Characterization of Color Centers in Diamond for Quantum Sensing

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Introduction

Nitrogen-Vacancy (NV) color centers are point defects in diamond, consisting of a substitutional nitrogen atom adjacent to a lattice vacancy [1]. Their unique quantum properties enable promising applications in quantum sensing, information processing and communication. In particular, the NV center's electron spin state can be read out through fluorescence changes, making it useful for sensing physical quantities such as magnetic fields and temperature [2].

NV Creation Method

In this work, NV centers in a [100] single-crystal diamond sample (≈1 ppm of nitrogen) were created using a 515 nm Satsuma HP femtosecond laser with a repetition rate of 500 kHz (at INESC TEC, Porto). Different fabrication condition were used, namely the laser power.

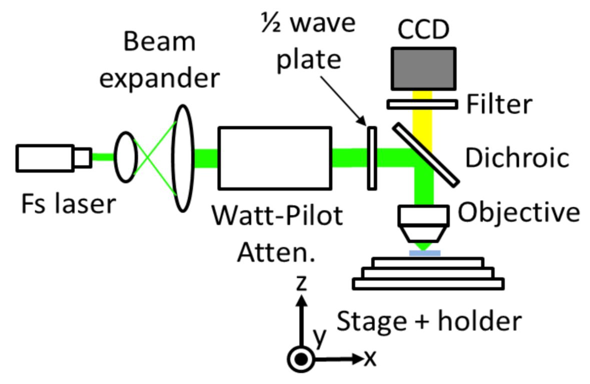

Fig. 1 – Femtosecond Writing Setup

Optical Characterization of NV centers

1 - Confocal Microscopy

The Zeiss LSM 780 confocal fluorescence microscope was used to obtain fluorescence image of the created NV centers (Fig. 2A).

