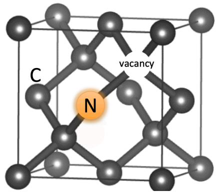
Implementation of zero field spin echo in NV centers

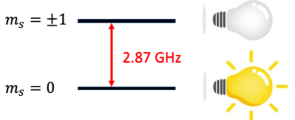
Chang Jin, Simon Meynell, Ania Bleszynski Jayich

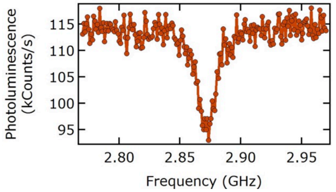
Fundamentals of NV centers

Nitrogen vacancy (NV) centers are point defects in diamond lattices that act like a trapped atom.



Optically addressable: we can probe the spin state of the NV using the increased photoluminescence of the 0 state.

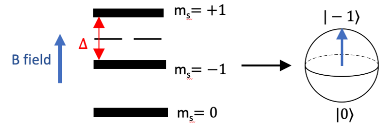




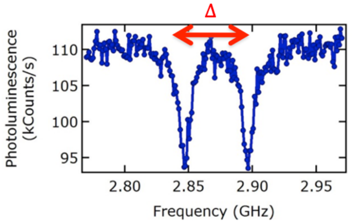
B. A. Myers, *Quantum decoherence of near-surface nitrogen-vacancy centers in diamond and implications for nanoscale imaging* (2016).

Application of NV centers in quantum sensing

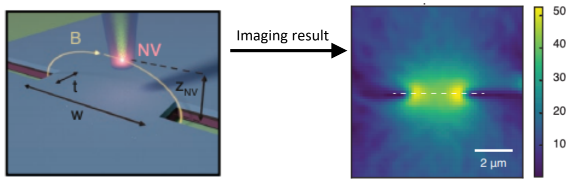
To construct a two-level system in the NV centers necessary for quantum sensing, we apply an external magnetic field that splits the ± 1 states



Using the newly constructed two-level system, we can implement numerous sensing schemes and use NV as magnetometers with sensitivity down to the single atom.



B. A. Myers, *Quantum decoherence of near-surface nitrogen-vacancy centers in diamond and implications for nanoscale imaging* (2016).

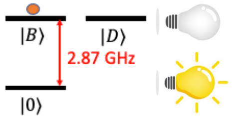


"Engineering quantum-coherent defects: the role of substrate miscut in chemical vapor deposition diamond growth", S. A. Meynell, C. A. McLellan, etc. (2020).

Sensing strategy under zero external magnetic field

1. A new two-level system:

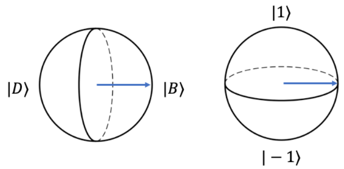
$$|B\rangle = \frac{1}{\sqrt{2}}(|1\rangle + |-1\rangle)$$
$$|D\rangle = \frac{1}{\sqrt{2}}(|1\rangle - |-1\rangle)$$



We define the two new basis states, $|D\rangle$ and $|B\rangle$, with the $|0\rangle$ detuned from the two-level system by the NV's inherent wide band gap.

Using a π pulse, we can convert the electrons in $|B\rangle$ to the optically addressable $|0\rangle$

2. Controlling the two-level system:

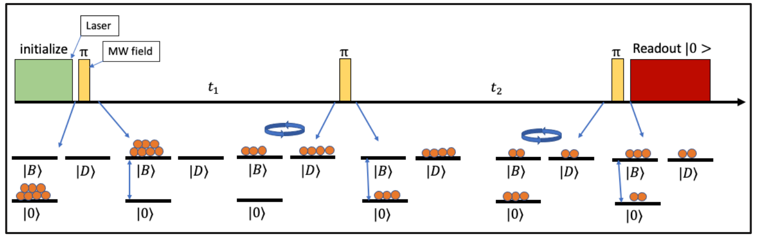


With microwave field applied

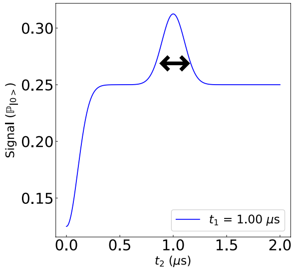
Without microwave field applied

By applying an external microwave field, we can modify the Hamiltonian of the system such that $|B\rangle$ and $|D\rangle$ become the new energy eigenstates. This enables us to activate the precession of the NV spin and use it to sense the desired magnetic field.

Additionally, the applied π pulse pumps the electrons in the $|0\rangle$ into the $|B\rangle$ and vice versa, providing us with a way to optically address the NV spin states.



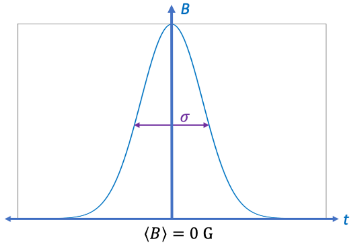
Simulated plot:



- The signal plotted here is the possibility for the NV to be in $|0\rangle$.

The theory predicts a revival of signal at $t_1 = t_2$ which demonstrates our ability to preserve the coherence of the two-level system.

The width of the peak is given by the rate of the free induction decay (characterized by T_2^*).



- The standard deviation of the external B field causes the signal to decay at a rate $\propto \exp\left[\left(\frac{\tau}{T_2^*}\right)^2\right]$.

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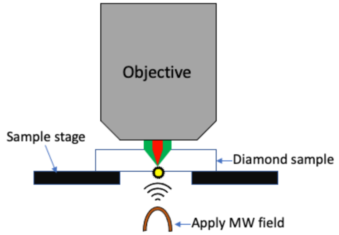
Experimental setup

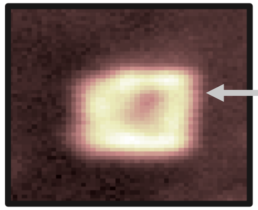


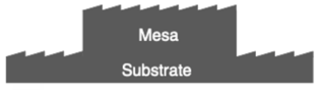
This is the schematic of a costume built confocal microscope we used for our experiment.

The MW pulse is delivered to the NV by an antenna inserted below the sample stage.

The photons emitted by the NV are converted into electronic signals to be read out by the computer.

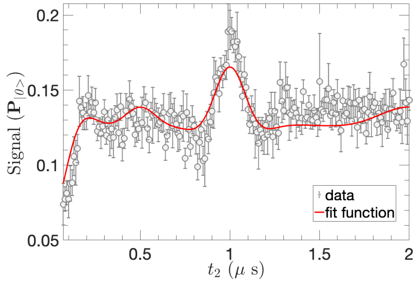
Results and conclusions





Tokuda, *Novel Aspects of Diamond*; *TAP*, **121**, (2015)

We are looking at the NV's embedded in the hillock structures on the diamond surface. They are usually products of the diamond manufacturing process (chemical vapor deposition).



The theory is able to predict most of the trends in our data.

There are still some deviations we are still looking to explain.

This new sensing strategy allows NV centers to operate in the previously inaccessible 0 field limit (E.g. skyrmions)

Doubled the sensitivity of the NV centers by doubling the difference in spin numbers of our basis. ($\Delta m = 1$ between $|0\rangle$ and $|-1\rangle$; $\Delta m = 2$ between $|1\rangle$ and $|-1\rangle$)