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Composition Effects on the Critical Current of MOCVD-processed Zr:GdYBCO Coated Conductors in an Applied Magnetic Field

Yimin Chen[1], T.Shi[2], A.P.Guevara[2], Y.Zhang[2], I. Kesgin[2], Y. Yao[2], A. Rar[1] and V. Selvamanickam[2]

[1]SuperPower Inc, 450 Duane Ave, Schenectady, NY 12304
[2]Dept. of Mechanical Engineering, Texas Center for Superconductivity, Univ. of Houston, 4800 Calhoun Rd, Houston, TX 77204

Supported by CRADAs with Oak Ridge National Laboratory and Argonne National Laboratory

Applied Superconductivity Conference, Washington D.C, Aug. 1 – 6, 2010

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Introduction

- Ic(B) of YBCO coated conductors can be modified through
  - Changing composition (RE:Ba:Cu ratios)
  - Rare eath substitution (replacing Y with Gd, Sm)
  - Adding extrinsic defects (Zr, Sn & more being searched)

- There have been many studies on the composition effects for REBCO, but little has been done for Zr:REBCO

- It is crucial to improve the understanding on the interaction between the intrinsic and extrinsic pinning centers

Some of the advancements in understanding

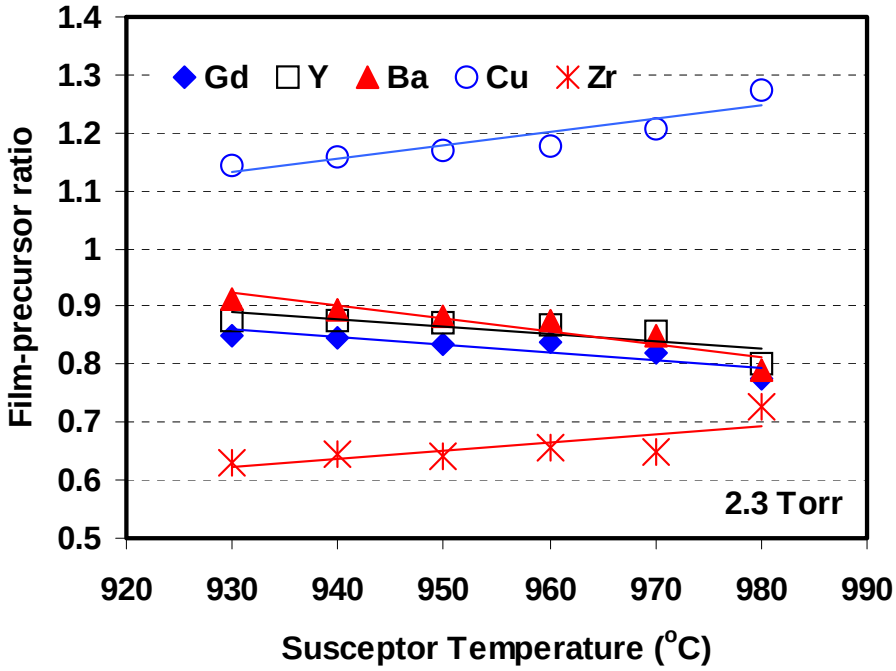
- RE2O3 precipitates
  - Lu, Li, Zhao (APL 1992): Y2O3 nanodots are effective pinning for 0T – 7T
  - Wang (J. Appl. Phys. 2006): Y1.1 for optimum Jc(B)
  - Chen, Selva (APL 2009): RE2O3 dots could be assembled to form layers, which were aligned with ab-plane and enhanced pinning in ab-plane
- BaZrO3 columns
  - Driscoll (Nature Mat 2004): Zr extrinsic defects, strong pinning along c-axis
  - Goyal (Superc. S&T 2005): nano-columns comprised of BZO dots
  - Yamada (APL 2005): BZO nano-columns through the film thickness
  - Chen, Selva (APL 2009): interaction of bidirectionally aligned defects; explained Jc(B)

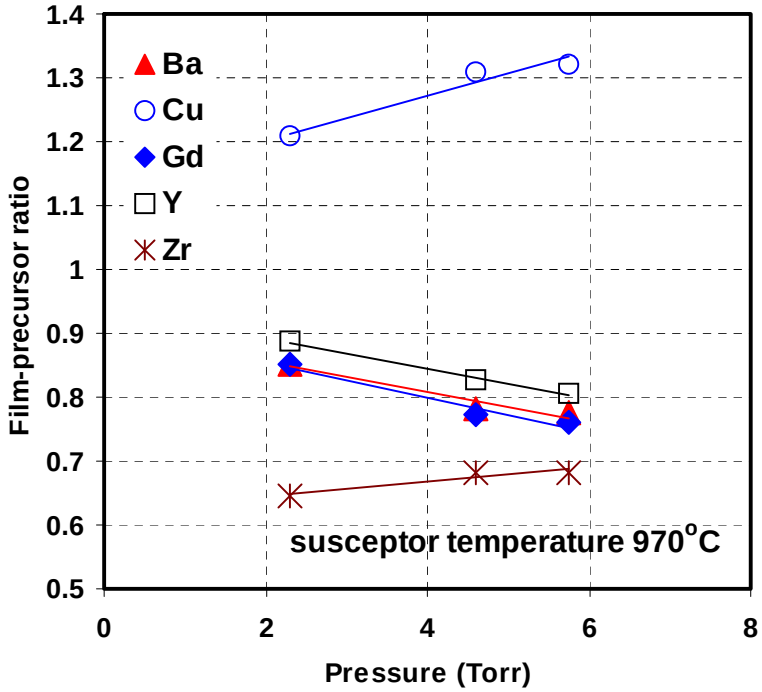
- In the present work, we want to improve our understanding of the Interaction between RE2O3 and BZO via investigating the composition effects:
  - Effects of Gd+Y content
  - Effects of Gd to Y ratio
  - Effects of Zr concentrations