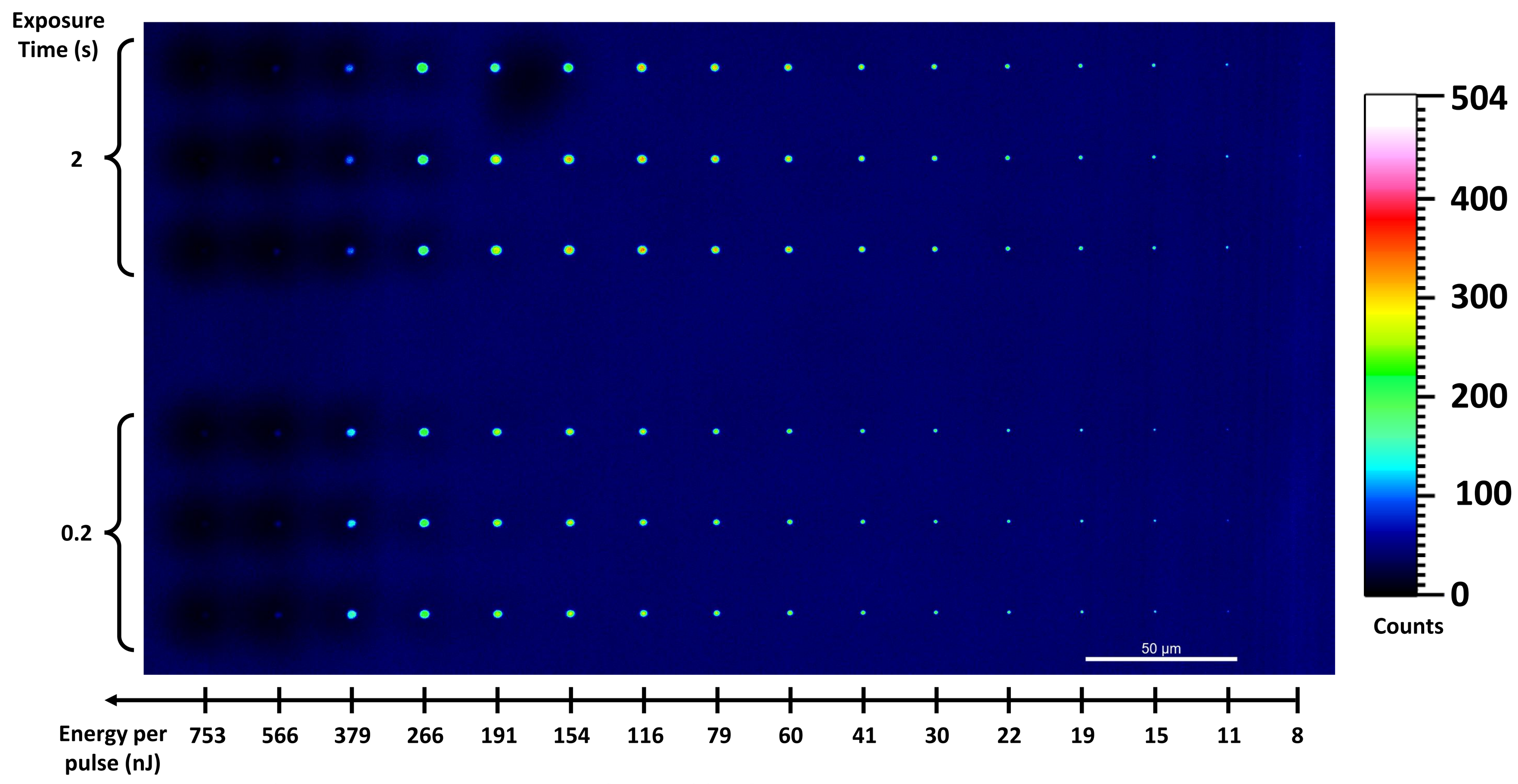

Fig. 2A – Fluorescence Intensity Image of ensemble of NV centers

Profile Analysis
+
Gaussian fit

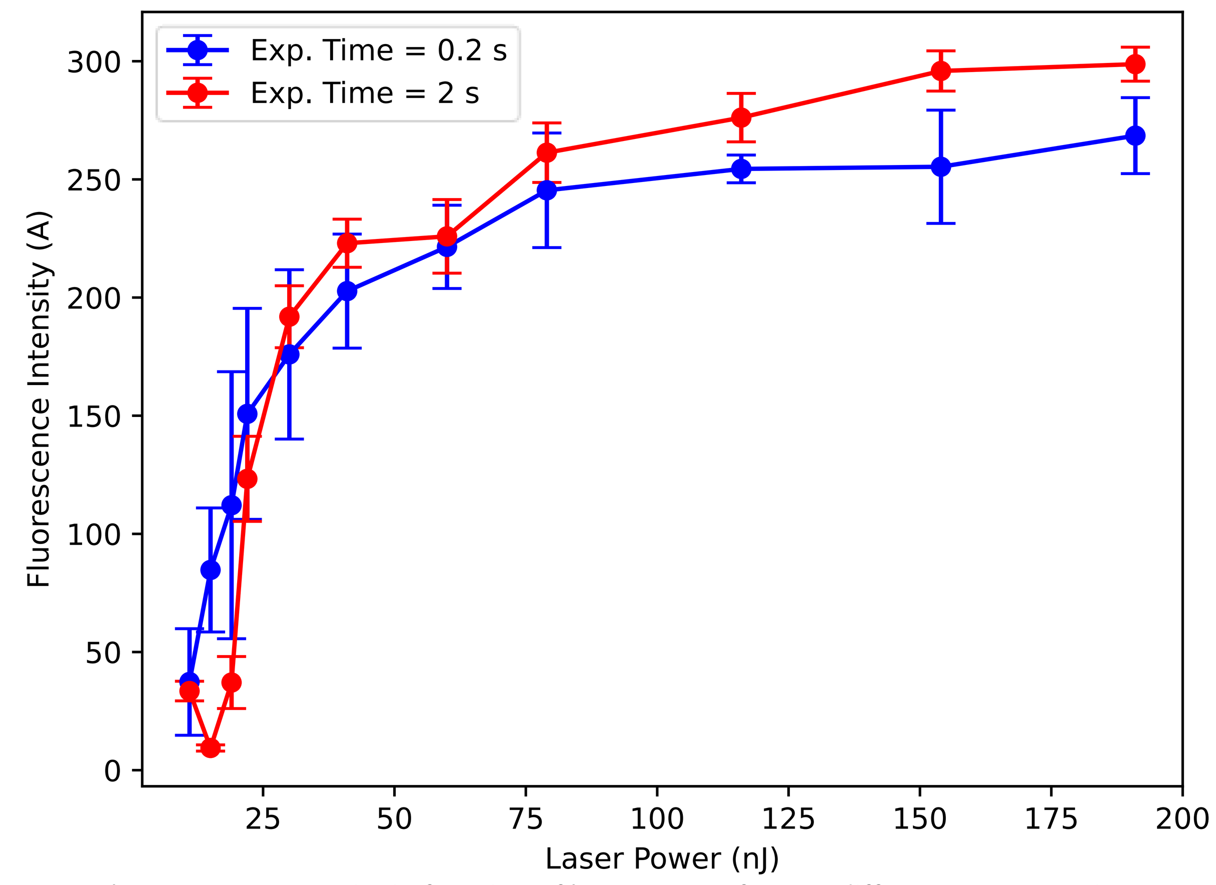

Fig. 2B – Fluorescence Intensity in function of laser power, for two different exposure time

2 – Emission Spectroscopy

Emission Spectroscopy was performed using a custom-built confocal microscope (excitation provided by a cw 531 nm laser) the AvaSpec-2048 Fiber Optic Spectrometer.

