Application Note CI05

Scanning Hall Probe Microscopy down to 300 mK based on ANP positioners

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Introduction

The magnetic properties of superconducting (SC) and ferro-magnetic materials at ultra-low temperatures represent some of the most interesting contemporary problems in condensed matter physics. These properties are typically investigated using a magnetic force microscope (MFM) or a scanning Hall probe microscope (SHPM). In this note, we report on a self-built SHPM capable of working at temperatures as low as 300 mK and magnetic fields of up to 10 T, while still having sub-micron lateral spatial resolution.

The scanner head is depicted in Figure 1. The setup consists of a three-axis attocube systems ANPxyz100 nanopositioner set (see no. 1,2, and 3 in Figure 1(b)) that enables precise *in situ* adjustment of the probe location within a 5 x 5 x 5 mm³ space, carrying a 2 inch piezoelectric tube (no. 4) to scan the SHPM head (no. 5) over ranges up to 22 x 22 x 0.6 µm³ at 4.2 K. A readily exchangeable microfabricated Hall probe maps the local magnetic induction at the sample surface (no. 6), while the tip-sample distance is controlled using an integrated scanning tunnel microscopy (STM) tip. Advanced lithographic patterning is used to reduce the active Hall cross area down to typically ~0.4 x 0.4 µm² with the STM tip positioned as close as possible to the Hall effect sensor.

Hence, the instrument is capable of simultaneous tunneling and Hall signal acquisition with minimum detectable fields ≥ 10 mG/Hz1/2. It is possible to use the instrument in fixed height as well as constant distance modes with the scan speed in fixed height mode being as fast as 300 µm/s. The whole setup is mounted on the cold flange of a commercial 3He-refrigerator and operates between room temperature and 300 mK.

The potential of the system is illustrated with images of SC vortices at temperatures down to 300 mK. Figures 2(a),(b) show vortices at the surface of a sputtered 700 nm SC Nb thin film at temperatures of 1.575 K and 372 mK, respectively [1]. Figures 2(c),(d) show lower contrast vortex structures at the cleaved surface of a single crystal of the unconventional SC Sr_2RuO_4 (*Tc* = 1.5 K) captured at 303 mK with somewhat higher spatial resolution (courtesy of V. V. Khotkevych, P. J. Curran & S. J. Bending (Univ. of Bath) and A. S. Gibbs & A. P. Mackenzie (Univ. of St. Andrews). The scan height of the SHPM sensor was set in the range 0.7 - 0.9 µm for the Nb film and less than 0.5 µm for the Sr_2RuO_4 single crystal.

In summary, a versatile and stable SHPM has been built using attocube systems nanopositioners. The microscope is opera-tional in temperatures down to 300 mK and magnetic fields of up to 10 T.

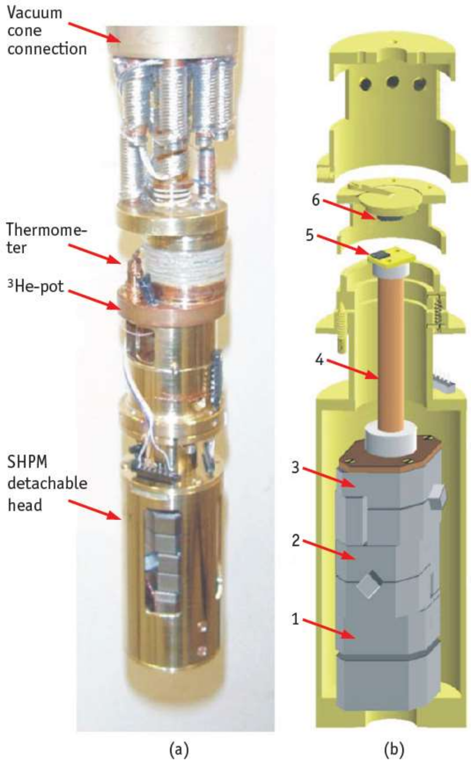

Figure 1: *Photograph (a) and sketch (b) of the LT compatible SHPM scanner head (see text). For a more complete description of all details, refer to [1].*

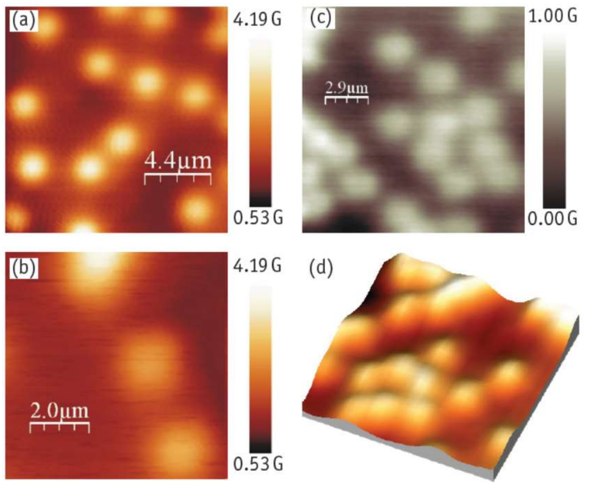

Figure 2: *SHPM images of SC vortices. (a),(b) Vortices in a 700 nm thick Nb film at (a) T = 1.575 K and (b) T = 372 mK.*
(c) Disordered vortex structures at the cleaved surface of a single crystal of the unconventional SC Sr2RuO4 at T = 303 mK.
(d) 3D view of (c).

References

[1] V. V. Khotkevych, M. V. Milošević, and S. J. Bending, Rev. Sci. Instrum. **79**, 123708 (2008).