Composition Control in MOCVD for Zr:GdYBCO

- **Our control is based on the functional relation of the film composition with the precursor composition, deposition temperature and pressure.**
- **Incorporate rate or film-precursor ratio depends on T and P**

For example, precursor $Zr_{0.065}Gd_{0.6}Y_{0.6}Ba_2Cu_{2.3}$ + Susceptor 965°C + Pressure 2.3Torr = film of $Zr_{0.05}Gd_{0.6}Y_{0.6}Ba_2Cu_{3.3}O_7$

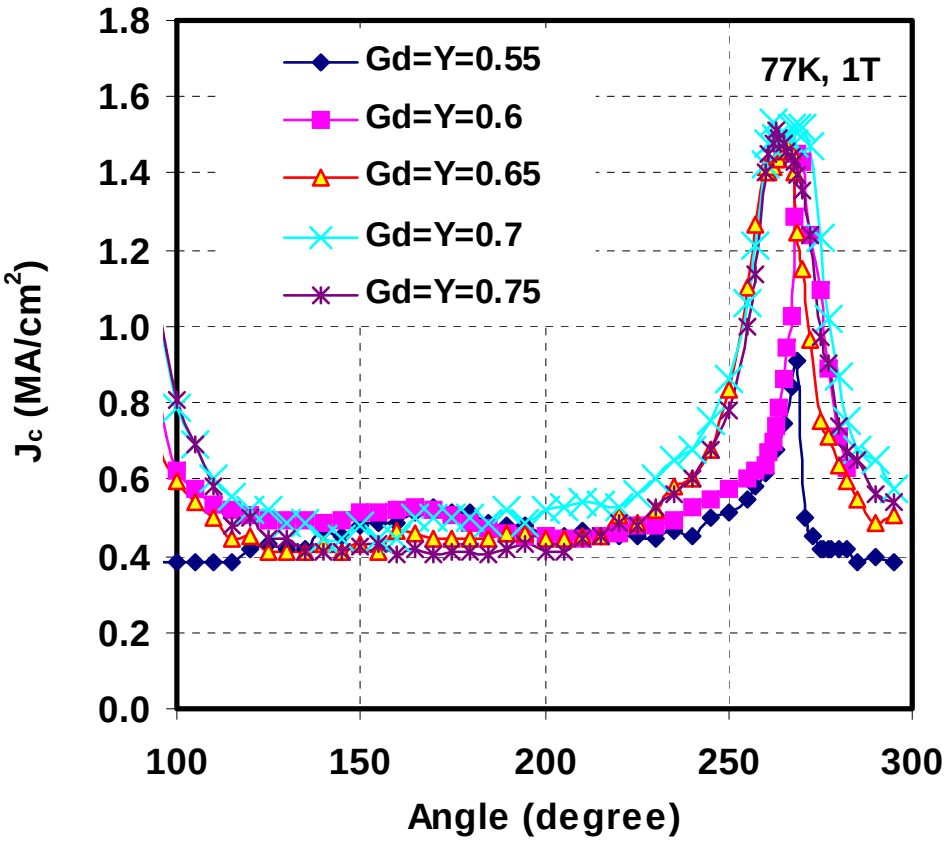




Effects of Gd+Y content in GdYBCO

Rare-earth rich eliminate Ba-Cu-O phase; enhance pinning.

Aligned RE_2O_3 dots enhance ab-peak.

