Microstructural Study of Strong Vortex Pinning in a Coated Conductor for Use in Specific Fields and Temperatures

Fumitake Kametani, Zhijun Chen, Alex Gurevich and David Larbalestier
Applied Superconductivity Center, National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL32301

Yimin Chen, Yi-Yuan Xie and Venkat Selvamanickam
SuperPower Inc. Schenectady, NY 12304

Abstract— **It is still unclear what type, size, shape and distribution of defects and nano particles in a coated conductor are optimum for specific temperatures and fields. Cross-sectional transmission electron microscopy has been performed to study the microstructure of YBCO films and coated conductors (CCs) with defects and nano particles and its correlation to vortex pinning at various temperatures and fields. The MOCVD CC we examined contains dense ab-plane stacking faults and three-dimensional Y_2O_3 nanoprecipitates. We also made PLD YBCO films containing Y_2O_3 nanoprecipitates of smaller size and spacing. Although the volume fractions of Y_2O_3 are comparable (~12-15%), the MOCVD CC shows higher H_{irr} at 77 K, indicating stronger resistance to thermal fluctuations at high fields. However, deconvolution of the strong and weak pinning components indicates a crossover at lower temperatures where the PLD film with smaller nanoprecipitates shows stronger pinning. We are attempting to incorporate thermal fluctuation effects into our description of the optimum pinning nanaostructures.**

I. Introduction

Since YBCO films are aimed for practical application in the form of coated conductor, various effective pinning structures – especially addition of nano particles – have been proposed [1-3]. However it is still unclear what type, size, shape and distribution of defects and nano particles in a coated conductor are optimum for specific temperatures and fields. Cross-sectional transmission electron microscopy (TEM) has been performed to study the microstructure of YBCO films and coated conductors (CCs) with defects and nano particles of different size, shape and distribution so as to make correlation to vortex pinning at various temperatures and fields. Here we compare a home-grown multi-layer PLD sample with a commercial MOCVD CC, both of them contain dense ab-plane stacking faults and three-dimensional Y_2O_3 or $(Y, Sm)_2O_3$ nanoprecipitates. The PLD YBCO film contains Y_2O_3 nanoprecipitates of smaller size and spacing than those in the MOCVD CC. Although the volume fractions of Y_2O_3 are comparable (~12-15%), the MOCVD CC shows higher H_{irr} at 77 K, indicating stronger resistance to thermal fluctuations at high fields. However, deconvolution of the strong and weak pinning components derived from analysis of the J_c-T curves over a wide range of H and T using the Barcelona group approach [1] indicates a crossover at lower temperatures where the PLD film with smaller nanoprecipitates shows stronger pinning. This crossover indicates that thermal fluctuation effects should be taken into account for description of the optimum pinning nanaostructures.

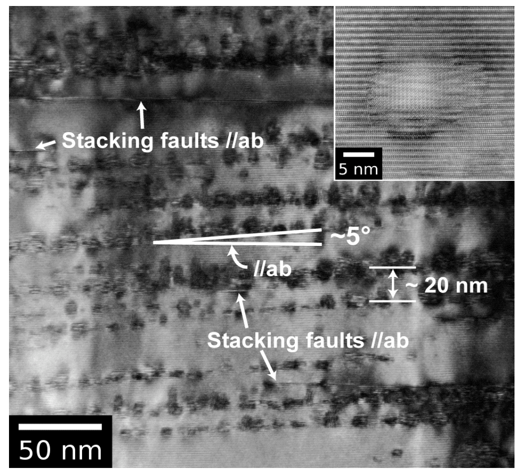

Figure 1. Cross-sectional TEM image of the MOCVD CC showing the Y_2O_3 nano precipitate arrays and stacking faults. The typical HREM of precipitate is shown in the inset.

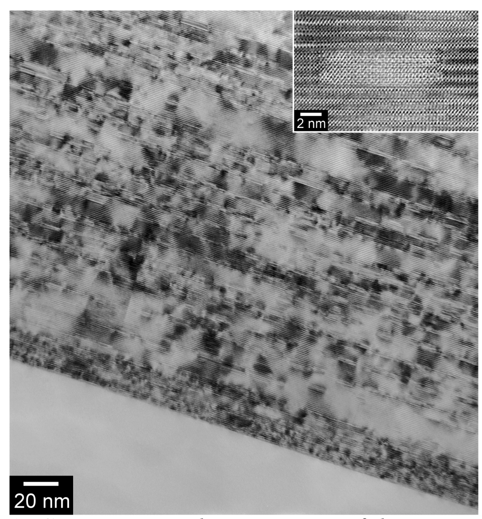

Figure 2. Cross-sectional TEM image of the PLD YBCO film showing Y_2O_3 precipitates of smaller size and spacing. The inset HREM shows the typical shape of the precipitate.