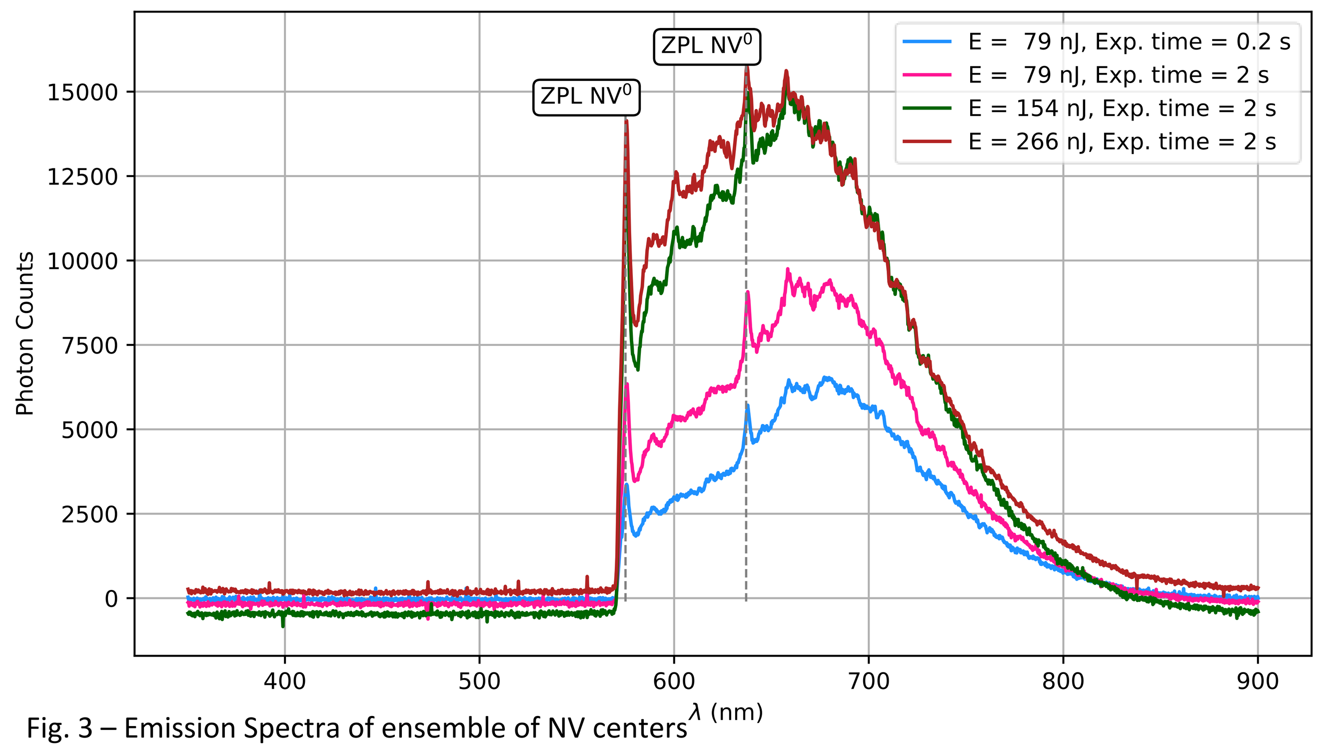

Fig. 3 – Emission Spectra of ensemble of NV centers

- ZPL corresponds to the Zero Phonon Line (fluorescence emission without phonons).
- NV^- has an extra electron in the vacancy site (in contrast with NV^0). This extra electron is responsible for the magnetic sensibility of this defect.

3 – Fluorescence Lifetime Image Microscopy (FLIM)

FLIM was carried out using a custom-built confocal microscope (excitation provided by a pulsed 561 nm laser).

