Coated Conductor Strategic Research

OAK RIDGE NATIONAL LABORATORY

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FY 2005 Funding: 800 K

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Relevance to DOE Superconductivity Program and Technical Targets

"R&D Needs/Knowledge gaps" identified in the DOE Coated Conductor Technology Development Roadmap *and* addressed in this project:

- **Enhancing flux-pinning in superconductor**
- **Preventing delamination at metal/oxide interfaces**
- **Understanding interfaces between epitaxial layers**
- **Understanding of microstructural factors affecting critical current density**
- **Developing better and improved buffer layers**

Specific Objectives/Milestones

- Extend work to incorporate self-aligned nanodots and nanorods in PLD YBCO films on RABiTS from 0.2-μm-thick thicker films. Fabricate REBCO films on RABiTS.
- Conduct microstructural and texture characterization of YBCO tapes produced via high rate in-situ MOCVD of REBCO films. Characterize transport properties of tapes and correlate to microstructure.
- Investigate improvement in flux-pinning via defects generated by substrate surface modifications.
- Extend analysis by thermal desorption spectroscopy coupled with Auger Spectroscopy to minimize delamination effects in IBAD substrates.
- Develop a robust buffer layer stack that is compatible with IBAD templates for use in subsequent YBCO deposition via MOCVD.

Presentation Outline

- **FY 2005 Results**

  Flux-pinning by BZO nanodots & nanorods on RABiTS (Amit)

  Microstructure – Property correlations of MOCVD (Y,Sm)BCO Films on IBAD YSZ substrates

  Pinning by surface decoration (Tolga)

  Preventing delamination of IBAD YSZ buffers (Fred)

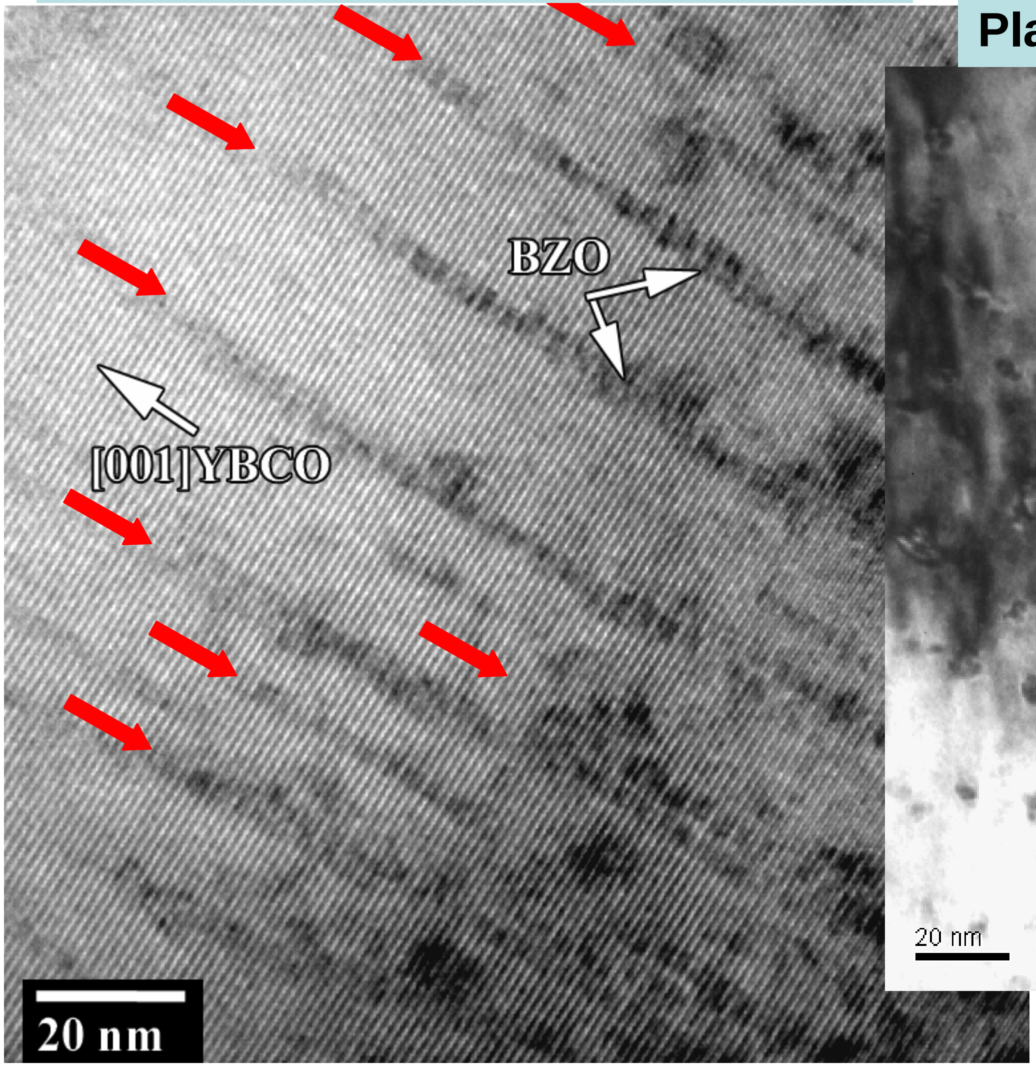
  Development of buffer layers for IBAD substrates and overview of SuperPower-ORNL CRADA (Selva)

- **FY 2005 Performance and FY 2006 Plans (Fred)**

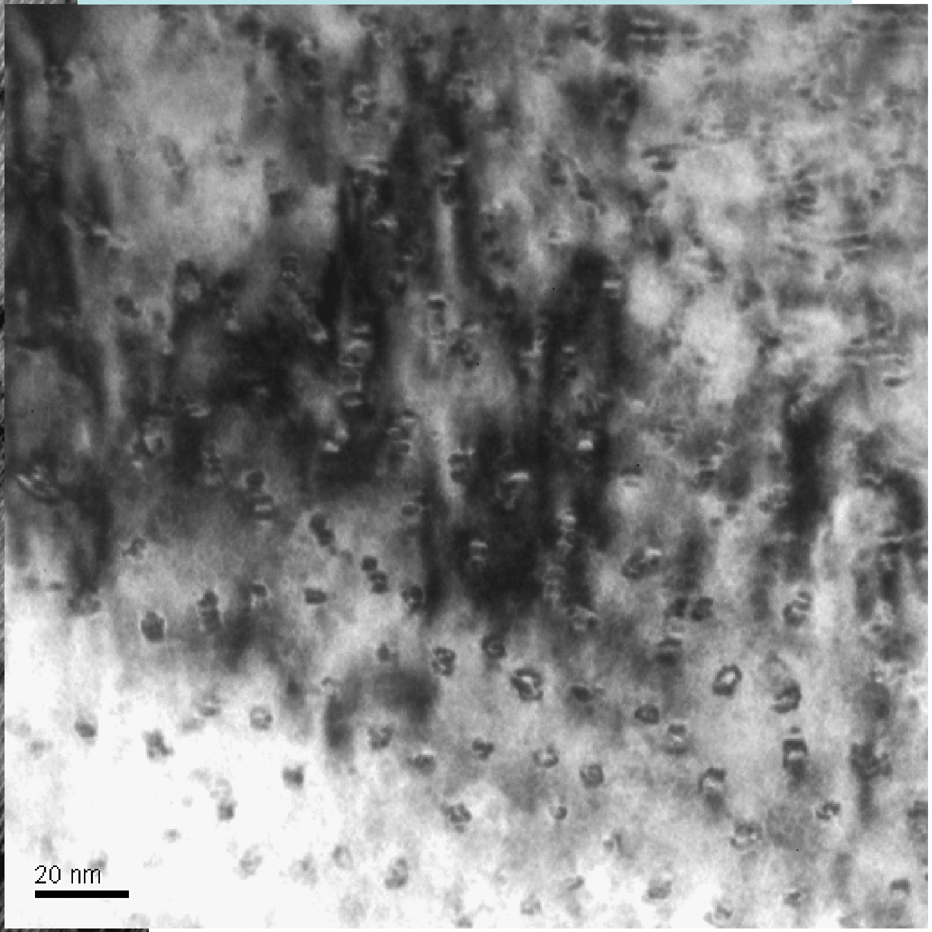
- **Research Integration**

Objective 1: Enhance pinning in YBCO thick films on RABiTS

Cross-section TEM of YBCO/RABiTS

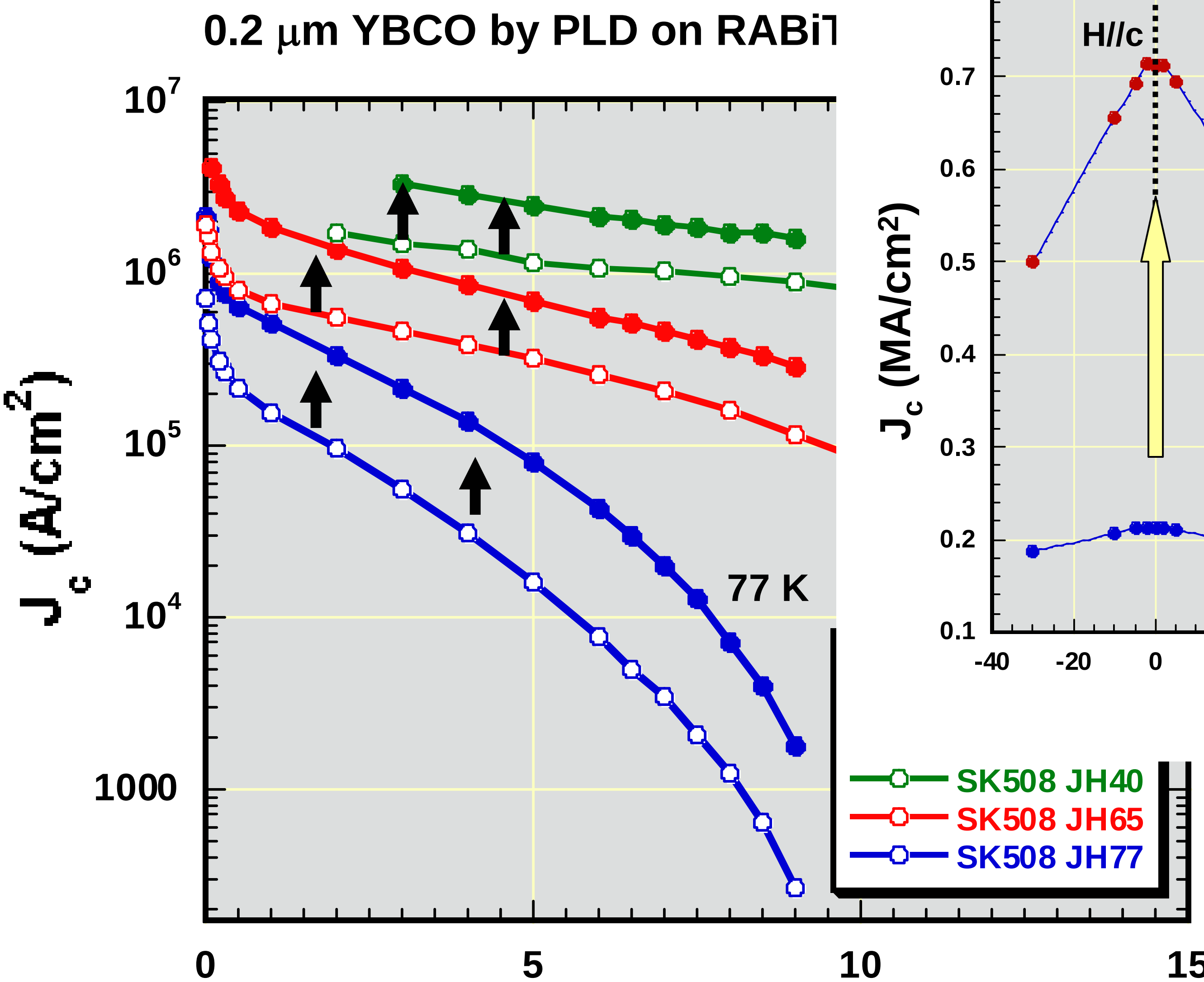


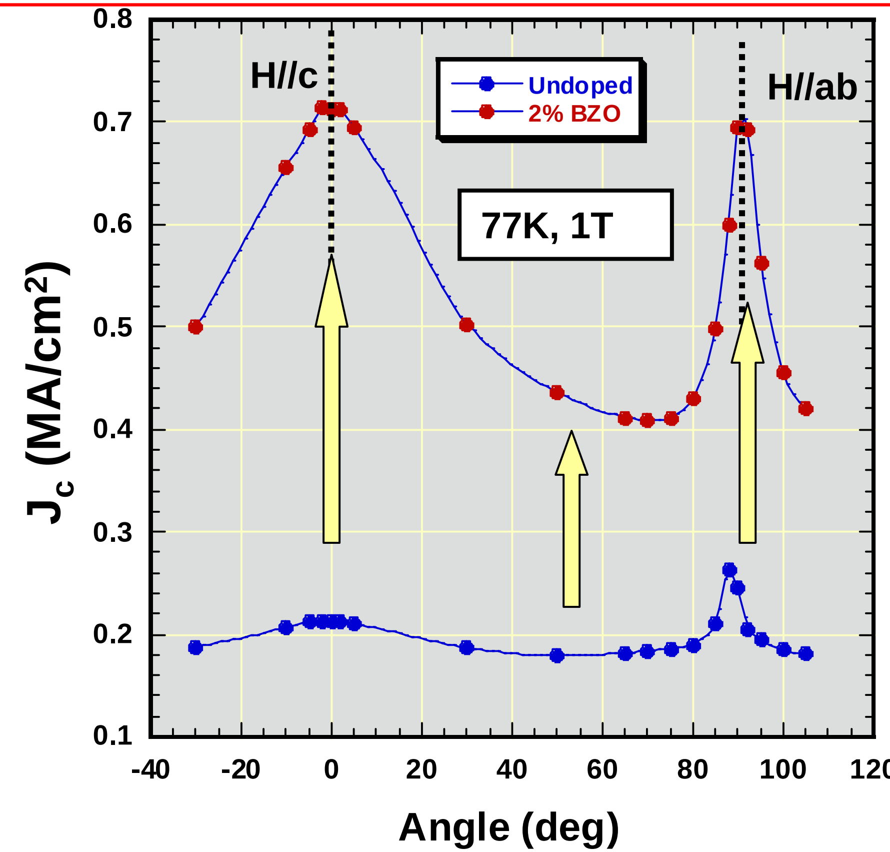
Plan view TEM of YBCO/RABiTS



20 nm

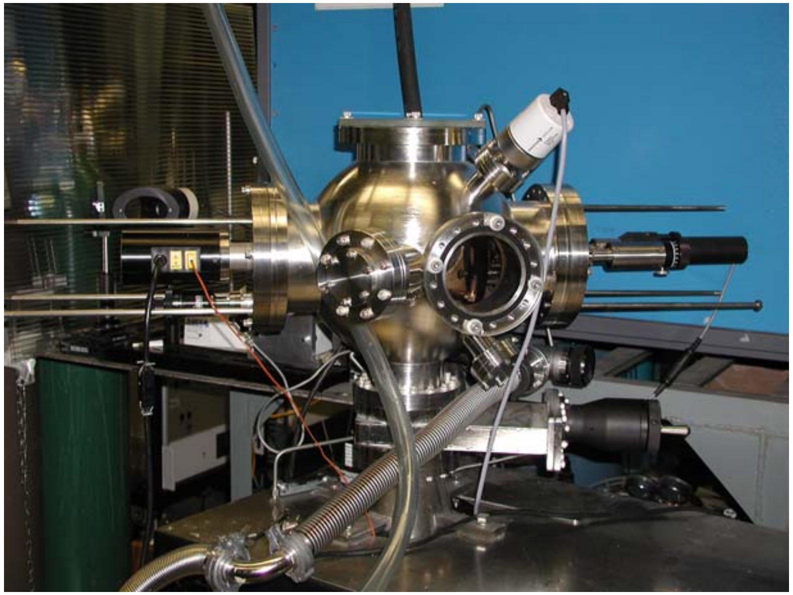
*Intra*granular J_c can be significantly enhanced by incorporation of self-aligned nanodots in YBCO on RABiTS





Significant enhancement in J_c is observed

Method used to incorporate self-aligned nanodots & nanorods

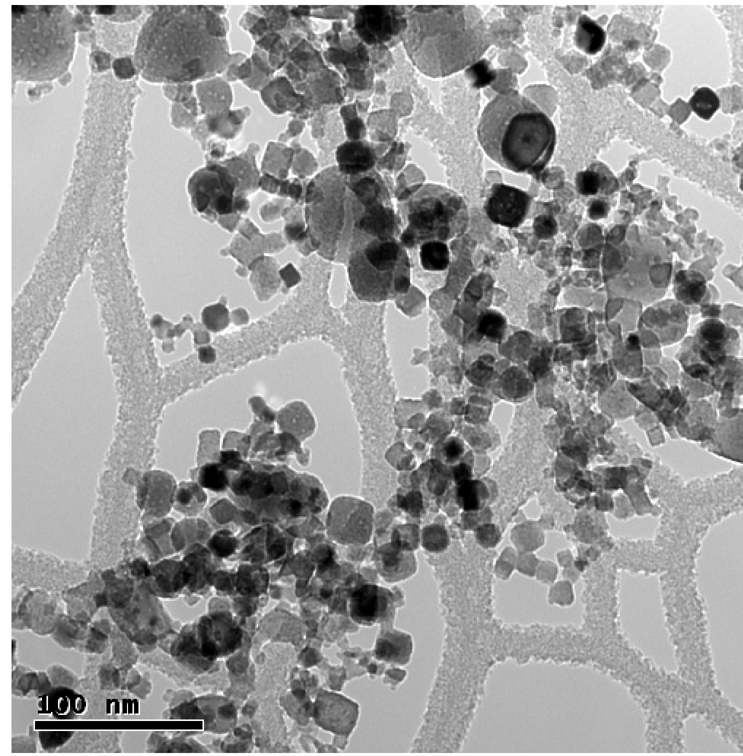


PLD YBCO deposition system

- XeCl(308nm) excimer laser Model LPX 305
- Rep. Rate: 10-20 Hz
- Subs. Temp. = 790°C
- PO2 = 120 mTorr

Substrate used: RABiTS

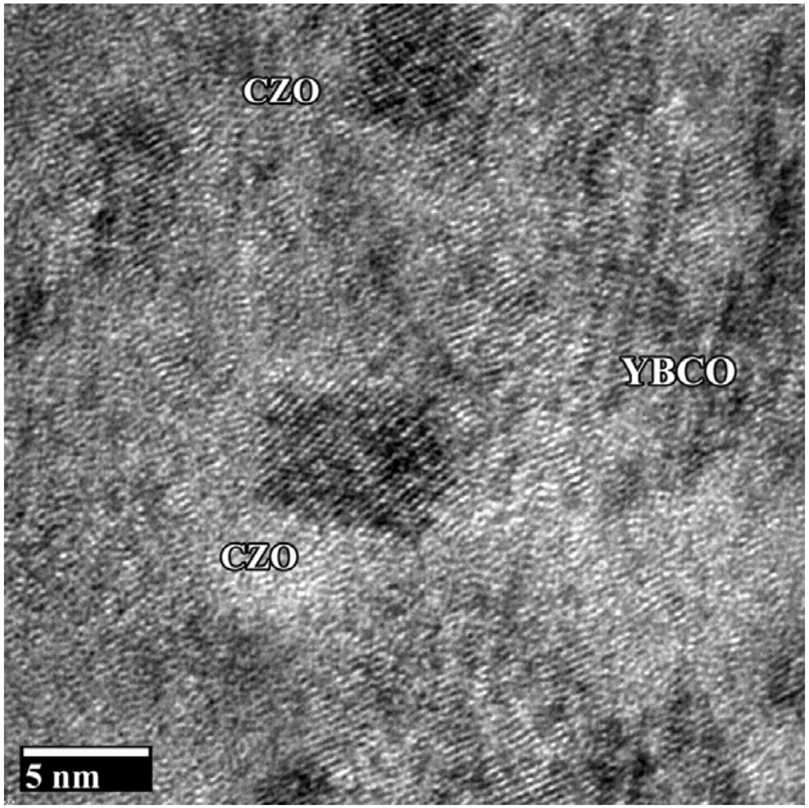
Use a single sintered target of YBCO mixed with $BaZrO_3$ nanoparticles



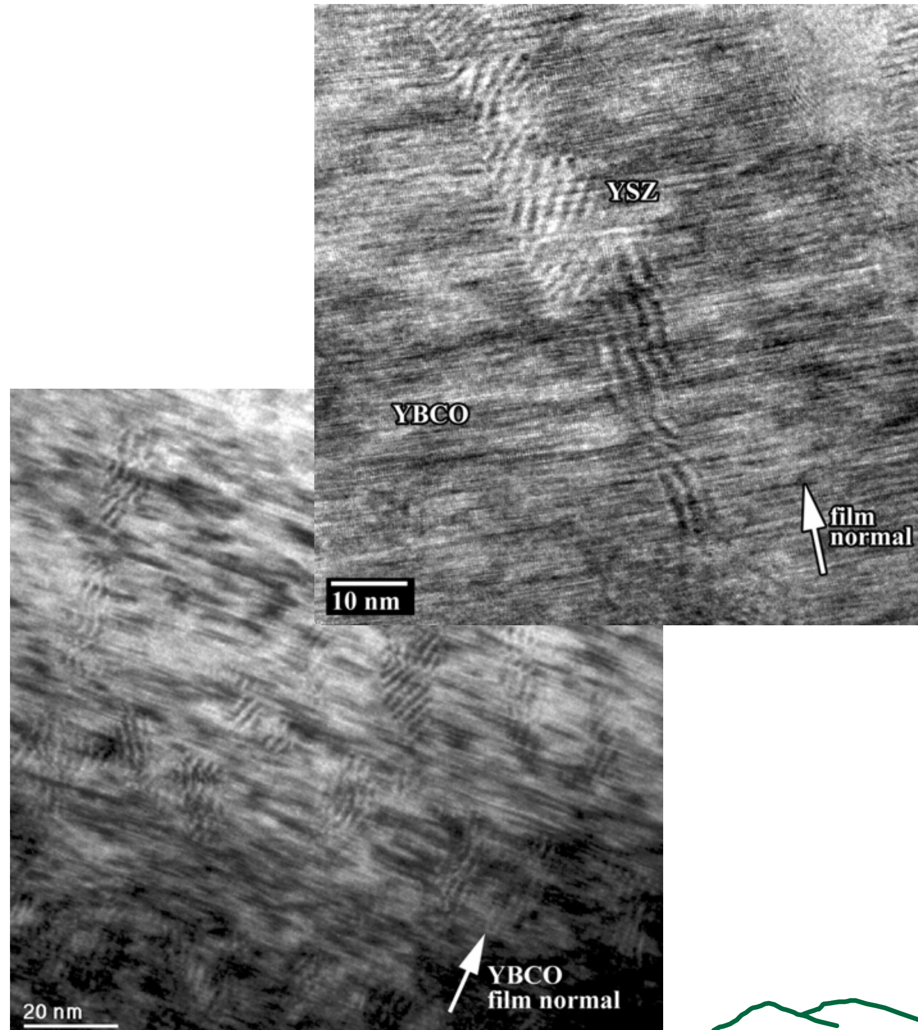
Commercially available powder from Sigma-Aldrich Co. Not expensive!

