Hybrid spin-superconducting circuits for quantum technologies

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Hybrid structures that combine spins and superconducting quantum circuits offer an appealing playground for developing various quantum technologies using the powerful tools of circuit Quantum Electrodynamics, noticeably high quality factor superconducting micro-resonators and Josephson parametric amplifiers that operate at the quantum limit when cooled at 20 mK [1]. We report a sizeable increase of the sensitivity of inductively detected Electron Spin Resonance (ESR), and we investigate a new resonance regime in which the quantum nature of the microwave field plays a role. We demonstrate the detection of 300 Bismuth donor spins in silicon with a signal-to-noise ratio of 1 in a single echo experiment [2-3], and a detection sensitivity of 10 spin/sqrt(Hz) achieved by making spin relaxation by spontaneous emission through the cavity, i.e. the Purcell effect, the dominant relaxation mechanism [4]. We show that the sensitivity can be further enhanced by using quantum squeezed states of the microwave field. Applications of this new regime to ultra-high-sensitivity nuclear spin detection and electron spin hyperpolarization will be also presented. For implementing quantum bits, electro-nuclear levels of spin impurities in insulators could provide quantum bits with excellent quantum coherence, which would alleviate the challenge of quantum error correction when operating a quantum processor. A preliminary experiment aiming at controlling a single electronic spin coupled to a microwave resonator will be described. The perspectives of hybrid routes for quantum computing will also be discussed in a broad perspective.

[1] X. Zhou et al., Physical Review B 89, 214517 (2014).

[2] A. Bienfait et al., Nature Nanotechnology 11(3), 253-257 (2016).

[3] S. Probst et al, Appl. Phys. Lett. 111, 202604 (2017).

[4] A. Bienfait et al., Nature 531, 74 (2016).