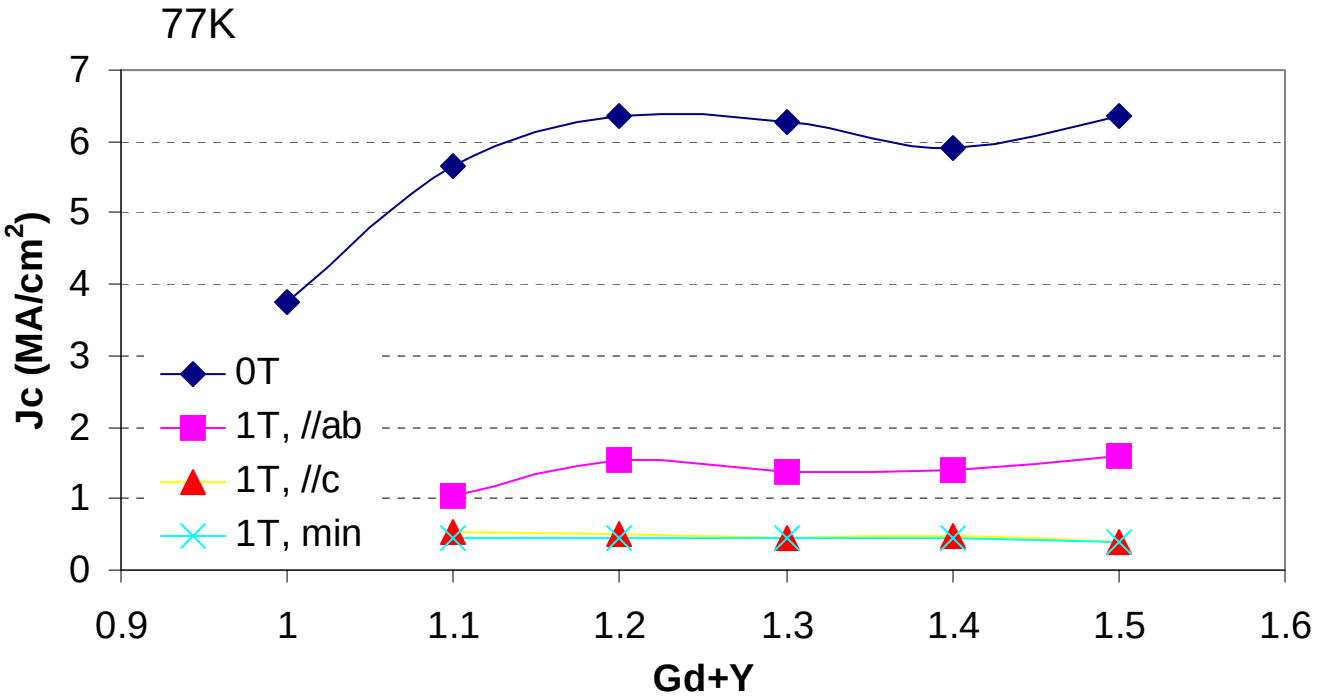


Varying Gd+Y in 0.5 μm thick GdYBCO film with Ba=2, Cu=3.3

Gd+Y content dependence of J_c(sf), J_c(1T,//ab), J_c(1T, //c), J_{c_min}(1T, any angle)

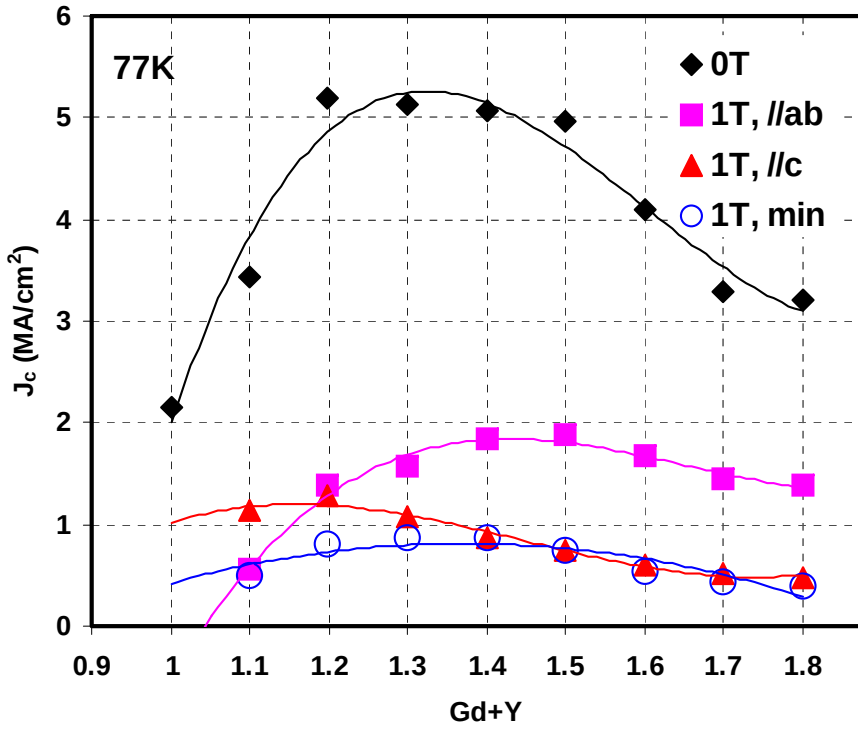
In a wide range of rare-earth content (RE = 1.2 – 1.5), J_c varied not much.

