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Tunable spin interactions in self-assembled semiconductor quantum dot molecules

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Carrier spins in coupled semiconductor quantum dots have been proposed as logic elements for quantum information processing. The spatial localization of spins in quantum dots has two obvious advantages: common dephasing mechanisms are suppressed and the spins can be spatially selected using a focused laser beam. Here we describe a very important but less obvious advantage. In a cluster of tunnel-coupled dots, Coulomb interactions are substantial, and state energies are very sensitive to the position of each carrier. Through the Pauli principle, small shifts in position can be used to induce large changes in spin energies. This provides a high degree of flexibility and is particularly useful in an optically controlled system, where exciton dipoles produce additional energy shifts. We have developed two-spin quantum dot molecules where one or more electrons or holes can tunnel between two quantum dots [1]. Combining applied magnetic and electric fields, kinetic spin exchange [2] and Zeeman splittings can be used to generate new spin mixings that are not easily obtained in single quantum dots. The mixing results from small asymmetric exchange interactions and produces optical selection rules that can be used for spin initialization, rotation, and measurement [3]. Tunable exchange energies also provide an important level of control over the two-spin resident carrier states that are a model for two-qubit gates and spin entanglement in a semiconductor system.

[1] E. Stinaff, et al., 311, 636 (2006).
[2] M. Scheibner, et al., Phys. Rev. B 75, 245318 (2007).
[3] D. Kim, et al., Phys. Rev. Lett. 101, 236804 (2008).