Toward Novel Coherence Protection and Sensing Techniques: Closed Counter Interaction Using a Single Spin

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Abstract: By studying Nitrogen Vacancy (NV) centers embedded in diamond cantilevers, we show that the coupling between the cantilever and the NV leads to novel coherent population dynamics when combined with two microwave driving fields. © 2019 The Author(s)

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Hybrid mechanical systems offer a variety of routes to study fundamental questions regarding the coupling of the quantum states of disparate systems, including cooling the motion of mechanical oscillators to their ground states [1]. To study these effects, mechanical oscillators have been coupled to a variety of qubits, including superconducting circuits [2], quantum dots [3], cold atoms [4], and single spins [5].

In our work, we make use of the negatively charged nitrogen vacancy (NV^-, written here as just NV) center–an artificial atom comprising a nitrogen impurity and an adjacent vacancy in a diamond crystal lattice. The NV center has shown promise in a wide range of sensing and quantum information applications, including sensing of AC and DC magnetic fields [6] and coherence protection [7]. Their usefulness arises from their ease of use and preparation, including room temperature operation, long coherence times, and optical spin polarization [8]. Additionally, the $S = 1$ spin triplet ground state of the NV is easily manipulated with microwave magnetic fields [8]. Their coupling to the strain of the host crystal has long been studied, from static bending experiments to quantify the coupling parameters in the spin triplet ground state [9], to coupling single NVs or ensembles to mechanical resonators to study the effect of dynamic strain fields [7, 10, 11].

Here we exploit strain coupling to form a so-called closed contour interaction (CCI), i.e. we simultaneously address the two magnetic dipole (MD) transitions $|0\rangle \leftrightarrow |\pm 1\rangle$ of the $S = 1$ ground state with magnetic microwave fields while simultaneously using strain to drive the MD-forbidden $|+1\rangle \leftrightarrow |-1\rangle$ transition. We show that simultaneous driving of all three transitions gives rise to novel dynamics and coherence protection schemes, as well as offering new states for sensing and fundamental tests of state preparation. Fig. 1a shows the NV level structure along with our CCI driving scheme. When all three driving fields are present, a novel control parameter emerges: the global phase, given by the combination of the individual driving phases $\Phi = \phi_1 + \phi_2 - \phi_3$. By preparing our NV in the state $|m_s = 0\rangle$ and allowing it to evolve in the presence of all three driving fields, we observe oscillations in the population of the state $|0\rangle$ as a function of the evolution time, as shown in Fig. 1b. We show that these oscillations are due to the emergence of dressed states with Φ-dependent coherence times [7].

By controlling the ramp shape of our microwave pulses in our CCI driving scheme, we can initialize our system in a single dressed state and study its coherence properties directly [12]. We explore the properties of these three-level dressed states, studying both their coherence protection and sensing properties. We aim to use these properties to directly study dynamical decoupling and noise spectroscopy in the dressed state basis, as well as to use them as future testbeds for novel state transfer protocols.

References

1. J. Chan, T. P. Mayer Alegre, A. H. Safavi-Naeini, J. T. Hill, A. Krause, S. Gröblacher, M. Aspelmeyer, O. Painter, "Laser Cooling of a Nanomehcanical Oscillator into its Quantum Ground State," Nature **478**, 89–92 (2011).
2. M. D. LaHaye, J. Suh, P. M. Echternach, K. C. Schwab, M. L. Roukes, "Nanomechanical Measurements of a Superconducting Qubit," Nature **459**, 960–964 (2009).
3. M. Montinaro, G. Wüst M. Munsch, Y. Fontana, E. Russo-Averchi, M. Heiss, A. Fontcuberta i Moral, R. J. Warburton, M. Poggio, "Quantum Dot Opto-Mechanics in a Fully Self-Assembled Nanowire," Nano Lett. **14**, 4454–4460 (2014).
4. A. Jöckel, A. Faber, T. Kampschulte, M. Korppi, M. T. Rakher, P. Treutlein, "Sympathetic Cooling of a Membrane Oscillator in a Hybrid Mechanical-Optical System," Nat. Nanotechnol. **10**, 55–59 (2015).

