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Bias-Tee quantum current sensor with temperature tracking based on modulated cw-ODMR with NV centers

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Summary:

A new current measurement setup is presented, which based on randomly orientated NV ensembles in diamonds with a diameter of 150µm. Diamonds are applied directly on a printed circuit board (PCB) track which is used as a Bias-Tee to combine DC current and microwave (MW) excitation. By scanning the MW frequency, characteristic dips in fluorescence intensity are used to deduce DC current and temperature in a measurement range of 2 A to 8 A and 300 K to 380 K.

Keywords: NV center, room temperature, quantum sensor, current sensor, temperature tracking

Background, Motivation and Objective

Quantum magnetometry based on optically detected magnetic resonance (ODMR) of nitrogen vacancy centers (NV-Centers) in nano- or micro-diamonds is a promising technology for precise and small magnetic field sensors and resulting from this current sensors [1]. Nevertheless, few practical approaches have been pursued so far to translate this technology into viable approaches to concrete current sensing setups [1][2].

Here, we propose a new measurement setup based on the idea of a Bias-Tee that combines a DC current and the MW needed to drive the quantum states of the NV center on one simple printed circuit board (PCB) track with only a few surface mounted device (SMD) components and randomly orientated 150 µm diamonds (Adámas Nanotechnologies). Additionally the specific shifts of the zero field splitting (ZFS) could be used to track the temperature of the PCB track. The DC current can be measured directly or used after calibration to bias an external magnetic field. The use of standard components and randomly oriented diamonds makes the setup cost effective and mechanically simple to assemble compared to other sensing setups [1][2].

Description of the New Method or System

The proposed system is based on a two layer 18 µm copper thickness, 0.5 mm FR4 PCB. For coupling MW into the DC current track coupling capacitor C1 is used (Fig. 1). Inductors L1 and L2 (also L3 and L4) together with the respective filter capacities Cf build a LC filter with a theoretical corner frequency of 1.5 MHz. In the area where DC current and MW are combined five diamonds are applied across the trace (Fig. 1). The diamonds have a diameter of about 150 µm and a NV-Center concentration of approx. 2.5-3 ppm. This results in a bright fluorescence.

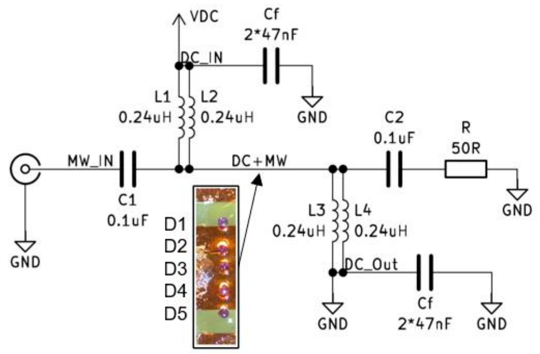

Fig. 1 Schematic of Bias Tee. The sensing area is located at the track where MW and DC Current are combined. Five diamonds are applied to the PCB track in the sensing area to investigate the properties of the setup. DC current direction is changeable.

Diamonds are excited with a 520 nm Laser diode focused onto the diamond by a microscope objective. The fluorescence beam is split by a dichroic mirror and detected with photodiode. The MW is provided by a Rohde & Schwarz SMBV100B and continuously amplitude modulated with a frequency of 5 kHz to improve signal to noise ratio [3] using a lock in amplifier (Zurich Instruments MFLI). The temperature is tracked by an FLIR E40 infrared camera.

Results

As shown in Fig. 2 it is possible to shift the resonance frequencies of the NV center with rising currents. As mentioned, the diamonds are not aligned, which leads to significantly different spectra (Fig. 2a). With the well know physics of the NV ground state and the geometric properties of the diamond lattice [4], the total magnetic magnitude can be estimated from the eight, partially overlaid, resonance frequencies in the ODMR spectrum. The results are shown in Fig 2c.

