Application Note CI10

Transition from slow Abrikosov to fast moving Josephson vortices using the ANR31

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In this paper, we report about an especially challenging transport experiment in a liquid Helium cryostat requiring milli-degree rotational accuracy and perfect angle stability over a wide range of temperatures (80 K - 2 K) and magnetic fields (±14 T), far beyond the capabilities of other rotators. Using the attocube ANR31 rotator, a precise nano-rotator setup was designed to fit on a small (25 mm diameter) standard sample carrier. It performed extraordinary well, extending our capabilities of research into areas where extreme angular precision and stability are required.

We have investigated the vortex matter of the iron-pnictide high temperature superconductors and the results were recently published in [1]. We studied the mobility of magnetic vortices in the layered superconductor SmFeAs(O,F) and could show an enormous enhancement of vortex mobility associated with a transition of the vortex nature itself, changing from Abrikosov to Josephson. The unit cell of SmFeAs(O,F) consists of layers of superconducting FeAs separated by non-superconducting Sm(O,F) layers. A perfectly in-plane Josephson vortex, centered in a "non-superconducting" Sm(O,F) layer, can only be weakly pinned and thus experiences the mentioned enhancement in mobility.

This feature, however, is immediately lost if the field is tilted out of the FeAs planes and even the smallest misalignment (< 0.1°) completely destroys the effect as the misaligned vortex is not parallel to the crystallographic layers anymore. As mobile vortices cause dissipation, their mobility is observed as a very sharp spike in voltage as shown in Figure 1 (see also [1]). Therefore angular precision and stability is the key to observing this effect. In previous experiments using other rotators we missed this extremely sharp feature.

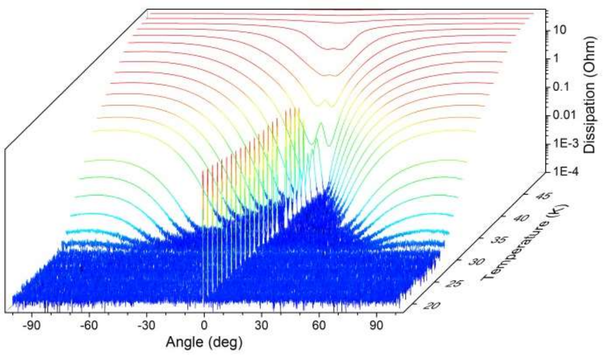

Figure 1: *Flux -flow dissipation as a function of the angle between the magnetic field(H = 12 T) and the FeAs layers (= 0°) for several temperatures. The main observation is the appearance of a sharp voltage spike (< 0.1°) below a temperature T*≈ 42 K. This flux-flow voltage is caused by fast flowing in-plane Josephson vortices, remaining unpinned even down to the lowest temperatures.*

On the technical side, the rotator design addresses many issues:

- The ANR31 provides enough torque to turn even with 10(!) insulated Ag wires even at 1.9 K! These were guided as twisted pairs through the hole at the rotator axis. Hence, the rotator is more than sufficient for highly complex multi-channel transport experiments.
- The lack of angle encoding was overcome by two orthogonally mounted cryogenic hall sensors.
- The studied effect is extremely sensitive to even the smallest change in angle in the milli-degree range. Most amazingly, **no drift** on this scale has been observed even after a day when sweeping the temperature between 80 K and 2 K as well as ramping the field up to 14 T.

This unique study of the vortex nature in these high Tc compounds shows that its vortex matter still holds many surprises for us. The discovered Abrikosov- to Josephson transition was unexpected, as the materials' electronic anisotropy is low. Moreover, Josephson vortices are believed to be a feature of highly anisotropic superconductors. This finding challenges our "global" understanding of superconducting anisotropies and their relevance for the microscopic, intra-unit cell modulation of the order parameter.

References

[1] P. J. W. Moll, L. Balicas, V. Geshkenbein, G. Blatter, J. Karpinski, N. D. Zhigadlo, and B. Batlogg, Transition from slow Abrikosov to fast moving Josephson vortices in iron pnictide superconductors, Nature Materials **12**, 134–138 (2013), DOI: 10.1038/NMAT3489 .

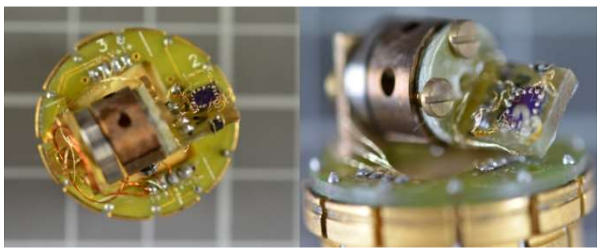

Figure 2: *Rotator setup showing the ANR31/LT rotator carrying the sample and two Hall sensors. The diameter of complete assembly is below 25 mm.*