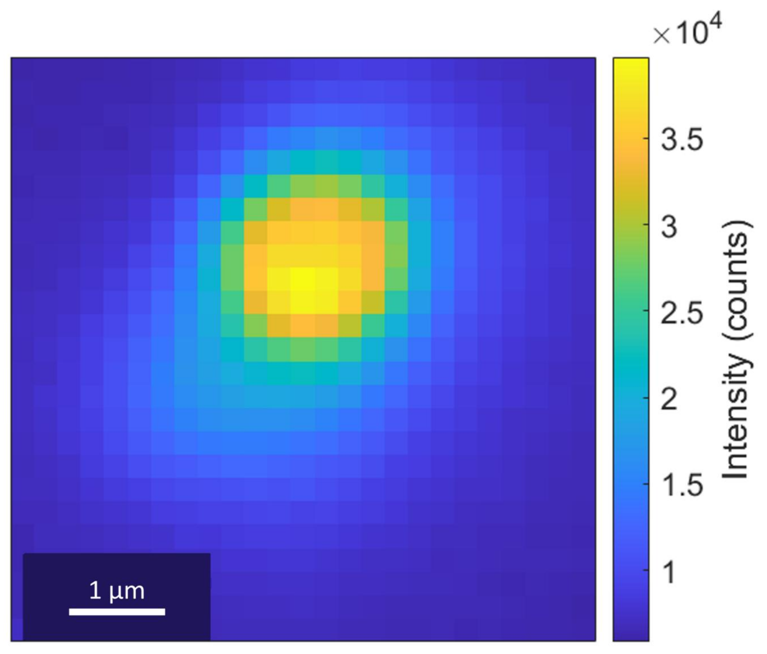

Fig. 4B – Fluorescence Intensity of ensemble of NV centers, created with a E = 79 nJ and Exposure time of 0.2 s.

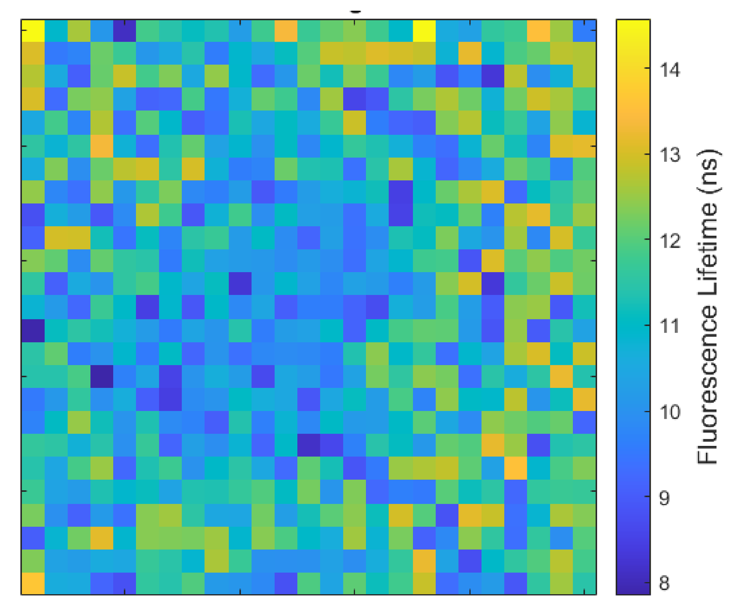

Fig. 4B – FLIM image, obtained through a single exponential fitting process.

The analyses was performed by fitting a single exponential to each decay curve present in every pixel.

Fluorescence lifetime ≈ 10 – 11 s

Quantum Sensing via Optically Detect Magnetic Resonance (ODMR)

The ODMR technique relies on the photoluminescence response of NV centers. By sweeping microwaves between 2.8 and 2.94 GHz, a fluorescence dip appears at about 2.87 GHz (see Fig 5A.), corresponding to the energy difference between the degenerate triplet ground state levels, also called zero field splitting.

In presence of an external magnetic field, the $m_s = \pm 1$ states lift their degeneracy, and the distance between resulting dips reveals the local magnetic field (see Fig. 4B) at the location of the NV center, enabling magnetometry.

Pulsed protocols exploiting long spin coherence times can further improve sensitivity.

