Electrons on Helium as Mobile Spin Qubits

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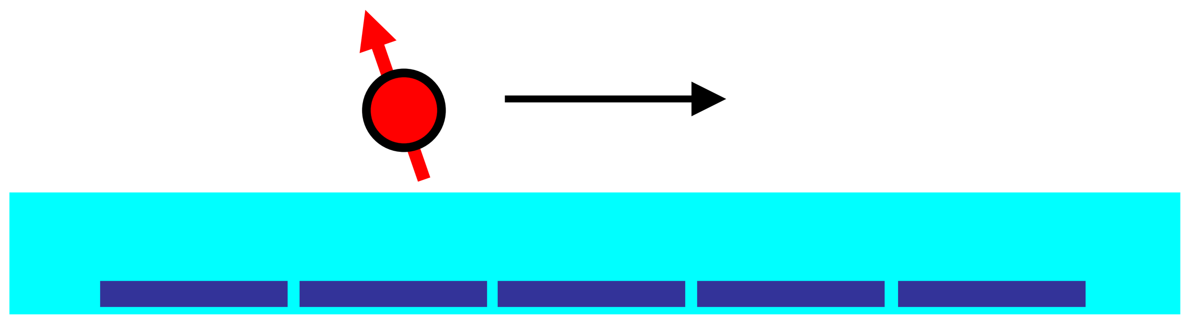
Emerging Models and Technologies
Computer & Information Science & Technology



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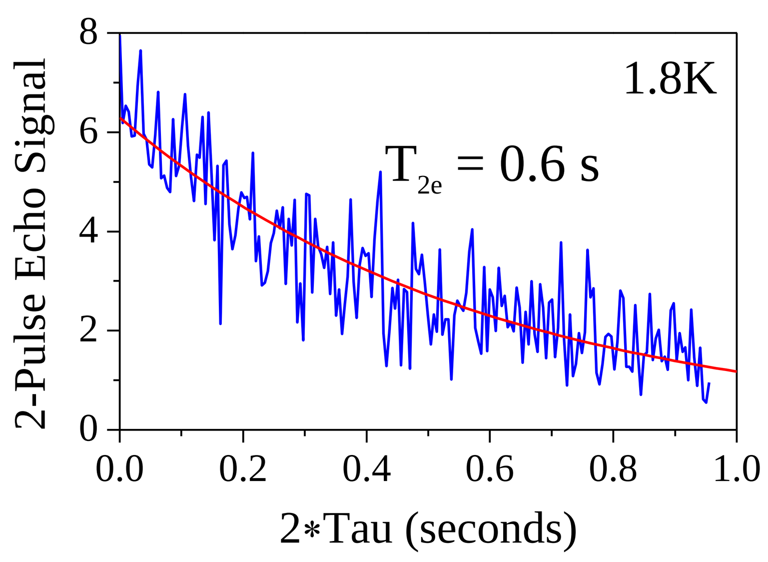
Wanted: mobile spins with long coherence

Electron spins in silicon have extremely long coherence when localized, but much shorter coherence when mobile:

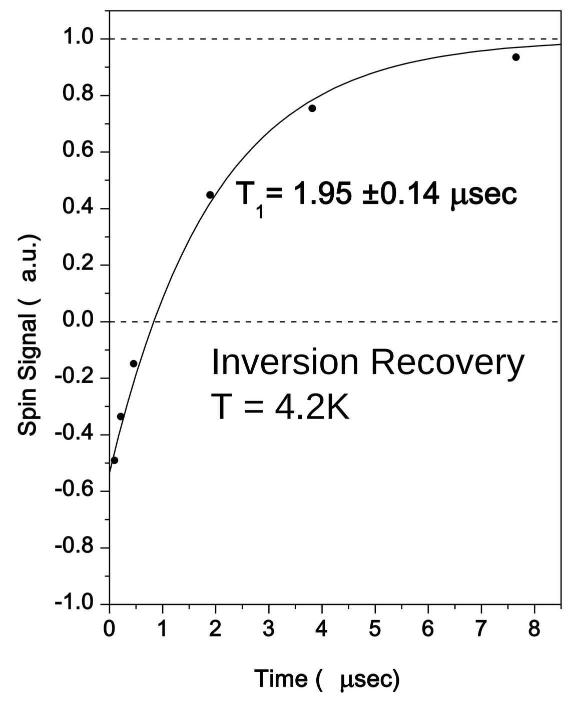
Extremely long spin coherence observed for localized donor electrons in enriched silicon-28

