Single donor qubits in isotopically purified ^{28}Si: New benchmarks for solid-state qubits

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A phosphorus donor in silicon is, almost literally, the equivalent of a hydrogen atom in vacuum. It possesses electron and nuclear spins of 1/2 which act as natural qubits [1], and the host material can be isotopically purified to be almost perfectly free of other spin species, ensuring extraordinary coherence times (~180 s) [2]. It is, however, still embedded in a semiconductor host material, allowing electric gates to be used to manipulate its electrostatic environment and a microwave transmission line to apply spin resonant pulses.

The single-shot readout [3] and coherent control of both the electron [4] and the nuclear spin [5] of a single P atom in silicon have been recently demonstrated, using ion-implanted donors in MOS nanostructures. It is known from bulk experiments that P donors in isotopically purified ^{28}Si exhibit record coherences [2], but it is also suspected that the proximity to a Si/SiO_2 interface will deteriorate the coherence time. Here, we present the first experiment on single electron and nuclear spin qubits in an isotopically engineered ^{28}Si nanostructure [6]. We measure free induction decay-limited electron spin resonance lines (< 2 kHz FWHM), and we obtain average single-qubit control fidelities of 99.95% for the electron and 99.99% for the nucleus. Noise spectroscopy experiments indicate that, contrary to widespread belief, the ultimate limit for single-spin coherence in our nanostructure is not set by charge noise and interface effects, but simply by broadband thermal radiation coupled to the qubit through a high-bandwidth transmission line. Using dynamical decoupling, we measured coherence times up to T_{2e}^{DD} = 0.5 s for the electron, and T_{2n}^{DD} = 35 s for the ^{31}P nucleus.

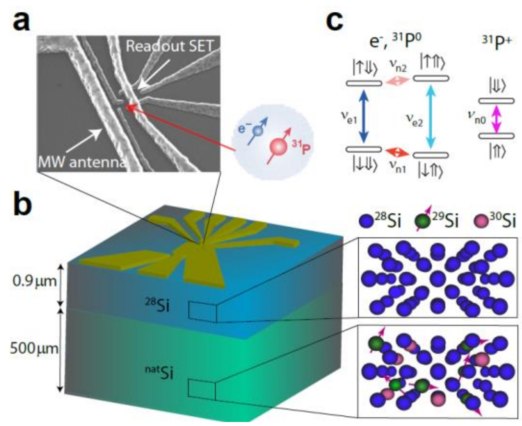

Figure 1: a) SEM image of the device, b) schematic of the substrate, and c) energy level diagram of the qubit states.

Finally, we will present an innovative qubit control scheme, which employs the Stark shifts of the gyromagnetic ratio and hyperfine coupling to electrically tune the spin transitions in resonance with the microwave source. The ability to electrically control the resonance frequency greatly simplifies the operation of a multi-qubit device, as it allows independent, high-fidelity qubit operations without the need to pulse the microwave source.

References

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