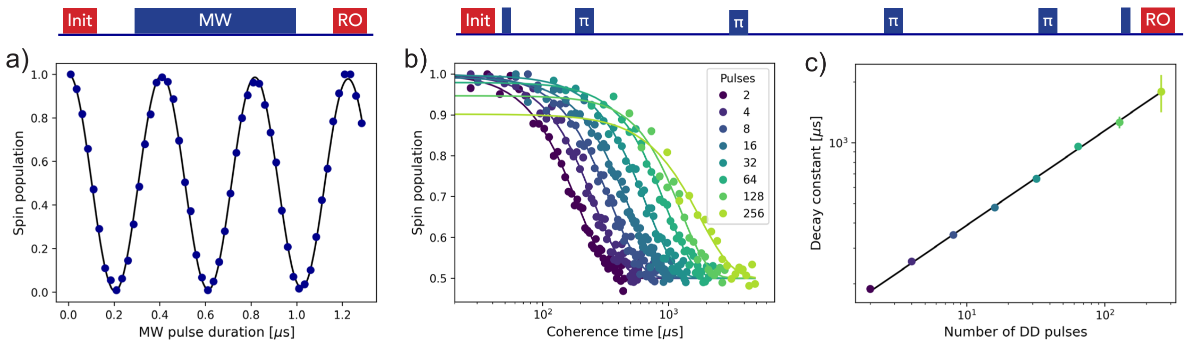

Fig. 2. Quantum control of the electronic spin of SnV. a) Rabi oscillations of with a frequency of 2.4 MHz induced by a resonant microwave driving field. (b) Dynamical decoupling of the SnV spin qubit with an increasing number of decoupling pulses. (c) The 1/e decay constants of the fits in (b). On top of fig. (b) and (c) the pulse sequence for decoupling with 4 pulses is shown.

3. Microwave control

The spin control experiments are performed on a bulk diamond device with a suspended bond wire over the sample in a Helium-3 fridge operating at 0.4 K. The bond wire isolates the MW transmission from the sample, reducing the local heating effects. Fig. 2(a) displays the Rabi oscillations when driving the spin transition at 3.14 GHz, where depending on the power Rabi frequencies up to of 15.7(1) MHz are achieved. To extend the T_2^* coherence of 1.0(1) μs we use the dynamical decoupling (DD) with an XY8 sequence using up to 256 π-pulses, increasing the coherence to 1.8(4) ms. The decay curves of DD can be fitted with $A \cdot \exp(-(\frac{t}{\tau})^n)$, where τ is the coherence time. These coherence times follow the relation aN^{χ} with χ is 0.47(1) (fig. 2(c)).

4. Conclusion

We have shown waveguide integration of the SnV center with coherent and stable optical transitions and coupling of 20% to the waveguide. Furthermore, we show microwave control of the SnV allowing for coherence times of over a millisecond. When combining the spin-photon interface with the control an efficient quantum network node based on the SnV could be realized.

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