Quantum Control at the Atomic Scale: From Ångstrom-Scale Qubit Platforms to Topological Superconductivity

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In the context of quantum science and technology, our study achieves harnessing individual electron spins within solid materials with precise atomic-level connections. Scanning Tunneling Microscope (STM) emerges as a mature technique for studying magnetic impurities on different substrates, serving as quantum sensors and building blocks for quantum information [1]. We successfully build, manipulate, and observe linked electron-spin qubits on an atom-by-atom basis [2]. Coherent control of these "remote" qubits is empowered through the introduction of localized magnetic field gradients generated by nearby single-atom magnets. Our readout methodology utilizes a sensor qubit within the tunnel junction, featuring pulsed double electron spin resonance. This enables swift single-, dual-, and triple-qubit operations, entirely through electrical means. The resulting Ångstrom-scale qubit platform opens the door to harnessing quantum capabilities, utilizing arrays of electron spins meticulously assembled atom by atom upon a surface.

In the second part of my talk, the experimental focus shifts to utilizing single magnetic atoms to assemble a 1-D spin chain on a superconducting surface, leading to diverse spin orderings, closing the superconducting gap, and approaching a topological quantum phase transition [3]. Calculations employing Bogoliubov-de Gennes theory anticipate the appearance of clear Majorana bound states for relatively small chains in specific arrangements [4], showcasing the potential for exploring topological quantum phenomena in a controlled manner.

References

[1] Colloquium: Atomic spin chains on surfaces. Review of Modern Physics 91, 041001 (2019)
[2] An atomic-scale multi-qubit platform, Science 382 (6666), 87-92 (2023)
[3] Atomic Manipulation of In-gap States on the β-Bi2Pd Superconductors, Physical Review B 104 (4), 045406 (2021).
[4] Calculations of in-gap states of ferromagnetic spin chains on s-wave wide-band superconductors, Physical Review B 104 (24), 245415 (2021).

Figures

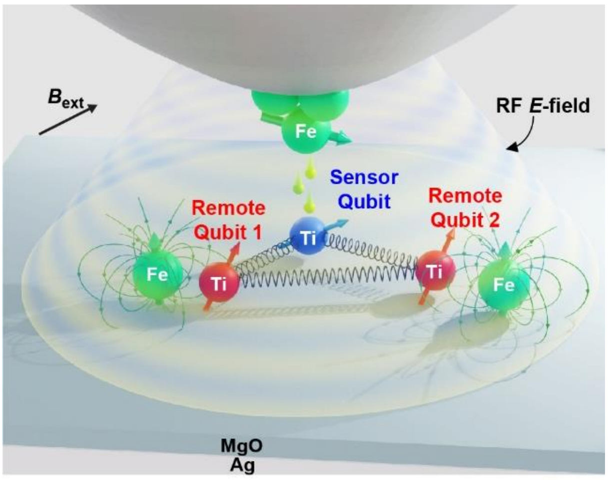

Figure 1: Three-Dimensional Model of a Single-Atom Electron Spin Qubit.