Nanoscale magnetic sensing with an individual electronic spin in diamond

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**Motivation:**

present technique to detect very weak magnetic fields with nanospatial resolution
(e.g. electron spin ~ 1μT; proton ~ 1nT)

→ possibility to detect magnetic resonance signals from electron or nuclear spins in complex biological molecules

→ read-out of classical or quantum bits of information encoded in an electron or nuclear spin memory
Overview:

- nanoscale magnetic sensing using coherent manipulation of an individual electron spin qubit associated with a NV impurity in diamond

- detection of 3nT B-field at kHz frequencies (with ultra pure diamond sample)

- 0.5µTHz\(^{-1/2}\) sensitivity (with diamond nanocrystal)
Spin of individual nitrogen vacancy (NV) centre is used as magnetic sensor:

- NV center can be used to sense an externally applied AC magnetic field
- Microwave pulses are generated to manipulate the electronic spin states
Method:

- electronic spin of individual NV impurity can be polarized by optical pumping and measured via state-selective fluorescence

- ESR is used for coherently manipulating the spin orientation

- spin precession is monitored (depends on external B-fields due to Zeeman effect)

Challenge: coupling of spins to environment limits precession time

Solution: Decoupling via coherent control over a coupled electron-nuclear system

→ spin-echo sequence refocuses unwanted evolution of the magnetometer spin
→ AC B-field affects spin dynamics constructively

\[ \Rightarrow \delta B_{min} \approx \frac{\hbar}{g\mu_B \sqrt{T_2 T}} \]

with \( T_2 \approx 1\text{ms} \)
sensitivity \( \approx 1\text{nT Hz}^{-1/2} \)
Spin of individual NV impurity is polarized by optical pumping and measured via state-selective fluorescence.


**Proof-Of-Principle experiments**

a) spin echo signal observed from single NV centre

\[ \Delta = \frac{1}{2} \omega_L = \nu_{13C} B_{DC} \]

→ adjust \( \omega_L \) and \( \nu_{AC} \)

b) magnetometer sensitivity experiment:

→ peak height in dependence of external AC-field strength

→ variation due to phase accumulated by the NV spin due to AC-field and resulting varying Zeeman shift during the spins precession

\[ \delta B_{min} \propto \sqrt{\nu/F(1/\nu)} \]
a) sensitivity measurements as a function of AC-field frequency:

decreasing $\nu \rightarrow$ accumulated zeeman phase shift of NV spin during one period increases $\rightarrow$ higher sensitivity

$\rightarrow$ limit: when the NV spin decoheres during one single period of the AC-field oscillation

b) sensitivity as a function of averaging time
experiments using commercially available nanocrystals

large number of impurities shortens $T_2$ to 10μs
$\rightarrow$ but still magnetic sensing with $\nu_{AC} = 380$ kHz with sensitivity 0,5μT Hz$^{-1/2}$
**Possibilities for improvement:**

- using isotopically pure diamond  
  \[\rightarrow\] longer coherence and interrogation times

- increasing measurement read-out for better signal-to-noise ratio

- magnetic sensing with multiple NV centers

- using more complex pulse sequences