Controlling and Sensing Spin Systems with Free Space Electrons

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Coherent control and detection of quantum systems are central to quantum technologies. Beyond excitation with optical and microwave fields, free-space electrons can be used to manipulate and detect quantum systems with unique spatial and spectroscopic resolution. In this talk, I outline our theoretical framework [1] showing that the non-radiative near-field of a spatially modulated electron beam can coherently drive quantum systems and show preliminary experimental data [2]. I then present our SPINEM (Spin Electron Microscopy) platform [3], which integrates continuous-wave electron spin resonance (ESR) spectroscopy into a transmission electron microscope (TEM). Using a miniaturized microwave resonator with the free-space electrons of a TEM [4], we enable in-situ, phase-locked detection of microwave-driven spin precession with picoradian deflection sensitivity (~280 prad) for localized spin spectroscopy. Finally, I discuss a roadmap toward atomic resolution and single-spin sensitivity [5], opening opportunities in nanoscale spintronics, magnonics, and quantum materials.

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