Application of InAs/GaAsSb/GaAs type-II Quantum Dots as quantum gates

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The InAs/GaAs quantum dots (QDs) covered by $GaAs_{1-y}Sb_y$ capping layer exhibit a lot of interesting properties. The prominent one is the possibility to tune the type of the band alignment continuously from type-I to type-II by changing the Sb content in the layer. We have previously found that the holes form a molecular-like states that might be of use in the information technology [1]. Here, we further elaborate this idea and show that such QDs are suitable for realization of a quantum gate (a device for a manipulation with qubits) according to a proposal of Burkard [2]. In that proposal, a qubit is represented by a spin of a hole. For a qubit manipulation, two-hole molecular states with a controllable singlet-triplet splitting are required.

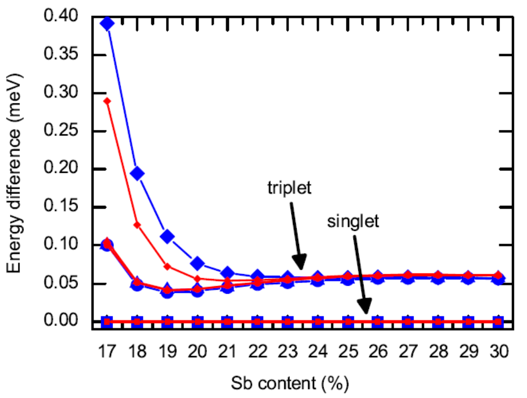

Fig.1 Dependence of the energy of the two-hole complex on the Sb content in the capping layer. The energy of the lowest state is set as a zero energy. The calculated values are for six (blue curve) and ten (red curve) single particle basis states. For the Sb content larger than ~0.23 singlet and triplet states are formed with energy splitting between them of ~60 μeV.

We have calculated two-hole states first by obtaining the single-particle states using Nextnano simulation suite [3] followed by multi-particle states calculated by the method of configuration interaction (CI). We have varied the Sb content in the layer and the external magnetic field acting on the structure. The latter is needed in order to bring both singlet and triplet states to the same energy as required by the proposal of Burkard. The calculations were done for two structures with different distributions of Sb in the capping layer leading to the hole states being localized either (i) close to the base of the dot, or (ii) above it.

We have found that singlet-triplet states are formed for both cases (see Fig. 1) and the exchange energy is 60 μeV / 180 μeV for the case (i) / (ii). By varying the externally applied magnetic flux density B along the QD axis, an anticrossing of the singlet and triplet was found for the case (i). Thus, GaAsSb capped InAs QDs fulfill the Burkard's requirements (molecular hole states with adjustable singlet-triplet splitting) and can serve for a realization of a quantum gate device.

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[3] S. Birner et al., IEEE Trans. El. Dev. **54**, 2137 (2007).