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Highly Sensitive Compact Room Temperature Quantum Scalar Magnetometer

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Summary:
A new detection scheme for all optical magnetometry using nitrogen-vacancies in diamond is proposed.

Keywords: Nitrogen vacancy, room temperature, quantum, scalar, magnetometer

Motivation

Magnetometry with nitrogen–vacancy (NV) defects in diamond has been extensively studied in the past [1]. While most approaches include the use of microwaves (MW) for the detection of electron spin resonance, only few investigate the sensitivity of the photoluminescence (PL) from NV centers to an external magnetic field without MW [2, 3, 4]. This work aims to utilize this effect to build a highly sensitive and compact room temperature magnetometer. The avoidance of MW serves the reduction of production costs and allows a commercialization at the current patent situation.

Description of the System

The proposed system is based on the magnetic field dependent red fluorescence of NV-diamonds. The luminescence occurs when optically pumped by green light and is attenuated by magnetic fields between 10 mT and 50 mT because of the magnetic-field-induced mixing of NV spin states [5]. Recently some of us published a new methodology to create NV-centers by ion implantation into diamond [6].

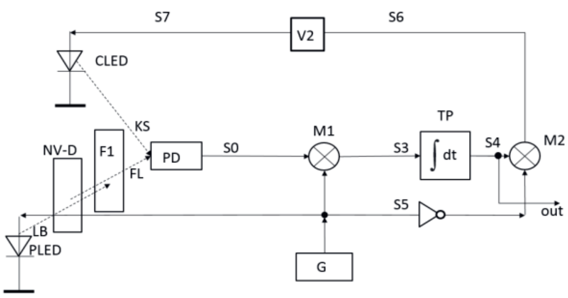

Figure 2: Transmission measurement system schematic.

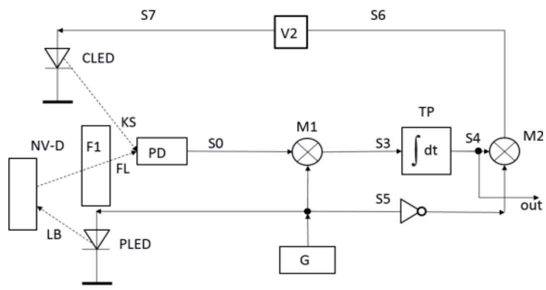

Figure 1: Reflection measurement system schematic.

This allows to create arrays of NV centers and the fabrication of quantum computer becomes possible. However, for magnetic sensing diamonds with a high density of NVs (so called red diamonds) are necessary. Electron irradiation of HPHT diamonds enables to create these diamonds with a high NV content with regard to carbon atoms. In these “red” diamonds, we observe a magnetic flux density dependent red fluorescence.

Figure 1 and 2 show schematics of the measurement systems in reflection and transmission mode, respectively. Exemplarily, Figure 3 reflects a compact working prototype realization of our room temperature quantum transmission magnetometer. Anyhow, the following functional principal holds true for both modes: A generator G produces a square wave signal S5 with frequency ω to drive a 520 nm laser. This laser optically pumps the NV-diamond through a collimating lens. The luminescent light passes through a longpass filter with a cut on wavelength of 600 nm onto a silicon PIN photodiode. After appropriate amplification and high pass filtering to remove the DC bias the multiplier M1

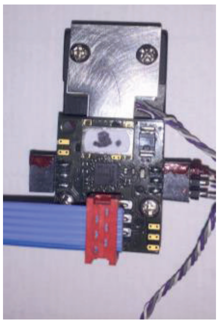

Figure 3: room temperature quantum transmission magnetometer.

multiplies the resulting signal S1 and the signal S5. Subsequent integration of the resulting signal S3 suppresses the sin(2ω) term because of the low pass filter property. A second multiplier M2 multiplies the integrator output with the generator signal, phase shifted by 180°. An amplifier V2 amplifies the resulting signal S6 and drives a compensating LED using the signal S7. The compensating red LED irradiates directly into the photodiode. This ensures, once the integrator has settled to a constant value for the photodetector to stay in the same operating point independent of the generator signal. This avoids negative effects of non-linear photodetector behavior. Thus, only the difference of fluorescence and compensation light is amplified by the phase sensitive detection and becomes zero once the control system has settled to its operating point. So the integrator value which is proportional to the photoluminescence is also the measurement output. An Elmos HALIOS® gesture recognition device performs the described measurement procedure.