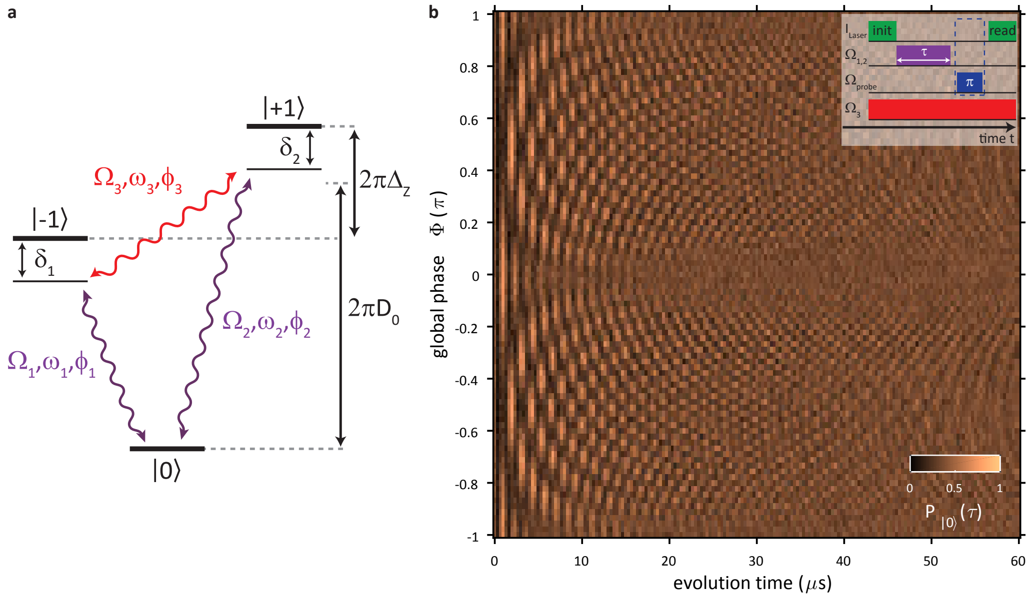

Fig. 1. Three-level dressed state dynamics. a) Level diagram of the NV, in which the microwave fields of frequency $\omega_{1,2}$ and Rabi frequency $\Omega_{1,2}$ drive the $|0\rangle \leftrightarrow |\mp 1\rangle$ magnetic dipole transitions and a dynamic strain field of frequency ω_3 and Rabi frequency Ω_3 drives the $|+1\rangle \leftrightarrow |-1\rangle$ transition. The phases of the driving fields are indicated by ϕ_i. b) The population of the $|0\rangle$ state $P_{|0\rangle}$ shows oscillations in the presence of the three driving fields, with both the oscillation frequencies and decay times depending on the global phase $\Phi = \phi_1 + \phi_2 - \phi_3$. The inset shows the pulse sequence used in the measurements. Figures reused with permission from [7].

5. D. Lee, K. W. Lee, J. V. Cady, P. Ovartchaiyapong, A. C. Bleszynski Jayich, "Topical Review: Spins and Mechanics in Diamond," J. Opt. **19**, 033001 (2017).
6. C. L. Degen, F. Reinhard, P. Cappellaro, "Quantum Sensing," Rev. Mod. Phys. **89**, 035002 (2017).
7. A. Barfuss, J. Kölbl, L. Thiel, J. Teissier, M. Kasperczyk, P. Maletinsky, "Phase-Controlled Coherent Dynamics of a Single Spin Under Closed-Contour Interaction," Nat. Phys. **14**, 1087–1091 (2018).
8. M. W. Doherty, N. B. Manson, P. Delaney, F. Jelezko, J. Wrachtrup, L. C. L. Hollenberg, "The Nitrogen-Vacancy Colour Centre in Diamond," Phys. Rep. **528**, 1–45 (2013).
9. J. Teissier, A. Barfuss, P. Appel, E. Neu, P. Maletinsky, "Strain Coupling of a Nitrogen-Vacancy Center Spin to a Diamond Mechanical Oscillator," Phys. Rev. Lett. **113**, 020503 (2014).
10. P. Ovartchaiyapong, K. W. Lee, B. A. Myers, A. C. Blaszynski Jayich, "Dynamic Strain-Mediated Coupling of a Single Diamond Spin to a Mechanical Resonator," Nat. Comm. **5**, 4429 (2014).
11. E. R. MacQuarrie, T. A. Gosavi, N. R. Jungwirth, S. A. Bhave, G. D. Fuchs, "Mechanical Spin Control of Nitrogen-Vacancy Centers in Diamond," Phys. Rev. Lett. **111**, 227602 (2013).
12. J. Kölbl, M. S. Kasperczyk, L. Thiel. A. A. Clerk, H. Ribeiro, P. Maletinsky, "Initialization of Single Spin Dressed States using Shortcuts to Adiabaticity," Phys. Rev. Lett. **122**, 090502 (2019).