Atomic-Scale Quantum Sensing of Electric and Magnetic Fields in a Scanning Tunneling Microscope

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Abstract

Quantum sensing harnesses the innate sensitivity of quantum systems to external perturbations, enabling precise measurements of physical quantities. The most prevalent platforms like color centers in insulators and superconducting circuits excel in detecting magnetic or electric fields but the spatial resolution of existing techniques remains elusive as a consequence of retaining the sensor location and size. In contrast, conventional probe techniques, such as scanning tunneling microscopy (STM), achieve atomic-scale resolution routinely. Recent advances integrating electron spin resonance (ESR) with STM [1,2] have paved the way for quantum sensing while the studies have focused on quantum sensors located on a surface, which prevents tunable couplings and three dimensional characterization. This work presents a fully integrated, mobile quantum sensor positioned at the STM tip. The quantum sensor is composed of a magnetic atom cluster for readout and a free radical for ESR-based quantum sensing. By measuring the magnetic and electric dipole moments of an iron atom and a silver dimer on Ag(111), we demonstrate the functionality of our quantum sensor, providing sub-microvolt energy resolution and simultaneous atomic-scale spatial resolution for magnetic and electric field measurements. We anticipate that our fully integrated sensing and read-out unit can further facilitate the characterization of spin ordering in newly emerging materials, thereby advancing the application of quantum sensing technologies to the realm of quantum materials.

References

[1] S. Baumann, W. Paul, T. Choi, C. P. Lutz, A. Ardavan, and A. J. Heinrich, Science, 350 (2015) 417-420.
[2] Y. Chen, Y. Bae, and A. J. Heinrich, Adv. Mater., 35 (2023) 2107534.

Figures

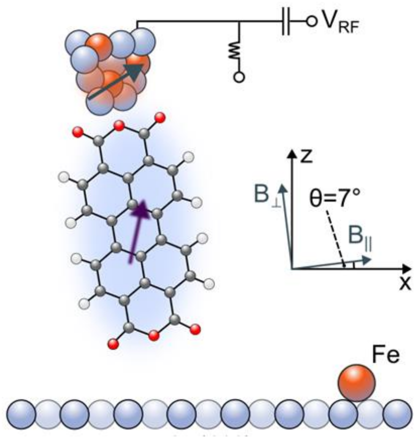

Figure 1: Molecular quantum sensor attached to the STM tip, which can be electrically detected by ESR and deliver atomic resolution to read out magnetic and electric fields.