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**Magnetic force microscopy of superconductors: vortex manipulation and measuring the penetration depth**

OPHIR AUSLAENDER, Technion - Israel Institute of Technology

We use a low temperature magnetic force microscope (MFM) to image superconductors. The interaction between the magnetic tip and individual vortices allows us to both image vortices and to manipulate them. The manipulation results depend on sample thickness and on the superconducting properties. Here I concentrate on $YBa_2Cu_3O_{6+x}$ (YBCO) samples and on $Ba(Fe_{0.95}Co_{0.05})_2As_2$, an underdoped pnictide. In thin films, if the force exerted by the tip is strong enough to overcome the pinning potential a vortex jumps as a whole to a new pinning site. The behavior in thick YBCO single crystals depends on the doping level. In a slightly overdoped sample vortices stretch rather than jump when we perturb them strongly [1]. The dragging distance in this crystal is anisotropic: it is easier to drag vortices along the Cu-O chains than across them, consistent with the tilt modulus and the pinning potential being weaker along the chains. We also find that when we "wiggle" the top of a vortex we can drag it significantly farther than when we do not, giving rise to a striking dynamic anisotropy between the fast and the slow directions of the scan pattern. In an underdoped YBCO single crystal, where superconductivity is so anisotropic that a vortex should be viewed as a stack of two dimensional pancakes, we show that vortices kink rather than tilt when we perturb them [2]. Since the discovery of the pnictides, a new family of high temperature superconductors, we have also been developing ways to determine the absolute value of the magnetic penetration depth, which is notoriously difficult to measure, as well as its dependence on temperature. For that we either use the Meissner repulsion of the magnetic MFM tip from the sample or the magnetic interaction between the tip and the magnetic field from a vortex. The temperature dependence that we find allows us to comment on the symmetry of the order parameter [3].

Work done in collaboration with Lan Luan and Kathryn A. Moler (Stanford)

[1] O. M. Auslaender et al., Nat. Phys. 5, 35 (2009).
[2] Lan Luan et al., Phys. Rev. B 79, 214530 (2009).
[3] Lan Luan et al., Phys. Rev. B 81, 100501 (2010).