Dissipative dynamics in quantum materials using a mK scanning probe microscope

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The most intriguing emergent behaviors of quantum materials are determined not only by their static band structure, but by the dynamics of their quasiparticle interactions. For example, various quantum critical fluctuations may drive unconventional superconductivity, while spin fluctuations may drive exotic topological phases. Such dynamics are largely invisible to conventional scanning tunneling microscopy (STM), while ultrafast optics typically average over the spatial variations that are common to strongly correlated materials. We have developed a unique scanning probe microscope (SPM) combining STM and pendulum atomic force microscopy (pAFM) operating below 100 mK in magnetic fields up to 14 Tesla. Atomic-scale fluctuation-dissipation dynamics are quantified by local shifts in resonance frequency (reflecting tip-sample force) and quality factor (indicating dissipation) of a scanned cantilever oscillating like a tiny pendulum above the sample [1]. Our pAFM flexibly employs a qPlus sensor [2] with custom cryogenic preamplifier, or an optically detected soft-silicon cantilever for improved force and power resolution. To achieve ultra-low electron temperatures, we introduce a new method for fabricating powder filters with bendable PCBs, for integration in the confined space of a dilution refrigerator.

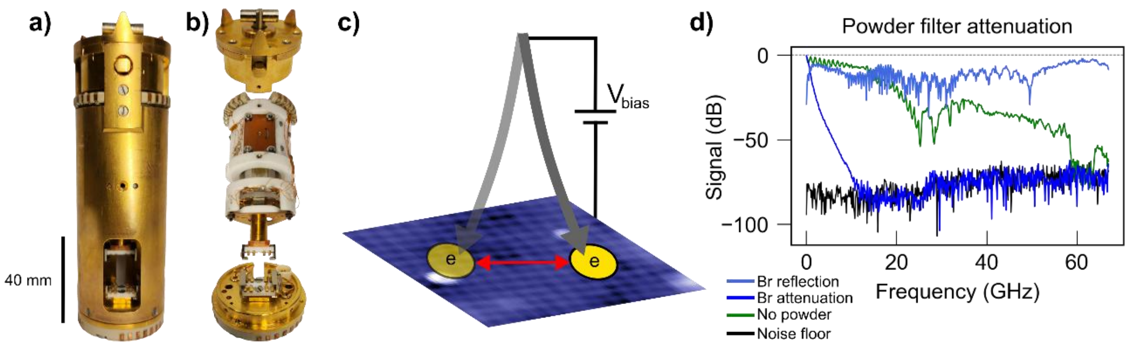

Figure 1. a) Modular shuttle-style SPM head. **b)** Microscope head parts including clamping mechanism (top), 3-axis walker and multi-contact sample holder (middle), and probe holder (bottom). **c)** Dissipation pAFM demonstrating electron puddle movement associated with cantilever oscillation. **d)** Attenuation and reflection data for 50 µm bronze (Br) powder filter.

Reference

[1] A. DiCarlo, *et. al.* (1992) Magnetic Force microscope utilizing an ultra-small-spring-constant vertically cantilevered. Ultramicroscopy, 47, p 383-392. https://doi.org/10.1016/0304-3991(92)90169-K
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