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Two-Spin Decoherence and Disentanglement in Semiconductor Nanostructures[1]

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A crucial issue in spin-based quantum information processing is spin coherence. Decoherence of a single electron spin confined in a quantum dot or to a donor ion has been studied extensively, with hyperfine interaction to the environmental nuclear spins being identified as the most important channel of spin decoherence [1]. Decoherence of two-spin-qubit states is inevitably affected by singe-spin decoherence. Moreover, for exchange-coupled spin qubits, there are new decoherence channels beyond those for single spins because of the Coulombic nature of the exchange interaction. Here we discuss a series of studies of two-spin decoherence mechanisms [2-6], including both known single-spin decoherence and relaxation channels due to nuclear spins and new channels based on electrostatic coupling. More specifically, we examine two-spin relaxation due to hyperfine interaction and phonon emission [2], spin-orbit interaction and phonon emission [3], nuclear spin dynamics mediated by electrons, charge noise [4,5], and electron-phonon interaction [6]. We also analyze the associated disentanglement of the two spins as the decoherence processes go on. Our results show that while nuclear spins affect two-spin states in a qualitatively similar manner as for single spin states, there are interesting new twists because of the weaker hyperfine interaction due to the electron orbital symmetry. On the other hand, the charge noise and phonon induced dephasing depends strongly on the electrical features of the nanostructure, and could pose a significant constraint on two-qubit gates and quantum computing schemes based on two-spin encoding.

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