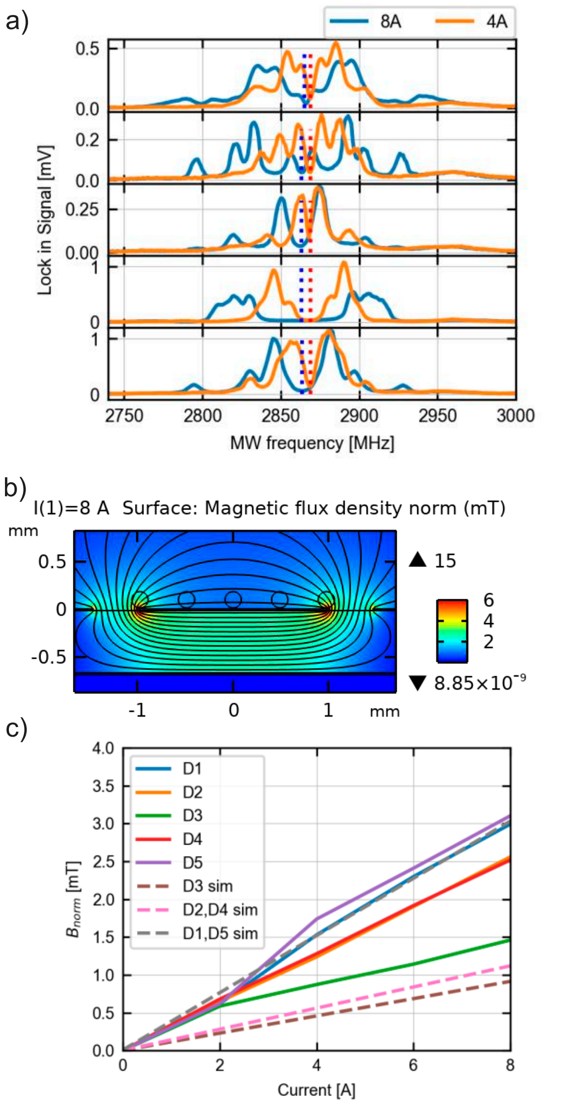

Fig. 2a) Exemplary spectra measured at 8 A and 4 A DC current on all five diamonds D1 to D5. Shifts in the ZFS between different current values (dotted line). b) 2D COMSOL simulation of 8 A DC current with combined MW excitation of 10 dBm c) measured and simulated magnetic field from all five diamonds over a current range from 0 A to 8 A.

The magnitude increases in the diamonds at the outer edges which follows the theoretical simulation (Fig. 2b). However, measurement results and simulation for D1 and D5 differ on average by 8.8 %. For D3 by 46.3 % and for D2 and D4 even by 56.2 %. Nevertheless through the linear dependence between magnitude and current on every diamond it is shown that a current sensor could be easily calibrated.

Furthermore one can see a shift in the ZFS on higher current values (Fig 2a – dotted line) and therefor higher temperatures [5]. Due to the small cross-section of the PCB trace, high temperatures are reached. These do not affect the linear behavior of the measured field in the present measurements. Current and temperature measurement can therefore be performed simultaneously and independent.

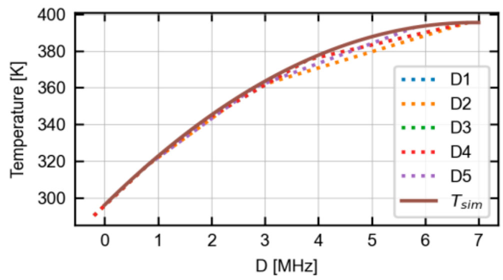

Fig. 3 Temperature Values calculated from $D = f_{ZFS0A} - f_{ZFS}$ of every diamond.

By a reference measurement a polynomial function is fit to calculate the current temperature directly from $D = f_{ZFS} - f_{ZFS0A}$ (Fig 3), where at 297.05 K the ZFS frequency at 0 Af_{ZFS0A} is measured as 2869.8 MHz.

The results show a cost effective and scalable way to use randomly orientated diamonds with NV centers in a quantum sensor application.

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