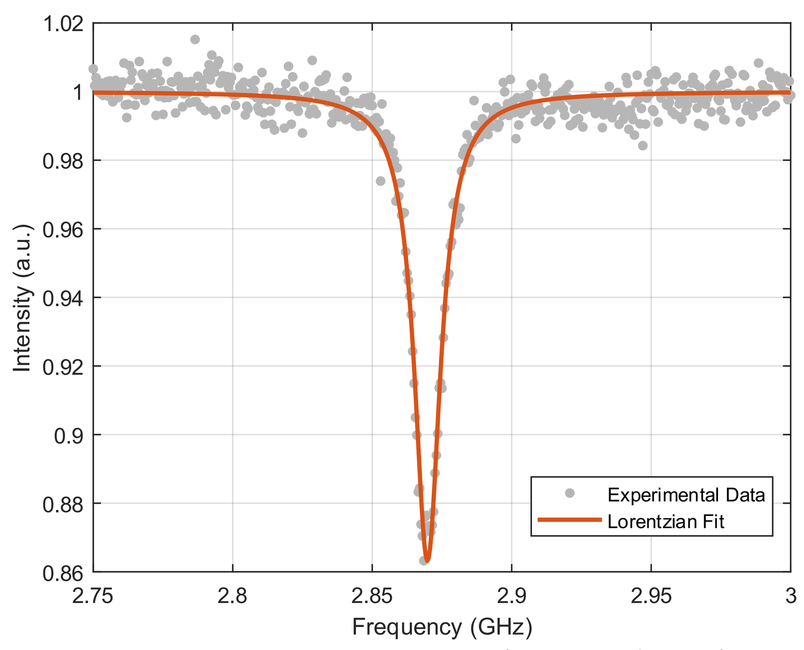

Fig. 5A – ODMR measurement, showing a dip at the NV center's Zero-Field Splitting at 2.869 GHz.

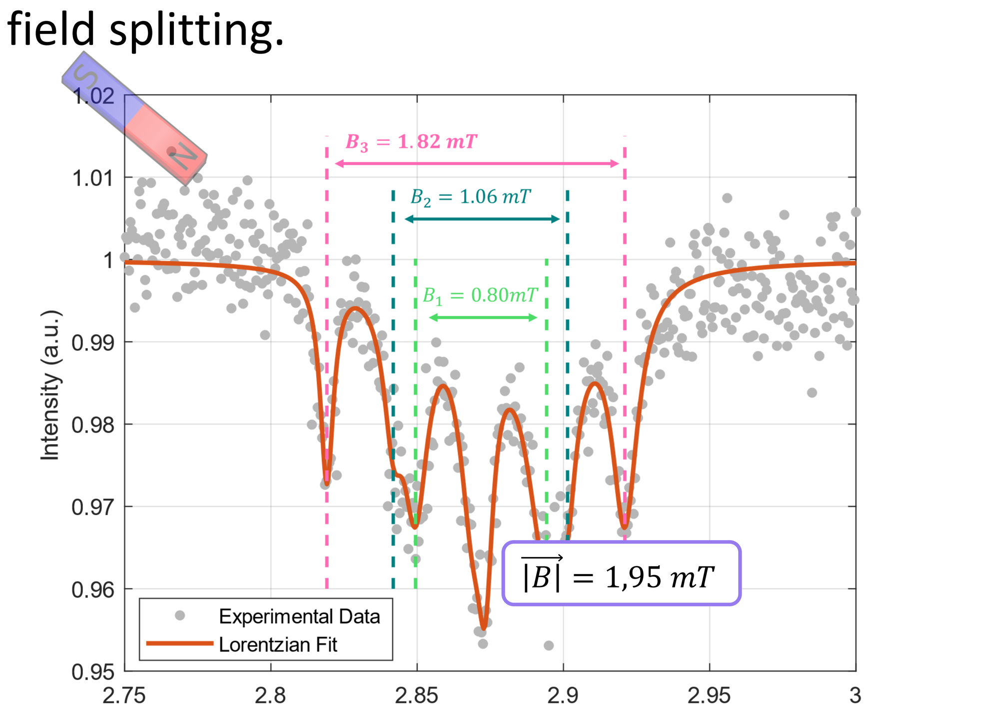

Fig. 5B – ODMR measurement in an external magnetic field. NVs in different crystal orientations can be associated with emerging dip-doublets.

Conclusions and Outlook:

- Femtosecond laser fabrication enables creation of NV center ensembles (NV^0 and NV^-), with properties dependent on laser conditions.
- Magnetic field sensitivity of these NV centers was demonstrated.

Next Steps:

- Exploit quantum coherence to enhance ODMR, reduce linewidth, and calculate the T2* and T1 relaxation times.
- Compare NVs created by ion implantation, high-temperature irradiation and femtosecond laser.
- Apply (vector) magnetometry on magnetic samples as well as on biological samples

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DIAMOND-CONNECT

Reference:

[1] M.W. Doherty, et al., "The nitrogen-vacancy colour centre in diamond", Physics Reports, vol. 528, no. 1, pp. 1–45, 2013.
[2] G. Balasubramanian, et al., "Nitrogen-vacancy color center in diamond - emerging nanoscale applications in bioimaging and biosensing", Current Opinion in Chemical Biology, vol. 20, pp. 69–77, 2014.