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A Scanning Quantum Cryogenic Atom Microscope

BENJAMIN LEV, Stanford University

Microscopic imaging of local magnetic fields provides a window into the organizing principles of complex and technologically relevant condensed matter materials. However, a wide variety of intriguing strongly correlated and topologically nontrivial materials exhibit poorly understood phenomena outside the detection capability of state-of-the-art high-sensitivity, high-resolution scanning probe magnetometers. We introduce a quantum-noise-limited scanning probe magnetometer that can operate from room-to-cryogenic temperatures with unprecedented DC-field sensitivity and micron-scale resolution. The Scanning Quantum Cryogenic Atom Microscope (SQCRAMscope) employs a magnetically levitated atomic Bose-Einstein condensate (BEC), thereby providing immunity to conductive and blackbody radiative heating. The SQCRAMscope has a field sensitivity of 1.4 nT per resolution-limited point (2 um), or $6nT/Hz^1/2$ per point at its duty cycle. Compared to point-by-point sensors, the long length of the BEC provides a naturally parallel measurement, allowing one to measure nearly one-hundred points with an effective field sensitivity of 600 $pT/Hz^1/2$ each point during the same time as a point-by-point scanner would measure these points sequentially. Moreover, it has a noise floor of 300 pT and provides nearly two orders of magnitude improvement in magnetic flux sensitivity (down to $10^-6Phi_0/Hz^1/2$) over previous atomic probe magnetometers capable of scanning near samples. These capabilities are for the first time carefully benchmarked by imaging magnetic fields arising from microfabricated wire patterns and done so using samples that may be scanned, cryogenically cooled, and easily exchanged. We anticipate the SQCRAMscope will provide charge transport images at temperatures from room–to 4K in unconventional superconductors and topologically nontrivial materials.