Angular Dependence of the YBa$_2$Cu$_3$O$_7$+BaZrO$_3$ Irreversibility Line

S. A. Baily, B. Maiorov, H. Zhou, S. R. Foltyn, L. Civale (MPA-STC, LANL); J. Durrell (Dept. of Materials Science & Metallurgy, University of Cambridge); F. F. Balakirev, M. Jaime (NHMFL, LANL)

Introduction
The high transition temperature and anisotropy of high temperature superconductors leads to melting of the vortex lattice into a vortex liquid phase. This transition marks the upper limits for the use of superconductors; therefore increasing it is highly desirable. This transition is affected by the nature and density of the defects present in the superconductor. In the presence of a magnetic field ($\mathbf{H}$), for 3-D anisotropic superconductors containing random point-like defects the angular dependence of the vortex liquid-solid transition is governed by the electronic-mass anisotropy ($\gamma$), and scales with $\alpha(\theta) H = H[\cos^2(\theta)+\gamma^2\sin^2(\theta)]^{1/2}$, where $\theta$ is the angle between $\mathbf{H}$ and the crystallographic c axis. In contrast, pinning by correlated defects leads to a solid phase known as Bose-glass that can be distinguished from random point-like defects by the presence of a peak in the angular dependence of the melting line when $\mathbf{H}$ is aligned with the defects [1]. The addition of BaZrO$_3$ (BZO) into YBa$_2$Cu$_3$O$_7$ (YBCO) films can be tailored such that both random nanoparticles and self-assembled nanorods (correlated defects) can be introduced, depending on growth conditions [2, 3].

Experimental
Electrical ac-transport was used to measure the vortex dissipation in the liquid phase as well as to determine the melting line (where dissipation goes to zero), as a function of angle for YBCO+BZO films in the 15 T staff-lab magnet using the new DC rotator probe acquired using UCGP funds (PI B. Maiorov). This work builds on previous results obtained in pulsed and DC fields. Two additional YBCO+BZO films were studied, a 0.2 micron film and a 0.7 micron film grown at a lower rate resulting in many columnar defects.

Results and Discussion
Angular dependent measurements were consistent with results from films studied previously in that there is no clear c-axis peak in the vortex melting line at moderate to high fields, but a broad enhancement over a large angular range.

Measurements of the c-axis melting field shown in Fig. 1 indicate that the 0.2 micron film with BZO has the highest melting line at moderate fields. This advantage becomes marginal at higher fields where optimized samples show a similar vortex melting. In contrast, for $\mathbf{H}$ oriented away from the crystalline axis extended BZO particles significantly enhance the vortex melting line. These results indicate that although artificially introduced defects don’t significantly enhance $H_m$ for $\mathbf{H}||c$ at high fields in comparison to what can be achieved with naturally occurring defects, they can result in important enhancements over a much broader angular range, something much desired for applications.

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References