Cavity-Enhanced Nitrogen-Vacancy Magnetometry

Sepehr Ahmadi, Haitham A. R. El-Ella, Adam M. Wojciechowski,
Tobias Gehring, Jørn O. B. Hansen, Alexander Huck, and Ulrik L. Andersen
Department of Physics, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

We report on the combination of a diamond sample and an optical cavity resonant with the pump field of nitrogen-vacancy (NV) centers. This combination allows us to reach an enhanced magnetic-field sensitivity and enables sensing by recording the remaining pump light level.

The optically detected magnetic resonance (ODMR) technique is commonly used for continuous-wave magnetometry with NV centers. In our experiments, we used the native NV^- concentration of <0.2 ppb of an untreated single-crystal diamond. Two concave mirrors form a confocal cavity around the diamond which was placed at its Brewster angle inside the cavity. The optical cavity is resonant at the pump wavelength of 532 nm and has a measured finesse of 45. The ODMR spectrum is presented in Fig. 1(a). A static magnetic field was aligned along the [111] crystal axis, resulting in the outermost electron spin resonances (SR1,SR4), while the inner peaks (SR2,SR3) correspond to the electron spin resonances of the other three crystallographic orientations. We excited all ^{14}N hyperfine transitions simultaneously in this measurement.

The use of the optical cavity allows us to reach the linewidth-narrowing regime, thereby maximizing the measured ODMR slope and the sensitivity [1]. For deducing the sensitivity of the magnetometer, we independently measured three time traces of the lock-in signal for 0.4 W optical input power. The Fourier transforms of these time traces are presented in Fig. 1(b), where the y-axis is displayed in units of sensitivity. After optimizing all system parameters, a noise floor of $\sim$400 pT/$\sqrt{\text{Hz}}$ is reached.

Under continuous optical pumping and microwave (MW) excitation, the total ground state population of NV centers depends on the electron spin-state, and hence the electron spin may be detected by recording the absorption of the pump field. In the experiment, we monitored the cavity transmission using the same diamond crystal. The result after sweeping frequency-modulated MW is an absorption detected magnetic resonance (ADMR) spectrum [2], which is presented in Fig. 1(c). The magnetic noise spectral density for an optical input power of 0.4 W is shown in Fig. 1(d), demonstrating a noise floor of $\sim$100 nT/$\sqrt{\text{Hz}}$ achieved with the ADMR technique.

The simulation results agree very well with the measured ADMR spectrum, as evidenced by the dashed line in Fig.1(c). Based on our simulations and considering a diamond with an optimized NV density, we estimate a photon shot-noise-limited sensitivity of $\sim$1 pT/$\sqrt{\text{Hz}}$ when measuring the power reflected from a cavity near the impedance-matching point.

In conclusion, we report on a cavity-enhanced magnetometer using the native NV concentration of an untreated diamond crystal. A sensitivity in the sub-nT/$\sqrt{\text{Hz}}$ regime is reached based on fluorescence light detection. In addition, we introduced an alternative spin resonance detection technique which is based on pump light absorption. We measured the cavity-assisted ADMR spectrum and obtained a magnetic noise floor of $\sim$100 nT/$\sqrt{\text{Hz}}$. Using this technique we circumvent challenges associated with inefficient fluorescence collection.

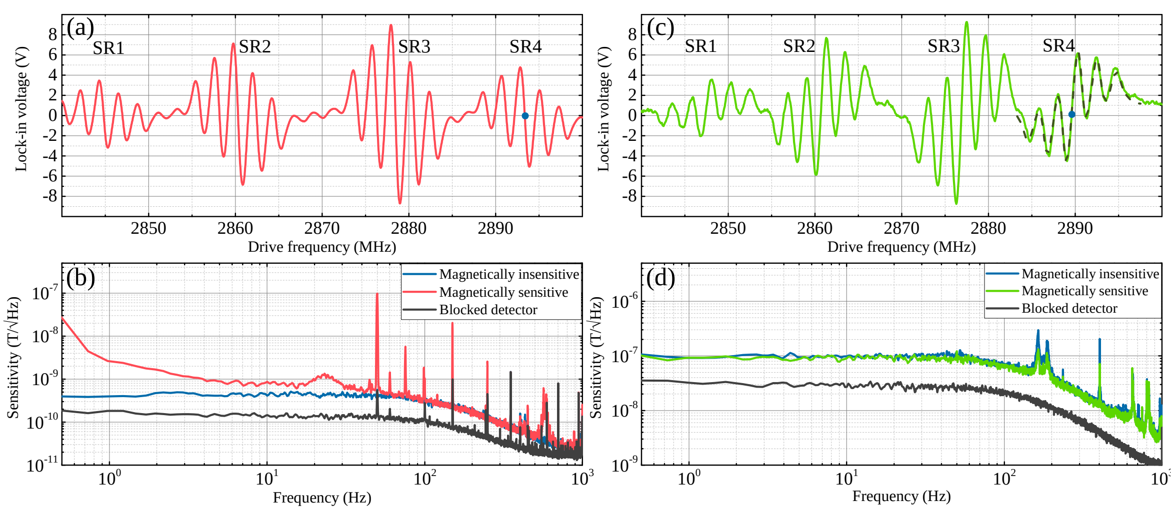

Fig. 1: Measured frequency-modulated (a) ODMR and (c) ADMR spectra. The magnetic noise spectral densities are presented in (b) and (d), corresponding to ODMR and ADMR, respectively.

1. S. Ahmadi et al., Phys. Rev. Appl. **8**, 034001 (2017).
2. S. Ahmadi et al., Phys. Rev. B **97**, 024105 (2018).