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A biocompatible technique for magnetic field sensing at (sub)cellular scale using Nitrogen-Vacancy centers

Ettore Bernardi[1*], Ekaterina Moreva[1], Paolo Traina[1], Giulia Petrini[1,2], Sviatoslav Ditalia Tchernij[2], Jacopo Forneris[2,3], Željko Pastuović[4], Ivo Pietro Degiovanni[1], Paolo Olivero[2,3] and Marco Genovese[1]

*Correspondence:
e.bernardi@inrim.it
[1]Istituto Nazionale di Ricerca Metrologica, Strada delle cacce 91, Turin, Italy
Full list of author information is available at the end of the article

Abstract

We present an innovative experimental set-up that uses Nitrogen-Vacancy centres in diamonds to measure magnetic fields with the sensitivity of $\eta = 68 \pm 3\ \mathrm{nT}/\sqrt{\mathrm{Hz}}$ at demonstrated (sub)cellular scale. The presented method of magnetic sensing, utilizing a lock-in based ODMR technique for the optical detection of microwave-driven spin resonances induced in NV centers, is characterized by the excellent magnetic sensitivity at such small scale and the full biocompatibility. The cellular scale is obtained using a NV-rich sensing layer of 15 nm thickness along *z* axis and a focused laser spot of (10 × 10) $\mu\mathrm{m}^2$ in *x*-*y* plane. The biocompatibility derives from an accurate choice of the applied optical power. For this regard, we also report how the magnetic sensitivity changes for different applied laser power and discuss the limits of the sensitivity sustainable with biosystem at such small volume scale. As such, this method offers a whole range of research possibilities for biosciences.

Keywords: NV centers; Quantum sensing; Magnetic measurements

1 Introduction

Magnetometry in biological systems is of the utmost importance for fundamental biological science and medicine [1]. Mapping brain activity by recording magnetic fields produced by the electrical currents which are naturally occurring in the brain is of extreme interest [2, 3], with direct applications in the timely detection and cure of psychic and neurodegenerative disorders [4–6]. Measuring the magnetic fields produced by electrical currents in the heart is also of the utmost importance [7], since this could lead to a new generation of non-invasive diagnostic and therapeutic techniques [8]. Superconductive quantum interference device (SQUID) magnetometers are usually used for both these kinds of measurements. Nonetheless, the significant drawbacks of SQUID magnetometers are represented by the facts that they are unable to sense single nerve pulses, and they are costly, bulky, and require cryogenic refrigeration [9, 10].

Magnetometers based on Nitrogen-Vacancy (NV) centers in diamond represent a valid alternative to SQUID-based magnetometry. Firstly, diamond offers the substantial advan-