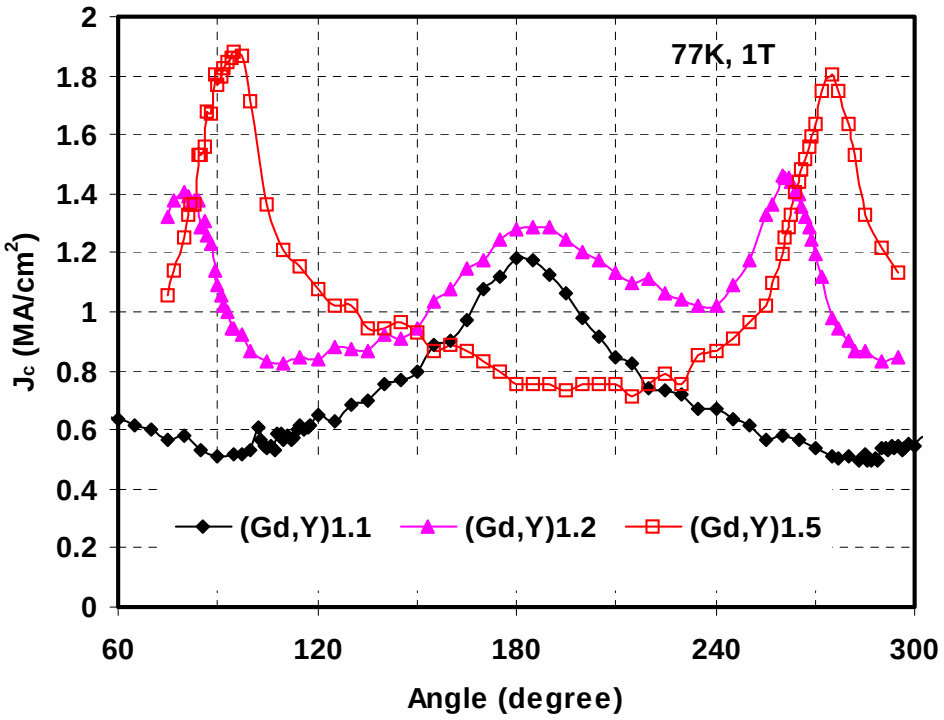
This finding is in contrast to that reported by Wang for PLD YBCO, where J_c dropped dramatically when Y content varying from 1.1 to 1.3.



Gd+Y content dependence for in 0.5 μm thick GdYBCO film with Ba=2, Cu=3.3

Effects of Gd+Y content in Zr:GdYBCO





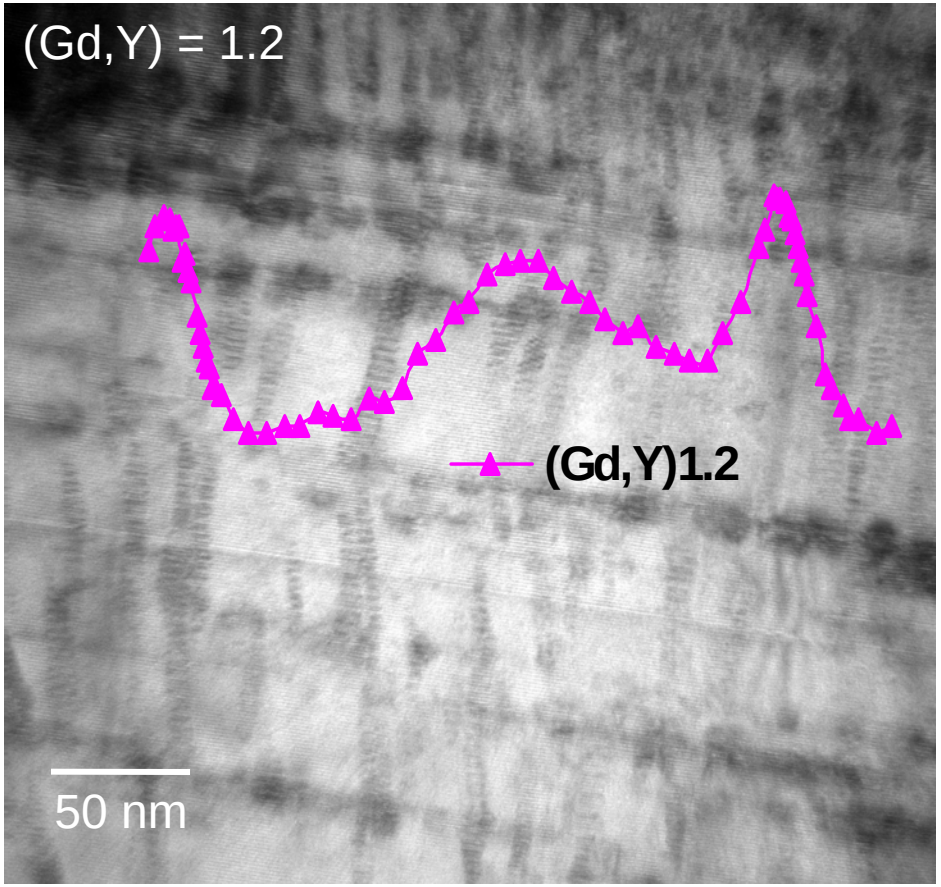
RE content dependence for 0.5 μm thick Zr:GdYBCO film with Ba=2, Cu=3.3, Zr=0.055

