Application Note CI34

Vortex Imaging on Iron Pnictides using the attoMFM Ixs

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Introduction

In their latest publication [1], H. Yang and co-workers from the group of Prof. Hai-Hu Wen, from Nanjing University, present results on vortex studies on $Ba_{1-x}K_xFe_2As_2$ - a potassium-doped superconductor of the pnictide family. Since their discovery in 2008, the iron-pnictides have drawn intensive attention, not only because they have broken the monopoly of the cuprates but also because of strong pinning effects observed in certain pnictide-compounds. A vortex consists of a circular supercurrent, which allows for exactly one flux quantum each to penetrate the superconductor. Through the mutual repulsion of neighboring circular currents, a vortex lattice forms, which in the easiest case is hexagonal [2]. In contrast to e.g. a cuprate superconductor such as $Bi_2Sr_2CaCu_2O_{8+x}$ (BiSCCO-2212), the pnictide samples show strong pinning leading to significantly disordered vortex lattices.

In the measurements shown here, the authors present magnetic force microscopy (MFM) images on pnictide samples at different magnetic fields as recorded with an attocube attoMFM Ixs inside a Quantum Design PPMS.

As demonstrated by H. Yang *et al.*, the vortex arrangement in their samples evolves from strong disorder at very low fields (several Oe) to more uniform patterns at higher field (100 Oe) as the density increases and vortex-vortex interactions overcome the pinning forces.

Experimental Setup

The attoMFM Ixs setup is shown on the right as well as sketched in Figure 1. On top of an ANPxyz51 positioner stack (3 x 3 x 2.5 mm³ range), an ANSxy50 (here 19 x 19 µm² scan range @ 4 K) and an ANSz50 scanner (2 µm scan range @ 4 K) are mounted, together with a heater / temperature sensor element and the sample holder. The interferometric sensor head is mounted to the top of a rigid housing while the sample is scanned. For the MFM measurements, standard hard magnetic point probes from NanoWorld were used. For each field, the sample was first heated to above its transition temperature, field-cooled to 2 K, and subsequently imaged by MFM.

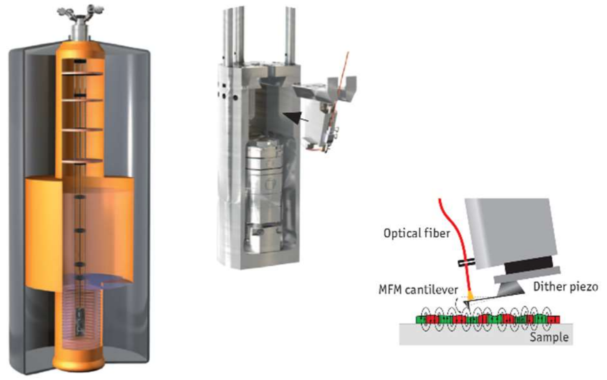

Figure 1: *The attoMFM Ixs (left) and the measurement head. On the right, the MFM measurement principle and the interferometric deflection detection is shown.*

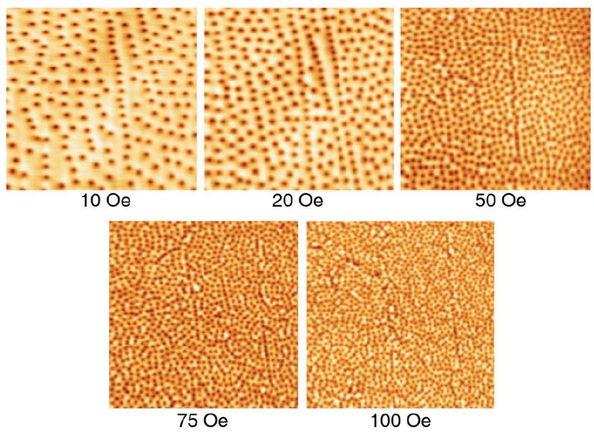

Figure 2: *MFM scans of 19 x 19 µm² size at 2 K and different magnetic fields ranging from 10 to 100 Oe*

As the sample surface was well prepared by cleaving, the surface was extremely flat. After slope compensation utilizing a tapping mode scan, the MFM images are scanned with a constant lift height of only 10-20 nm (see Figure 2).

The open-loop xy-scanners ANSxy50 do show the typical artifacts known from piezo scanners, as e.g. non-linearities and hysteresis. In the measurements presented here, the authors performed calibration scans on a known grating sample, thus achieving distorted images of this standard pattern. By using a non-linear afitting procedure as shown below, the parameters for linearizing identical scan images were found (identical in temperature, scan size, and speed). The vortex images measured in a separate cooling cycle were then post-corrected for linearity and hysteresis using these parameters.

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Correction of Scanner Hysteresis and Non-linearity

To discuss the linearization procedure in detail, an example scan is shown in the upper image of Figure 3. Here, a 32 x 32 µm² area of a calibrationgrating was scanned using a different scanner. The image can now be linearized using additional software. The following steps were performed to find out the linearization parameters:

- First, the image was flattened,
- then the coordinates of selected (equidistant) features were identified,
- and finally fitted using a third order polynomial.
- The so received correction parameters can now be used in a polynomial distortion routine.

