Quantifying NV Center Spectral Diffusion by Symmetry

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Principal Investigator(s): Gregory D. Fuchs

User(s): Brendan Andrew McCullian

Affiliation(s): School of Applied and Engineering Physics, Cornell University

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Contact: gdf9@cornell.edu, bam327@cornell.edu

Primary CNF Tools Used: GCA 6300 DSW 5X g-line Wafer Stepper, Heidelberg Mask Writer – DWL2000, AJA Sputter Deposition, Westbond 7400A Ultrasonic Wire Bonder

Abstract:

The spectrally narrow, spin-dependent optical transitions of nitrogen vacancy (NV) center defects in diamond can be harnessed for quantum networking applications. Two challenges limit scalability: defect-to-defect variations of the optical transition frequencies caused by local strain variation, and spectral diffusion of the optical frequencies on repeated measurement caused by photoexcitation of nearby charge traps. We quantify spectral diffusion and strain, decomposing each into components of specific symmetry, and investigate correlations between spectral diffusion, strain, and depth from surface. Our correlation study reveals that ideal NV centers are likely found to have large transverse strain and are at depths which balance surface charge trap effects with laser focal aberration effects.

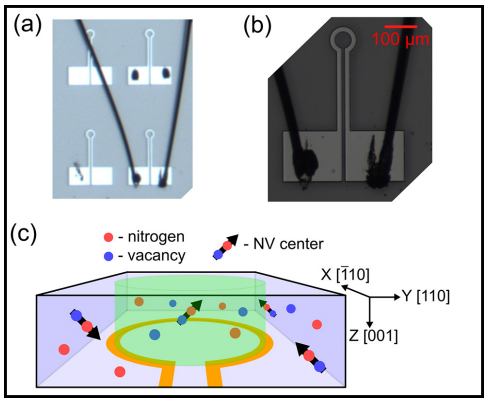

Figure 1: (a, b) Optical micrographs of litho-graphically defined loop antennas grown on diamond surface and wire bonds to microwave source. (c) Schematic of diamond sample with spatially isolated single NV centers and nearby bulk charge traps.

Summary of Research:

NV centers in diamond exhibit narrow, spin-preserving optical transitions at cryogenic temperatures that can be harnessed for quantum networking applications [1]. Such applications are limited by two key factors: spectral diffusion of the optical transition frequencies on repeated measurement [2] and defect-to-defect variation in optical transition frequencies resulting from strain [3]. Though there has been significant progress toward quantum networking with NV centers [4], only carefully chosen defects are able to be incorporated into such devices.

We quantify spectral diffusion and investigate how spectral diffusion correlates with other physical parameters of NV centers. We quantify both the spectral diffusion and the static strain for 16 individual bulk NV centers, breaking each into components of a given Jahn-Teller symmetry. We then calculate the correlation and significance (p-value) between the different components of spectral diffusion, components of strain, and depth from the diamond surface.

Our sample (Figure 1) is a type IIa diamond with individually addressable single NV centers formed via electron irradiation and subsequent annealing. We patterned a microwave loop antenna for spin control on the diamond surface, using the Heidelberg Mask Writer – DWL2000 to make the mask, the GCA 6300 DSW 5X g-line stepper to write the pattern,

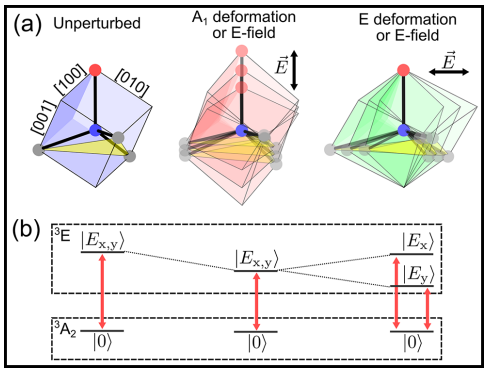

Figure 2: (a) An unperturbed NV center has C_{3v} symmetry and can undergo either A_1-symmetric (longitudinal) or E-symmetric (transverse) perturbation from strain or electric field. (b) Longitudinal perturbations globally shift the optical transition frequencies, while transverse perturbations split the excited-state orbital doublet into two branches.

the AJA sputter deposition system to deposit 25 nm of Ti and 225 nm of Pt. After lift-off the device was wire bonded to our cryostat microwave feed lines using the Westbond 7400A Ultrasonic Wire Bonder.

