TIGHT-BINDING APPROACH TO THE SOLUTION OF *N*>2 QUANTUM DOT NETWORKS: A DETAILED STUDY OF THE NUCLEAR SPIN RELAXATION FOR MEMORY-STORAGE DEVICES

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We investigate the conductance spectra of coupled quantum dots (QDs) to study systematically the geometry and the nuclear spin relaxation of a two-dimensional network of *N* QDs, represented as boxes containing two double-degenerate levels. These spectra reveal the occupancy of the QDs vs the applied gate voltage [1]. We then derive the conductance using the Beenakker approach generalized to an array of QDs [2] and calculate in the linear response regime the nuclear spin relaxation rate. This allows us to predict the relevant memory effects of the system [3,4].

The experimental system consist of *N*=3,4, and 5 QDs weakly coupled to *N* different leads in thermodynamic equilibrium. A metallic gate defines the occupancy in the QDs and enables tuning of the network. In Fig. 1 a quantum dot circuit defined by electron beam lithography is shown: the five dots are coupled through the center dot, while the four outer dots can be loaded individually with single electrons. Aim of this complex geometry is to define entangled electron spin states in the dots which are then transferred to the nuclear matrix. This transfer is achieved by the hyperfine interaction, mediated through microwave and radio frequency pulses, as indicated in Fig. 2. Thus the extremely large retention time of the nuclear system (several 10 min at low temperatures) can be exploited for storing quantum information of the entangled electron spin states in the dots.

The Hamiltonian of the system is defined using the extended-Hubbard model, where we include inter- and intra-dot (*U*) Coulomb interactions and inter-dot hopping. We take into account the hyperfine coupling (HC) and calculate the nuclear spin relaxation rate ($1/T_1$) in the QDs in the presence of an external magnetic field, in order to model memory effects due the HC in the conductance peaks, already observed experimentally [4].

Exact diagonalization is used to calculate the eigenstates of arrays containing *N* QDs and the addition spectrum is calculated using the Beenakker approach for a single-dot generalized to an array of QDs. The Zeeman magnetic field induced by the nuclei determines the nuclear spin relaxation rate, which is calculated in the linear response regime. Different effects in the conductance resonance and in the Coulomb blockade (CB) valleys are observed. In the latter, a time relaxation of minutes is observed [4], a crucial feature to realize spin-based memory devices.

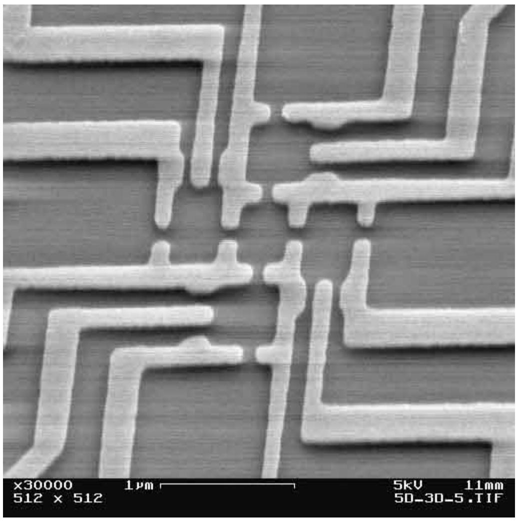

Fig. 1: Matrix of five coupled quantum dots defined by electron beam written Schottky gates. The outer four dots can be charged individually, while coupling is achieved through the center dot. The electron spin configuration in the dot network is then transferred to the nuclear system of th e host lattice.

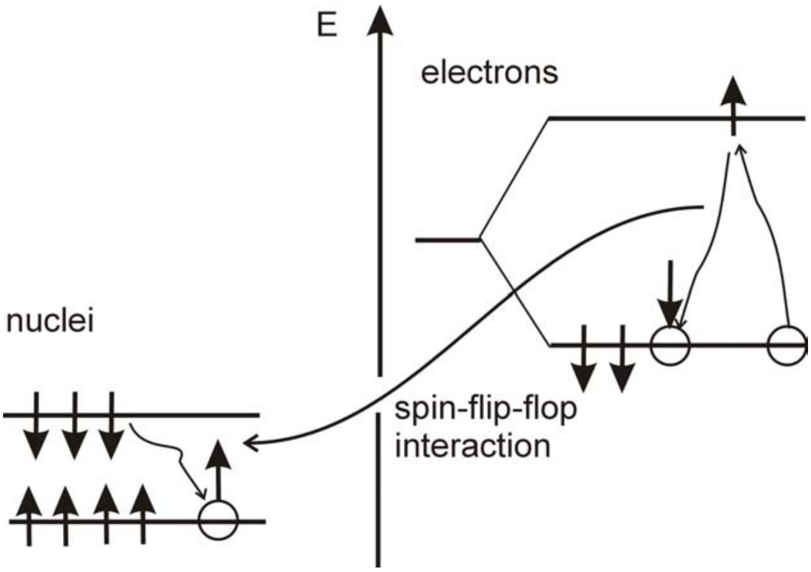

Fig. 2: Level scheme indicating how the electron spin states are split under application of a magnetic field with a spin transition induced by, e.g. microwave radiation. The electron will relax back and interact via a spin-flip-flop with the nuclear spin states. The nuclear spins are excited by radio frequency pulses. The energy scales of the two systems differ by two orders of magnitude. Hence, electron and nuclear spins can be addressed independently.

References:

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