博士論文 (要約)

Control and detection of electron spin states in triple quantum dots
(3重量子ドットにおける電子スピン状態の操作と検出)

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Abstract

Quantum computing utilizes the most fundamental concepts of quantum mechanics, superposition and entanglement, to perform parallel computing which boosts up the computing speed compared to the classical computing. Recently, spins in quantum dots (QDs) are attracting a lot of interest in applications to quantum computing hardware devices because of their potential scalability and coherence robustness. Superposition of single spin states, $|\uparrow\rangle$ and $|\downarrow\rangle$, confined to a QD is used to make a single spin quantum bit (qubit). Also, two electron spins confined to a double quantum dot (DQD) can be operated as a qubit made out of superposition of two-spin states, $|\uparrow\downarrow\rangle$ and $|\downarrow\uparrow\rangle$, which is called a Singlet-Triplet (ST) qubit. Indeed fundamental qubit operations, single-qubit rotation gates, and two-qubit entangling gates, have been demonstrated with the single spin qubit, and the ST qubit, respectively. The next step is therefore to implement practical quantum algorithms which have never been demonstrated with QD spins to date. Especially, some important algorithms such as quantum teleportation and quantum error correction are only feasible with three or more qubits. Scaling up the spin qubit system and improving the fidelity of quantum gate operations are two central issues to be sorted out in performing these algorithms or more.

This thesis presents a technique to precisely control and detect the three-spin states in GaAs triple quantum dots (TQDs). Throughout the work we conduct experiments to define the spin states of TQD and use them for various kinds of spin control and finally obtain four main results. First, we study a key technique of realizing Pauli spin blockade (PSB) in TQDs. We demonstrate high tunability of inter-dot couplings to achieve PSB. Secondly we realize electron-spin-resonance (ESR)-control Rabi oscillations of individual three electron spins in a TQD device with a micro-magnet. Thirdly we study the effect of fast measurement on dephasing of spin qubits with GaAs QDs. We show the qubit dephasing and the control fidelity can be improved by the fast mea-

surement. Finally we realize a hybrid system of a single spin and a ST qubit in TQD. We demonstrate a control-NOT (CNOT) gate operation between the two qubits based on a control-PHASE (CPHASE) gate using the exchange coupling. Also, we realize a quantum non-demolition (QND) readout of the single spin qubit with the ST qubit as a detector by observing quantum jumps.

The results obtained here will offer solid approaches to scaling up the qubit system and improving the spin control fidelity. We believe our techniques of controlling three spins will be useful for future developments in quantum computing with QDs, e.g. implementation of practical quantum algorithms such as quantum teleportation and quantum error correction.