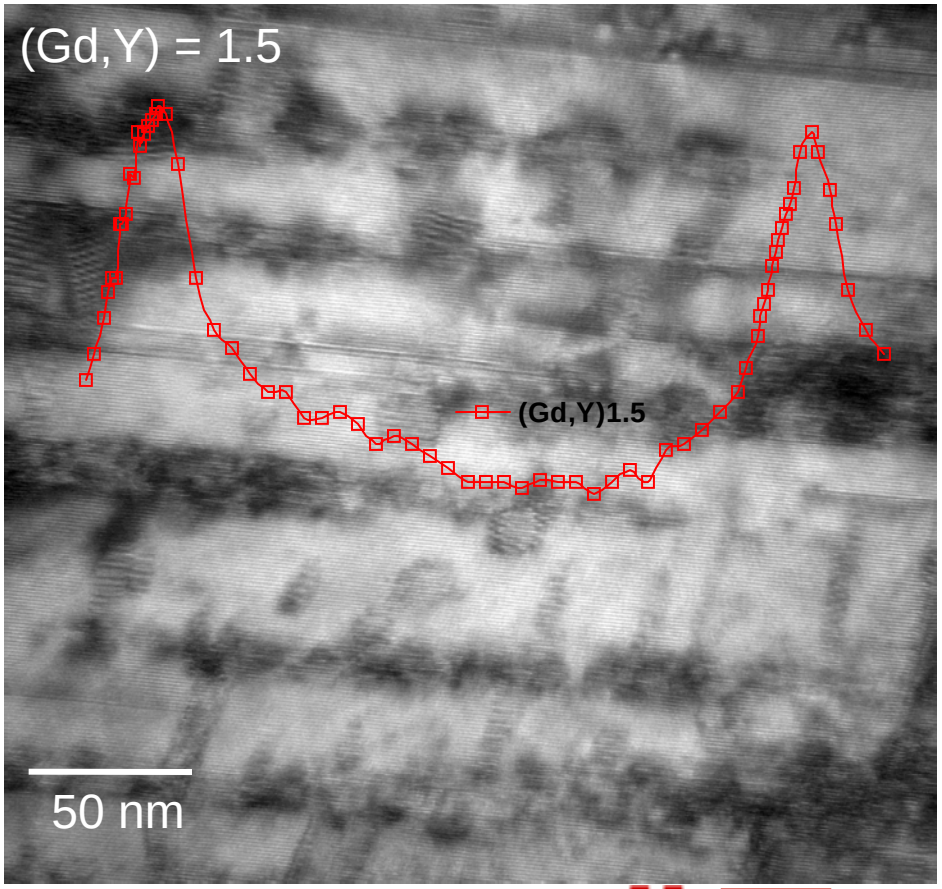
The c-peak was leveled off completely when RE>1.4.
The a-b peak could also be leveled off under certain conditions.
However, the Jc_min(B=1T) is still about 2 times of that without Zr.

Interaction between vertically aligned BZO columns and horizontally aligned RE_2O_3 precipitates

RE=1.2 content shows both columnar defects and layers comprised of nano-precipitates

RE=1.5 exhibits only short columnar segments; instead “thicker” precipitates are aligned with ab-planes





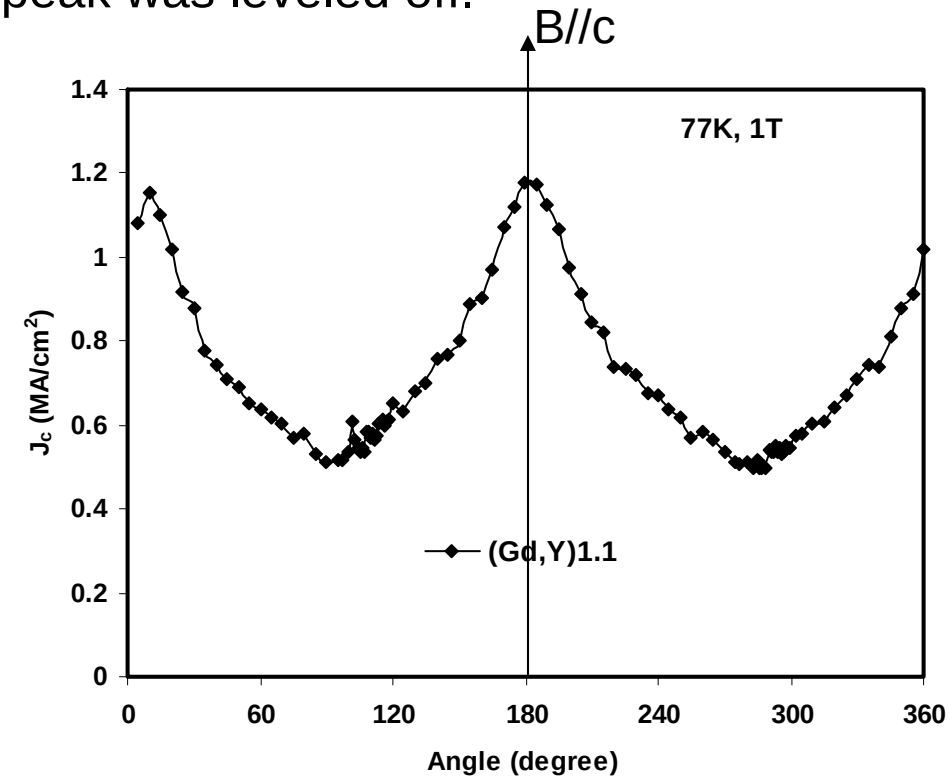
TEM cross-sectional images by Dean Miller of ANL

