Hybrid acousto-optical spin control in quantum dots

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Mechanical degrees of freedom very weakly couple to spins in semiconductors. The lack of an efficient coupling mechanism between phonons and electron spins in semiconductor quantum dots (QDs) stands in the way of their future integration in on-chip acoustically coupled quantum hybrid systems. Overcoming this limitation is highly demanded, as QDs are otherwise a perfect building block of such architectures, thanks to combining charge and spin degrees of freedom and many available interfaces.

Here, we propose a hybrid acousto-optical method of spin control that circumvents this problem and effectively introduces acoustic spin rotation to QDs [1]. This complements our recent acousto-optical charge control scheme [2], as well as the rich set of controllable QD interfaces with external fields and light [3], microwaves, and nuclear spin ensembles or registers [4,5].

We show that combining continuous-wave detuned optical coupling to a trion state with acoustic modulation results in spin rotation around an axis determined by the acoustic field. The optical field breaks spin conservation, allowing phonons to drive transitions between mixed spin states when at resonance with the Zeeman frequency. Our method is compatible with pulse sequences that mitigate quasistatic noise effects, which makes trion recombination the primary limitation to gate fidelity under cooled nuclear-spin conditions.

We derive an effective model that intuitively explains the observed spin qubit evolution, while our full numerical simulations shoacw that spin rotation fidelity can be very high, given that the trion lifetime is long and Zeeman splitting is large enough, with currently feasible 50 ns lifetime and 44 GHz splitting giving 99.9% fidelity in a double quantum dot.

Applying our advancement not only supplements QDs with previously lacking coupling, but also could enable acoustic QD spin state transfer first to quantized acoustic modes, and further to diverse solid-state systems. Additionally, thanks to QDs featuring many couplings, it can lead to transduction between acoustic, optical, and microwave domains, all within an on-chip integration-ready setting.

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