FY05 Result: Such a method can be used to incorporate self-aligned nanodots & nanorods of materials other than BZO

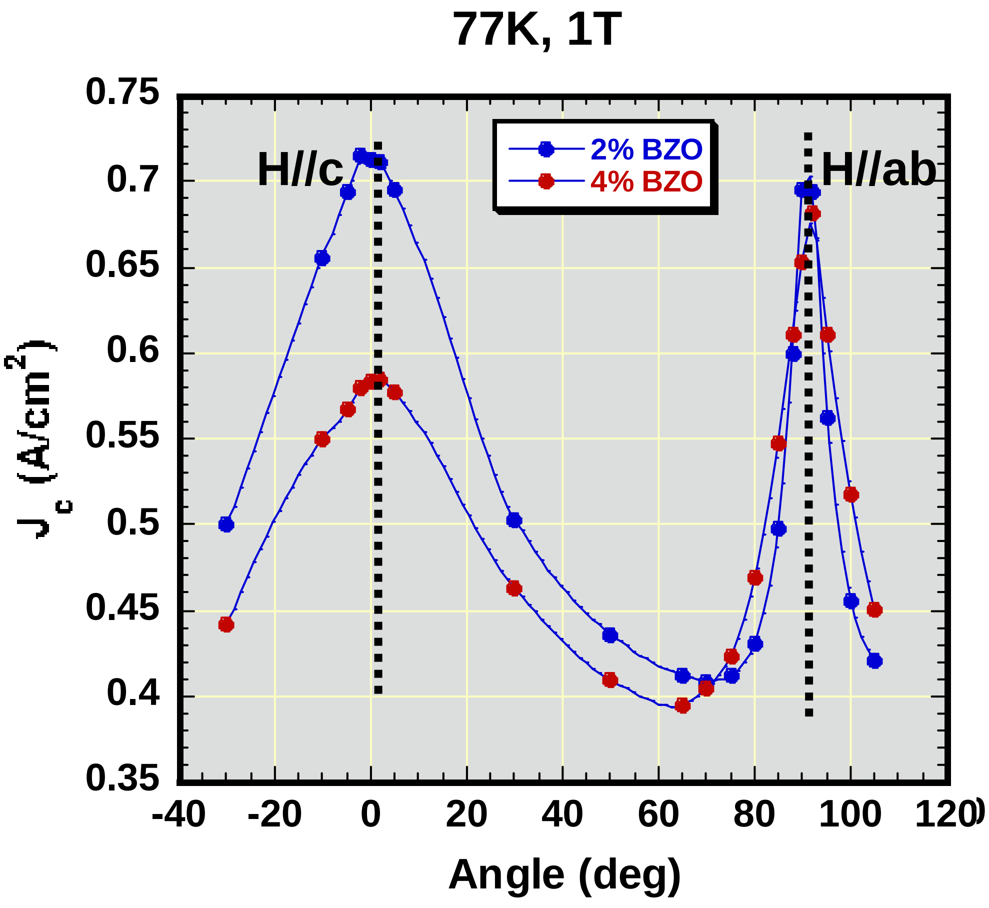
1 vol% $CaZrO_3$

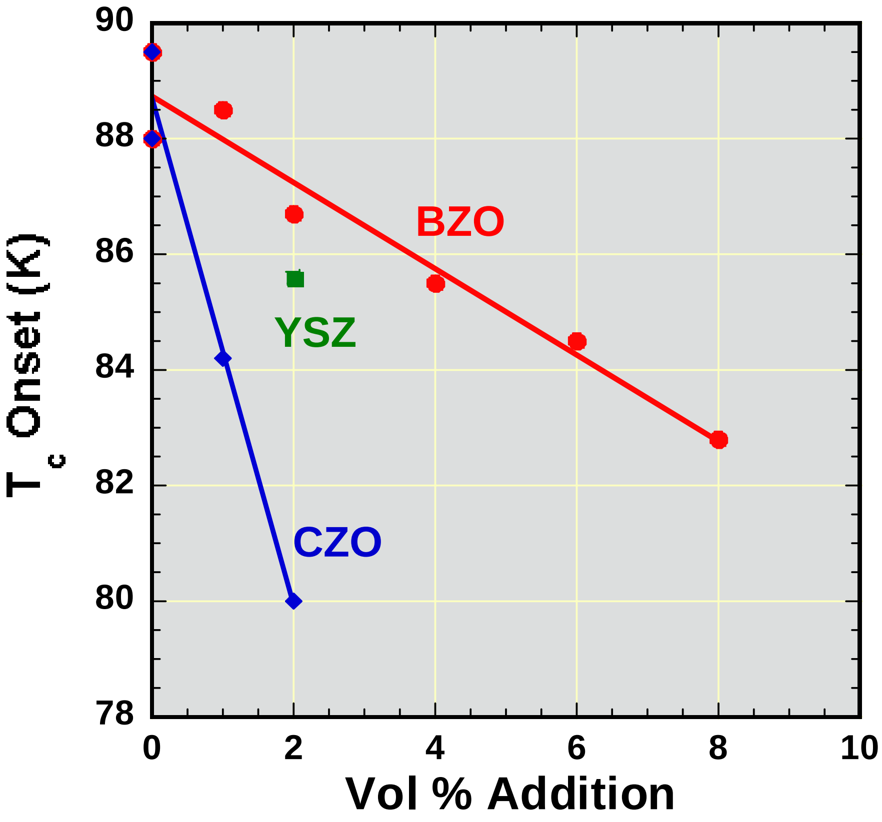


2 vol% YSZ

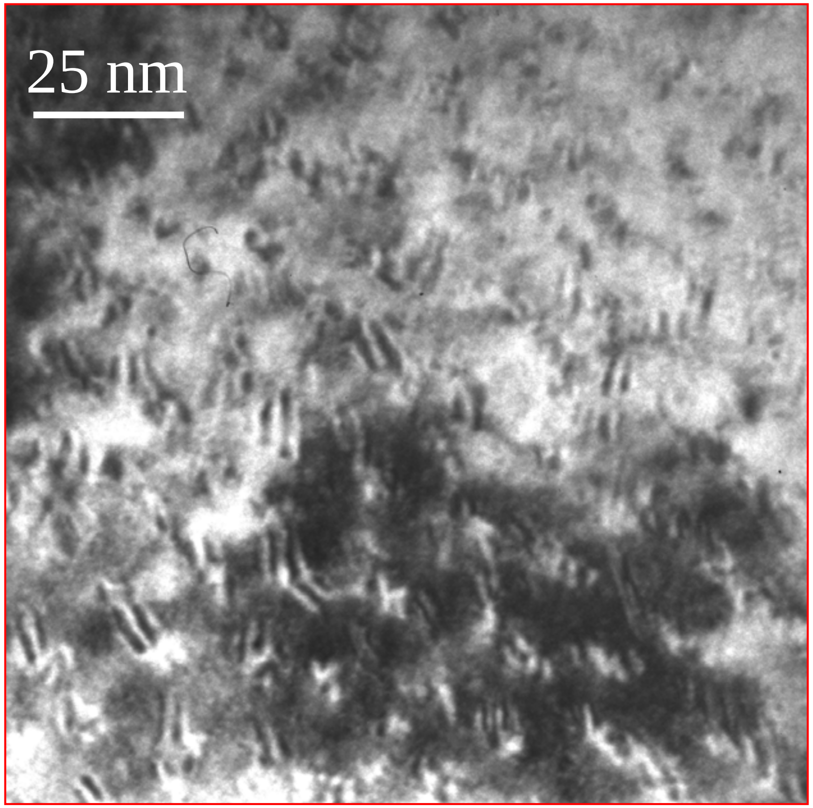


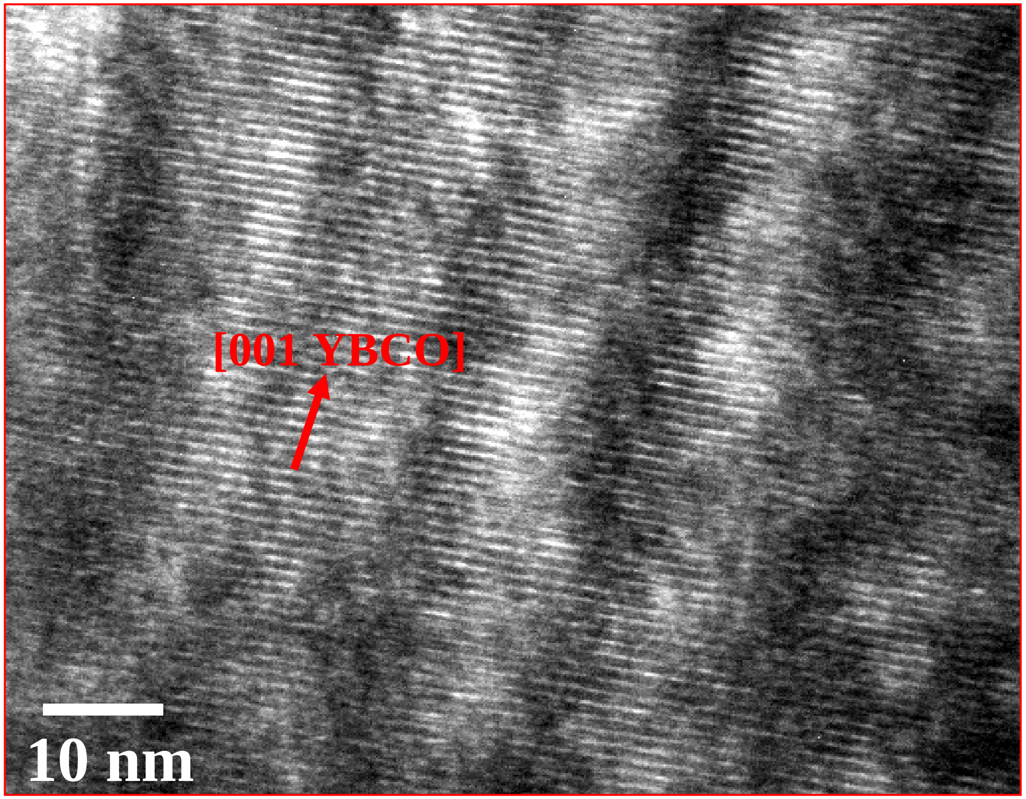
Increase in vol% of BZO reduces T_c further





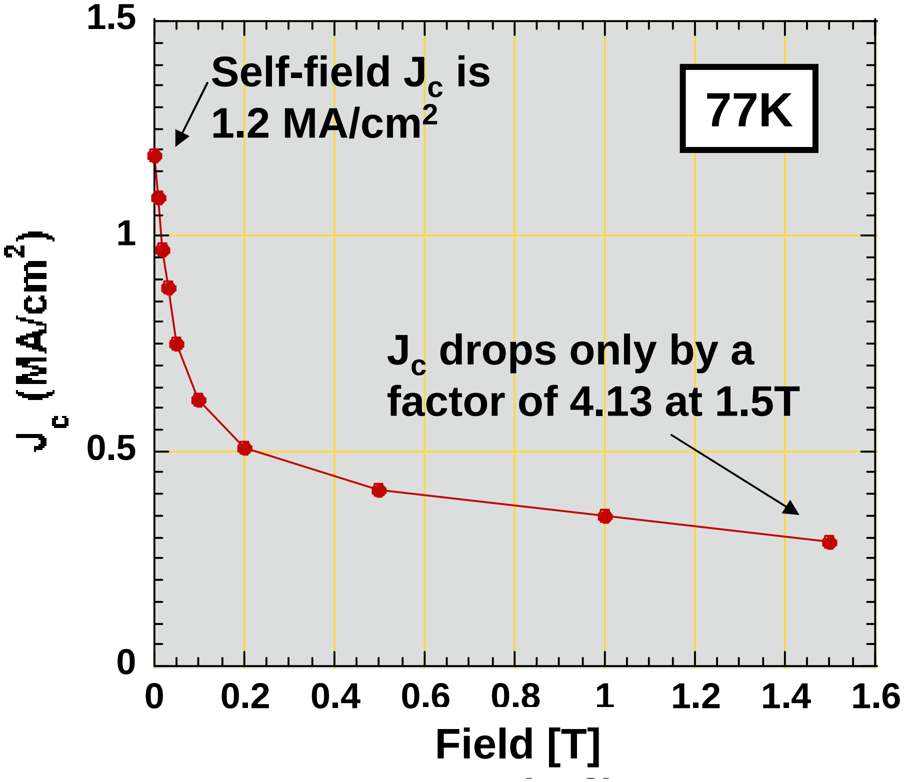
FY05 Result: Defect density of self-aligned BZO nanodots increases in 4 vol. % BZO incorporation

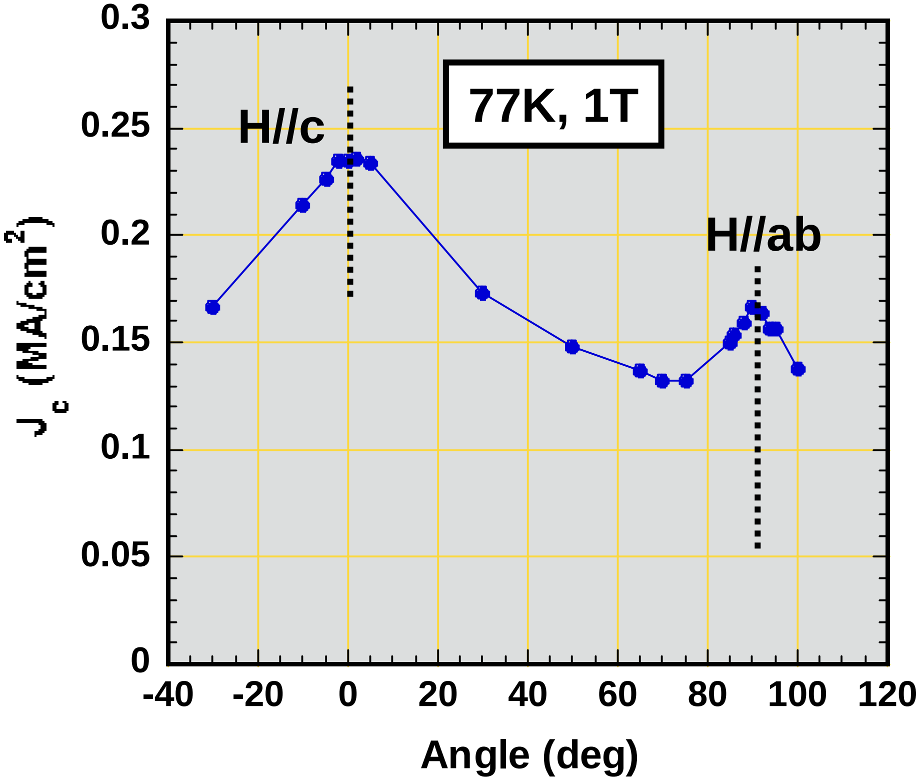




Areal density = 5.5 x 10^{11}; B_{ϕ} ~ 11.5 T

FY05 Result: 1 micron thick YBCO films with 2vol%BZO on RABiTS with a configuration of CeO_2/YSZ/Y_2O_3/Ni-5at%W

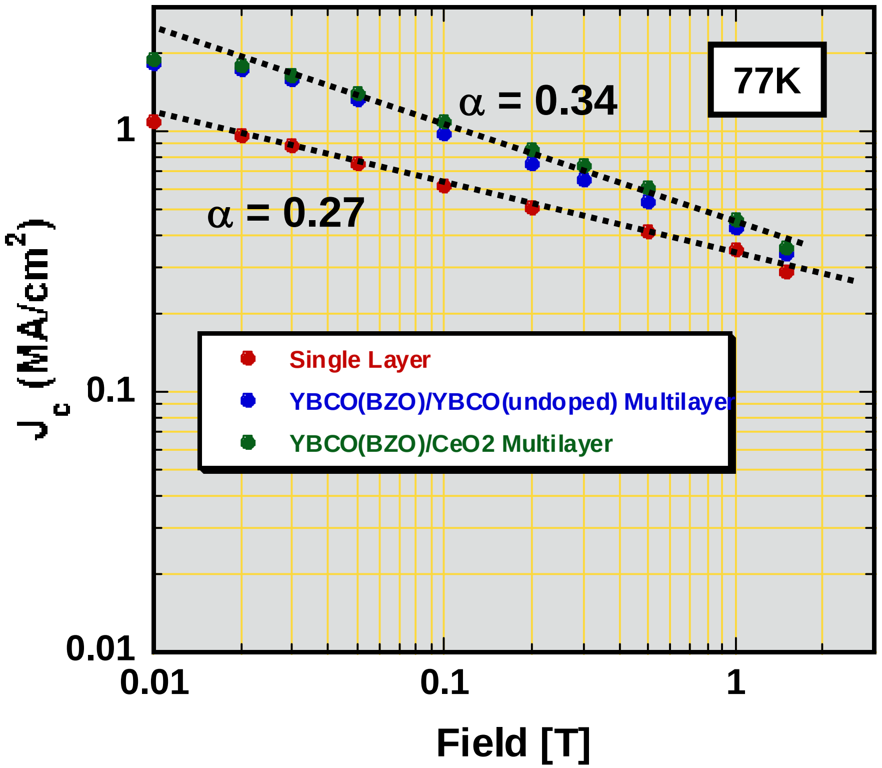


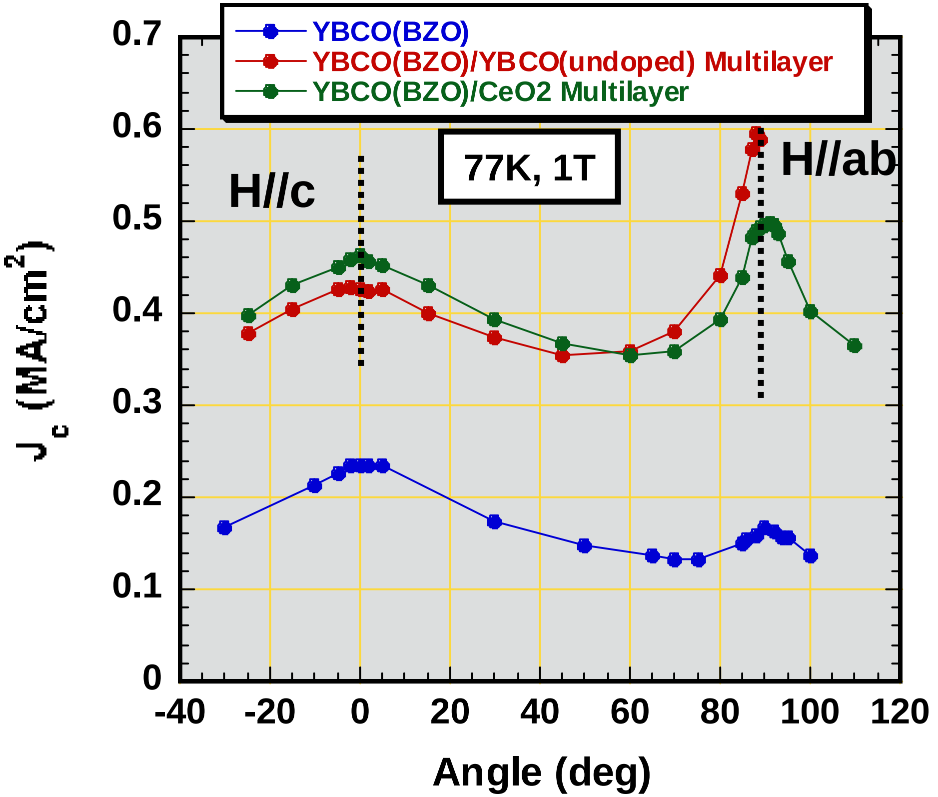


$J_c \sim H^{-\alpha}$, $\alpha = 0.27$

Can we increase pinning for H//ab by breaking up the columns and create some planar defects such as stacking faults parallel to the ab-plane?