II. Results and discussion

A cross-sectional TEM image of the MOCVD CC is shown in Fig.1. The black dot contrasts represent the (Y, Sm)$_2$O$_3$

Sample	Tc (K)	Jc (77K, sf)	Jc (10K, sf)	Hirr (77K)	ppt thickness (nm)	ppt spacing along ab-plane (nm)	ppt spacing along c-axis (nm)	Vol%
MOCVD 2μm thick CC	90.8	3.82	38.4	8.8T	~8nm	~10-20	non-uniform ~20-50	13%
PLD 0.6μm thick	90.1	4.21	48	6.8T	~3nm	~20	~10	15%

Table 1

nano precipitates of ~8x15 nm in size as shown in the inset HREM image. The strain field contrast can be seen on the top and bottom of the precipitates. It may extend the effective size of the pinning centers. Y_2O_3 preferentially aligns in 10~20 nm spacing along the horizontal direction at a 5° tilt away from the ab-plane, forming precipitate arrays, whose spacing of ~20-50 nm along the c-axis is not uniform. The image also shows ab-plane stacking faults, another major pinning defect. The volume fraction of Y_2O_3 measured with ImageJ software is ~13 %.

Fig.2 shows a cross-sectional TEM image of the PLD YBCO film. Y_2O_3 nano precipitates were found as in the MOCVD CC. Y_2O_3 in this film also preferentially aligns along ab-plane in ~20 nm spacing. The inset HREM shows that the typical size of Y_2O_3 is ~3x10 nm, smaller than that in the MOCVD CC. The volume fraction of Y_2O_3 is ~15 % resulting in smaller spacing of ~10 nm along c-axis and higher density compared to the MOCVD CC. The inset HREM also indicates that, despite the semi-coherency of Y_2O_3 and YBCO, less strain field is visible around precipitates because of its smaller size.

Table 1 briefly summarizes the basic properties and microstructure of those two samples. Although T_c and the volume fraction of precipitates are comparable, H_{irr}(77K) of MOCVD CC is more enhanced than that of the PLD YBCO, while self-field J_c of the PLD YBCO is higher at both 77K and 10K, beyond explanation by 0.7K T_c difference.

To investigate more details of the pinning, deconvolution of the strong and weak pinning components was derived from analysis of the J_c-T curves over a wide range of H and T using the Barcelona group approach [1], partly shown in Fig.3. Striking is that a crossover of the strong pinning component occurs around 40K at 8T indicating greater pinning enhancement in the PLD YBCO at low temperature and high field, although H_{irr}(77K) of the MOCVD CC is more enhanced as shown in the inset. According to the model of Gurevich et al [4], thermal fluctuation of vortices becomes greater especially near H_{irr} as temperature increases. Comparing the size and distribution of precipitates in Table 1 indicates that, when thermal fluctuations diminish at low temperatures, the pin density becomes dominant rather than the pin size. However we need the strong separated pins – precipitates in bigger size and spacing in this case – to chop vortices into short segment at 77K near H_{irr}, indicating that we need to optimize the pinning nanostructure taking thermal fluctuation into account at each T and H.

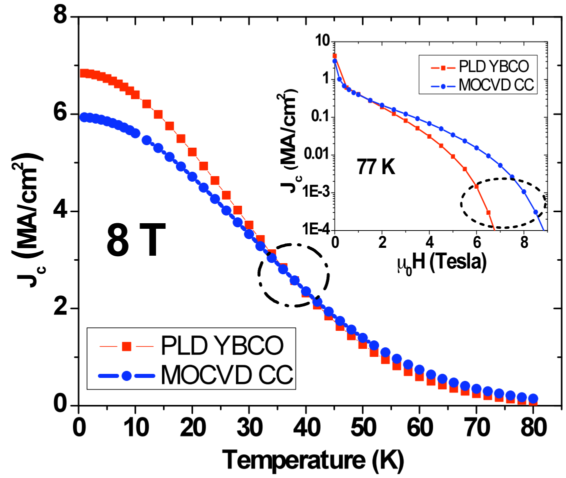

Figure 3. The strong pinning component of the pinning at 8 T, while the inset shows J_c vs H at 77 K. A crossover occurs around 40K at 8T.

III. Conclusion

We compared the nanostructure of pins in the MOCVD CC and PLD YBCO film both of which have Y_2O_3 nano precipitates of similar volume fraction but with different size and distribution. Deconvolution of the strong and weak pinning components from analysis of the J_c-T curves over a wide range of H and T showed a crossover of the strong pinning component at high T and H where we need the precipitates in bigger size and larger spacing at 77K near H_{irr}. Our results suggest that we must take the thermal fluctuation effect into account to optimize the pinning nanostructure at each T and H.

Acknowledgment

This work was supported by SuperPower Inc., by the Air Force Office of Scientific Research, and by the US Department of Energy.

References

[1] J. Gutierrez et al. *Nature Mat*.,. **6**, 367-373, 2007
[2] T. Haugan et al. *Nature* **430**, 867-870, 2004

[3] J. L. Macmanus-Driscoll et al. *Nature Mat*. **3**, 439-443, 2004
[4] A. Gurevich et al., *Supercond. Sci. Technol*. **20**, S128, 2007