Hole-spin qubits formed in a Ge quantum well

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Electrons bound to quantum dots provide well defined (spin-1/2) physical qubits. Here we demonstrate that hole spins in a Si$_x$Ge$_{1-x}$/Ge/ Si$_x$Ge$_{1-x}$ quantum well possess highly desirable properties as qubits, including a high natural abundance of nuclear spin-0 isotopes, a large ($\sim 100$ meV) intrinsic splitting between the light and heavy hole bands, and a very light (about 0.05 $m_0$) effective mass. Such qubits benefit from larger sizes, and do not suffer from the presence of nearby quantum levels (e.g., valley states) that detract from the operation of silicon spin qubits. The strong spin-orbit coupling in Ge quantum wells may be harnessed to implement electric dipole spin resonance.

In this study, we perform density functional theory (DFT) and $\vec{k} \cdot \vec{p}$ calculations to demonstrate that the limitations for hosting hole-spin qubits in bulk Ge are overcome when epitaxial strain is present. The tetragonal distortion causes a strong hybridization of heavy and light-hole states, a sudden change in the valence band dispersion, and a large intrinsic splitting of the degenerate hole bands. The hole mobility in Ge can be as large as $10^6$ cm$^2$/V s, which approaches that of GaAs, but occurs in material with much lower nuclear spin densities. Such high quality Ge quantum wells, appropriate for forming quantum dots, have now been successfully grown by several groups.