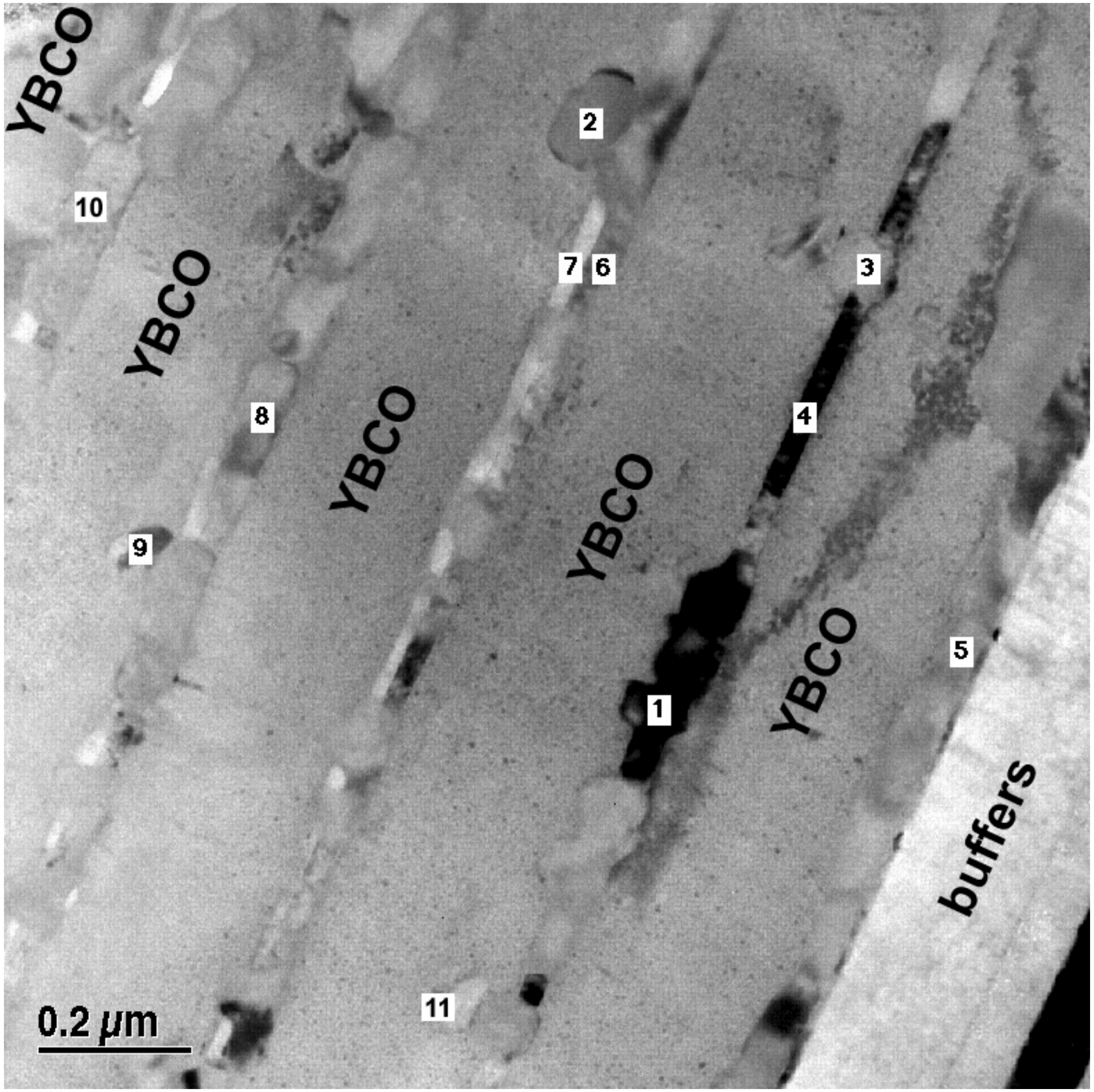
Two 1 μm thick multilayers were fabricated:
1) YBCO-BZO (200 nm)/YBCO (30nm)
2) YBCO-BZO (200 nm)/CeO_2 (30nm)





For both multilayers, the J_c was significantly enhanced

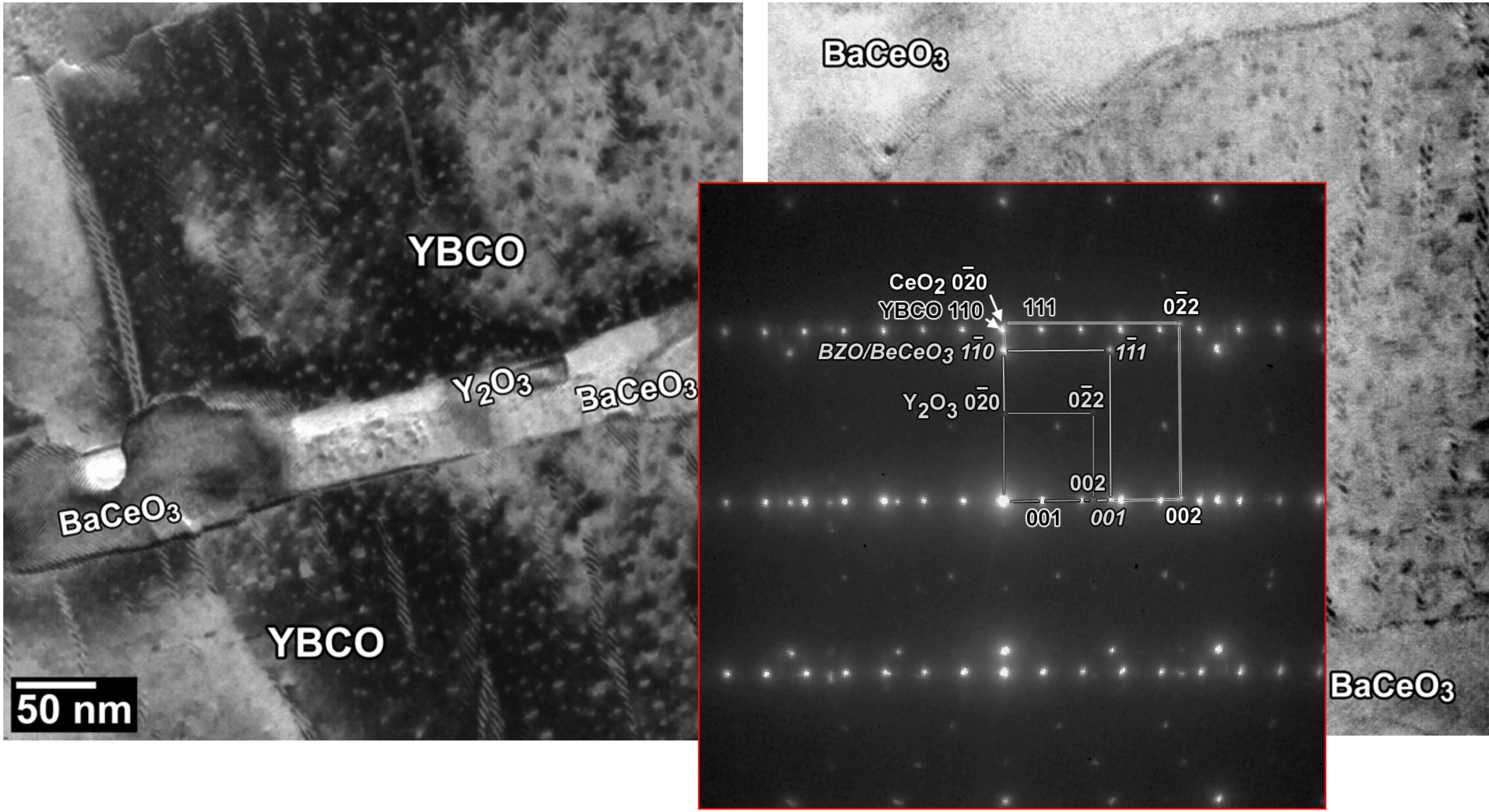
Microstructural characteristics of 5x[YBCO-BZO (200 nm)/CeO2 (30nm)]



YBCO and CeO_2 react to form additional defects!

1. $BaCeO_3$
2. Y211
3. $BaCeO_3$
4. CeO_2
5. $BaCeO_3$
6. $BaCeO_3$
7. Y_2O_3
8. $BaCeO_3$
9. Y_2O_3
10. $BaCeO_3$
11. Y211

Microstructural characteristics of 5x[YBCO-BZO (200 nm)/CeO_2 (30nm)]



YBCO[001] // BZO[001] // BCO [001] // CeO_2 [001] // Y_2O_3 [001]

YBCO[110] // BZO[110] // BCO [100] // CeO_2 [100] // Y_2O_3 [100]

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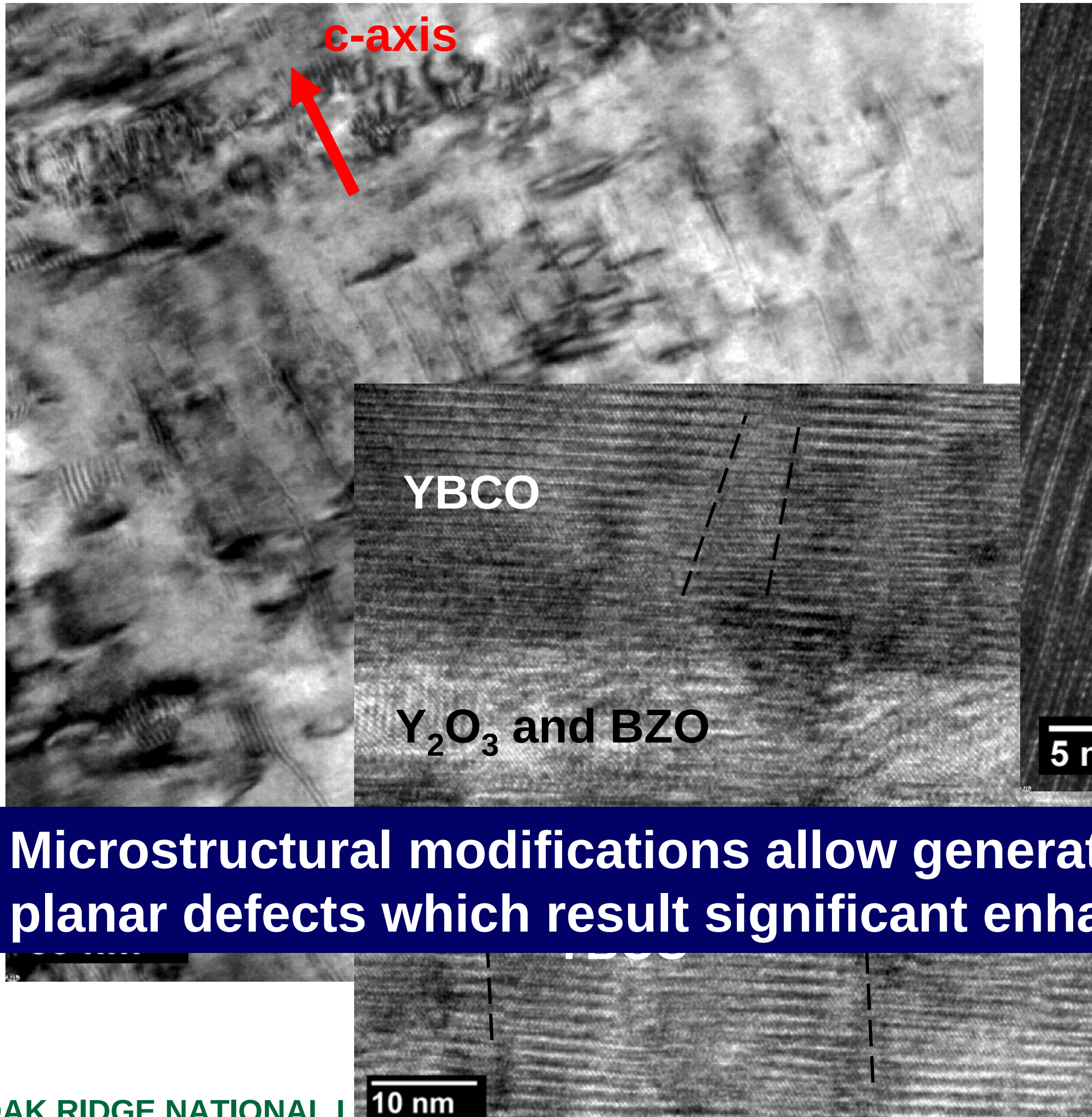
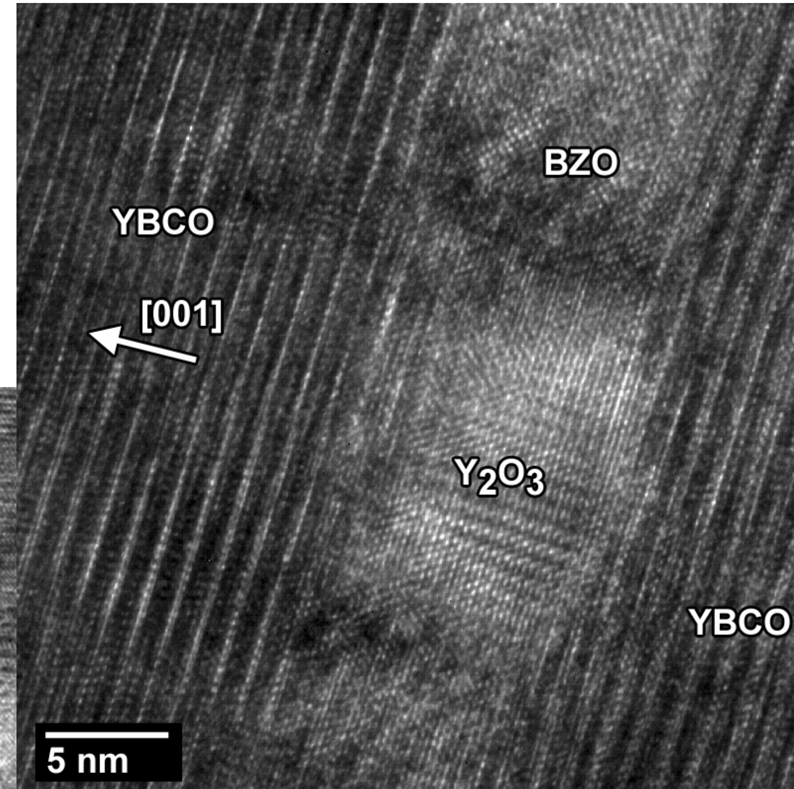
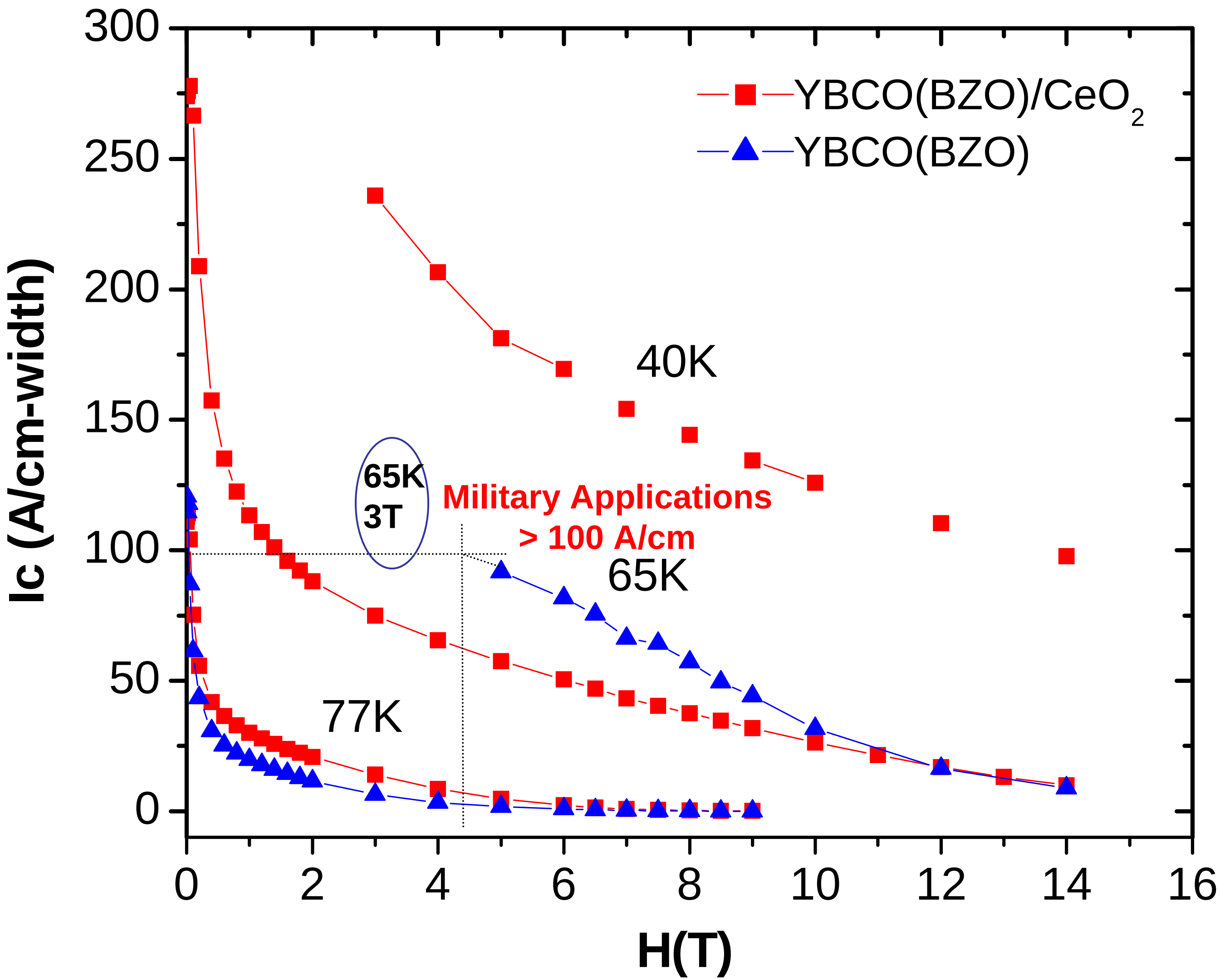
Microstructural characteristics of 5x[YBCO-BZO (200 nm)/YBCO (30nm)]



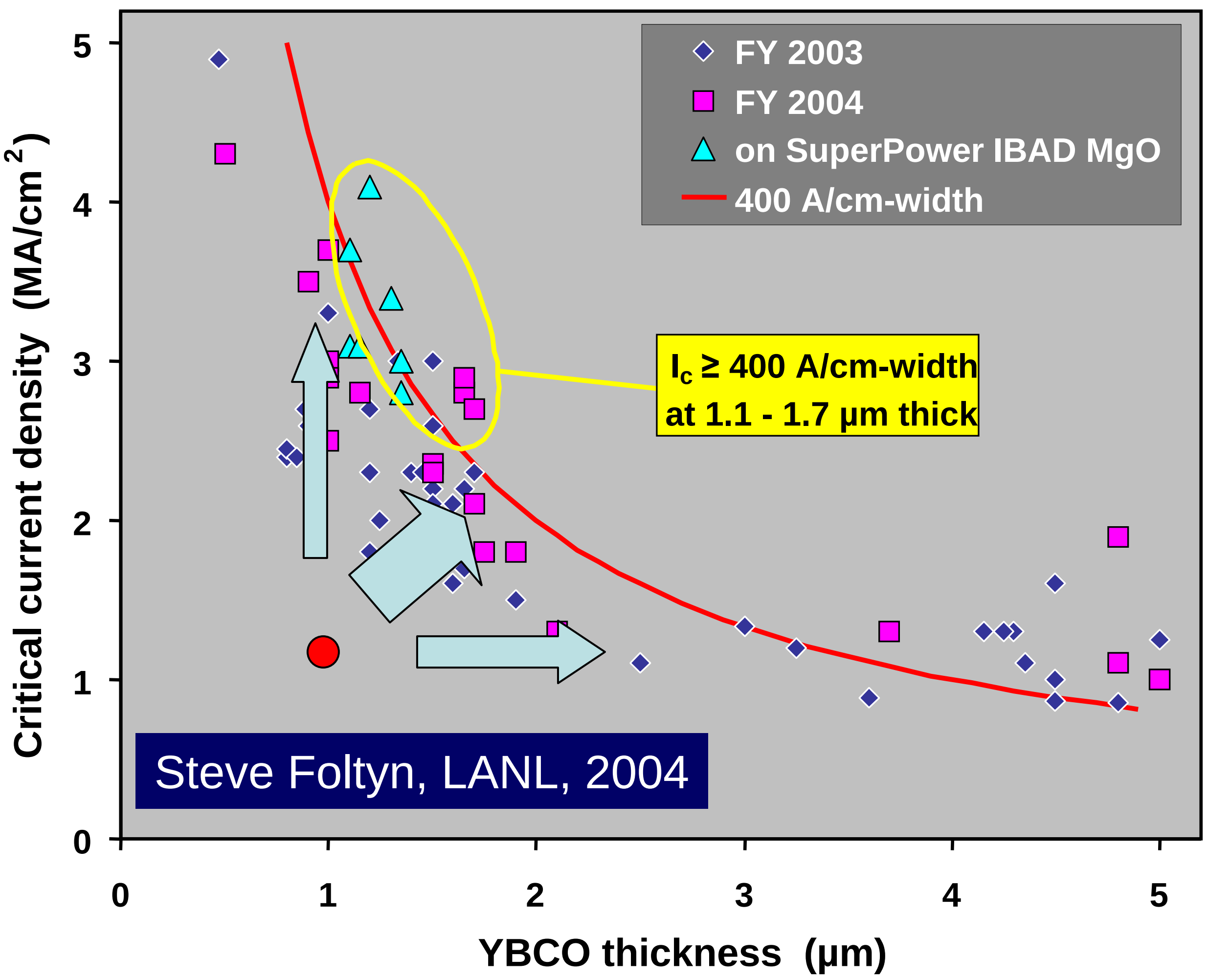


Microstructural modifications allow generation of both columnar and planar defects which result significant enhancements in the properties

Critical current per unit width as a function of applied field at various temperatures



Can properties of BZO-doped YBCO films on RABiTS be enhaced further?

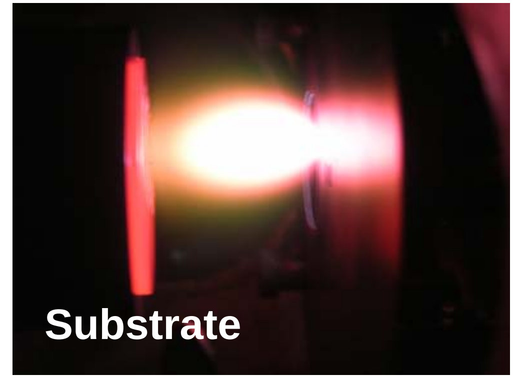


Experiments were done to optimize PLD deposition conditions for YBCO films on RABiTS

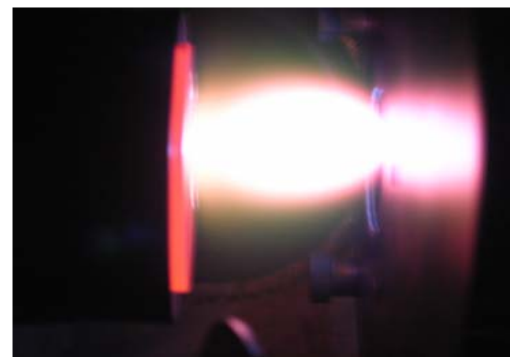
Variables investigated:

- Laser energy
- Substrate temperature
- Oxygen partial pressure
- Plume position relative to substrate

Suggestions from Quanxi Jia, LANL are appreciated!



