Spin-Lattice Relaxation Times of Nitrogen-Vacancy Centers in Diamond

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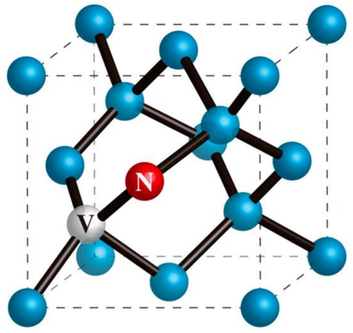
Abstract

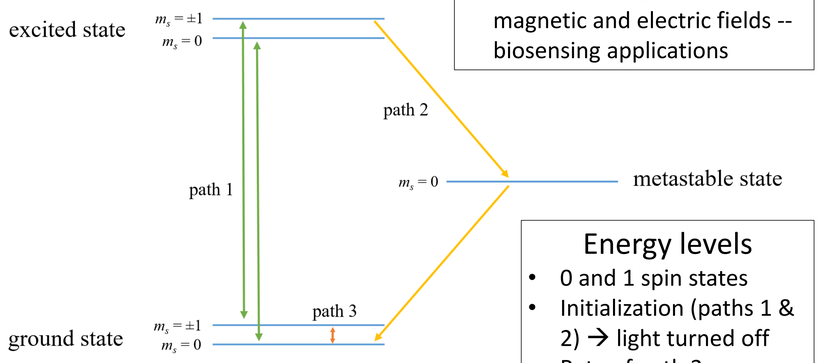
The nitrogen-vacancy (NV) center is a point defect in diamond that has applications in a variety of fields, due to its adaptability, stability, and isolation. Its chemical and physical properties enable it to function as a spin qubit with remarkable coherence times for quantum information processing. NV centers can also be utilized in improving the quality of nanoscale medical imaging, particularly important to which is spin-lattice relaxation time (T_1). In this research, T_1 measurements on nanodiamonds (NDs) are conducted and relaxation rates $1/T_1$ are analyzed as a function of ND size. An increase in size is found to correspond with a decrease in relaxation rate, as found in previous studies; the data is also compared to Tetienne et al.'s "best-case" and "worst-case" models.



Ishii et al. (2022)

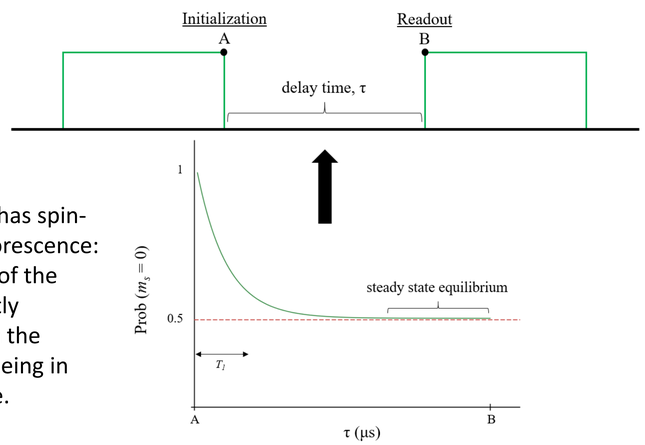
NV centers and biosensing

- Optically detected magnetic resonance (ODMR)
- Nanoscale detection of magnetic and electric fields -- biosensing applications

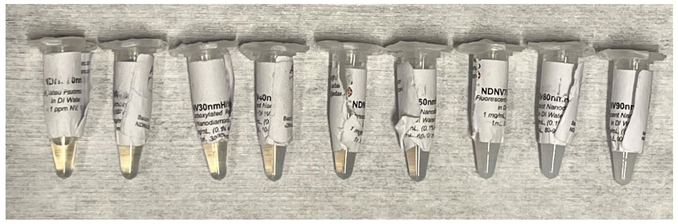


Energy levels

- 0 and 1 spin states
- Initialization (paths 1 & 2) → light turned off
- Rate of path 3 = relaxation rate ($1/T_1$)

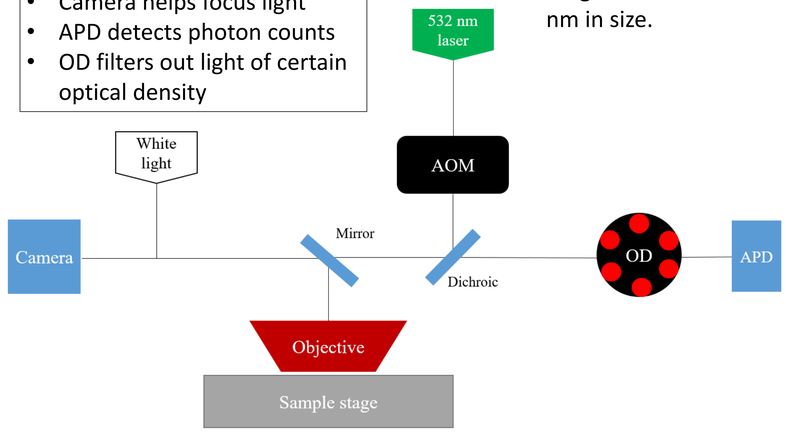


The NV center has spin-dependent fluorescence: the brightness of the system is directly correlated with the probability of being in the spin-0 state.