We perform photoluminescence excitation (PLE) spectroscopy measurements by tuning a red laser (~637.2nm) across the resonant optical transitions of the NV center while counting photons emitted into the phonon sideband. The spin-preserving optical transitions are from orbital singlet, spin triplet ground states to orbital doublet, spin triplet excited states. All measurements are carried out in a helium flow cryostat at 10 K.

An unperturbed NV center has C_{3v} point-group symmetry and two degenerate spin-0 optical transition energies (Figure 2) [5]. Longitudinal (A_1) perturbations shift the excited states together, while transverse perturbations (E) split the orbital branches.

We characterize the strain components for each NV center by applying 637.2 nm and 532 nm laser pulses while tuning the red laser frequency. The 532 nm laser ensures that the defects is always in spin-0. As shown in Figure 3, by measuring the splitting of the two optical transitions, the rotation of the optical dipole [6], and the absolute center frequency of the PLE peaks we fully quantify the strain components for each NV center.

We then characterize the spectral diffusion. We apply a single green laser pulse followed by a full red laser sweep and repeat 125 times on each defect. These spectra are summed, and the changes in splitting and center frequency are recorded for each of the sweeps in a histogram. By extracting the width of these histograms via fitting with a Gaussian response we can quantify the longitudinal and transverse components of spectral diffusion.

We calculate the correlations and p-values of each component of spectral diffusion, static strain, as well as the measured depth from surface. These correlations reveal that both strain and spectral diffusion are dominated by longitudinal perturbations. Also, NV centers with larger transverse strain are more protected from orthogonal and transverse spectral diffusion. Last, for bulk NV centers the spectral diffusion increases with depth due to laser aberration.

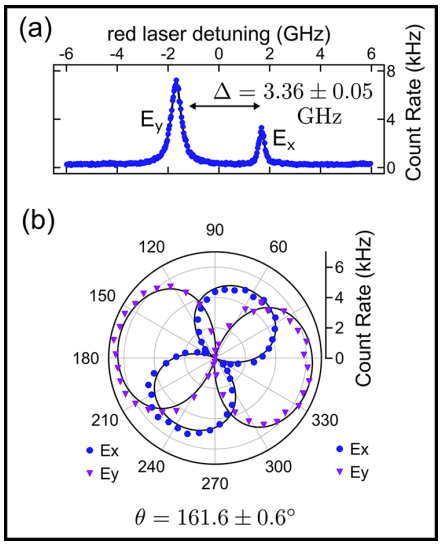

Figure 3: (a) PLE frequency sweep and extracted strain splitting Δ from two Lorentzian fits. (b) PLE laser polarization rotation and extracted dipole rotation θ.

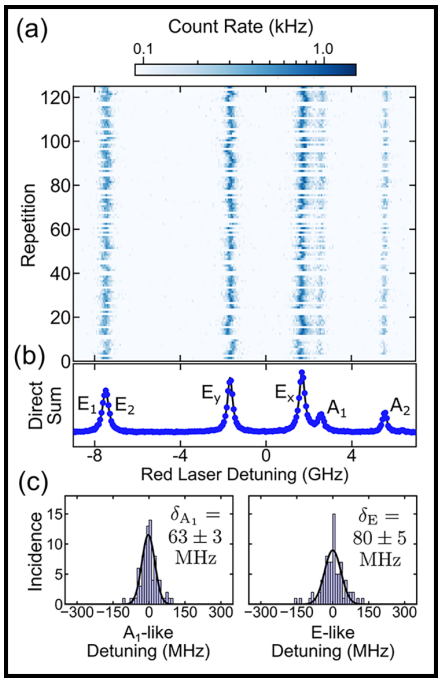

Figure 4: (a) 125 repetitions of frequency-swept PLE showing spectral diffusion on repeated measurement. (b) Direct sum of repeated PLE response. (c) Histogram of longitudinal and transverse spectral diffusion components including Gaussian fits to quantify degree of each symmetry of spectral diffusion.

Conclusions and Future Steps:

Our results indicate that NV centers with large transverse strain will on average have reduced spectral diffusion. This can provide a quick means of searching for good candidate defects for quantum networking. Also, defects should be located at a depth which balances the spectral diffusion known to occur from near-surface charge traps [7] with the depth-related spectral diffusion we uncovered. Future work will investigate how NV centers driven with mechanical resonators can be made robust to spectral diffusion.

Our manuscript is under review, and a preprint is available on arXiv [8].

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