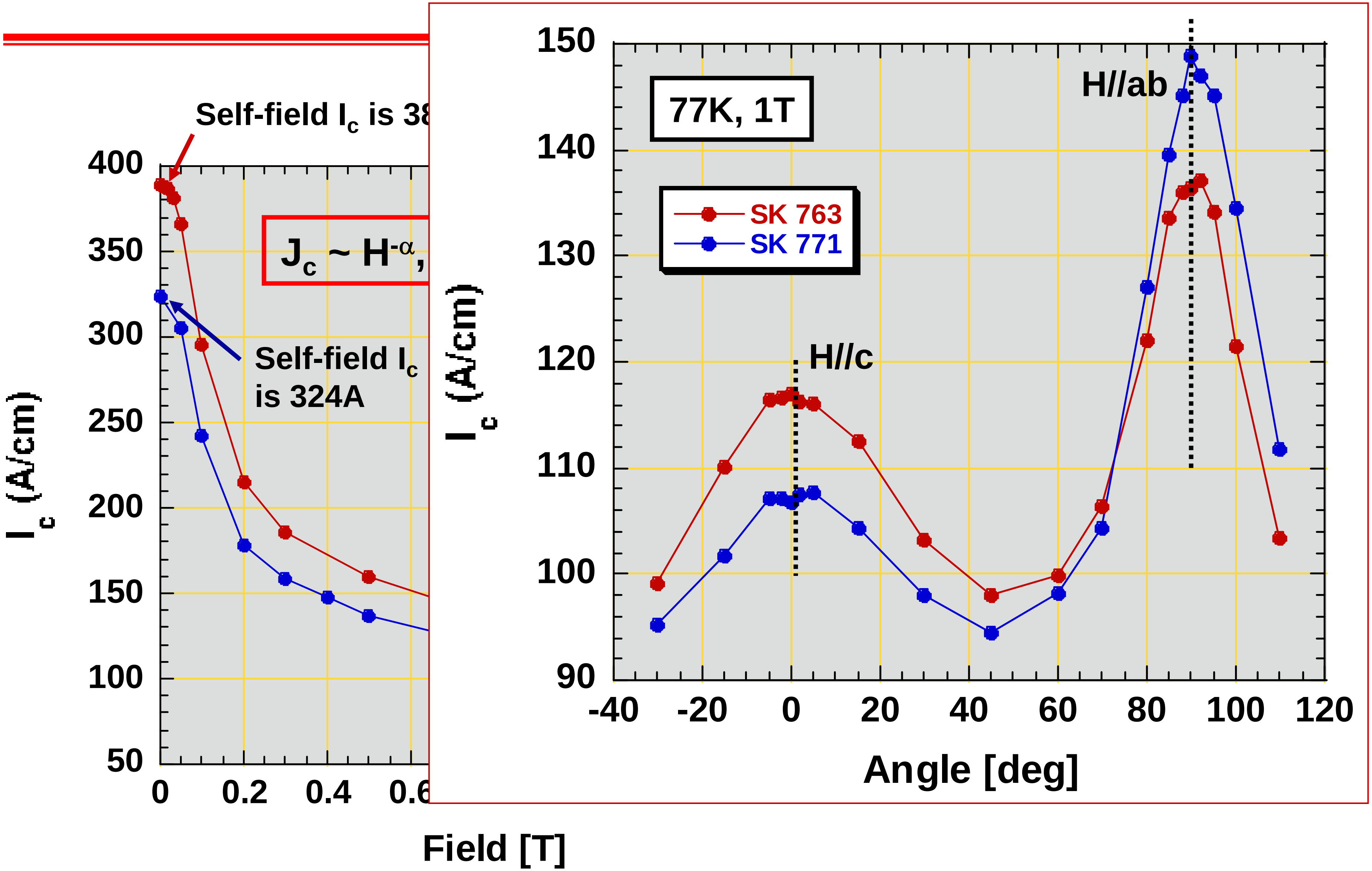
1cm apart
165mJ
(Laser energy)



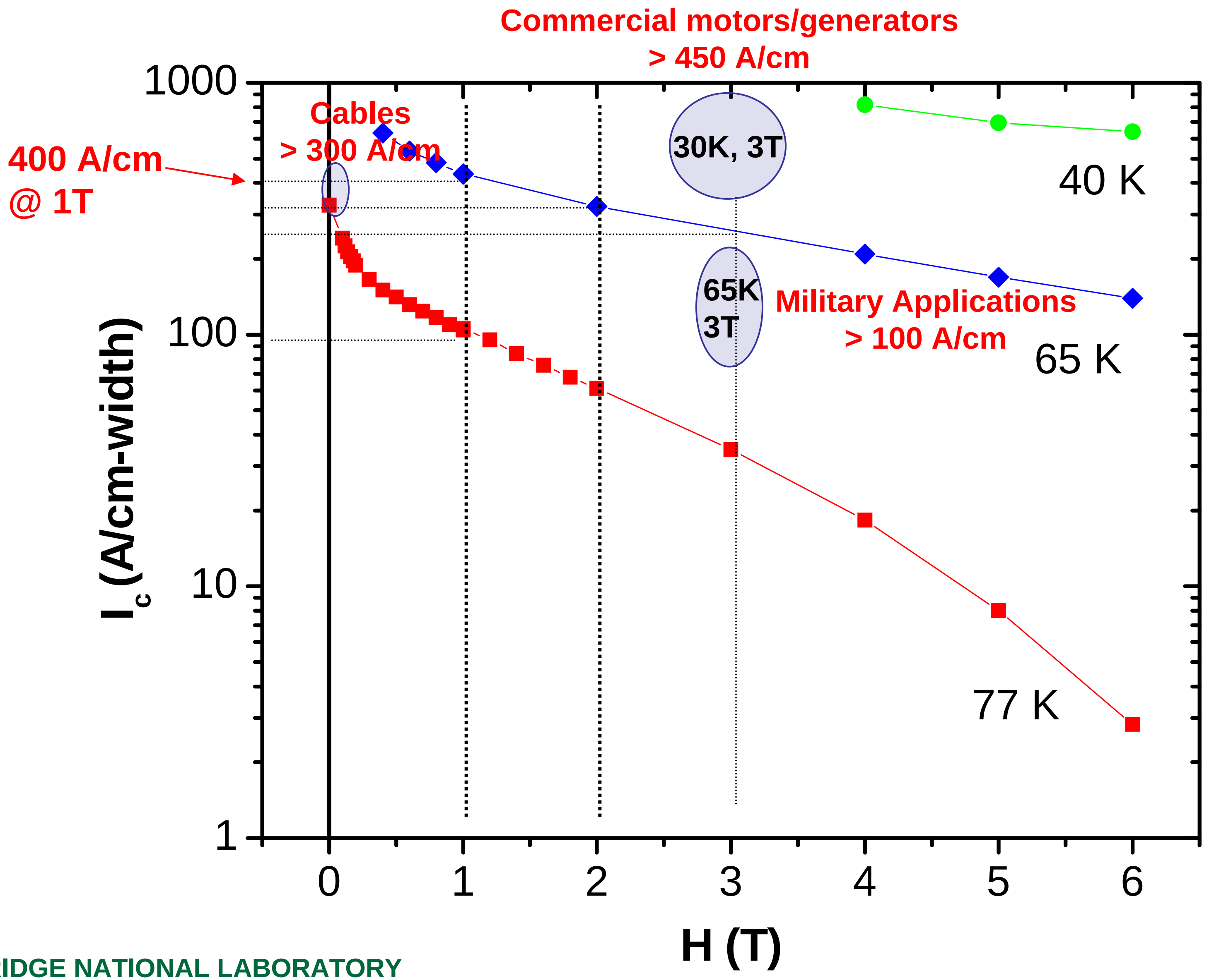
10%
193mJ

20%
220mJ

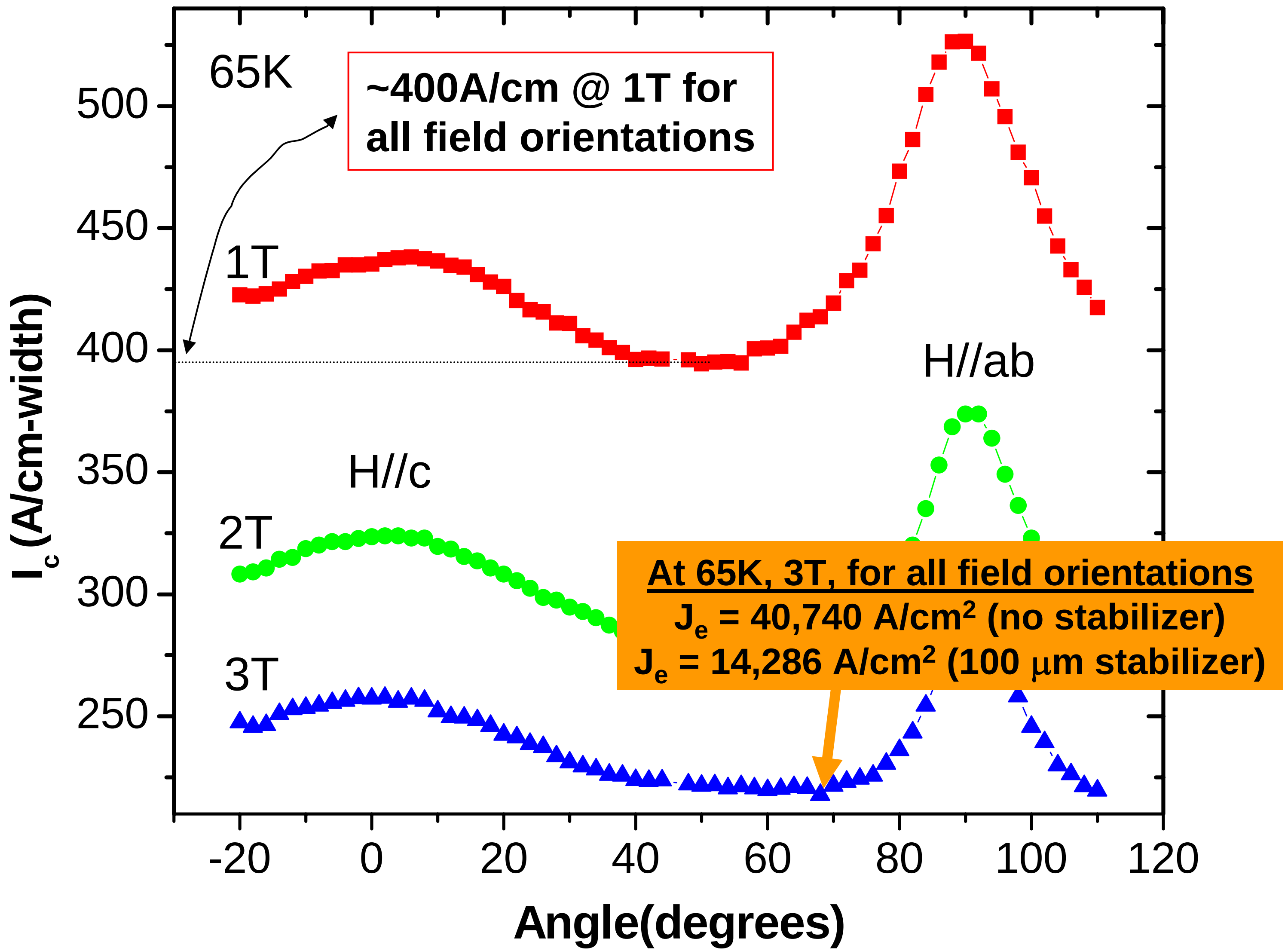
Under best conditions, promising results are obtained!



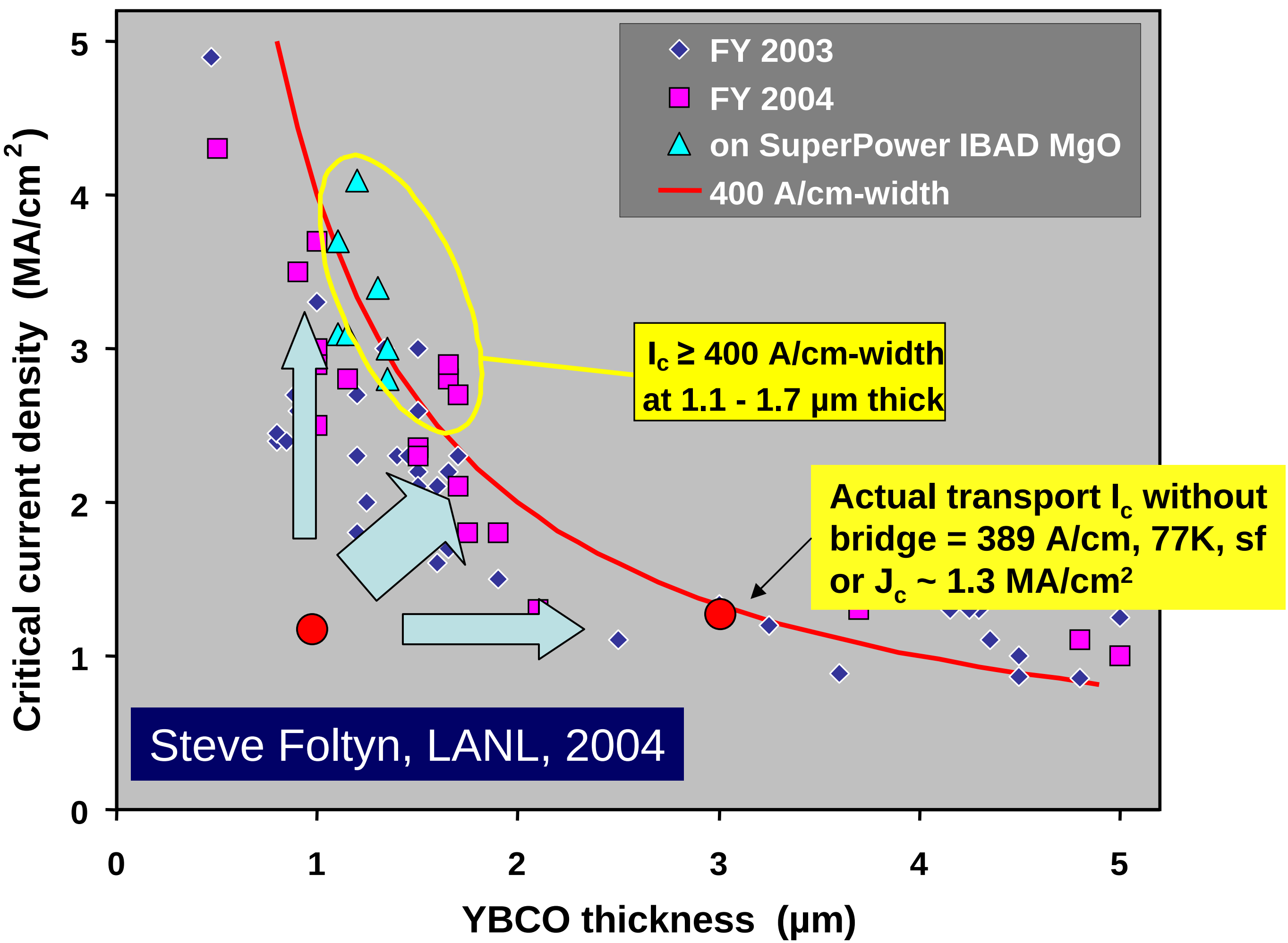
High I_c's are obtained at higher fields and lower temperatures due to strong pinning defects in the film!



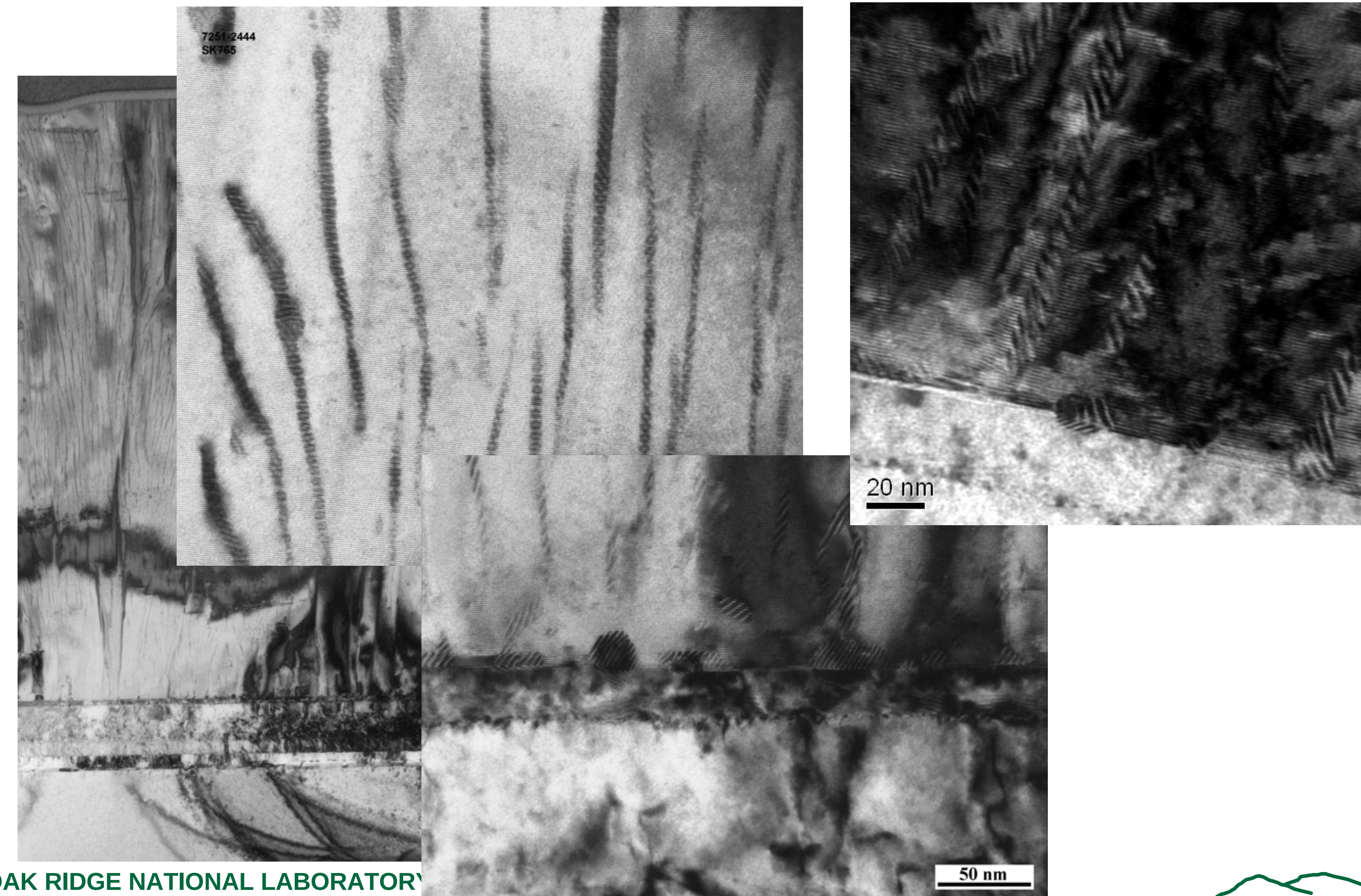
Angular dependence of J_c shows peaks for both H//c and H//ab



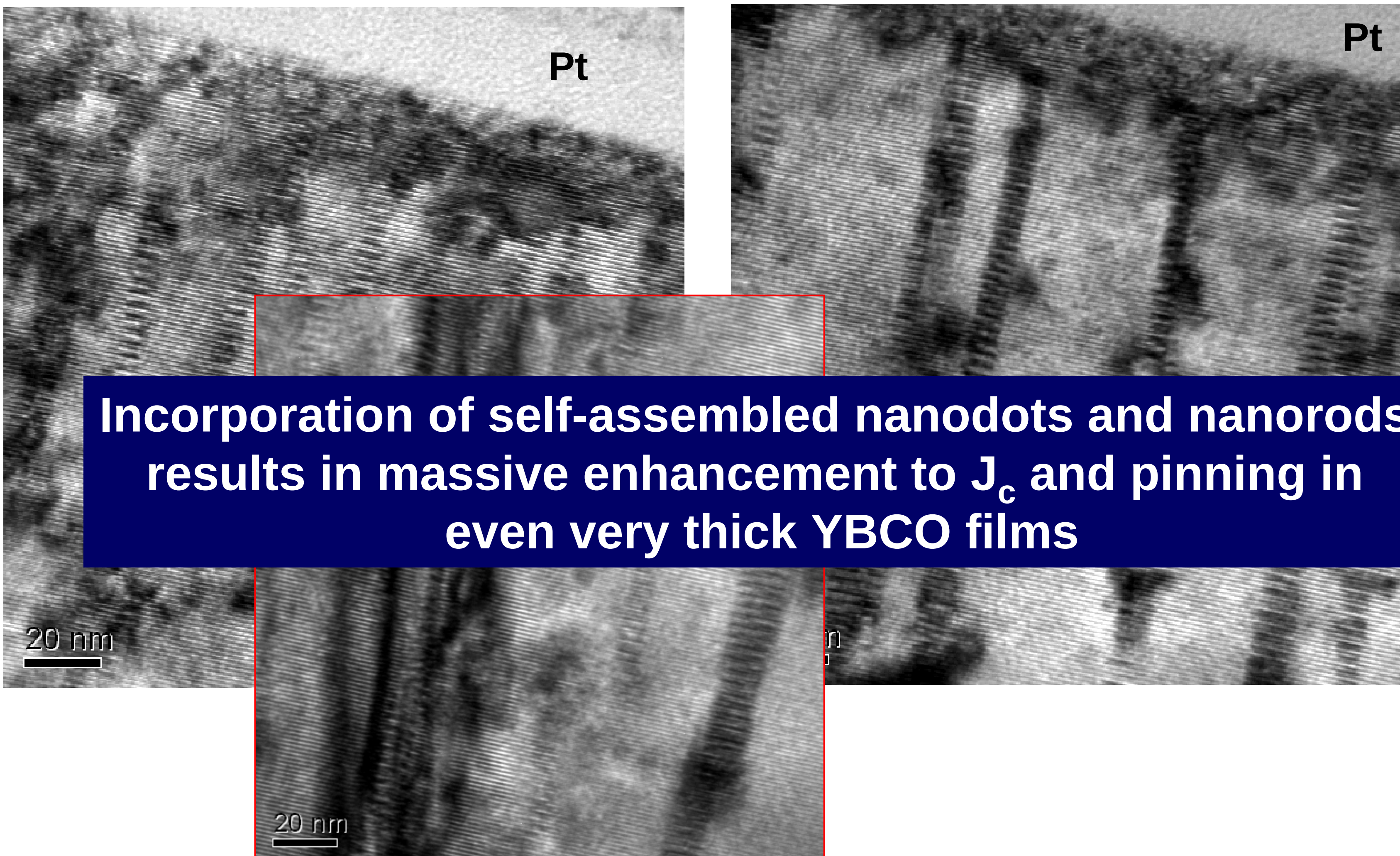
BZO-doped, YBCO film on RABiTS compared to J_c vs thickness plot



What is the microstructure of this film?



