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Probing microscopic and dynamical properties of superconducting vortices by vortex dragging

We have used a home built, low temperature magnetic force microscope (MFM) to image and to manipulate individual vortices. The MFM consists of sharp magnetic tip which we scan over the surface of a superconductor threaded by vortices. The interaction between the tip and the magnetic field from the vortices gives rise to a force, which we detect for imaging and use for vortex manipulation. We are able to tune from surveillance mode, when the tip is far from the surface and exerts a force too weak to perturb vortices, to manipulation mode, where the tip is close enough to the surface to depin vortices and even to drag them. I will report on experiments in two kinds of (YBCO) samples: a 200nm thick, optimally doped film, and detwinned single crystals, dozens of microns thick. In the film, if the force exerted by the magnetic tip of the MFM is strong enough to overcome the pinning potential a pinned vortex jumps as a whole to a new pinning site. The behavior in the single crystals depends on the doping level. In a slightly overdoped single crystal vortices stretch rather than jump when we perturb them strongly. 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 raster pattern in a scan. Surprisingly, we find that the depinning force is not well described by activation, but rather by an exponential. In an underdoped single crystal, a material 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. These results demonstrate the power afforded by direct single-vortex manipulation and imaging for exploring the interesting behavior of these extended objects.