Aligning Electron and Nuclear Spins in an Ensemble of NV Centers

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Accurately controlling nuclear spins would allow for the creation of qubits with second long spin-spin coherence times (Decoherence of nitrogen-vacancy spin ensembles... by Hujing Park et alia), however it is difficult to control and read out their nuclear spins. Electrons decohere quicker, but their spins are easier to manipulate and read out through microwave pulses. We propose a machine learning model to generate microwave pulses to accurately control electron magnetic spins. If we have the necessary resources, we will also explore the manipulation of nuclear spins through electron-proton resonance.

An NV^- center in diamond has a lone pair of electrons that form a triplet state with magnetic spins $m_s = 0, \pm 1$. The latter two magnetic spins are degenerate with about $3.03 \cdot 10^{-25}$ J ($f_s = 2.87$ GHz) more energery than the former. Applying a magnetic field will further split these through Zeeman shifting. Pumping a laser at 532nm ($f_L = 5.64 \cdot 10^{14}$ Hz) through the NV^- center will excite this triplet state, and let it preferentially decay to the ground state with spin $m_s = 0$.

After resetting spins through laser pumping, we push them towards $m_s = +1$ through a microwave pulse at $f_0 = 2.87 + \delta f$ GHz, where δf is the Zeeman shift. A second magnetic pulse should affect fewer electrons, and thus have a higher reflection. We can estimate the average spin in an ensemble of NV^- centers using this reflection coefficient. To get a better readout, we can place the diamond inside a cavity with frequency close to $f + \delta f$. If they are exactly the same we may get resonance between the cavity and electrons, so we keep them a few hundred megahertz apart.

The particular sequence for the first pulse is a difficult problem. Algorithms (references?) invented by (people?) have achieved (percent?) accuracy, but we propose an ML model to generate pulses that achieve accuracies beyond any human-devised sequence. We will place a Fizeau wheel (toothed wheel) between the laser and diamond, to give the model several thousand trial periods each second. Each iteration will consist of a random pulse generated by the model, followed by a second pulse to measure the reflectivity. We will first train the model to minimize the reflectivity, and then to generate a pulse somewhere between the minimum and maximum, controlling the electron spins to any $m_s \in [0, 1]$. There are also more nuanced pulse sequences to control the nuclear spins rather than electrons. If we have the resources, we will explore ML models to replace these as well.

NV^- centers within diamonds are a promising qubit device, but their use is limited by large control error (no clue if this is true). We hope that our ML approach will decrease this error by several orders of magnitude.