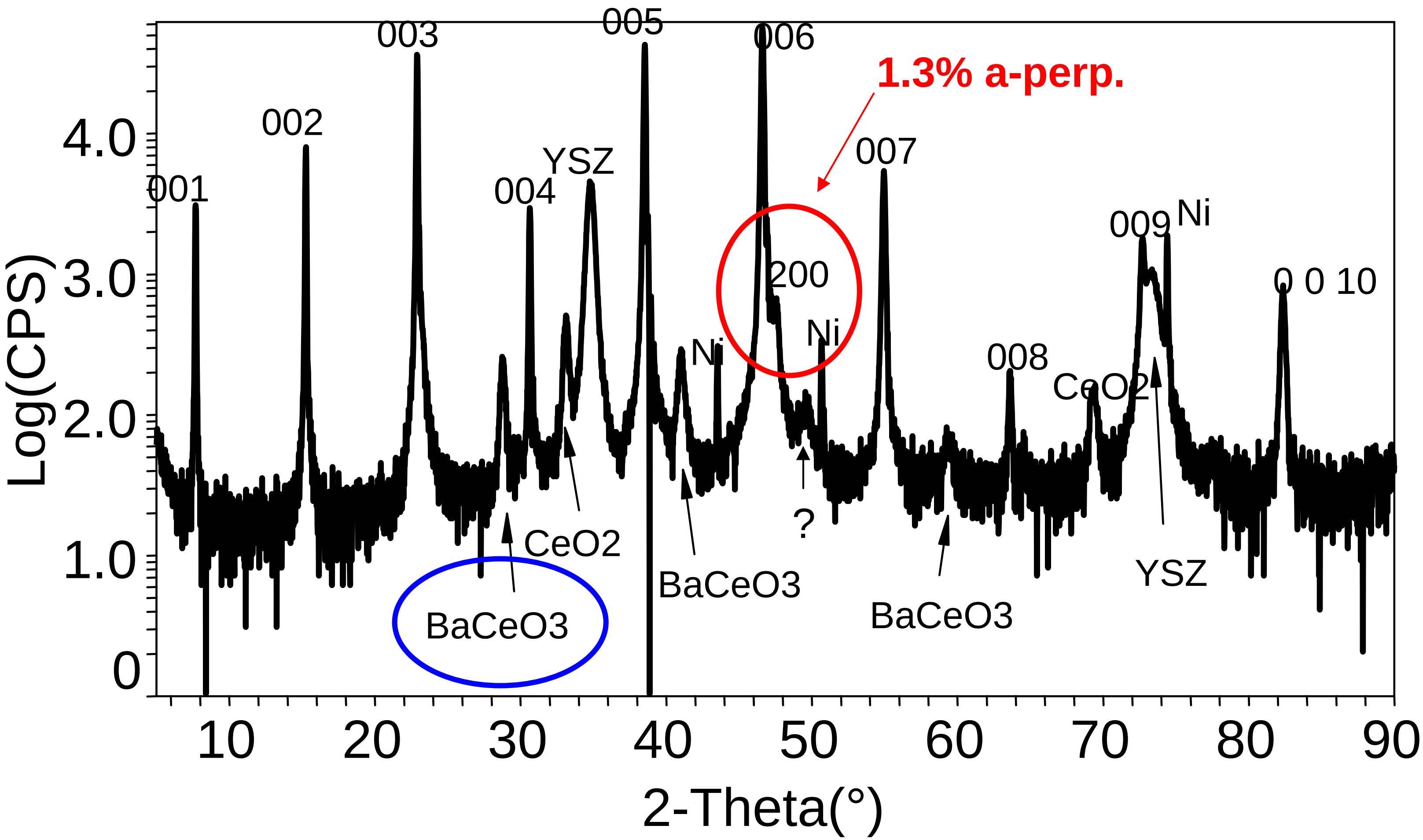
BZO columns extend to the top surface as well



Incorporation of self-assembled nanodots and nanorods results in massive enhancement to J_c and pinning in even very thick YBCO films

Objective 2: Microstructure-property correlations in REBCO in-situ MOCVD films on IBAD substrates from SuperPower

Standard 1.1 μm reel-to-reel processed (Y,Sm)$Ba_2Cu_3O_x$ tape from SuperPower



SuperPower Inc.

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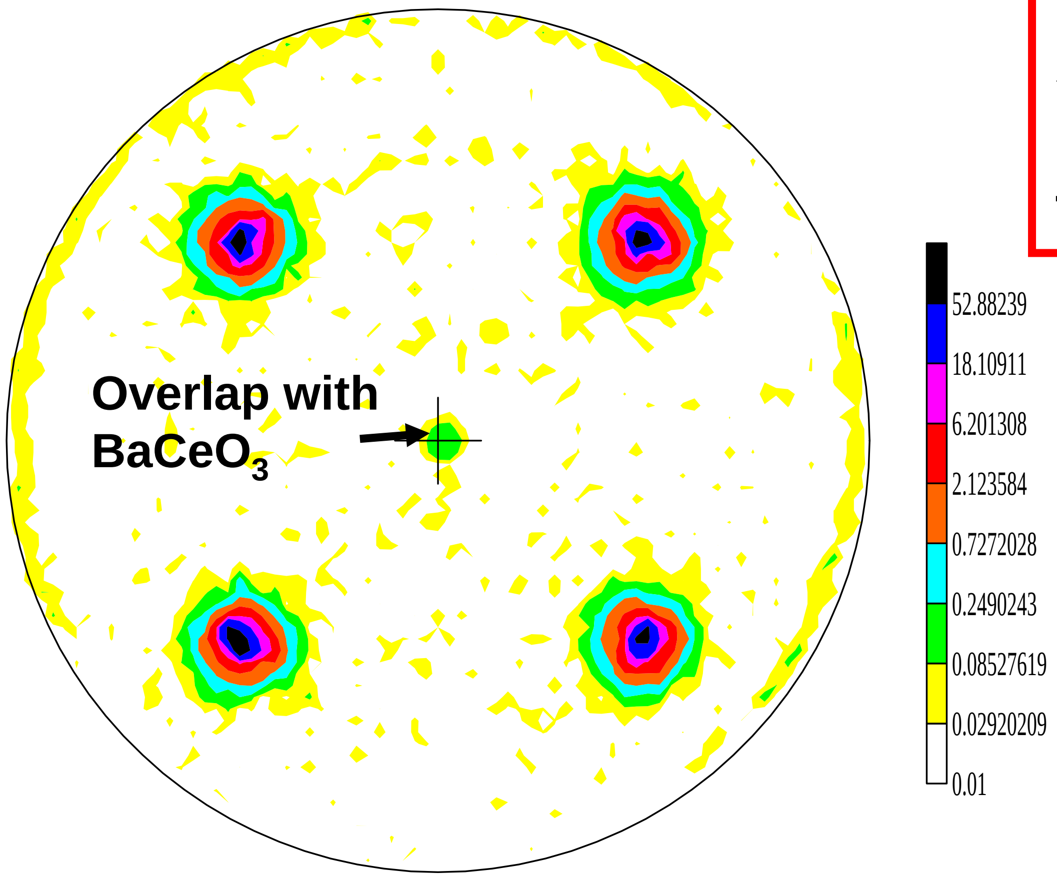
The film has a sharp cube texture

YBCO (113) pole figure



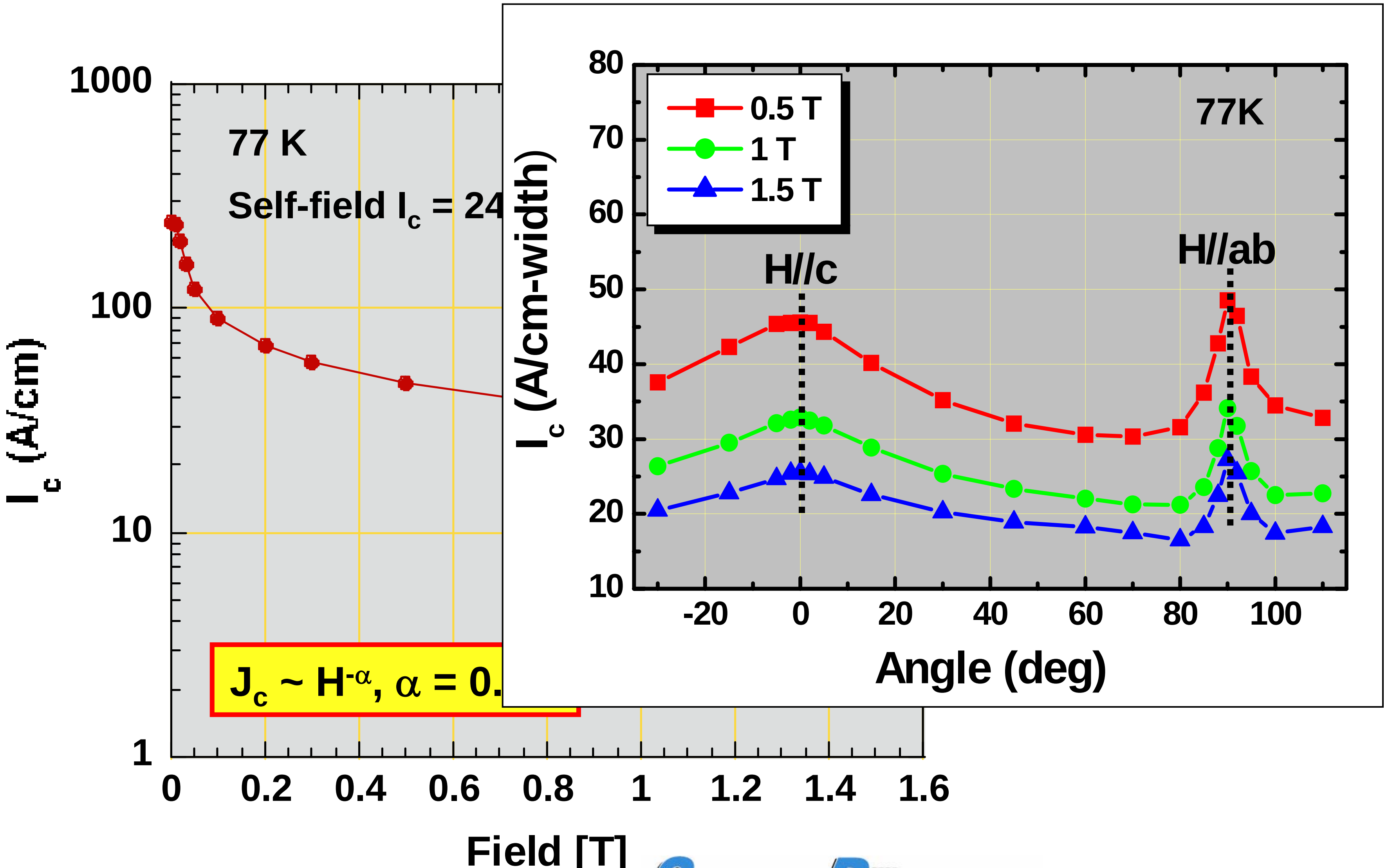
YBCO(006), $\Delta\omega$=1.82° FWHM

YBCO(113), $\Delta\phi$=4.90° FWHM

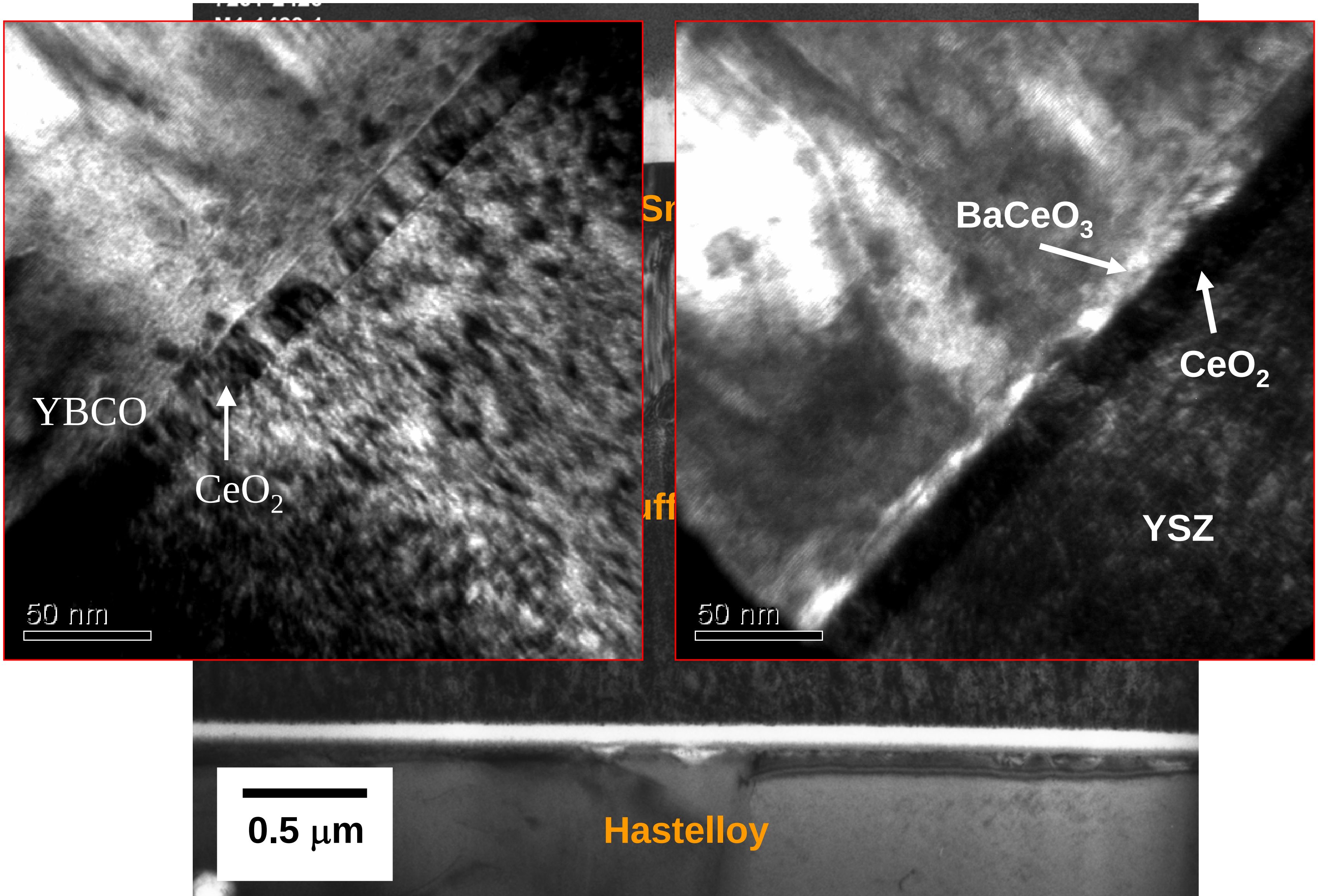
True in-plane $\Delta\phi$=4.73° FWHM

Greater than 95% cube!

Transport properties of SuperPower's standard long length reel-to-reel processed MOCVD/IBAD YSZ

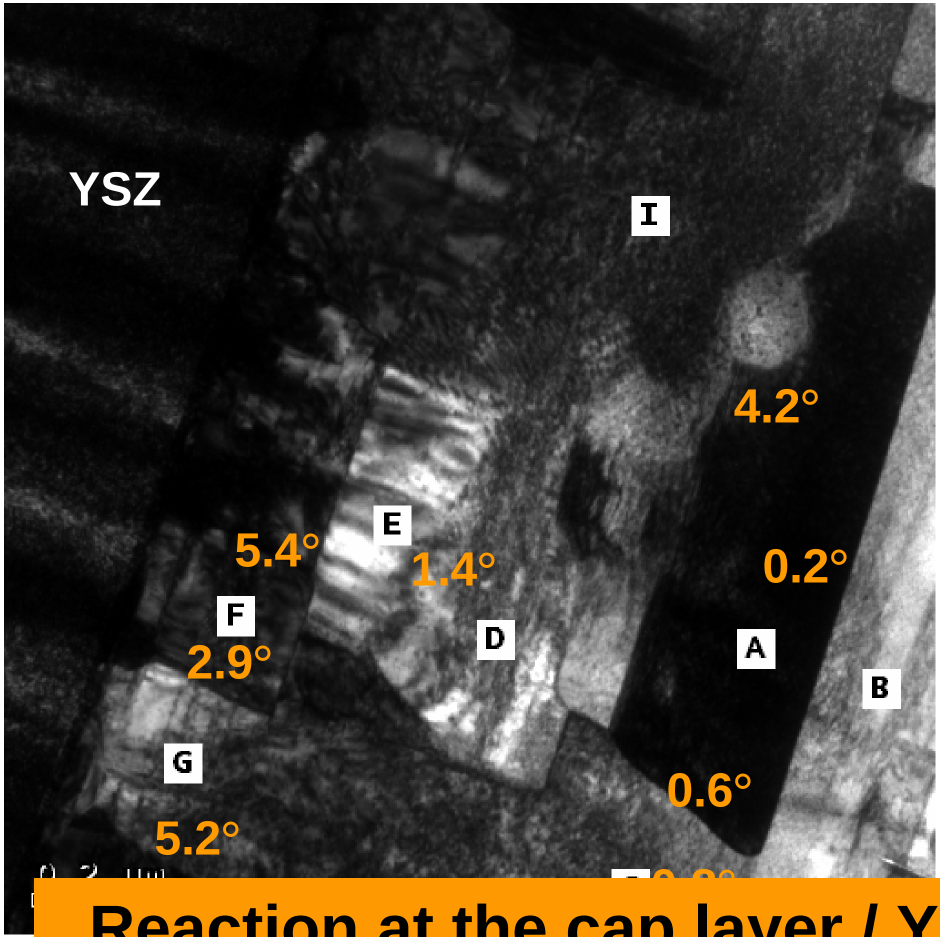


What are the microstructural features of this film? What can be improved?

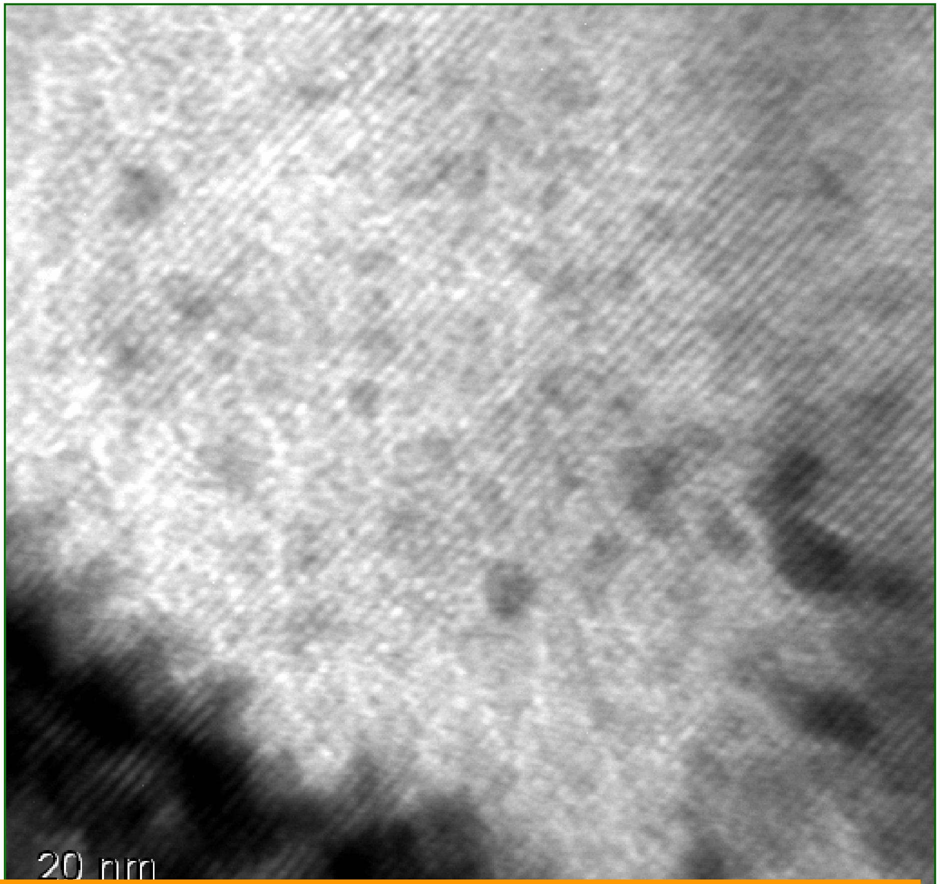


Grain boundaries and nanoparticles in (Y,Sm)BCO film by MOCVD on IBAD YSZ substrates