Results

Figure 4 shows the circuits measurement value C in reflection mode, which is proportional to the photoluminescence as a function of the external magnetic flux density B. It is non-monotonic due to a reproducible rise at about 6 mT which has not been reported before. Figure 5 shows the responsivity ∂C/∂B, with a peak value of ∂C/∂B ≈ -31 counts/mT in the range of 15 mT to 25 mT. Figure 6 shows the noise spectral density of 20 minutes sampling time at the systems maximum sampling frequency f_s = 53.3 Hz and an applied bias field of 20 mT. The integrated noise spectral density equates

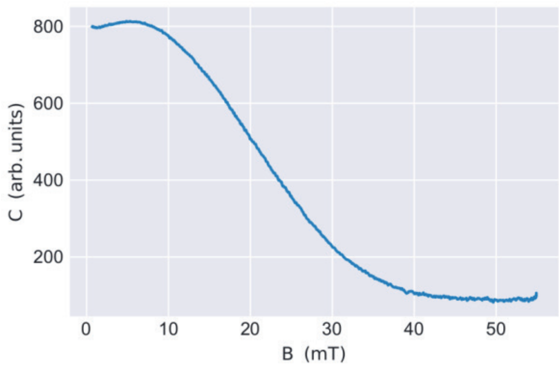

Figure 4: Reported value C of the sensor as a function of the external magnetic field (in reflection mode).

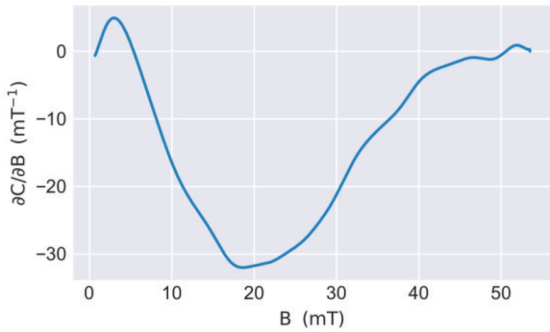

Figure 5: Derivative of measured value ∂C/∂B as a function of the external magnetic field. (in reflection mode)

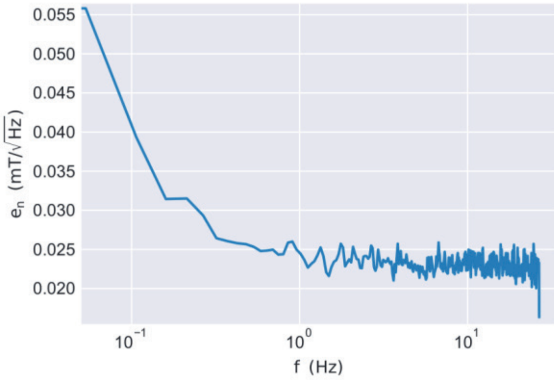

Figure 6: Noise spectral density at a bias field of 20 mT (in reflection mode).

to 32 μT/√Hz; which is slightly lower than the setup of Fedotov et al. [4] with 50 μT/√Hz.

References

[1] Lee, M.; Yoon, J. and Lee, D. (2019). In: (Ed.), Atomic Scale Magnetic Sensing and Imaging Based on Diamond NV Centers.

[2] Tetienne, J.-P.; Rondin, L.; Spinicelli, P.; Chipaux, M.; Debuisschert, T.; Roch, J.-F. and Jacques, V. (2012). Magnetic-field-dependent photodynamics of single NV defects in diamond: an application to qualitative all-optical magnetic imaging, New Journal of Physics 14: 103033.

[3] Wickenbrock, A.; Zheng, H.; Bougas, L.; Leefer, N.; Afach, S.; Jarmola, A.; Acosta, V. M. and Budker, D. (2016). Microwave-free magnetometry with nitrogen-vacancy centers in diamond, Applied Physics Letters 109: 053505.

[4] Fedotov, I.; Amitonova, L.; Sidorov-Biryukov, D.; Safronov, N.; Blakley, S.; Levchenko, A.; Zibrov, S.; Fedotov, A.; Kilin, S.; Scully, M.; Velichansky, V. and Zheltikov, A. (2014). Fiber-optic magnetic-field imaging, Optics Letters 39.

[5] Epstein, R. J.; Mendoza, F. M.; Kato, Y. K. and Awschalom, D. D. (2005). Anisotropic interactions of a single spin and dark-spin spectroscopy in diamond, Nature Physics 1: 94-98.

[6] Lühmann, T.; John, R.; Wunderlich, R.; Meijer, J. and Pezzagna, S. (2019). Coulomb-driven single defect engineering for scalable qubits and spin sensors in diamond, Nature Communications 10 4956.