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Local Project ID: chdo09

Introduction

Singly charged semiconductor quantum dots (Qds) were proposed as potential qubits for seamless integration of quantum information into the conventional semiconductor hardware architecture already two decades ago. The electron spin dynamics in the QD can be controlled by laser pulses and is governed by various interactions between the electron and nuclear spins. The hyperfine interaction of the confined electron spins with the surrounding nuclear spins limits the electron spin coherence time at the temperatures in the high-temperature situation typical for experimental setups. Surprisingly, an interaction between the electron spins in the different QDs of an QD ensemble that are far apart has been observed in two-color pump-probe experiments [1]. The microscopic origin of this interaction was unknown for more than a decade.

Enhanced optical techniques also relying on the application of an external magnetic field enable the coherent control of the spins dynamics via the orientation of a select set electron spins in the QD ensemble. One of the goals was to explore experimentally relevant non-equilibrium scenarios that (I) extend the spin coherent time and (ii) provide a microscopic understanding of the spin-spin interaction between the QD spins and (iii) propose a new crosscorrelation spectroscopy as a tool for revealing additional information on very small spin-spin interactions.

Origin of the effective QD-QD coupling

The effective electron spin-spin interactions between the QDs of an ensemble is caused by virtual charge fluctuations mediated through a very low conduction electron density in the growth induced wetting layer connecting all QDs. Due imperfections and disorder, not all charges of the semiconductor dopant are trapped by the QDs: some are filling up the wetting layer conduction band. An advanced numerical renormalization group approach was used to calculate the magnitude and distance dependency of the effective spin-spin coupling between the QDs using microscopically realistic parameters in such semiconductors [2] and demonstrate that this mechanism reproduces the magnitude of the experimentally reported phase shifts [1].

Nuclear Polaron Formation:

The spin dynamics of a single QD subject to laser cooling was studied for electron and hole charged QDs. In this open quantum system the electron spin is weakly coupled to the lattice it is embedded in while the nuclear spin bath experience spin-flip processes with its environment on a much longer time scale. As a consequence, the effective nuclear spin bath temperature is much smaller than the lattice temperature due to the laser coupling.

The hyperfine coupling between electron and nuclear spins favors a condensation into a polaronic ground state that entangles both spin species antiparallel. A quantum phase transition as function of the coupling anisotropy is found between different types of nuclear polaron ground states [3].

Cross-correlation noise spectroscopy:

Recently, it has been realized that probing systems simultaneously with two different laser frequencies gives access to cross-correlations between different parts of a system. The

spin noise spectroscopy in two sub-ensembles of QDs was investigated. In equilibrium, one can gain additional information on the nature of very weak interactions such as the nuclear-electric quadrupolar coupling [4].
For quantum information application, however, QD subject to periodical laser pulses are relevant in order to enhance the spin-coherence time. It turns out that in such systems the nuclear spin Overhauser field distributions evolves from a Gaussian noise to clear anti-correlations or mode-repulsions.

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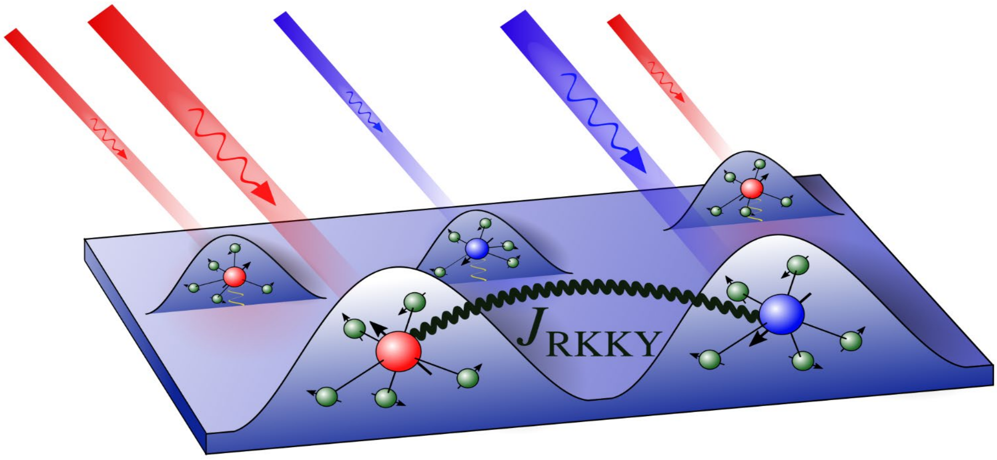

The sketch illustrates the effective interaction between two quantum point spins.