Grain Boundaries

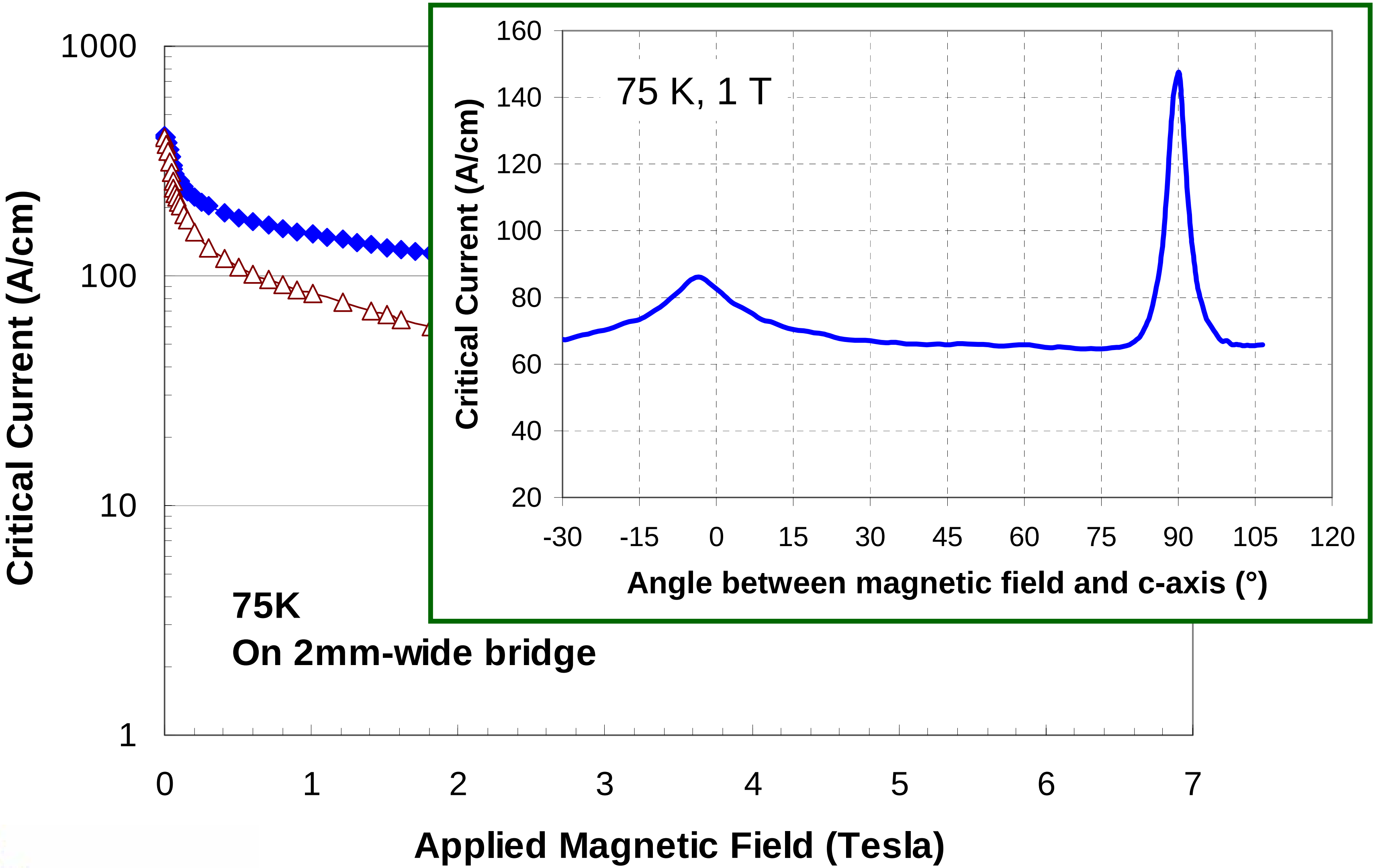


Nanoparticles



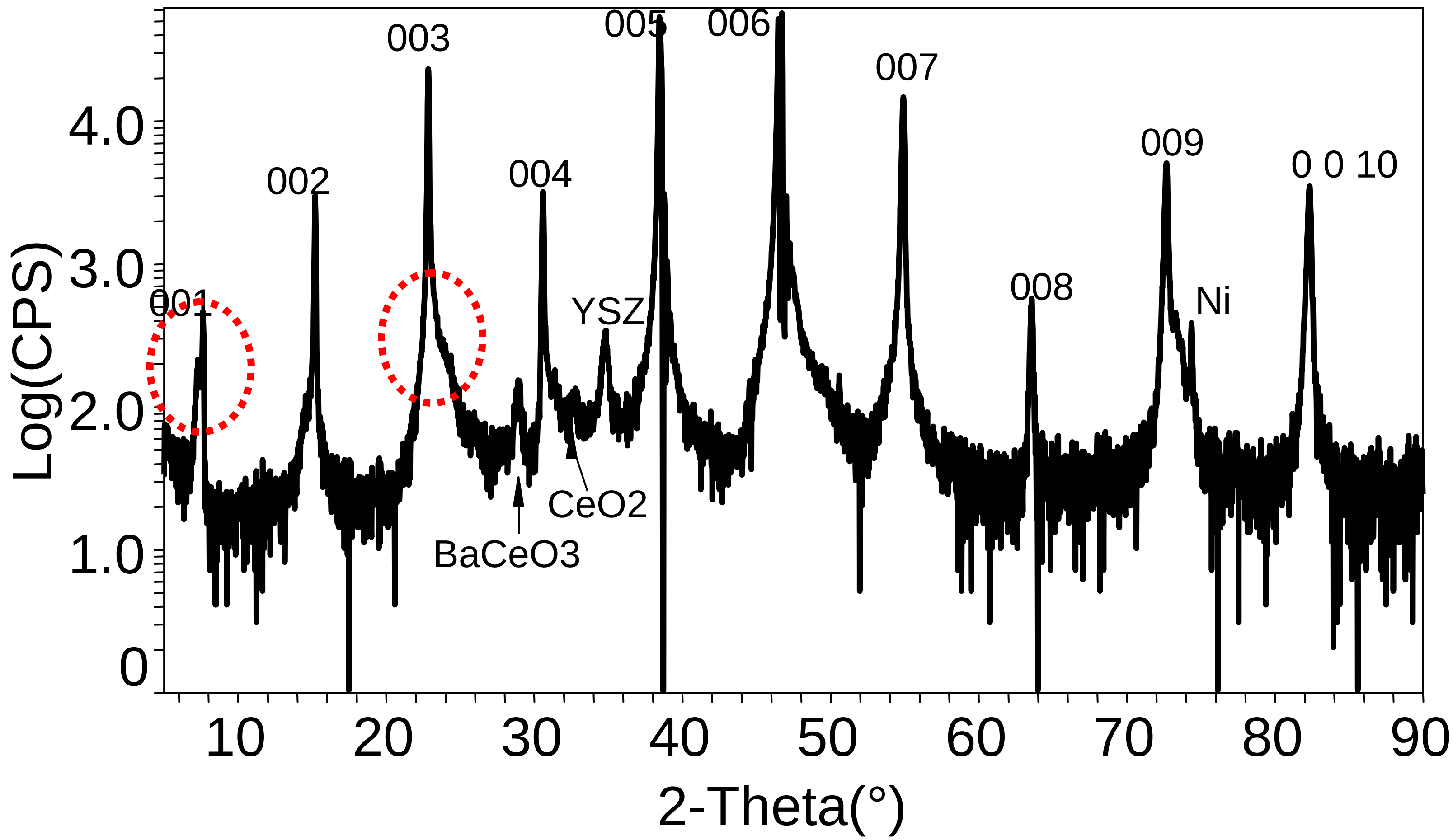
Reaction at the cap layer / YBCO interface, a-perp. grains and higher-angle GB's in the film could all be limiting the J_c

Microstructure-property correlations in SuperPower's highest I_c, 407 A/cm MOCVD film

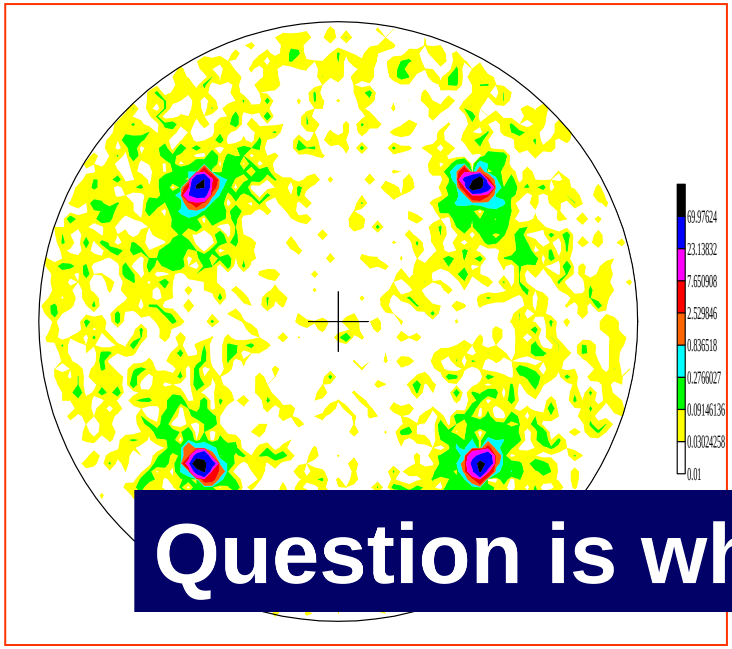


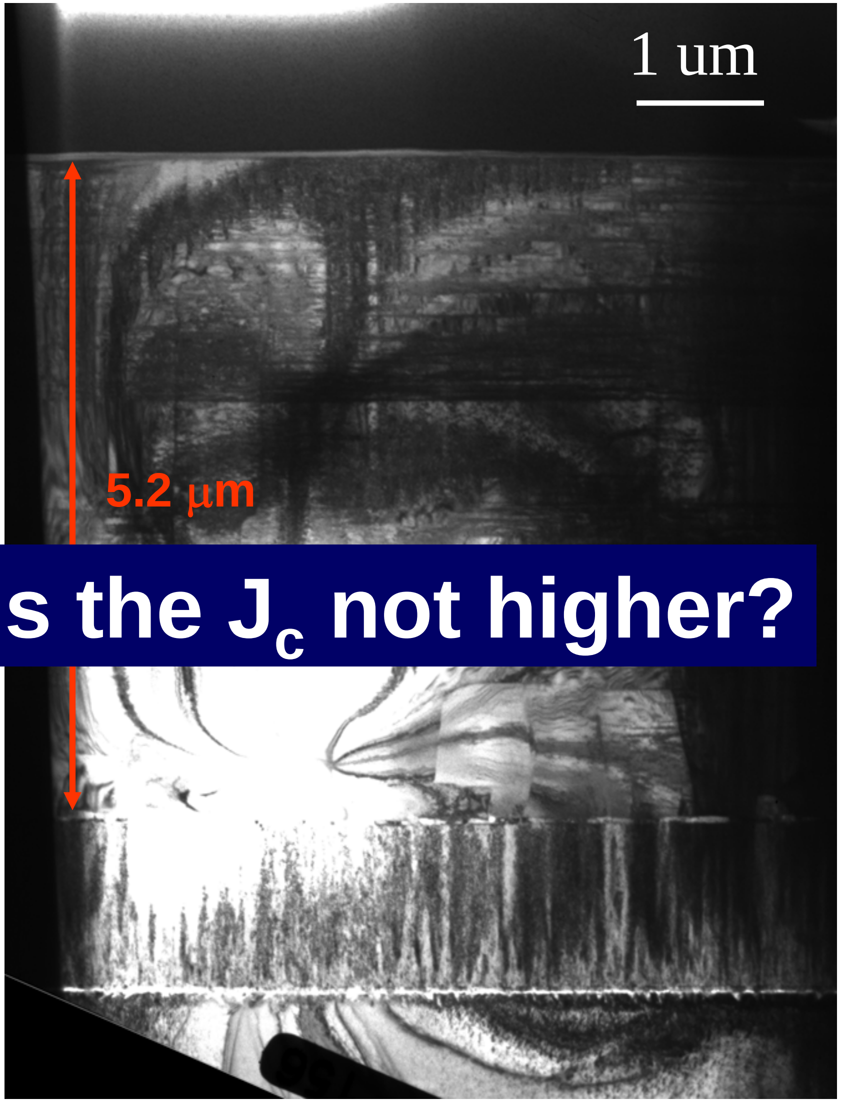
Los Alamos SuperPower Inc. UT-BATTELLE

θ-2θ X-ray diffraction shows good texture but peak shapes of (001) and (003) are unusual



The texture of the film is good and no macroscopic defects are seen through the cross-section





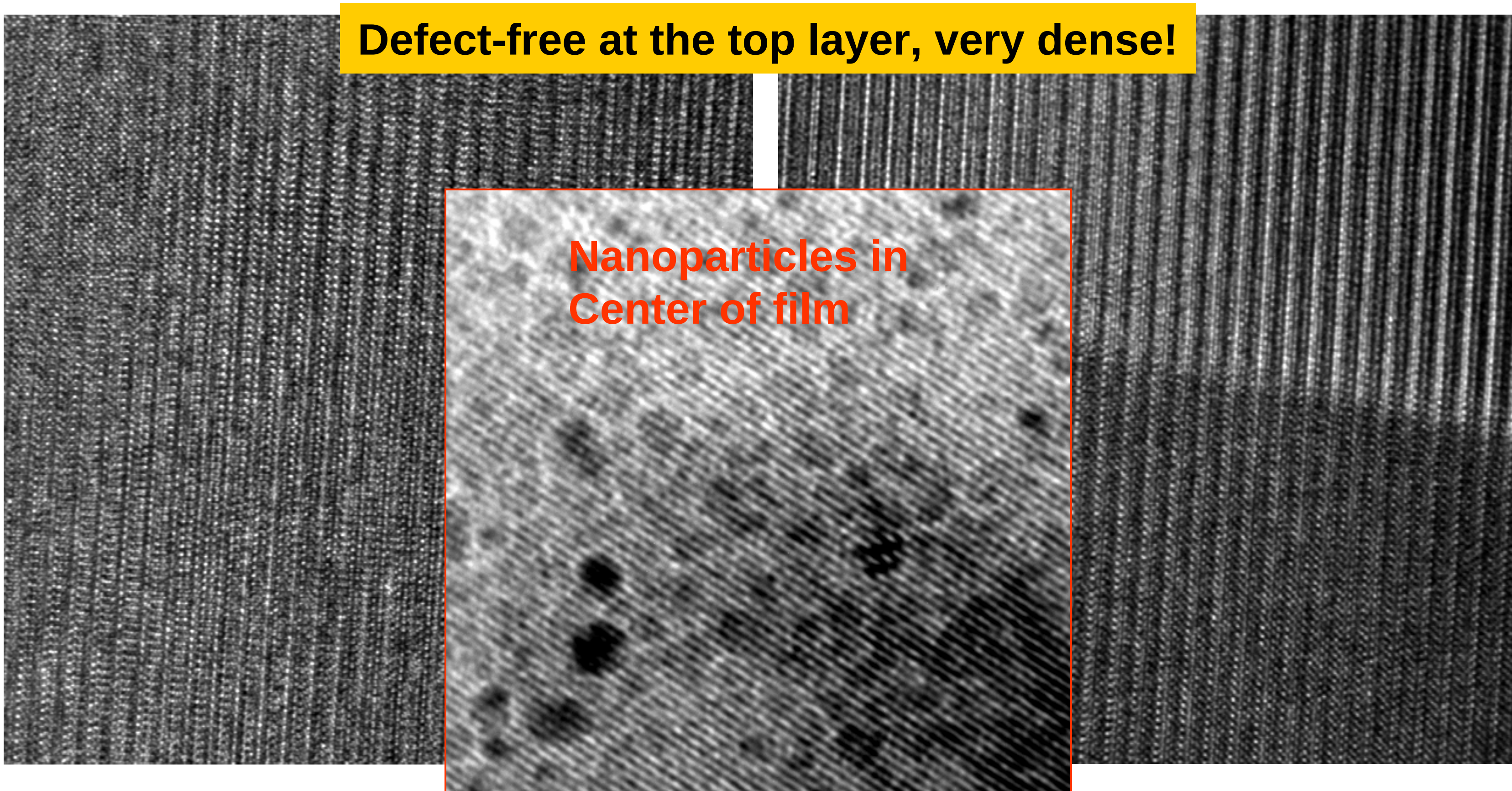
Question is why is the J_c not higher?

- **YBCO(006), $\Delta\omega$=3.21° FWHM**
- **YBCO(113), $\Delta\phi$=4.01° FWHM**
- **True in-plane, 3.31° FWHM**

SuperPower highest I_c, 407 A/cm MOCVD film

At the bottom, it is similar to the 1.1 μm film with GB's etc.

Defect-free at the top layer, very dense!



Need more defects in the film!

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  Pinning by surface decoration (Tolga)

  Preventing delamination of IBAD YSZ buffers (Fred)

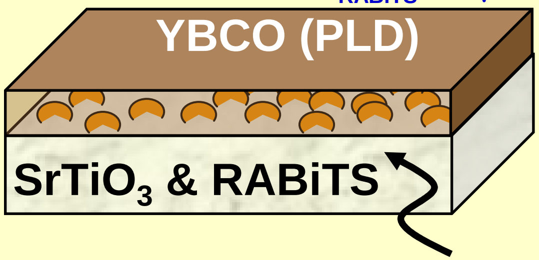
  Development of buffer layers for IBAD substrates and overview of SuperPower-ORNL CRADA (Selva)

- FY 2005 Performance and FY 2006 Plans (Fred)

- Research Integration

Objective: Enhancement of flux pinning in $YBa_2Cu_3O_{7-\delta}$ films via nano-scale substrate surface modifications

t_{STO} = 0.1-0.3 μm
t_{RABiTS} = 3 μm

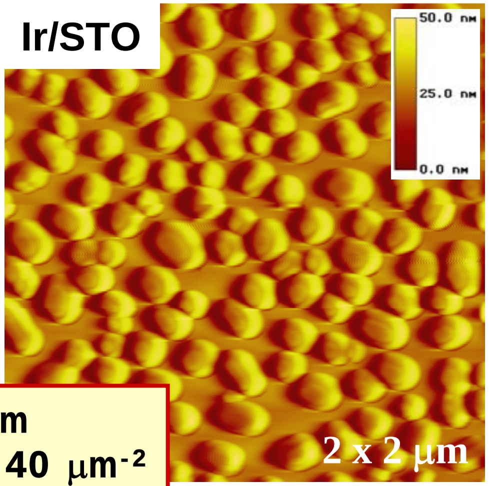


Approach:

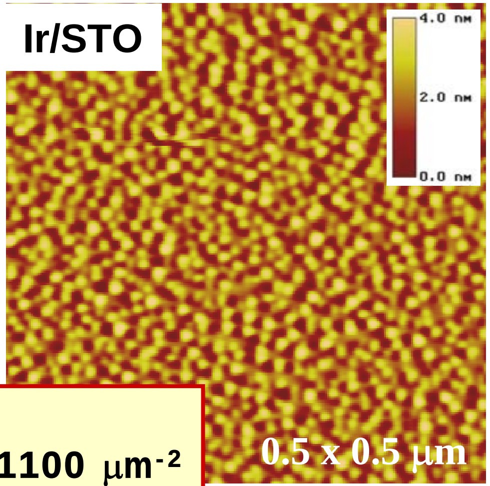
Modify single crystal $SrTiO_3$ & RABiTS surfaces by applying second-phase nanoparticles/islands using:

- **PVD-based (sputtering) → Iridium**
- **Solution-based (MOD) → MgO & $BaZrO_3$**
- **Suspension-based → CeO_2 (7nm, pre-formed)**

Easy to control number density & size by adjusting the process parameters



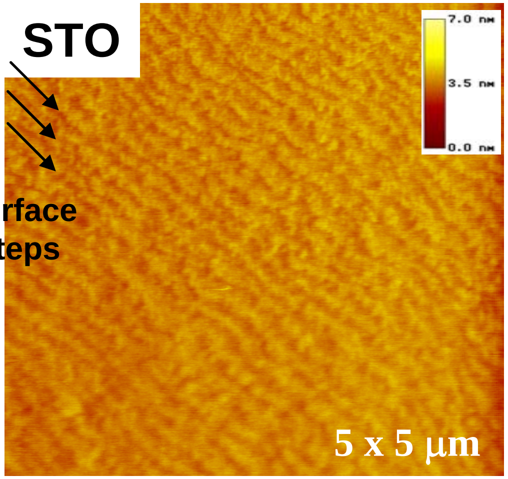
Size= 160 nm
Density, n = 40 μm^{-2}
$B_\phi = n\phi_o$ = 0.08 Tesla



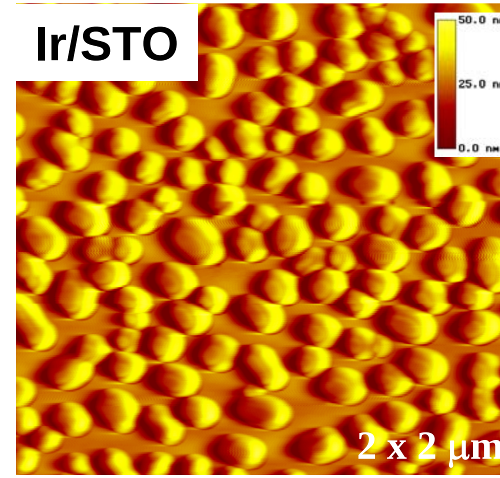
Size= 20 nm
Density, n = 1100 μm^{-2}
$B_\phi = n\phi_o$ = 2.2 Tesla

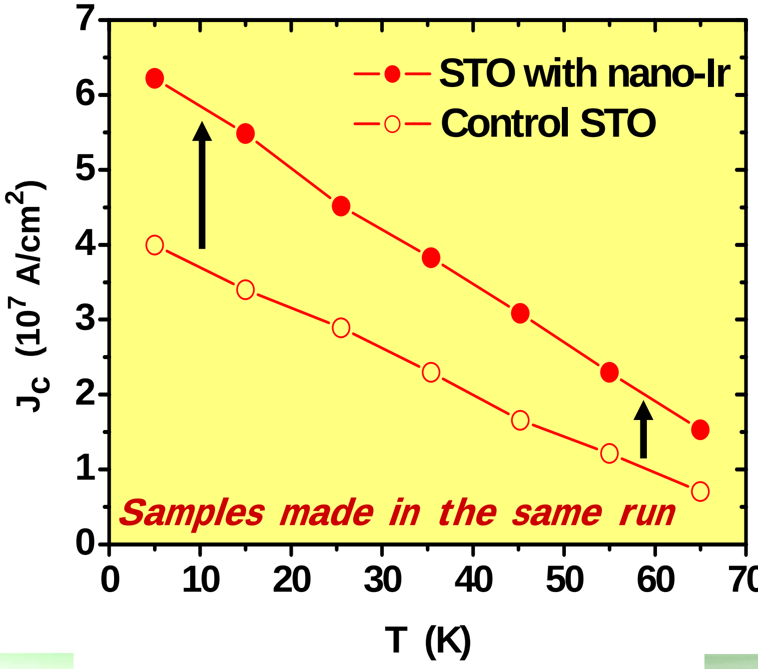
Magneto Optical imaging reveals enhancement of flux pinning and J_c of YBCO on Iridium modified substrates

