

# Scanning Hall Probe Microscopy using attocube systems Positioners down to 300 mK

The magnetic properties of superconducting (SC) and ferromagnetic 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 10T, while still having sub-micron lateral spatial resolution.

The scanner head is depicted in Fig. 1. The setup consists of a three-axis attocube systems ANPxyz100 nanopositioner set (see no. 1, 2, and 3 in Fig. 1(b)) that enables precise in situ adjustment of the probe location within a  $6 \times 6 \times 7 \text{ mm}^3$  space, carrying a 2 inch piezoelectric tube (no. 4) to scan the SHPM head (no. 5) over ranges up to  $22 \times 22 \times 0.6 \mu\text{m}^3$  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  $\sim 0.4 \times 0.4 \mu\text{m}^2$  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  $\geq 10 \text{ mG}/\text{Hz}^{1/2}$ . 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  $300 \mu\text{m}/\text{s}$ . The whole setup is mounted on the cold flange of a commercial  $^3\text{He}$ -refrigerator and operates between room temperature and 300 mK.

The potential of the system is illustrated with images of superconducting vortices at temperatures down to 300 mK. Figs. 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]. Figs. 2(c),(d) show lower contrast vortex structures at the cleaved surface of a single crystal of the unconventional SC  $\text{Sr}_2\text{RuO}_4$  ( $T_c = 1.5 \text{ K}$ ) 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  $0.7 - 0.9 \mu\text{m}$  for the Nb film and less than  $0.5 \mu\text{m}$  for the  $\text{Sr}_2\text{RuO}_4$  single crystal.

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

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

## RELATED PRODUCTS

ANPxyz101/LT	linear stepper positioners providing highest stability
ANC300/3	piezo positioning controller

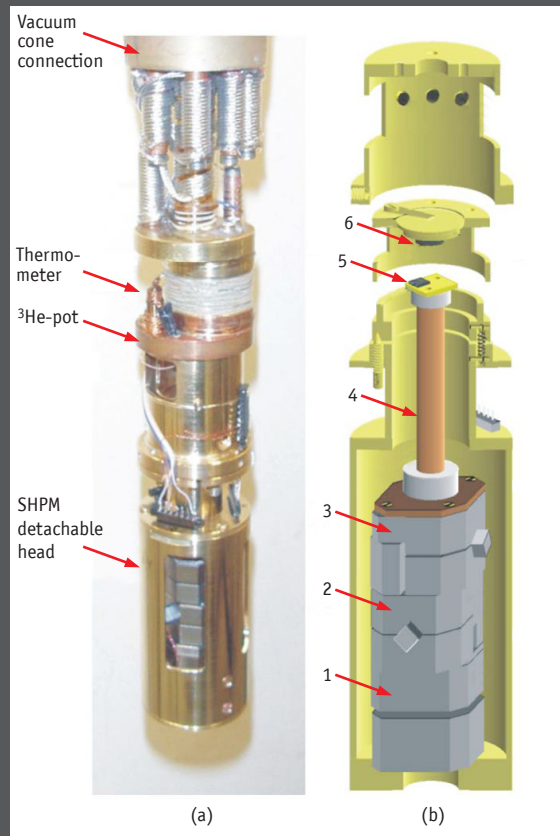


Fig. 1: Photograph (a) and sketch (b) of the LT compatible SHPM scanner head (see text). For a more complete description of all details, refer to [1].

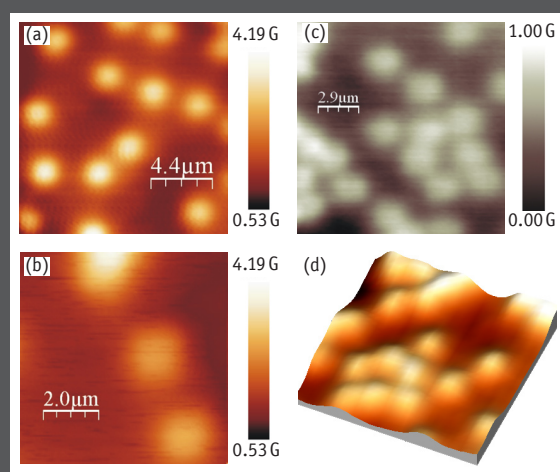


Fig. 2: SHPM images of SC vortices. (a),(b) Vortices in a 700 nm thick Nb film at (a)  $T=1.575 \text{ K}$  and (b)  $T=372 \text{ mK}$ . (c) Disordered vortex structures at the cleaved surface of a single crystal of the unconventional SC  $\text{Sr}_2\text{RuO}_4$  at  $T=303 \text{ mK}$ . (d) 3D view of (c).