Spatially resolving valley quantum interference of a donor in silicon

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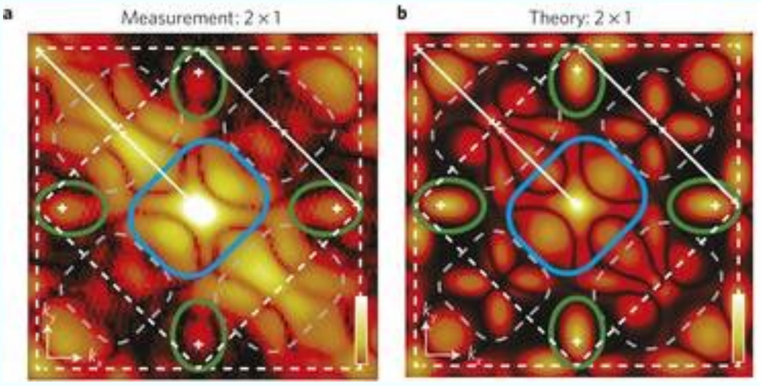

Fourier amplitudes of measured (left) and calculated (right) single-electron groundstate probabilities.

Electron and nuclear spins of donor ensembles in isotopically pure silicon experience a vacuum-like environment, giving them extraordinary coherence. However, in contrast to a real vacuum, electrons in silicon occupy quantum superpositions of valleys in momentum space. Addressable single-qubit and two-qubit operations in silicon require that qubits are placed near interfaces, modifying the valley degrees of freedom associated with these quantum superpositions and strongly influencing qubit relaxation and exchange processes. Yet to date, spectroscopic measurements have only probed wavefunctions indirectly, preventing direct experimental access to valley population, donor position and environment. Here we directly probe the probability density of single quantum states of individual subsurface donors, in real space and reciprocal space, using scanning tunnelling spectroscopy.We directly observe quantum mechanical valley interference patterns associated with linear superpositions of valleys in the donor ground state.The valley population is found to be within 5% of a bulk donor when 2.85 _0.45 nm from the interface, indicating that valley- perturbation-induced enhancement of spin relaxation will be negligible for depths greater than 3 nm. The observed valley interference will render two-qubit exchange gates sensitive to atomic-scale variations in positions of subsurface donors. Moreover, these results will also be of interest for emerging schemes proposing to encode information directly in valley polarization.

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