Understanding the Trade Off between Pinning and Thermal Fluctuations in Determining the Critical Current Density of YBCO Films

Z. Chen, A. Gurevich, F. Kametani, A. Xu, and D.C. Larbalestier (NHMFL)

Introduction

It has been theoretically proposed that the critical current density J_c of YBCO should increase monotonically with decreasing effective distance between pinning precipitates (L_c) in the strong three dimensional (3D) pinning regime. However, many times opposite results are observed. This work reveals the complicated interactions between optimizing pinning and minimizing thermal fluctuations. Our results provide guidance towards better pinning optimization in YBCO.

Experimental

The PLD method was used to grow YBCO films used in this study. Four-point transport $J_c(H)$ and $J_c(\theta)$ measurements were carried out in 9 T and 16 T PPMS systems. All experiments were performed using ASC/NHMFL facilities.

Results and Discussion

Although pinning tends to become stronger when the vortex lines are decoupled into shorter segments (effective length ~L_c) strongly pinned by 3D pinning centers, thermal fluctuation de-pinning effects also increase with decreasing L_c.[1] A net result is a peak in the $J_c(L_c)$ curve – decreasing L_c gives rise to J_c before J_c suddenly drops at the low L_c limit. However, this is only true at small temperatures (T) and fields (H) when thermal fluctuations are weak. At high T and H, decreasing L_c will simply destroy J_c. Such complicated relationships between J_c, pinning, and thermal fluctuations are revealed by our T- and H-dependent J_c measurements on YBCO films with specially designed pinning centers with various L_c values. As shown in fig. 1, our results indicate that stronger thermal fluctuations at higher H can be compensated by reducing T. Below a threshold T, even at 8 T, J_c will follow a single dependence on L_c, i.e. J_c increases monotonically with decreasing L_c.

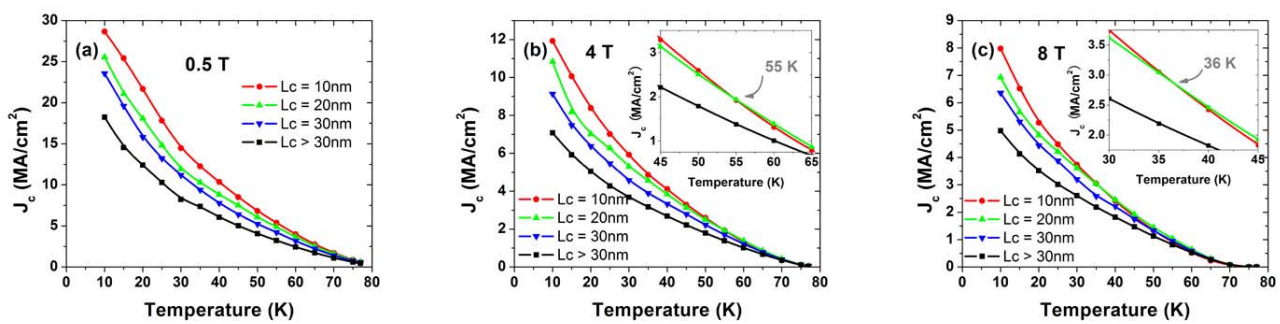

Fig. 1 $J_c(T)$ for four YBCO films with L_c values of 10, 20, 30 and >30 nm measured at (a) 0.5 T, (b) 4 T, and (c) 8 T, respectively. At 0.5 T, J_c increases monotonically with decreasing L_c at all temperatures. At 4 T and 8 T, cross-overs are found among all $J_c(T)$ curves, as amplified in the insets of (b) and (c). The cross-over shifts to lower T as H increases. Below the cross-over temperature, a single $J_c(L_c)$ dependence is found: J_c increases with decreasing L_c.

Conclusions

At low temperatures where YBCO-based high field magnets operate, pinning optimization is very different from the 77 K situation. Because thermal fluctuations are weak at such temperatures, J_c can be effectively enhanced by reducing L_c.

Acknowledgements

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References

[1] Gurevich, A., Superconductor Science & Technology **20,** S128-S135 (2007).