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Qubit control in phosphorus doped silicon nanowires

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Quantum confinement can turn thin silicon nanowires (SiNWs) to wide band gap material where the large surface-to-volume ratio indicates that its electronic structure may be tailored by surface termination. Here we show an example how these properties of thin SiNWs may be utilized to host quantum bits. A phosphorus (P) donor has been extensively studied in bulk silicon to realize the concept of Kane quantum computers. In most cases the quantum bit was realized as an entanglement between the donor electron spin and the nonzero nuclei spin of the donor impurity mediated by the hyperfine coupling between them. The donor ionization energies and the spin-lattice relaxation time limited the temperatures to a few kelvin in these experiments. Here, we demonstrate by means of ab initio density functional theory calculations that quantum confinement in thin SiNWs results in (i) larger excitation energies of donor impurity and (ii) a sensitive manipulation of the hyperfine coupling by external electric field. We propose that these features may allow to realize the quantum bit (qubit) experiments at elevated temperatures with a strength of electric fields applicable in current field-effect transistor technology. We also show that the strength of quantum confinement and the presence of strain induced by the surface termination may significantly affect the ground and excited states of the donors in thin SiNWs, possibly allowing an optical read-out of the electron spin [1]. Another forms of donor-related defects as potential qubits will be also discussed.

Work done in collaboration with Binghai Yan, Max Planck Institute for Chemical Physics of Solids, Dresden, and Riccardo Rurali, Institut de Ciència de Materials de Barcelona (ICMAB-CSIC).

[1] Binghai, Rurali, Gali, Nano Letters, 12, 3460 (2012).