Single Electron Trap Dynamics in Diamond Sensed by a Proximal Nitrogen-Vacancy Center

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A spectacular ground-state spin coherence time has established the negatively-charged nitrogen-vacancy center in diamond (NV) as an effective "quantum sensor" for magnetic fields [4]. Conversely, the exact frequency of an NV's zero-phonon line (ZPL) transition depends strongly on the local electric (and strain) field, and optical-addressing of NVs can lead to significant fluctuating Stark fields. This optically-induced charge noise causes "extrinsic" ZPL linewidth broadening, from the Fourier-transformed linewidth $\gamma_0/(2\pi) \approx 12.9\,\mathrm{MHz}$ to $10 \cdot \gamma_0$ (for "as-grown" NVs) and up to $> 1000 \cdot \gamma_0$ for NVs in micro and nano-structures, even in ultrapure CVD diamond ($[N_C] < 5\,\mathrm{ppb}$, $[B_C] < 1\,\mathrm{ppb}$) [5]. Charge noise significantly impedes NVs' performance as coherent single photon sources or electric field sensors, prompting a renewed interest aimed at understanding its underlying mechanism [1, 2].

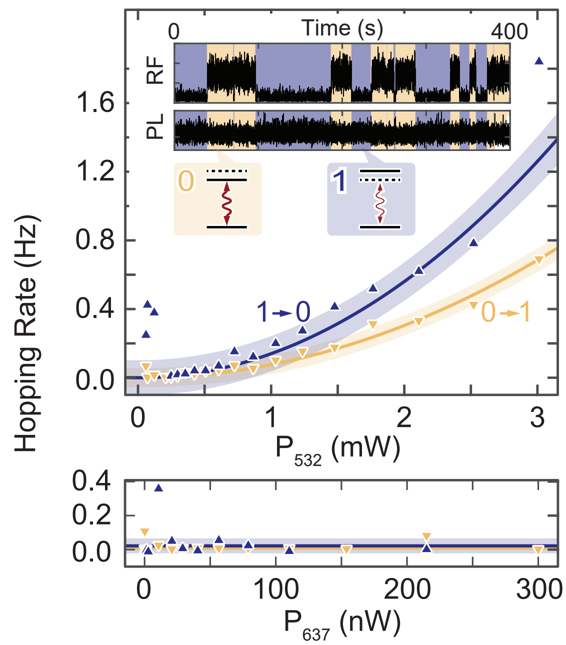

Fig. 1. Trap hopping rate versus illumination power for 532 nm (top) and 637 nm (bottom). Both the loading and unloading rates depends strongly on the 532 nm laser power, while staying constant upon increase of the 637 nm laser power. Inset: the two trap states (0/1) shift the NV transition frequency, leading to a resolved detuning between the resonant laser and the transition and thus to telegraph noise in the RF signal. The PL signal (excited non-resonantly) remains however constant, demonstrating that the NV's charge state itself is unaffected.

Using a single NV center located in a 1.6 µm-thick diamond membrane fabricated via a process optimized to yield narrow-extrinsic linewidths [3], we probe the electronic loading/unloading dynamics of a single trap by measuring time-traces and correlations in the resonance fluorescence (RF) signal from a proximal (few tens of nm) NV (see Fig. 1). We find that the resonant, 637 nm wavelength probe plays a negligible role in generating charge noise. In contrast, the 532 nm non-resonant repump pulses can charge or release an electron from the trap, with a probability scaling with power. Strikingly, evidence points at two-photon processes for both the loading and unloading of the trap, with reasonably comparable rates. Furthermore, our wide measurement bandwidth allows us to compare the dynamics of a single trap to the ensemble-noise resulting in continuous extrinsic linewidth broadening.

We expect that the combination of enhanced fabrication method such as the one presented here, together with a deeper understanding of charge-noise, will foster the development of more sensitive sensors and photon sources based on defect centers in diamond and other wide-bandgap semiconductors.

References

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