Tata Institute of Fundamental Research
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Webinar

High-sensitivity quantum-limited electron spin resonance spectroscopy

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In a conventional electron spin resonance (ESR) spectrometer based on the inductive detection method, the paramagnetic spins precess in an external magnetic field B_0 radiating weak microwave signals into a resonant cavity. Despite its widespread use, ESR spectroscopy has limited sensitivity and large amounts of spins are necessary to accumulate sufficient signal. Most conventional ESR spectrometers operate at room temperature and employ three-dimensional cavities. At X-band, they require approximately 10^{12} spins to obtain sufficient signal in a single echo. Enhancing this sensitivity to smaller spin ensembles and eventually the single spin limit is highly desirable.

Exploiting recent progress in circuit-quantum electrodynamics, we have combined high quality factor superconducting micro-resonators and noise-less Josephson Parametric Amplifiers to perform ESR spectroscopy at millikelvin temperatures, reaching a new regime where the sensitivity is limited by the quantum vacuum fluctuations of the microwave field. Quantum fluctuations of the field also directly affect the spin dynamics via Purcell effect: spin relaxation occurs dominantly by spontaneous emissions of microwave photons. Based on these principles, we first show an unprecedented measurement sensitivity of ~10 spins/√Hz for unit SNR in an inductive-detection ESR with an ensemble of bismuth donors in silicon. This high sensitivity enables us to characterise the coherence properties of an ensemble of donors in proximity (50-100 nm) to the silicon surface, with spatial resolution. We identify surface magnetic and electric noise as the main decoherence sources in our device. At the so-called "clock transition", the coherence time approaches one second, which is the longest reported for an electron spin close to a surface.

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