Control of spin-orbit coupling in single acceptor states in silicon

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Spins in silicon are suitable candidates for scalable quantum information devices, because of their long coherence times and inherent compatibility with current CMOS processing techniques. While quantum information devices in donor-based systems have been shown to be promising [1], the small dipole moment of donor spins make interaction of multiple qubits challenging to implement. The presence of spin-orbit coupling in acceptors however, could allow for fast quantum-gate manipulations [2] and effective long-range inter-qubit coupling [3]. Recent acceptor qubit proposals [4] suggest the possibility of maintaining the dipole moment between the spin-orbit states, without suffering from short coherence times.

In the first part of the presentation we show that long coherence times can be achieved for acceptor spins in bulk isotopically purified strained ^{28}Si. By coupling the bulk ^{28}Si crystal to a superconducting coplanar waveguide (CPW) resonator, we measured a coherence time (T2) of 0.7 ms for the acceptor spin ensemble in bulk ^{28}Si crystal under strain, in contrast to 0.04 ms for the same crystal without externally applied strain. The coherence time for the strained 28Si crystal was extended to 8.5 ms with the Carr-Purcell-Meiboom-Gill (CPMG) sequence [5]. This value for this coherence time is over 4 orders of magnitude higher than previously found in boron-doped silicon devices [6] and demonstrates the potential of boron-based acceptor spins in silicon as a candidate for scalable, electrically-driven qubits with long coherence times.

In the second part of the talk we focus on addressing single acceptors [7]. In general, J = 3/2 systems are much less studied than S = 1/2 electrons, and spin readout had not yet been demonstrated for acceptors in silicon. We present acceptor hole spin dynamics by dispersive readout of single-hole tunneling between two coupled acceptors in a nanowire transistor [8]. We identify mJ = ±1/2 and mJ = ±3/2 levels, and we use a magnetic field to overcome the initial heavy-light hole splitting and to tune the J = 3/2 energy spectrum. We find regimes of spin-like (+3/2 to −3/2) and charge-like (±1/2 to ±3/2) relaxations, separated by a regime of enhanced relaxation induced by mixing of light and heavy holes. The demonstrated control over the energy level ordering and hybridization are new tools in the J = 3/2 system that are crucial to optimize single-atom spin lifetime and electrical coupling.

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