Optical magnetometry with sub-wavelength spatial resolution using individual spins in diamond

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Abstract: The ability to map weak magnetic fields with nanometer resolution is of great importance in biological science, high precision metrology of nanoscale structures, and quantum information. We describe and demonstrate a new technique that combines high spatial resolution in the spirit of stimulating-emission-depletion (STED) fluorescence microscopy [1] and nanoscale magnetic sensing with individual spins in diamond [2,3]. This new approach for sub-diffraction magneto-optic imaging will allow detection of single electronic spins at a distance of 10 nm with 5-7 folds improvement beyond the diffraction limited lateral resolution.

- **Sub-diffraction magneto-optic imaging**
  - High spatial selectivity is achieved by applying a doughnut shaped beam which polarizes all NV defects that are off center. The polarized NV centers only contribute a constant background, which can be subtracted.
  - Using this scheme, the resolution is given by:
    
    $$ r = \frac{\lambda}{2nA \sqrt{1 + \frac{P_L}{I_{BA}}} } $$

  - For a doughnut with a perfect zero, the resolution is limited by the product of power and duration of the doughnut pulse. Therefore, long spin lifetime allows for high resolution with low power.

### Background

**Stimulated emission depletion (STED)**

$\frac{\lambda}{2nA \sqrt{1 + \frac{P_L}{I_{BA}}}}$

- $\lambda$ is the wavelength,
- $nA$ is the numerical aperture,
- $P_L$ is the beam power,
- $I_{BA}$ is the background.

- Resolution 8 - 16 nm for excitation depletion powers of ~300mW.

### Experimental setup

- Vortex phase plate used to create doughnut beam.
- Point spread function of doughnut shaped beam.
- Experimental implementation.

### Resolution

**Fluorescence profile versus doughnut duration and power**

- Since resolution depends on the product of power and doughnut duration, it is possible to achieve high resolution using very low power. For increasing the doughnut power, the resolution increases, which is the lifetime of the electronic spin.

- Comparison of the two profiles shows a 5-7 fold improvement.

**Contrast versus doughnut power and length**

- Our technique is currently limited by imperfections in the zero of the doughnut. This reduces the signal to noise ratio.

**Resolution versus doughnut power and length**

- Contrast versus doughnut power and length.

### Sub-diffraction magneto-optic imaging

- Example of confocal image - two centers cannot be resolved. The blue line represents the scanned trajectory.

- Two centers separated by less than the diffraction limit are resolved. Both centers are oriented along the same axis, showing the same ESR splitting.

### Outlook

- Projected resolution: 0.1 nm for a doughnut contrast of 10.

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