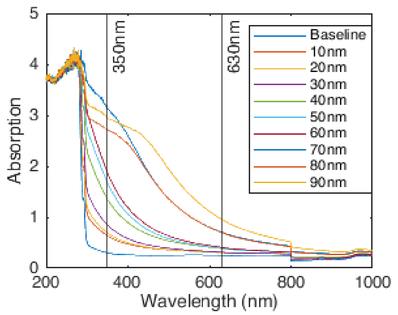


Experimental setup

- AOM dispatches pulses
- Camera helps focus light
- APD detects photon counts
- OD filters out light of certain optical density

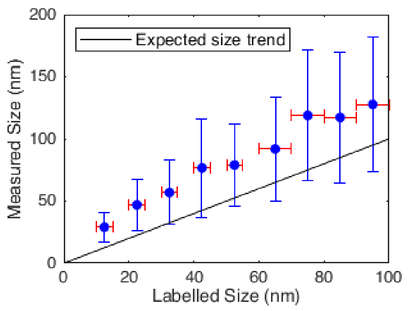


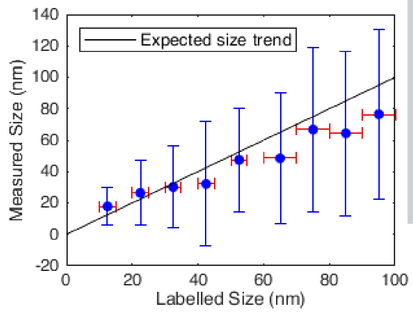
Fluorescent NDs are dispersed in water and range from 10 to 90 nm in size.

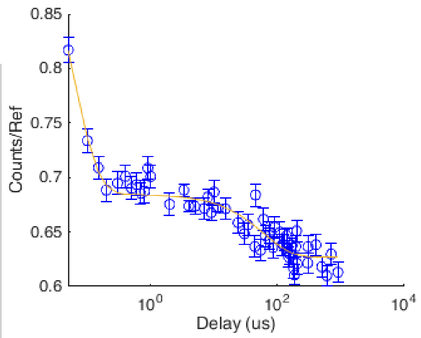


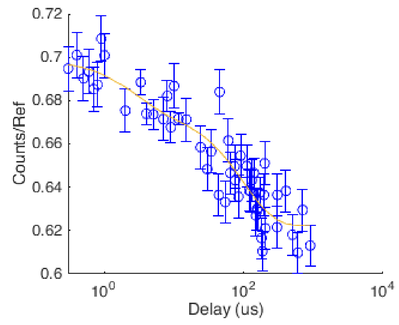
Characterization

- Ultraviolet-visible spectroscopy (UV-Vis) measures NDs' light absorption
- Dynamic light scattering (DLS) measures NDs' size distribution
- DLS provides an intensity-based and number-based measurement



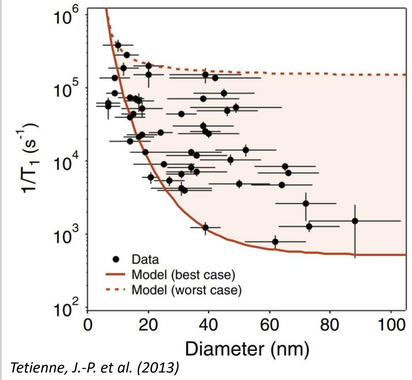




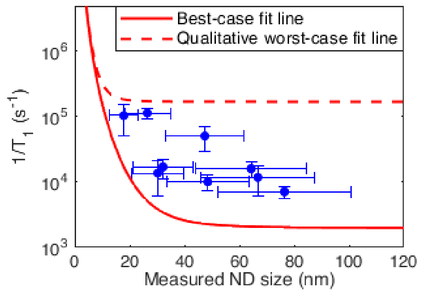


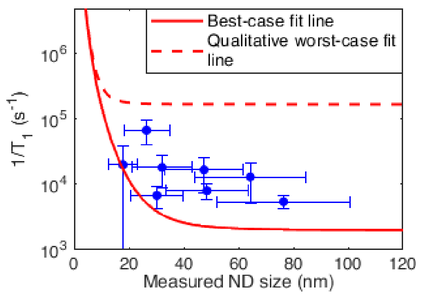
Analysis

- Extracted T_1 and other constants from one of three exponential fits
- Plotted rate $1/T_1$ against size, and compare with "best case" and "worst case" from Tetienne et al.



Tetienne, J.-P. et al. (2013)





Conclusions

- UV-Vis/DLS measurements mostly followed expected trends; high size uncertainty
- Similar $1/T_1$ decrease as previous studies; expected a less disjointed decay
- Relaxation rate ~ $1/d^6$ (spin-spin interactions on surface) ⇒ $1/d^4$ fit
- Single spins vs. ensembles

Future work

- Number vs. intensity measurements from DLS
- Milled vs. detonation NDs
- Perturbation to magnetic environment (Gd^{3+})
- Limitations in generating and using best-case model

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- Adámas Nanotechnologies

References

- Aslam et al. (2023)
- Awschalom et al. (2013)
- Childress et al. (2014)
- Schirhagl et al. (2014)
- Shulevitz et al. (2022)
- Tetienne et al. (2013)

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