Spin Exchange Energy For A Pair Of Valence Band Holes In Artificial Molecules

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In III-V semiconductor quantum dots the main source of decoherence of confined spin states is interaction of the electron and nuclear spins [1]. In the case of electrons the contact term of the hyperfine interaction is the leading one. This term vanishes for valence band holes due to their wave functions being composed of p orbitals [2,3]. In the field of quantum information storage and processing via confined spins this fact suggests using holes rather than electrons [4,5]. There is growing interest in the spin properties of confined holes of the valence band.

Both operations on a single spin and on a pair of spins localized in quantum molecule should be enabled by an universal quantum logic gate. The latter case involve spin-exchange interaction [6]. The time of such operation is inversely proportional to the singlet-triplet exchange energy. While exchange energy of two electrons in the double dot system was studied in a number of papers, the confined holes differ by a stronger Coulomb interaction and strong spin-orbit coupling that introduces the valence band mixing. Peculiar effects of the latter fact was encountered, inducing formation of the antibonding ground state for a certain distance between the dots [7].

We present a configuration interaction study of exchange energy for a pair of interacting holes in vertical InGaAs quantum molecule. The axially symmetric 4-band Kohn-Luttinger Hamiltonian, that reflects the cylindrical symmetry of this system, introduces mixing of the heavy and light-hole bands because of the spin-orbit interaction. We found a singlet-triplet degeneracy for a single specific value of the interdot barrier. In this case the energies of the bonding and antibonding states are the same. This degeneracy is further investigated by means of a simplified model matrix Hamiltonian. The origins of the phenomenon were traced to the interaction effects for a degenerate ground state of the hole. When the system is tuned to the singlet-triplet degeneracy, the external electric field in a broad interval has at most only slight effect on spin exchange energy. In the present paper, we demonstrate that vanishing of the exchange energy is a characteristic property of a localized fermion pair for a degenerate single-particle ground state. The degeneracy appears due to hybridization of the bonding and antibonding orbitals for a specific value of the interdot barrier.

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