High-Stability High-Precision Quantum Sensing via Lifetime Readout of NV Centers

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The nitrogen vacancy (NV) center in diamond has become a leading sensing platform due to a favorable combination of fluorescence brightness, spin coherence, and readout contrast.Yet conventional readout relies on fluorescence intensity, suffering from severe degradation in complex environments due to technical noise and thermal-induced instability including charge-state conversion, fluorescence quenching and blinking. Here, we present lifetime readout as a superior approach that leverages the inherent robustness of NV excited-state lifetime to overcome these limitations. We demonstrate that lifetime readout with single NVs achieves remarkable long-term stability and precision in magnetic field sensing, effectively circumventing technical noises such as laser fluctuations and sample drift [1]. Such robustness also enables precise magnetic and temperature tracking in biological medium solution with nanoscale resolution using fluorescent nanodiamonds [2]. We further explore its potential for high-temperature quantum sensing with NV ensembles in bulk diamond. By revealing the energy overlap in phonon occupation between the zero-field splitting and the off-resonant intersystem crossing, we theoretically establish a fundamental balance between temperature sensitivity enhancement and spin contrast degradation, ensuring robust sensing performance across a wide temperature range. Using a simple setup lacking position control with easily implemented continuous-wave optically detected magnetic resonance scheme, lifetime readout of NV ensemble achieves $0.7\ K/\sqrt{Hz}$ temperature sensitivity and $11.6\ \mu T/\sqrt{Hz}$ magnetic field sensitivity at 457 K, outperforming conventional intensity readout. Our proposed protocol lays the groundwork for future industralization of high-performance NV sensor under demanding conditions, with significant headroom for improvement via integration with advanced quantum control protocols.

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References

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