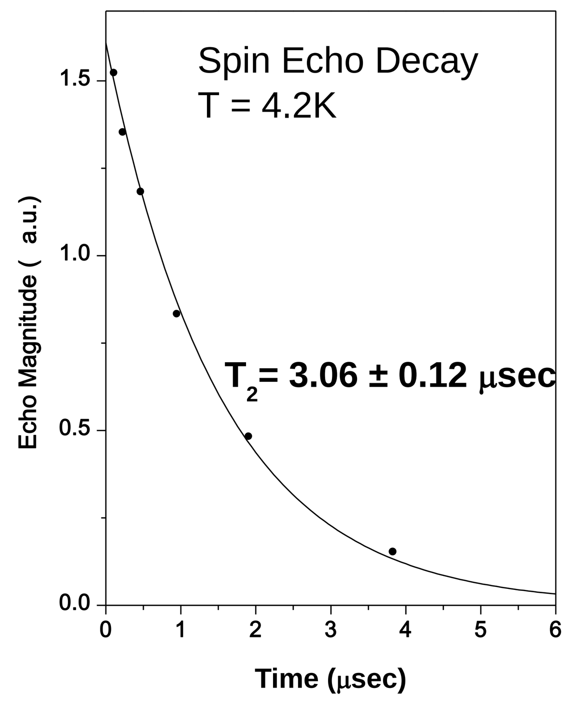
(^{28}Si:P, ~50ppm ^{29}Si, 1.2e14 P/cm^3)

Pulse sequence: 90° - t - 16° - t - echo



Coherence of high mobility 2D electron spins in silicon is only microseconds





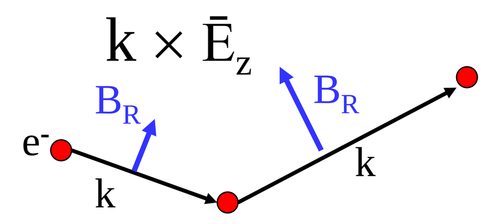
$T_2 > T_1$ requires anisotropic relaxation mechanism

Why the shorter spin coherence in 2D?

Coherence limited by fluctuating fields from the Rashba effect

(spin-orbit interaction from broken symmetry at 2DEG interface)

$$H_R = \underbrace{\alpha(\bar{k}\times\bar{E})}_{B_R}\cdot\hat{S}$$



Electron spins on the surface of superfluid helium are expected to have long coherence:

Spin-orbit effect from the normal electric field is much weaker than the Rashba fields in semiconductor devices.

Material interactions are small and non-local.

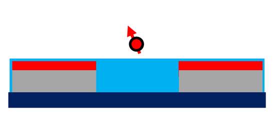
Spin resonance of electrons on helium

Experimental parameters

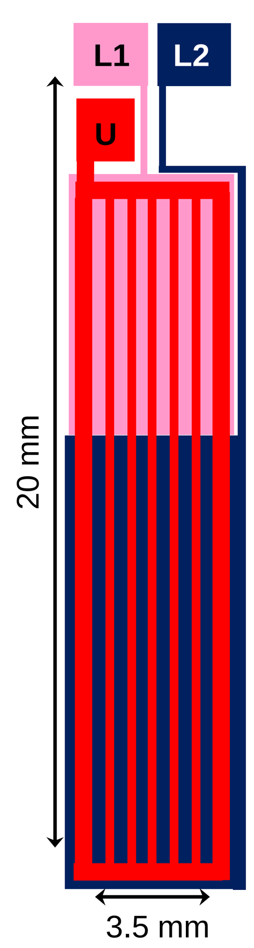
- X-band ESR: 10 GHz microwaves and 0.35 Tesla B_0
- Temperature of 1.8 Kelvin

Cartoon drawing of sample:

The 85 channels are 20µm wide by 2µm deep by 20mm tall, optimized for a standard cylindrical microwave cavity.



Cartoon cutaway view of a sample channel filled with superfluid helium and one bound electron



Electrons thermally emitted by tiny tungsten filament

Channel population measured by transport to be ~3x10^8 total spins

Sample

Understanding fast-passage spin resonance measurements is important for measuring the long relaxing electron spins on helium, so detection parameters are calibrated using ^{28}Si:P donor electrons with spins that can be relaxed by shining visible light on the crystal:

- Resonance linewidth limited by magnet homogeneity
- Spin relaxation, T_1 > 100 s
- As expected in the fast passage regime, dispersion mode CW ESR shown to be most sensitive to these long T_1 spins
- Single scan signal = noise for 1.5x10^9 spins in equilibrium polarization

Results

- signal averaged 100 scans around g = 2.0023 with 60 second delay between scans
- expect resonance dip = 2x noise
- repeat this with a range of ESR and electron loading parameters

1. No observed resonance at free electron g-factor suggests T_1 > 100 s
2. Long T_1 suggests long T_2?

Next measurement attempts

Thin Van der Waals helium films instead of channels

- Higher electron densities achievable
- Electrons held closer to substrate metal will relax due to Johnson noise currents
- Long surface state lifetimes on thin films require ultra smooth substrates and careful electron loading