The final image is shown in the Figure 3 (lower image). Note that this procedure can also be done in an automated way using the hysteresis correction tool of commercial software [3].

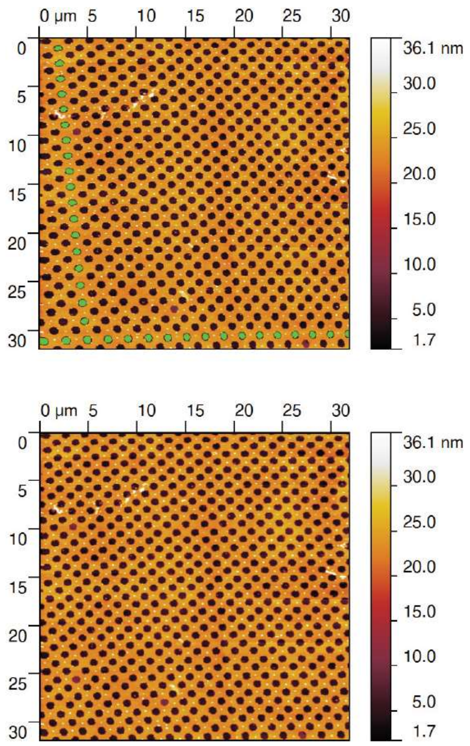

Figure 3: *Upper: Scan of a known calibration grating. The dots have been marked using a threshold criterion, while only one representative line and column was chosen.*
Lower: Resulting image after distortion correction.

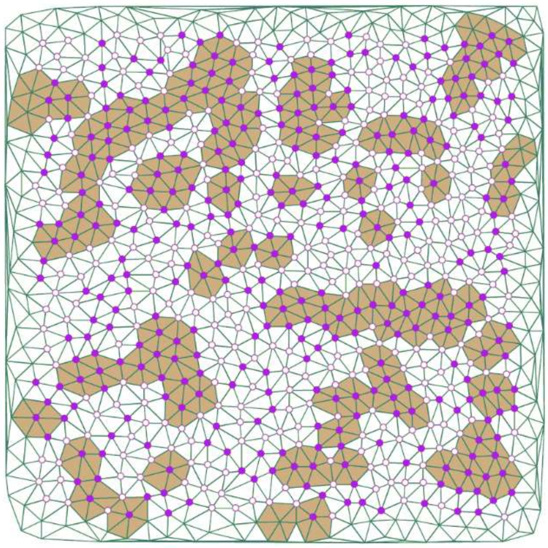

Figure 4: *Delaunay triangulation of the vortex centers at 100 Oe. Filled purple dots mark six-neighbored vortices. The brown areas show the area of the distorted triangle lattice.*

Measurements

After the correction procedure, the authors took the coordinates of all the vortex centers and used a Delaunay triangulation to find the vortex distribution (see Figure 4) as well as looked at self-correlation images. The statistics (not presented here) show that square and hexagonal structures coexist, with a more random distribution governed by pinning at low fields. At intermediate fields of 20-50 Oe a mostly square pattern dominates, while the six-neighbored structure is clearly favored at higher magnetic fields (≥100 Oe), due to higher forces and lower distances between the vortices. In addition to these findings, vortex chains are observed in underdoped samples with nearly randomly distributed vortices between the chains.

Moreover, in Figure 5 surface steps are found to behave as pinning centers. It is worth pointing out that this image was achieved already during the initial installation and training on the attoMFM Ixs.

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Summary

The authors observed a cooperative pinning induced by the large-scale twin boundaries and the weak local disorders, which may be a common picture to describe the vortex dynamics in iron pnictide superconductors.

References

[1] H. Yang, B. Shen, Z. Wang, L. Shan, C. Ren, and H.H. Wen, Phys. Rev. B **85**, 014524 (2012).

[2] A. Abrikosov, Zh. Eksp. i Teor. Fiz. **32**, 1442 (1957); Soviet Phys. JETP **5**, 1174 (1957).

[3] www.imagemet.com

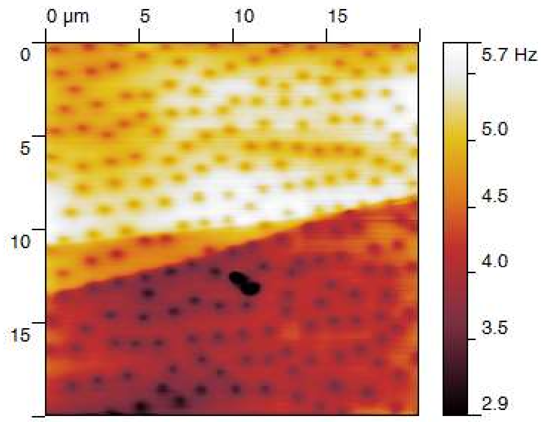

Figure 5: *Vortex image in the presence of two steps on the surface at 10 Oe and 2 K. From a topography scan one can see that the heights of the two steps are about 10 nm each. Image dimension is 19 x 19 µm2. The vortices near the steps are pinned along the edge of the steps.*