MFM vortex imaging on cuprates and iron pnictides inside the Quantum Design PPMS®

In this application note, atto**cube**'s ultra-compact Magnetic Force Microscope attoMFM Ixs was used inside the QD PPMS® to image vortices in different high-T_c superconductors at low magnetic fields. As a member of atto**cube**'s newest microscope xs family, the attoMFM Ixs has been specifically designed to fit any 1" (25.4 mm) free bore cryostat.

Vortex imaging was first achieved on a Pb sample in 1967 by taking advantage of a Bitter decoration technique[1]. The resulting data were the first direct proof of the theoretical prediction of a mixed superconducting state as proposed by Abrikosov[2] in 1957. Since these first experiments, vortex imaging has become a crucial tool providing information about various parameters of a superconductor, such as its coherence length ξ and magnetic penetration depth λ_L. In contrast to earlier experiments, however, vortex imaging is these days mainly accomplished with scanning probe microscopes such as the Magnetic Force Microscope (MFM) or Scanning Tunneling Microscope (STM) yielding significantly higher resolution and coping with much smaller sample sizes.

In the experiment shown here, a cuprate and an iron-pnictide sample have been investigated using atto**cube**'s Magnetic Force Microscope attoMFM Ixs. As first sample, optimum doped $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212) with a T_c of 91 K was analyzed. As known from literature, clean Bi-2212 shows only little bulk or surface pinning causing the vortices to arrange in a quasi hexagonal lattice. This is demonstrated in Fig. 1 which has been recorded at a temperature of 4.1 K and a magnetic field of 45 G.

In a second set of measurements, the iron pnictide compound $Ba_{1-x}K_xFe_2As_2$ was investigated. In contrast to Bi-2212, this sample shows a strongly disordered vortex lattice, see Fig. 2. Similar results have been observed on the sister compound $BaFe_{1.8}Co_{0.2}As_2$ by Scanning Tunneling Spectroscopy[3]. From the latter experiment it has also been concluded that bulk (in contrast to surface-) pinning is the dominant source for vortex pinning. This conclusion, however, can neither be confirmed nor denied by the presented MFM data as no surface defects (with a size equal or larger the pixel size) are present. Compared to the results obtained on the Bi-2212 sample, however, the weaker signal in the iron pnictide indicates a slightly larger magnetic penetration depth. This indication is also supported by the smaller apparent size of the vortices in the iron pnictide, corresponding to a larger value of the Ginzburg-Landau parameter $\kappa_{GL} = \lambda_L/\xi$ and consequently a larger λ_L, even when assuming a similar coherence length. Current measurements seem to indicate, however, that ξ is larger in the iron pnictides compared to optimum doped Bi2212, which would even emphasize this trend.

In summary, it can be stated that the attoMFM Ixs has proven to be perfectly suited for in-depth investigation of magnetic properties of superconductors at low temperatures and variable magnetic field.

[1] U. Essman and H. Trauble, Phys. Lett. 24A, 526 (1967)
[2] A.A. Abrikosov, Sov. JETP 5, 1174 (1957)
[3] Yin et al., PRL 102, 097002 (2009)

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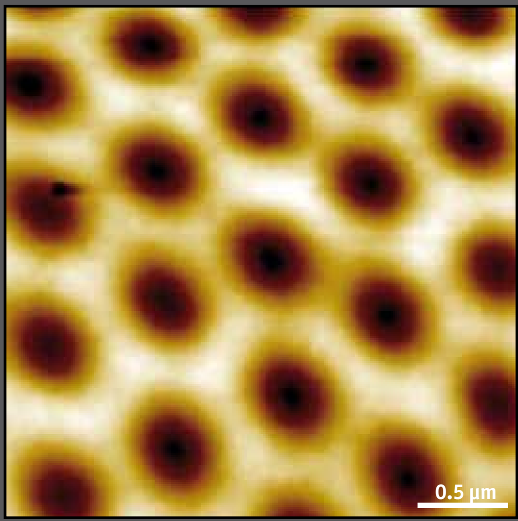

*Figure 1: Hexagonal vortex lattice in optimum doped Bi-2212 at a temperature of 4.1 K and a magnetic field of 45 Gauss. The image shows unprocessed, as-measured MFM phase data recorded at 70 nm constant height. The MFM cantilever had a resonance frequency of 62.17 kHz and a Q factor of about 3000 (atto**cube** application labs, 2009; sample courtesy of A. Erb, Walther Meissner Institute, Germany).*

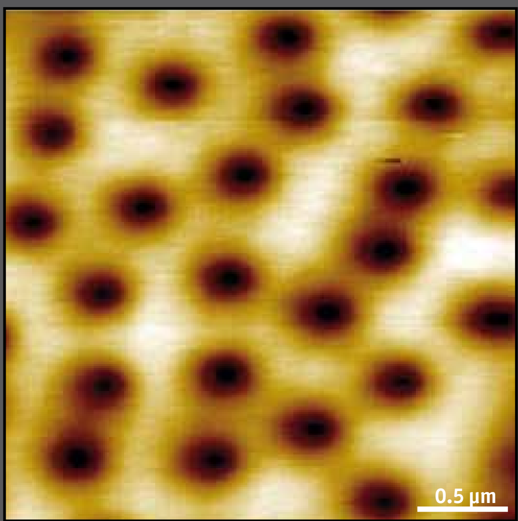

*Figure 2: Disordered vortex lattice in the iron pnictide $Ba_{1-x}K_xFe_2As_2$ at a temperature of 4.1 K and a magnetic field of 45 Gauss. The image shows unprocessed, as-measured MFM phase data recorded at 70 nm constant height (atto**cube** application labs, 2009; sample courtesy of Hai-Hu Wen, Chinese Academy of Science, Institute of Physics, Beijing, Republic of China).*

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