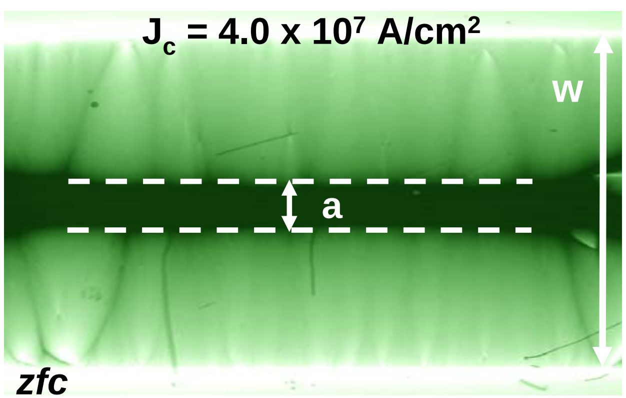
Control STO x-tal



Ir-nanoparticles on STO x-tal

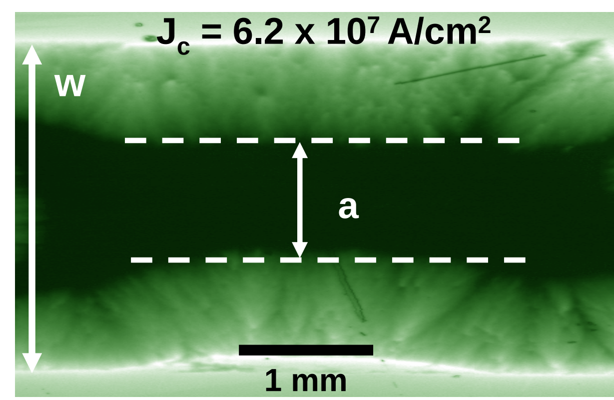






$$j_c = \frac{\pi B_a}{t\mu_0} \frac{1}{\cosh^{-1}(w/a)}$$

(E.H. Brandt *et al.*)



T = 5 K, B_a = 45 mT

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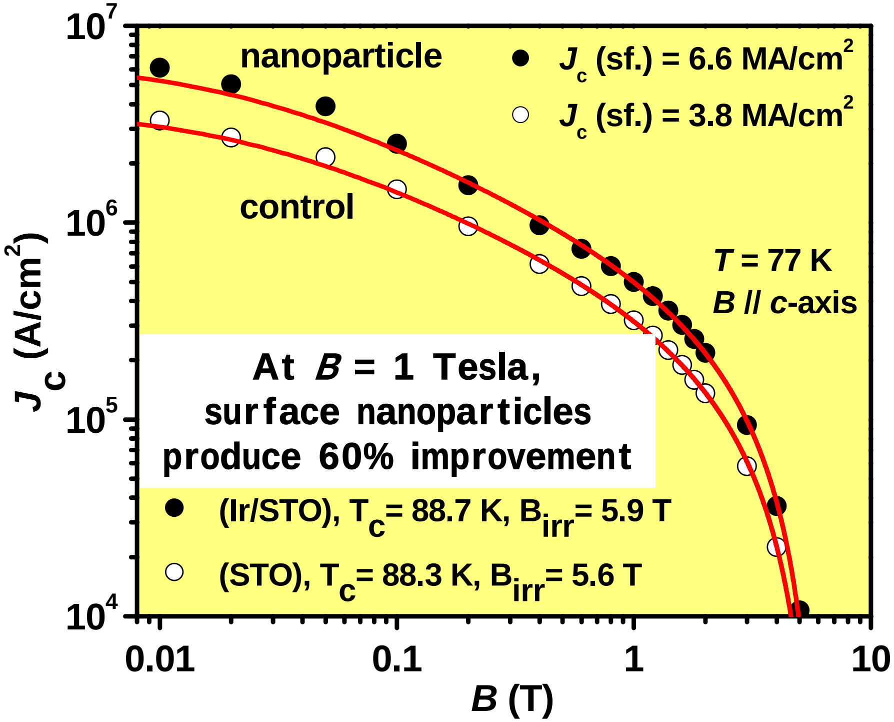
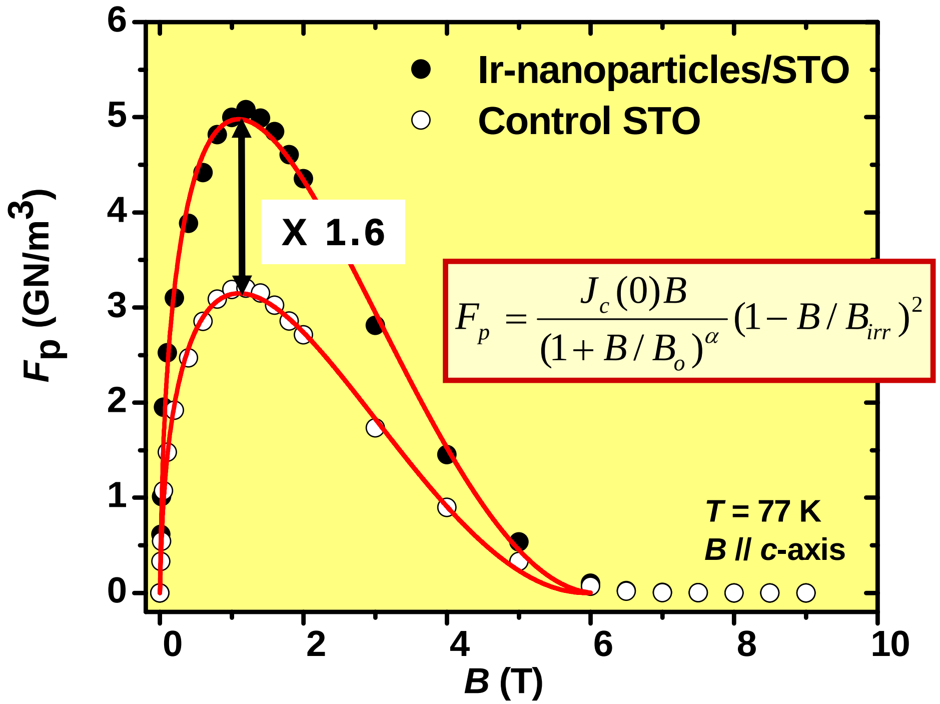
Transport measurements also show enhanced flux pinning & J_c in YBCO (200 nm) films by Ir-nanoparticles

Enhanced J_c performance by at least 60% over wide range of fields
Increased pinning strength ($F_{p,max}$) by factor of ~1.6 with nanoparticle modifications

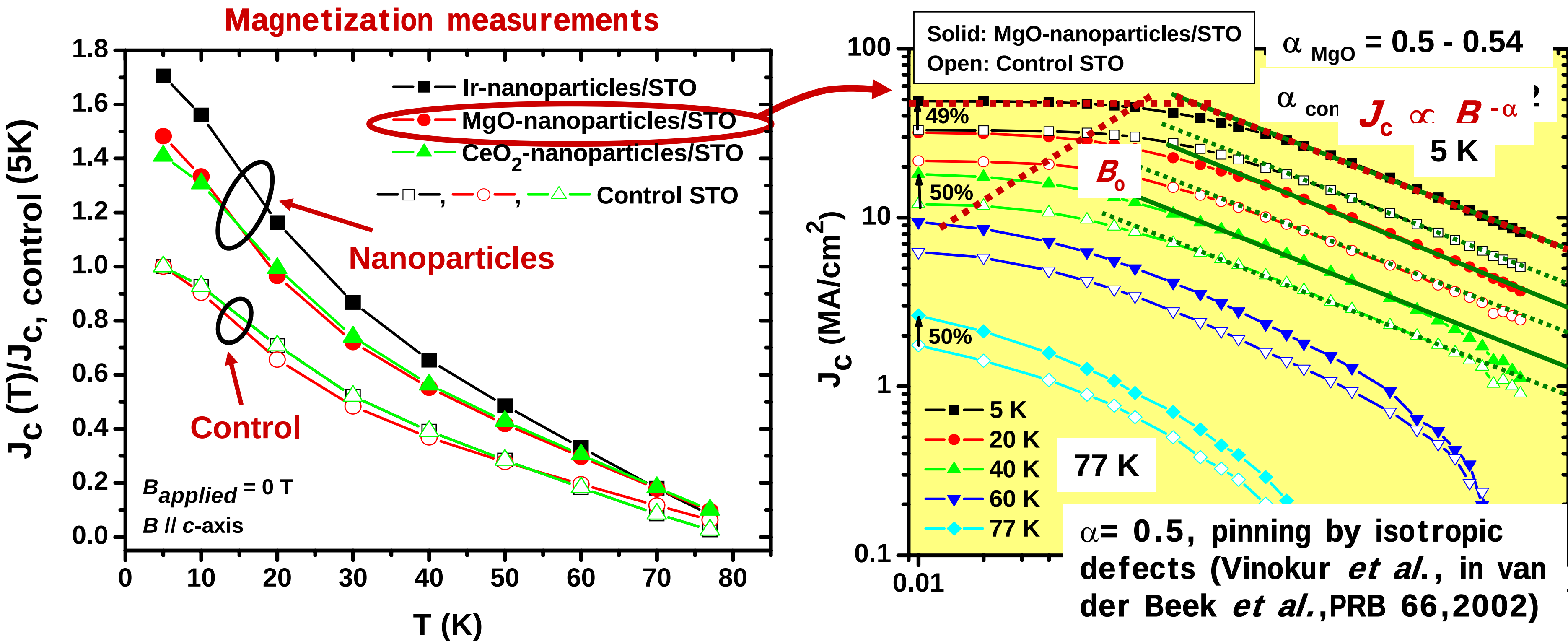




- **Ir-nanoparticles produce more effective pinning centers**
- **Increased low-field pinning strength sets scale for J_c(*sf.*)**

Other nanoparticle species applied via different techniques also produce significant improvement in pinning & J_c

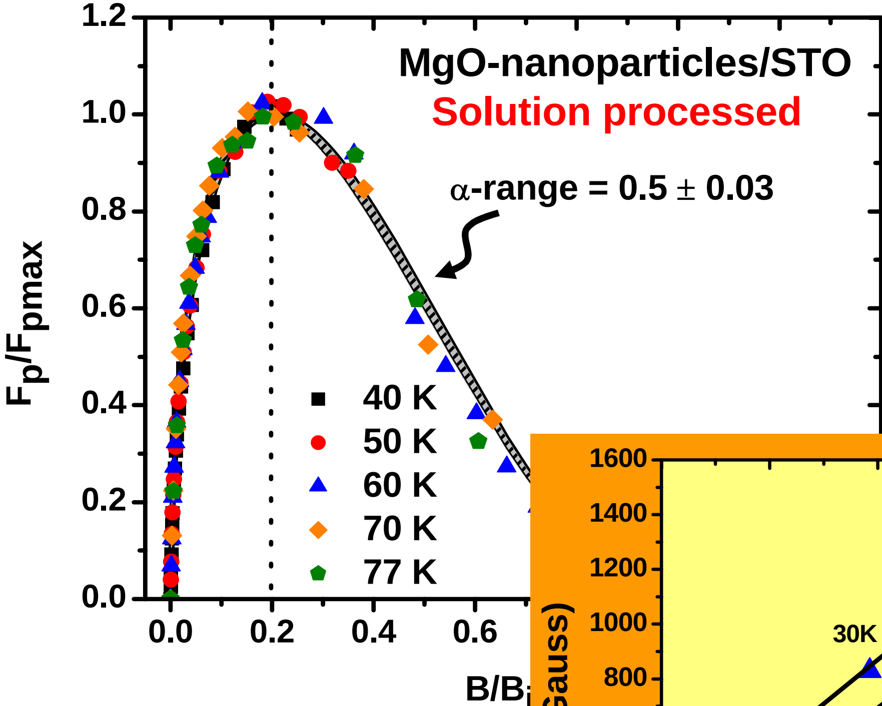
Enhanced J_c performance by ~ 50% over wide range of temperatures and fields

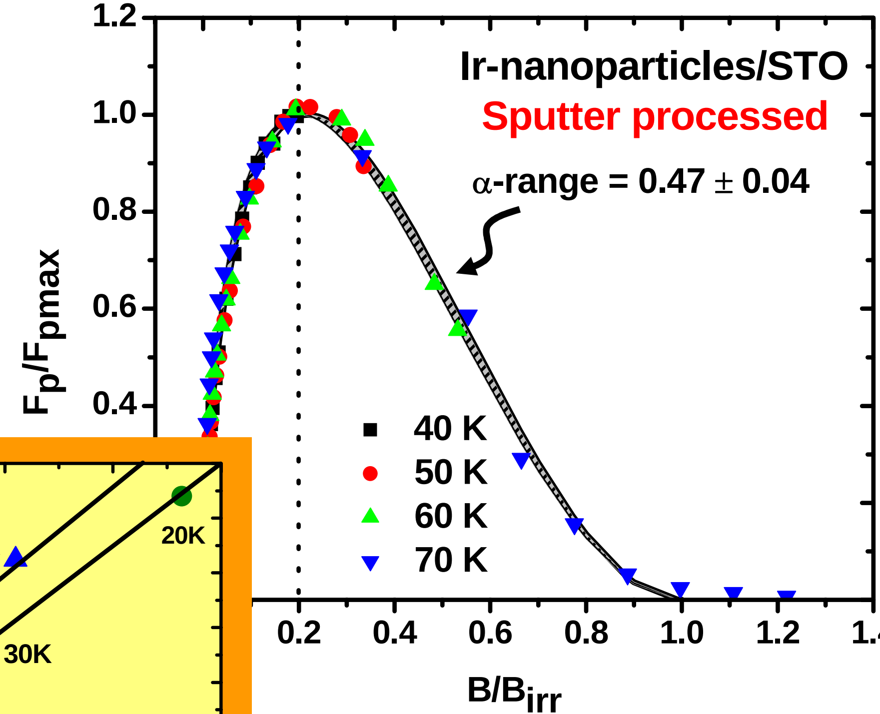


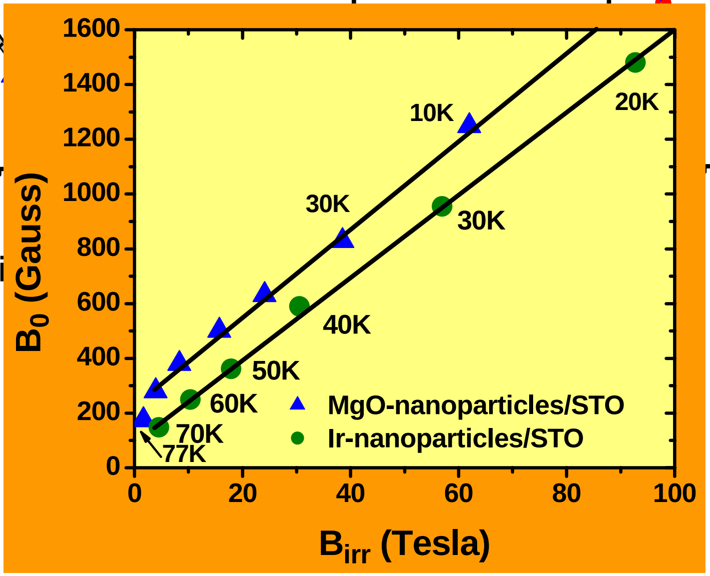
- **Similar α, ($J_c \propto B^{-\alpha}$) at intermediate B**
  - ➥ Pinning mechanisms are similar for both control & modified substrates

Scaling behavior of pinning force density F_p; F_p shows consistency of pinning mechanism wrt temperature

Similar pinning mechanism was obtained by solution and PVD processed nanoparticles
Scaling provides a powerful tool for predicting J_c at arbitrary B, T







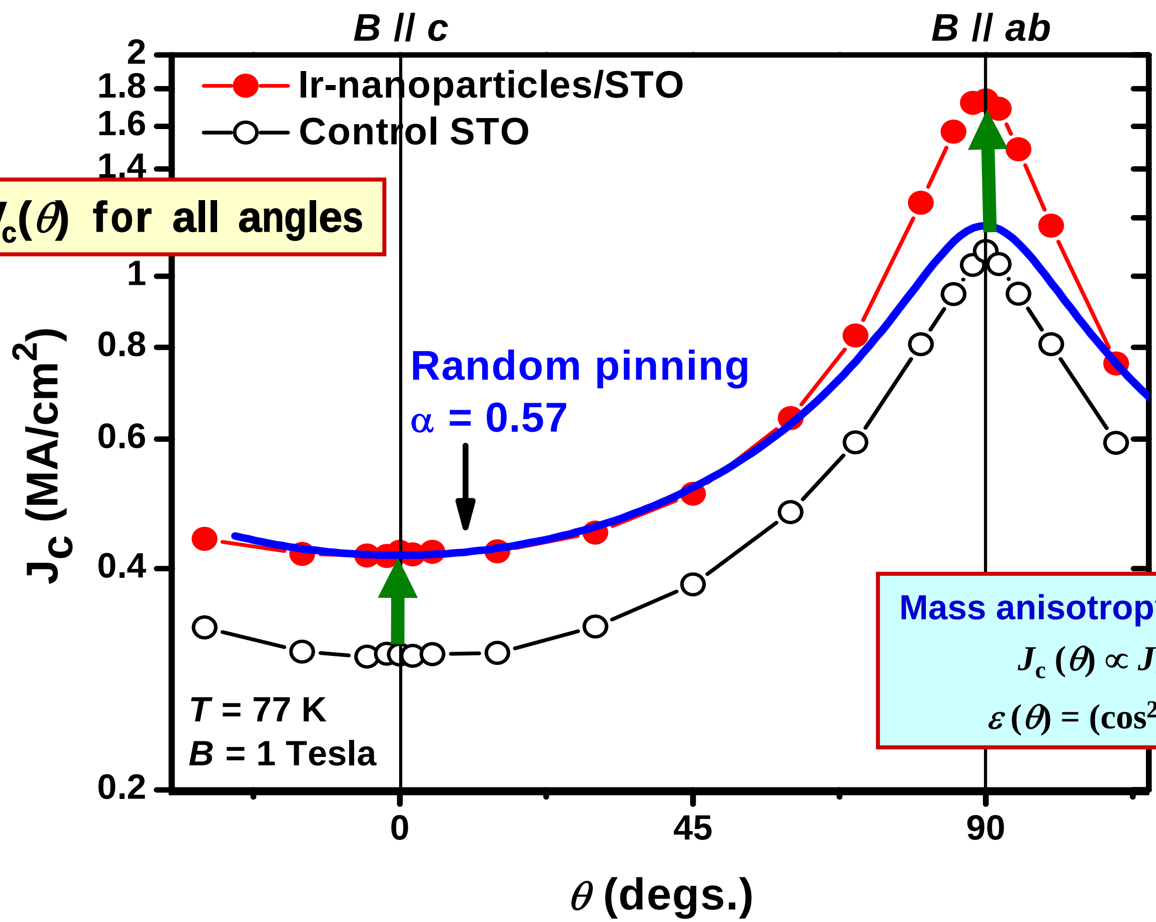
$$F_p = \frac{J_c(0)B}{(1+B/B_o)^{\alpha}}(1-B/B_{irr})^2$$

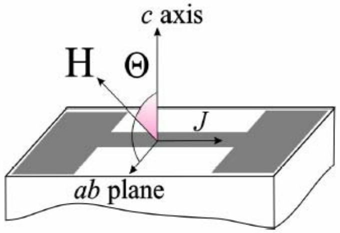
3-parameters: α, B_o, B_{irr}

- **Model fits data very well**
- **α is ~ independent of T**
- **F_p peaks at $B/B_{irr} \cong 0.2$**
- **$B_o(T)$ scales with $B_{irr}(T)$**

Angular dependence of J_c: Ir-nanoparticles (sputtered) with/without nanoparticle modifications

Improved $J_c(\theta)$ for all angles





Mass anisotropy scaling (Blatter *et al.*)

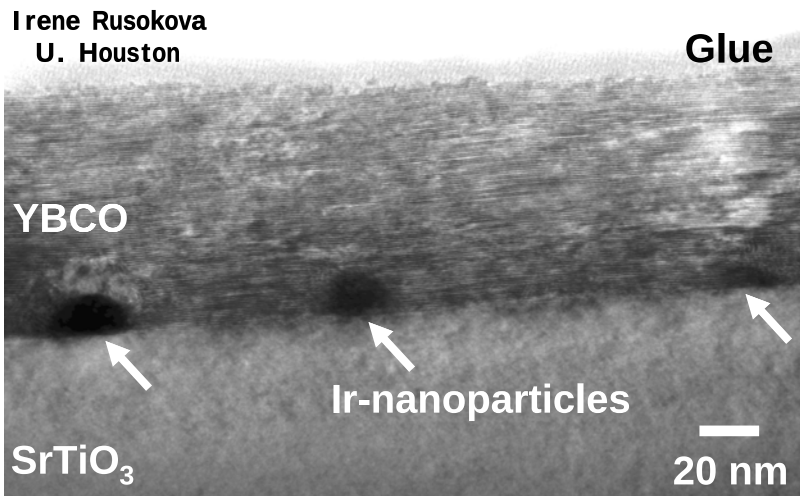
$J_c(\theta) \propto J_c(0)[\varepsilon(\theta)]^{-\alpha}$, where

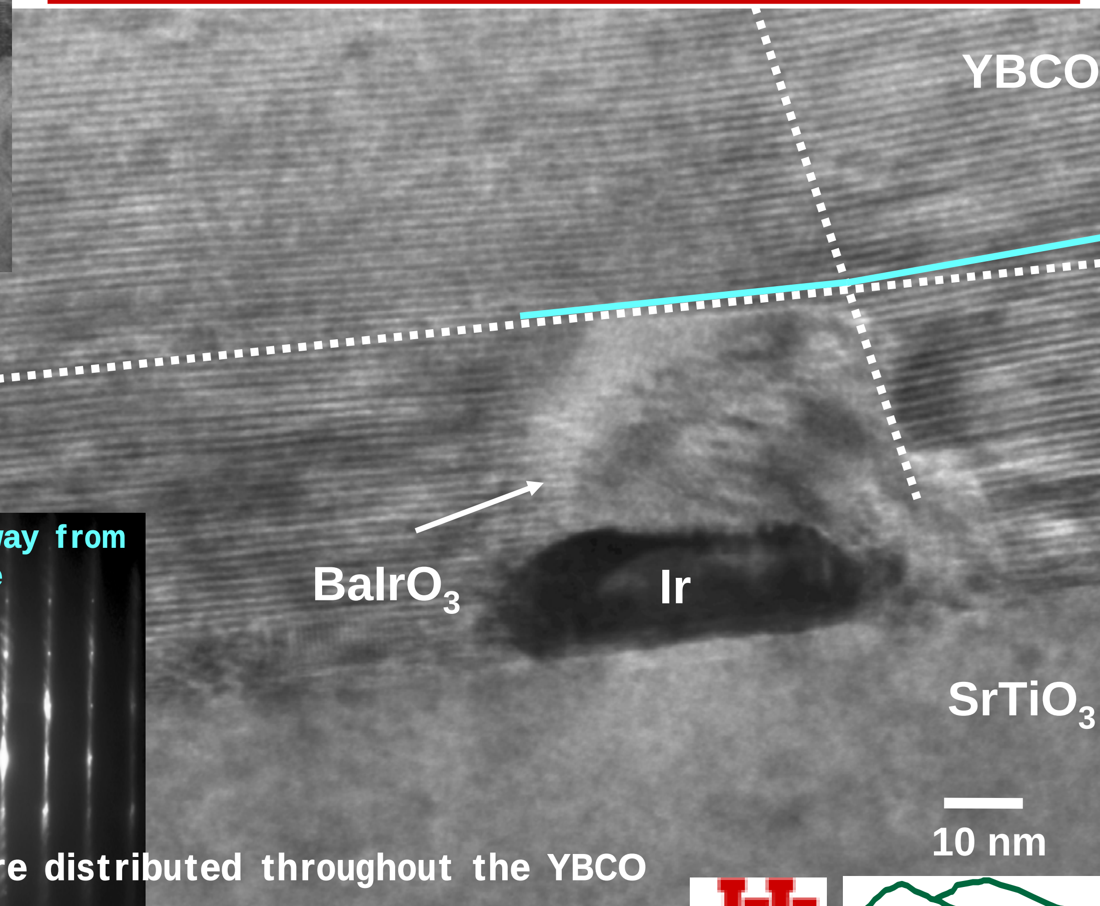
$\varepsilon(\theta) = (\cos^2\theta + \gamma^{-2}\sin^2\theta)^{1/2}$, $\gamma = 5$

