# Abstract

PhD thesis presents theoretical studies on a new type of a spin qubit built on three coherently coupled semiconductor quantum dots (TQD) in a triangular geometry with three electrons. In the implementation of the qubit the scheme proposed by DiVincenzo et al. [1] has been used and developed. The qubit was encoded in two spin states from the doublet subspace, which shows immunity to decoherence processes and is sensitive to breaking of triangular symmetry. An advantage of the idea is implementation of local potential gates and purely electrically control of the qubit states and perform quantum logical operations.

In the first part of the thesis the effect of an electric field and a magnetic flux on the entanglement between two spins in the doublet subspace was analyzed. The electric field shifts the electron levels (Stark effect), affects on exchange interactions between the spins and spin correlation functions. The magnetic flux causes circulation of electrons and their delocalization. The system was modeled by the Hubbard Hamiltonian and its canonical transformation to an effective Heisenberg Hamiltonian. The exchange interaction shows linear and quadratic dependence on the electric field. Moreover, for specific symmetries one can find dark spin states for which two spins are maximally entanglement and third one is separated. A concurrence was used as a measure of entanglement. It was shown, that the concurrence is connected with expectation values of the spin correlation functions and the chirality.

The next chapter shows how to obtain the doublet states by Landau-Zener transitions. Two geometries of TQD were considered, a linear and a triangular. It was demonstrated that the triangular system has an advantage over a linear one, because one can generate both doublet states, each for a different symmetry of the system.

The qubit encoded in two spin states from the doublet subspace in TQD is described in the next chapter. It was shown that the manipulation of the qubit is possible by changes of the TQD symmetry. Moreover a new method to read out of the qubit state was demonstrated. It bases on charge transport through TQD connected to electrodes. For some symmetries one of the doublet state is dark and the electron transport is blocked. It is related with the asymmetry of transfer rates between the electrodes and the doublet state, and therefore it is called the doublet blockade effect. The thesis presented also dynamics of the system in the doublet blockade regime. The studies gave information about the leakage processes to the two electron states, decoherence and spin-flip processes related to the electron relaxation in the electrodes. The leakage to the triplet is larger than to the singlet due to activation of quadruplet states. The relaxation time for spin flip processes is long enough to perform a quantum operation on the doublet states.

The last part of the thesis considered two interacting qubits, each encoded in the triangular TQD with three spins. Two qubit operations such as SWAP, CPHASE and CNOT was presented for various connections between two TQD. The operations can be performed only in a few control impulses, e.g. the CNOT gate requires only three impulses. This is an important advantage of the proposal because, previous solutions need at least tens of impulses to perform such the gate. The time estimated to implementation of the gates is at the level of tenths of nanoseconds.

The results showed in the thesis suggest that TQD in the triangular geometry is a good candidate for an experimental realization of the qubit.

[1] D. P. DiVincenzo, D. Bacon, J. Kempe, G. Burkard, and K. B. Whaley, Nature (London) **408**, 339 (2000).