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# Enhancing readout in nitrogen vavancy center in diamond: leveraging photon statistics for analyzing ionization dynamics

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Nitrogen-vacancy (NV) centers in diamond have emerged as exceptionally promising candidates for the implementation of quantum technologies. These centers exhibit atom-like properties, characterized by long-lived spin quantum states and well-defined optical transitions, all within a robust solid-state device. Notably, the electron spins of NV centers can be easily initialized, controlled, and read out at room temperature in ambient atmosphere, simplifying the experimental setup and providing practical advantages for the development and application of quantum technologies.

The interest in charge state dynamics has grown significantly in recent years, driven partly by the observation of spin-to-charge conversio. This phenomenon serves as the foundation for photoelectric detection of the magnetic resonance of NV centers (PDMR) and their coherent dynamics, even at the single-defect level. The development of this mechanism eliminates the necessity for collection optics and single-photon detectors, rendering the NV center system more adaptable to integrated technological applications, particularly in compact diamond quantum sensors.

Our objective is to scrutinize the presented ionization model using the photon statistics formalism for further refinements in the readout sequence. The treatment begins with an effective rate equation model, encompassing both spin and charge dynamics to replicate experimental time traces and derived spin contrasts. The model involves decay rates $\Gamma_{ji}$ and absorption cross-sections $\sigma_{ji}$, where $i$ and $j$ correspond to the involved levels.

To explore the readout capabilities of our system, we analyze the photon statistics from the emission of both $NV^-$ and $NV^0$. This analysis facilitates the introduction of the Chernoff information as a metric for readout quality, indicating the rate of information gain per measurement repetition when discerning the state of the NV center.

While earlier research primarily focused on exploring the initialization capabilities of the ionization model, our current investigation shifts its emphasis towards scrutinizing the readout process. We propose the use of a ramp readout pulse, in which the power of the laser is increased linearly instead of suddenly switch on. Consistently employing a ramp pulse results in a superior Chernoff value increase of $4\%$. Moreover, a ramp pulse allows for a higher contrast, increasing from 45.0\% to 45.1\%. Although this improvement may appear modest, it signifies a meaningful advancement in performance.

The maximum values are achieved under specific conditions: 1.6 mW power and a pulse length of 335 ns for the ramp pulse, while the square pulse attains its maximum with 1.1 mW power and a shorter excitation time of 305 ns. Despite the square pulse being marginally shorter and requiring a lower maximum power, the energy consumption is 17\% higher than that of the ramp pulse.

At lower powers, the square pulse provides a slightly better contrast of approximately 0.5\%. However, beyond its peak, the contrast diminishes rapidly, while for ramp pulses, this decay is more gradual. Around 2 mW, we achieve the same contrast with both protocols, but the ramp pulse attains a better Chernoff value.

## Abstract category

**Presenter:** PANADERO MUÑOZ, Ivan (Arquimea Research Center / Universidad Carlos III de Madrid)

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