What happened to RE1.1? How was the ab-peak leveled off?

Lacking excess RE?

No. 10% is a large amount. In the case of without Zr addition, the ab-peak constantly stand there.

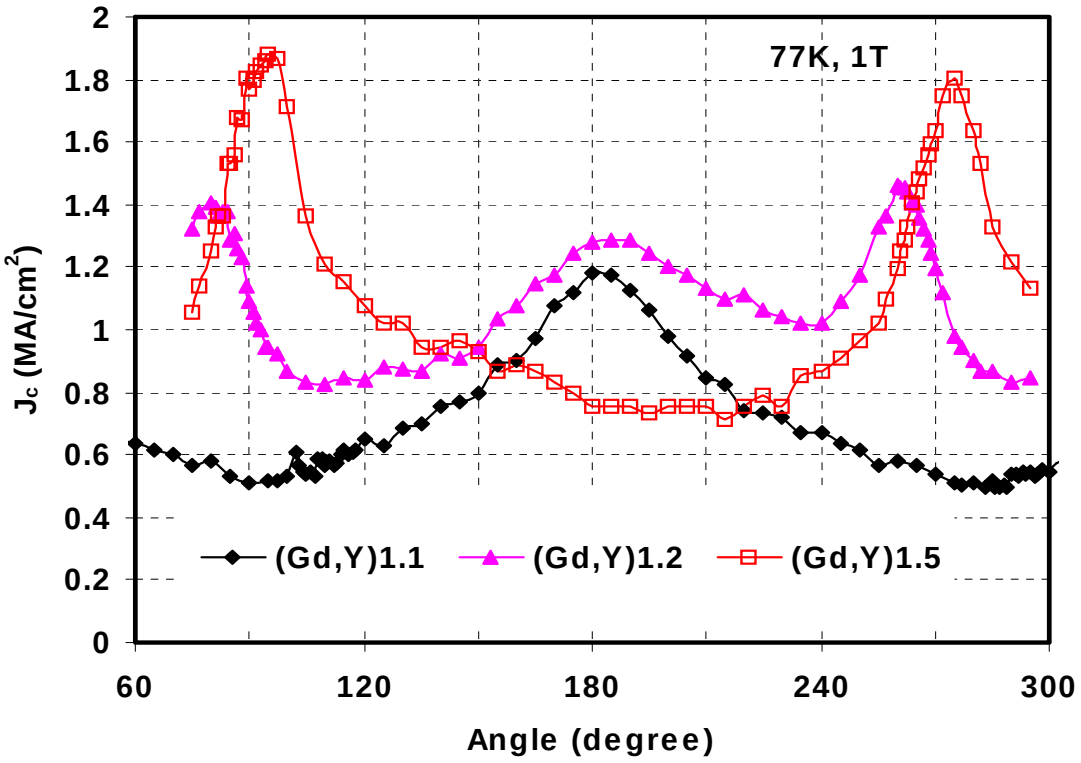
Under certain growth condition, the well formed BZO nanocolumns penetrating through the film thickness destroyed the horizotal alignment. Thus, the ab-peak was leveled off.



Can the superposition of the curves for low RE and high RE make a flat curve?

