Coherent control and interactions of spin and valley qubits in Si/SiGe quantum dots

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Semiconductor spin qubits in Si/SiGe quantum dots offer an appealing platform for scalable quantum computation. However, one major bottleneck that this platform must overcome is the presence of low-lying valley states.
Valley splitting energies have been reported in many studies [1, 2], and spin-valley coupling mechanisms have been documented [3, 4]. In this work, we report the first demonstration of coherent microwave control of valley states. We encode two 'valley' qubits in a double dot system and perform a robust characterization of their properties, achieving Rabi frequencies of up to ~100 MHz and coherence times on the order of ~100ns.
The ability to manipulate the valley states enables us directly to probe their effects on the spin qubits. Our experiments reveal that the valley states modify not only the g-factors of the spins, but also the exchange interaction between adjacent spins. With the latter, we show that we can leverage the valley degrees of freedom to perform logical conditional rotations, contingent on the state of both the spin and valley qubits.

References

[1] L. Schreiber, npj Quantum Inf, 10 (2024)
[2] E. Kawakami, Nat. Nanotech, 9 (2014) 666-670
[3] X. Cai, Nat. Phys, 19 (2023) 386-393
[4] R.M. Jock, Nat. Commun, 13 (2022) 641

Figures

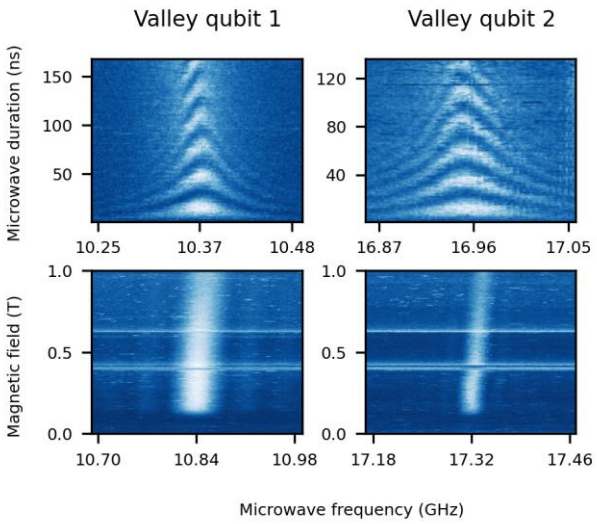

Figure 1: Coherent driving of the two valley qubits in our device. The top panels show two Rabi Chevron patterns. The bottom panels show the spectra of the two valleys as a function of external magnetic field, exhibiting only a slight dependence on the magnitude. The two horizontal lines (at approx. 0.4 and 0.6T) indicate the magnetic fields when the valley splitting of the electron coincides with the Zeeman splitting of the corresponding spin qubit.

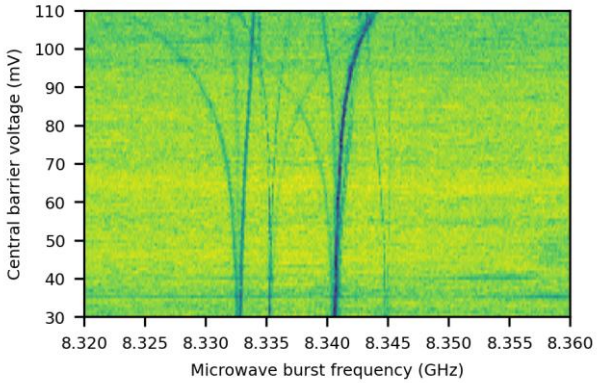

Figure 2: Exchange splitting maps of the two spin qubits modified by the presence of the valley states. The full dataset is a combination of several experiments that excite (or not) valley states. We observe valley-dependent exchange interactions of the two spins, as evidenced by the multiple pairs of exchange branches that we resolve.