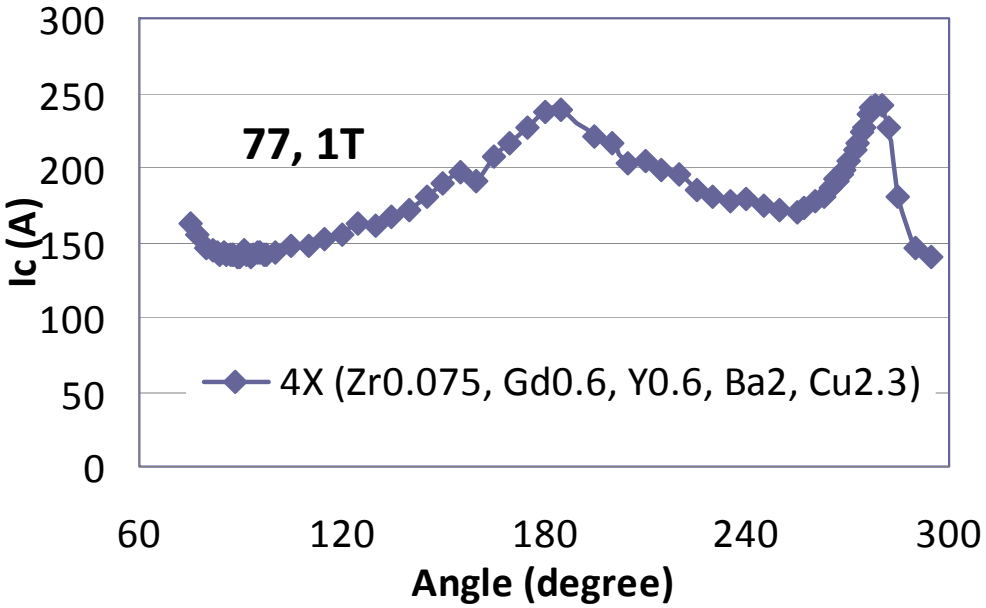
We can test it. However, it will not result in a higher J_{c_min}.

We are more interested in seeing the superposition with RE1.2.



In thicker Zr:GdYBCO films

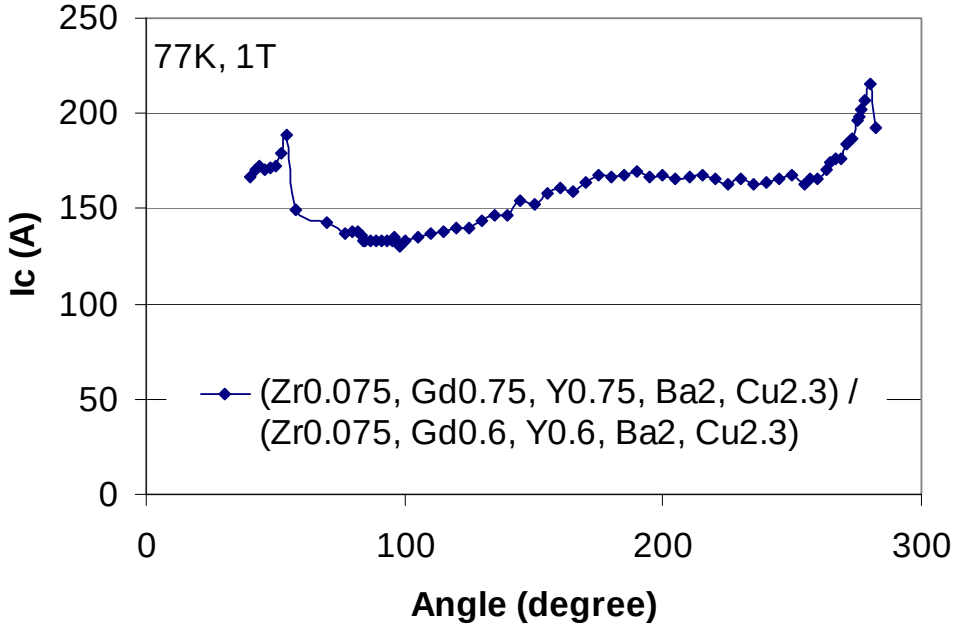
- 4 times-thick film of Zr0.055Gd0.6Y0.6Ba2Cu3.3O7, processed by 4 passes enhanced c-peak



B=	0	1T, //ab	1T, //c	1T
Ic (A)	529	241	237	142

In thicker Zr:GdYBCO films

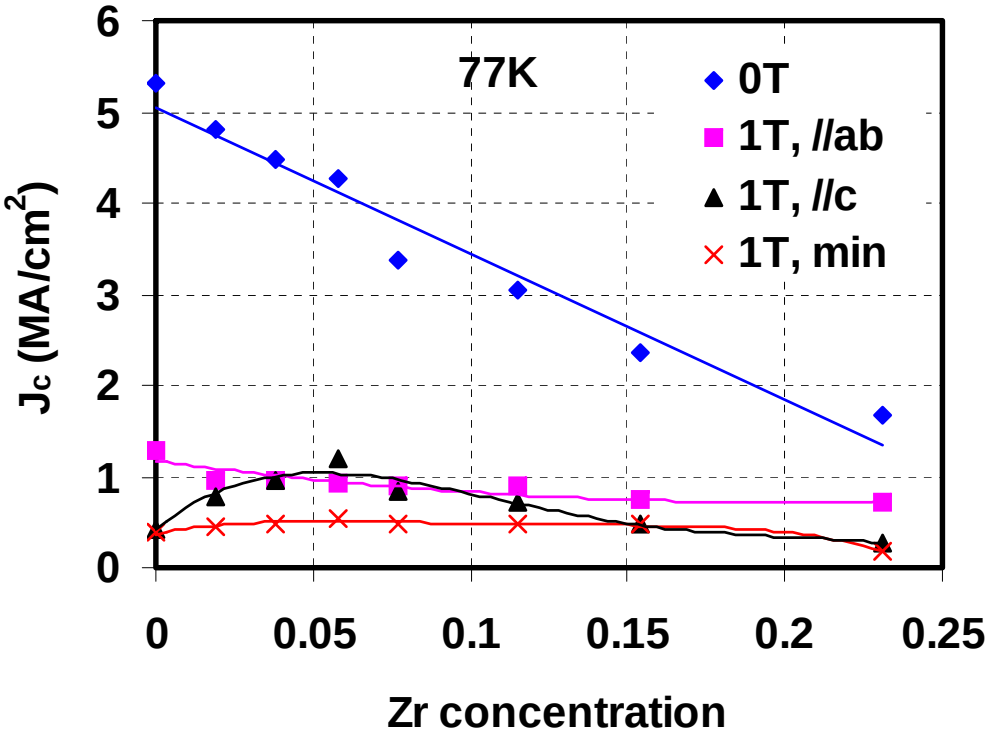
- Alternating composition from pass to pass
- Zr0.06Gd0.75Y0.75Ba2Cu3.3O7 \ Zr0.06Gd0.6Y0.6Ba2Cu3.3O7
- Zr0.06Gd0.75Y0.75Ba2Cu3.3O7 \ Zr0.06Gd0.6Y0.6Ba2Cu3.3O7
- The c-peak is still leveled off

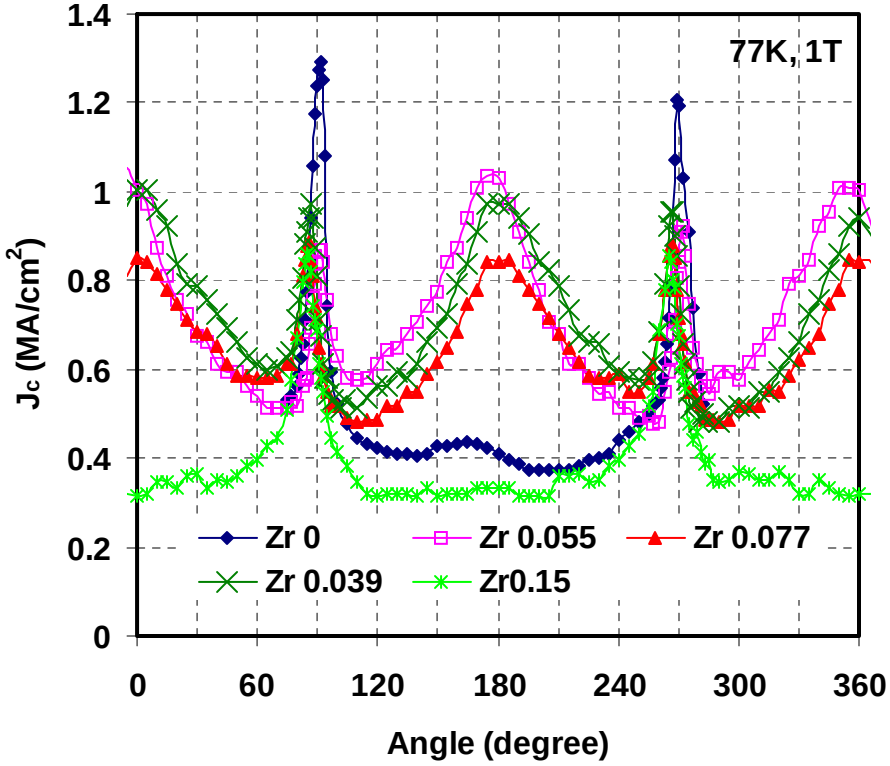


B=	0	1T, //ab	1T, //c	1T
Ic (A)	585	215	167	130

Zr concentration effects in Zr:GdYBCO

For Zr-concentration in the range of 0.04 – 0.075, c-peak can be higher than or the same height as ab-peak. J_c(1T, min) also takes its optimum value for Zr-concentration in this range, ~ 0.8MA/cm2, which is double of the value for GdYBCO without Zr doping.





Zr-concentration dependence of J_c for in 0.5 μm Zr:GdYBCO film with Gd=0.6, Y=0.6, Ba=2, Cu=3.3

Conclusion

- The composition ratio RE:Ba:Cu is the key to effective flux pinning of Zr-inclusions in MOCVD fabricated REBCO films. Over-high RE could suppress or level off c-peak associated with the pinning from BZO nano-columns; Insufficient RE leads to low Ic
- The removal of Jc peak at B//ab could be attributed to broken of horizontal alignment of RE_2O_3 dots by the well-formed BZO columns
- RE content greater than 1.4 could level off the Jc peak at B//c
- For RE content ranging from 1.2 to 1.5, Jc(sf) and Jc_min(77K, 1T) vary little
- The Zr-concentration in the range of 0.025 – 0.075 could be effective pinning centers
- Increasing Gd/Y ratio increased Jc(1T,77K). In self-field or low field, however, the optimized Gd/Y ratio is about 1