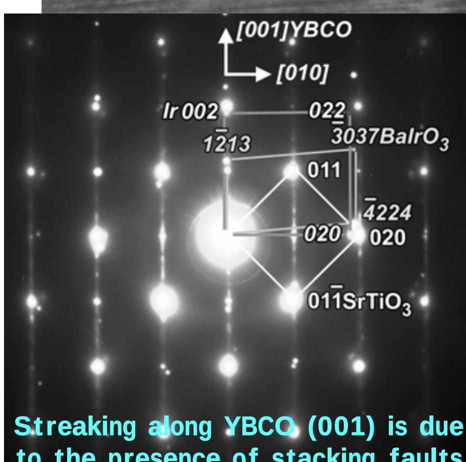
- Uncorrelated, random isotropic defects acting over large angular regime
  - ➥ Dilute precipitates or associated stress fields
  - ➥ Possible extended defects along *ab*-planes

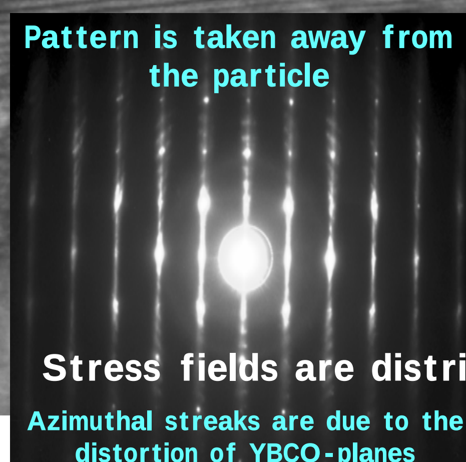
TEM and SAED show the presence of Ir-nanoparticles & $BaIrO_3$ inclusions at the YBCO/STO interface

- TEM is consistent w/the extra random pinning observed
- No *c*-axis extended defects observed
- ➥ Ir-particle, secondary phase inclusions ($BaIrO_3$)
- ➥ localized stress fields around the particles caused by azimuthal deviations (buckling) of *ab*-planes
- Extended defects along *ab*-planes (stacking faults)



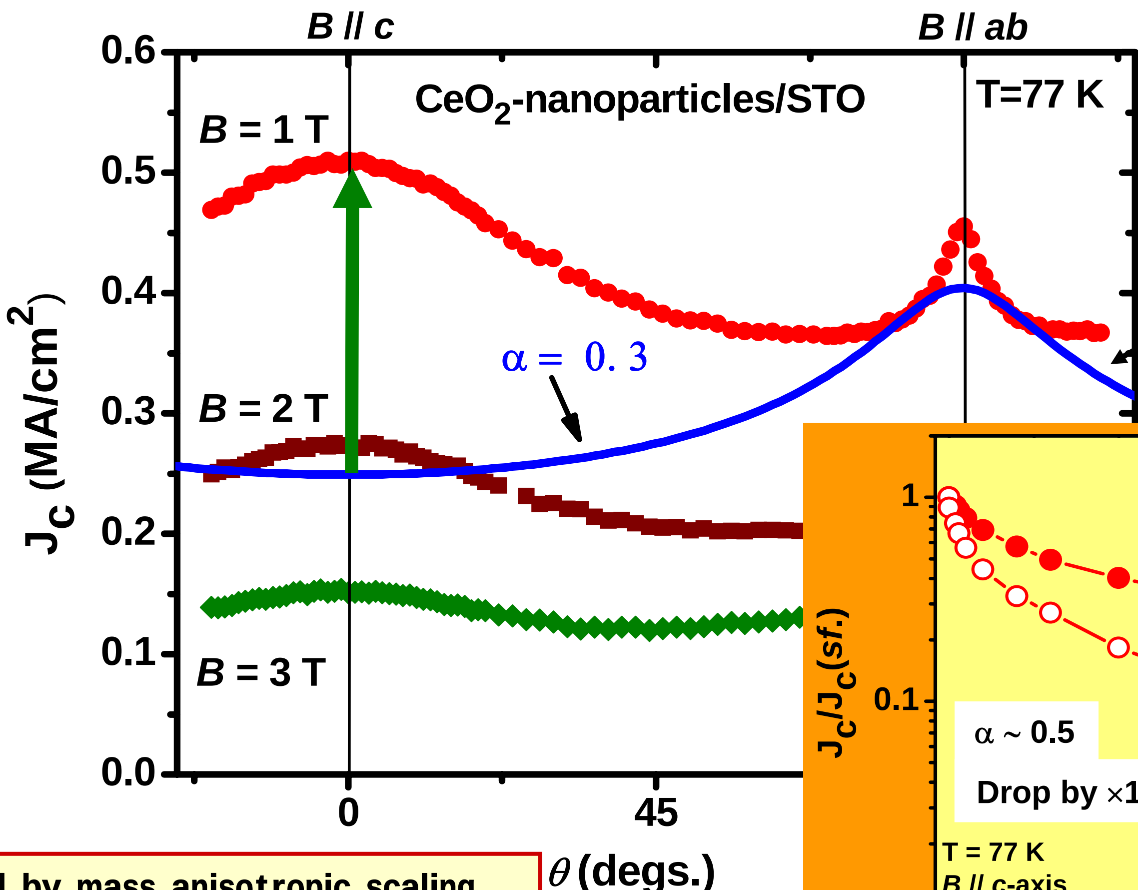


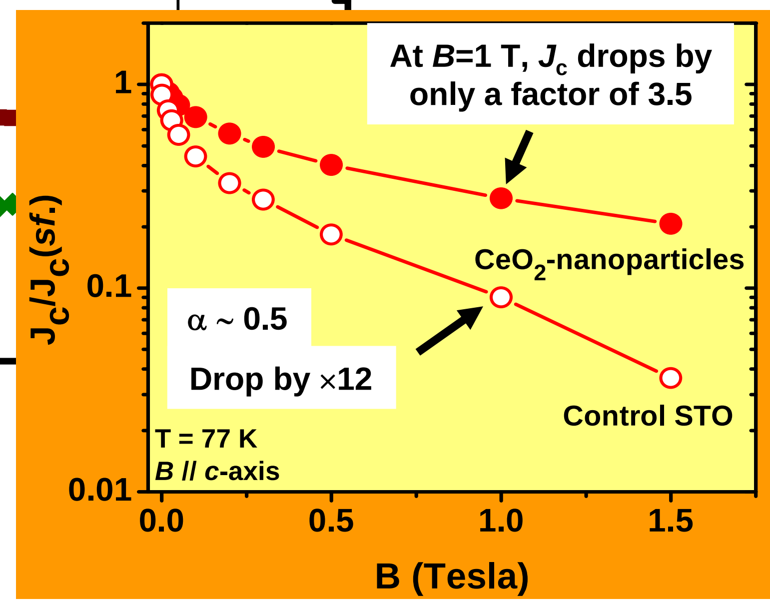




Angular dependence of J_c:
Decorated with suspended, pre-formed CeO_2-nanoparticles

Broad peak about *c*-axis & improved in-field J_c performance

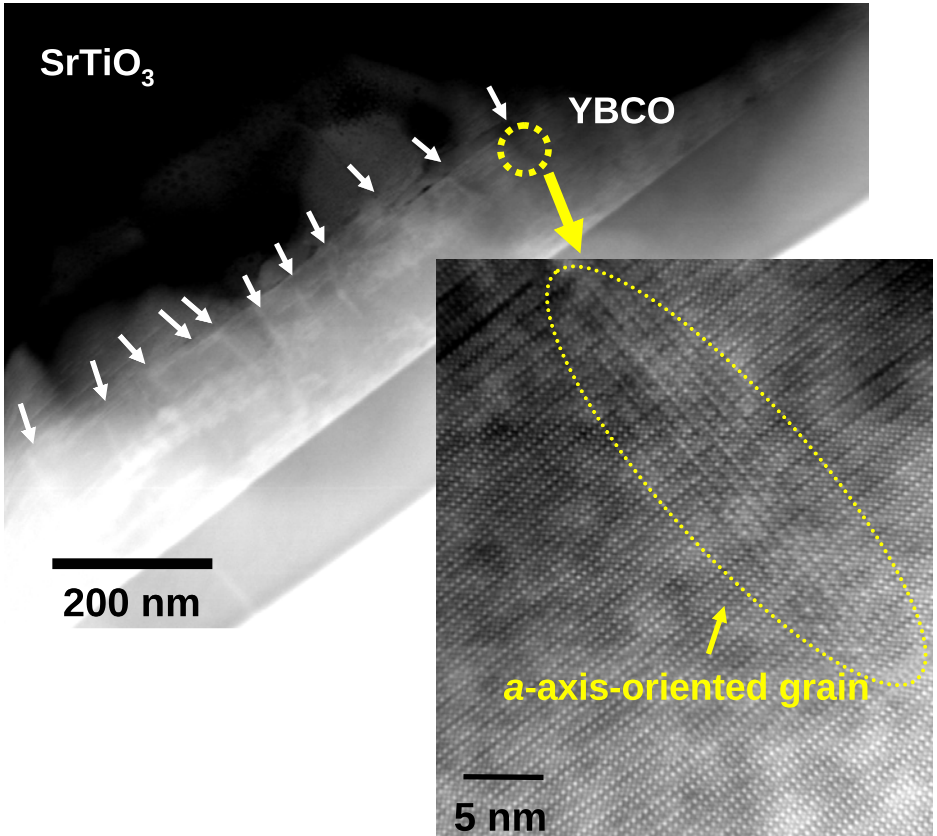


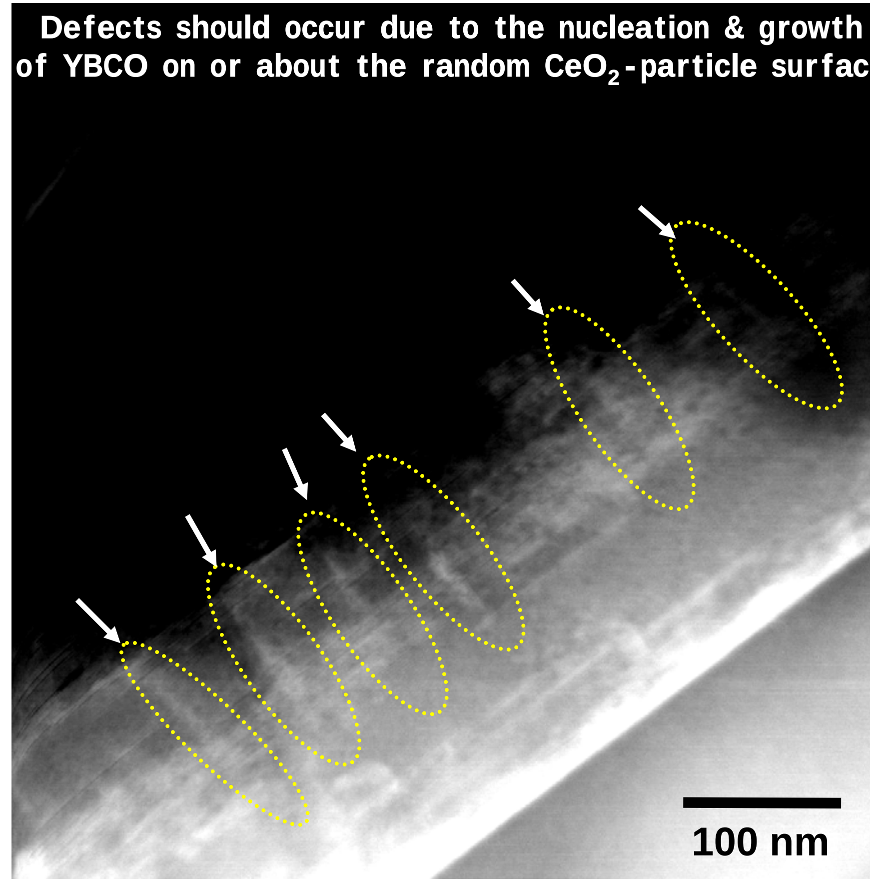


- Poorly described by mass anisotropic scaling
- strong pinning by defects distributed over large angular range

➥ Improved J_c-B performance, smaller α ~ 0.3

CeO_2 case: Surface nanoparticles produce extended linear defects propagating from substrate into the YBCO





- TEM analysis is consistent with the observed large peak around c-axis
  - Absence of CeO_2-nanoparticles at the interface
  - High number of c-axis extended defects originating from the interface (i.e., extended strain fields from low-angle grain boundaries or threading dislocations)
  - Presence of *a*-axis-oriented grains

Similar to observations of:

K. Matsumoto, *et al*., Jap. J. Appl. Phys. L246, 2005
J.C. Nie, *et al*., SUST, 845, 2004

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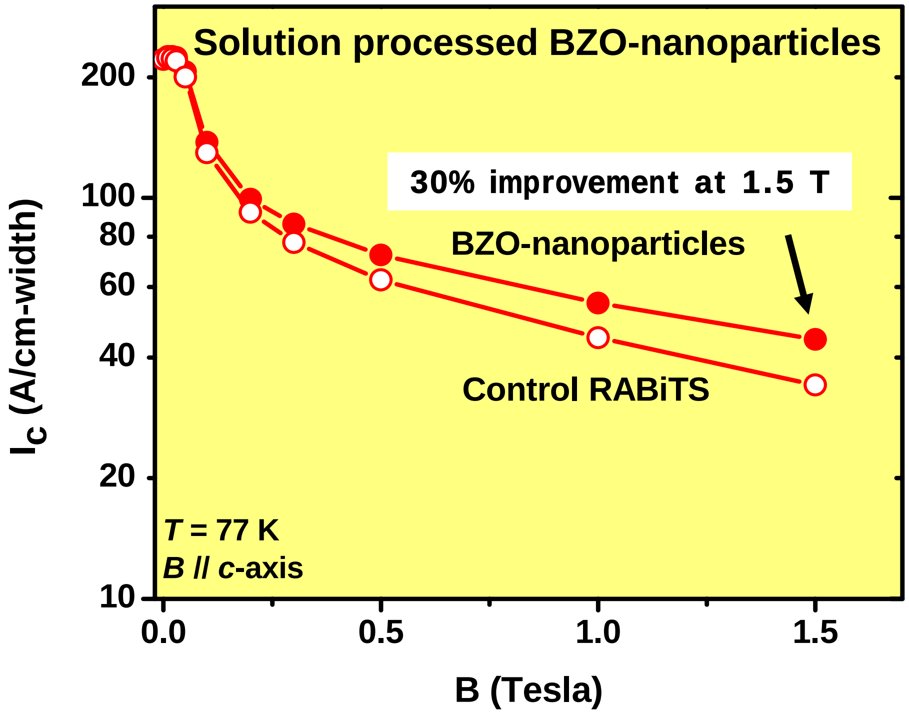
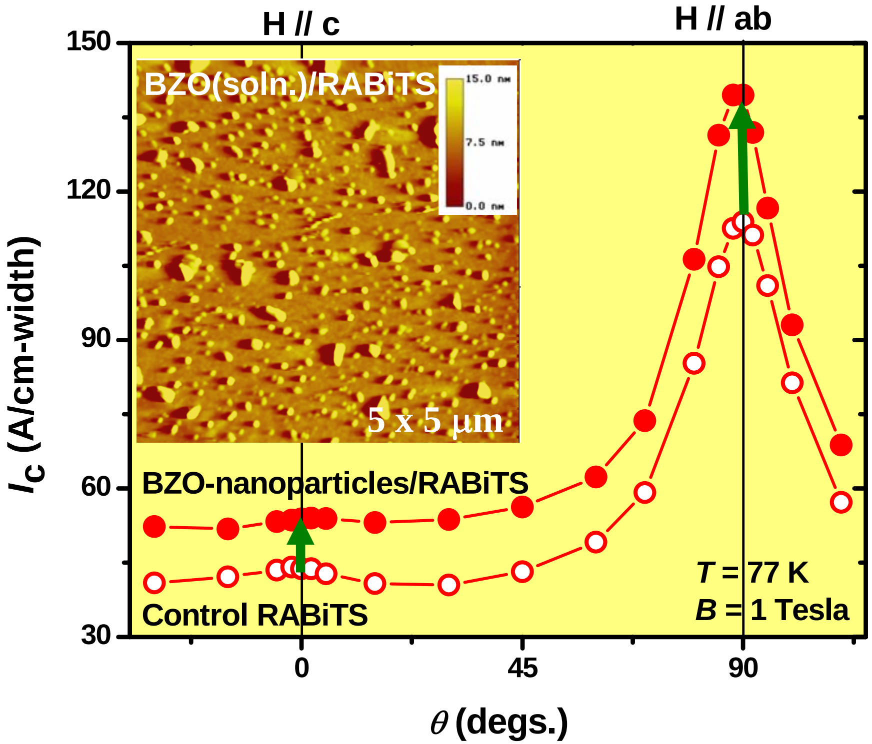
Nanoparticle surface modifications extended to RABiTS & thicker YBCO (PLD, 3 μm) films: Transport J_c

BZO surface nanoparticles produce better in-field J_c on RABiTS for all field orientations

[BZO (soln.)/RABiTS]: T_c = 90.4 K
(Control RABiTS): T_c = 90.5 K





Future work will investigate combined effects of substrate surface decoration & nanoparticle additions

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  Development of buffer layers for IBAD substrates and overview of SuperPower-ORNL CRADA (Selva)

- FY 2005 Performance and FY 2006 Plans (Fred)

- Research Integration

Objective 4: Progress toward understanding and controlling buffer delamination

Los Alamos

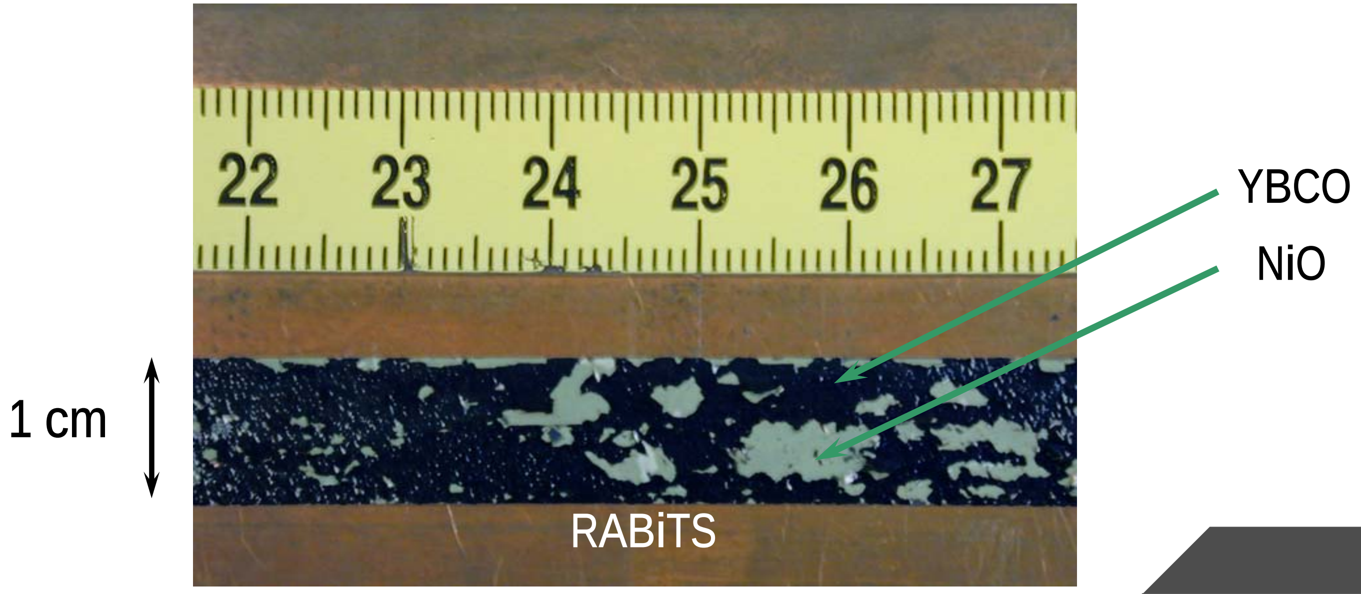
ornl
OAK RIDGE NATIONAL LABORATORY

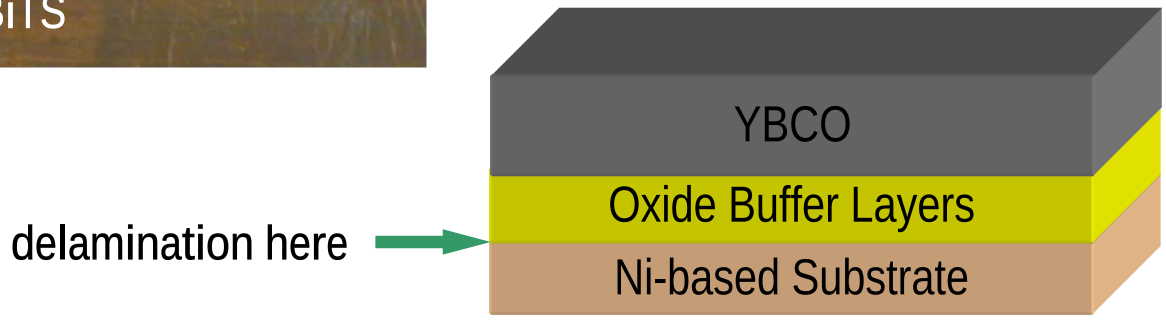
SuperPower Inc.

Delamination is sometimes observed for both RABiTS and IBAD coated conductors.

Delaminated Conductor

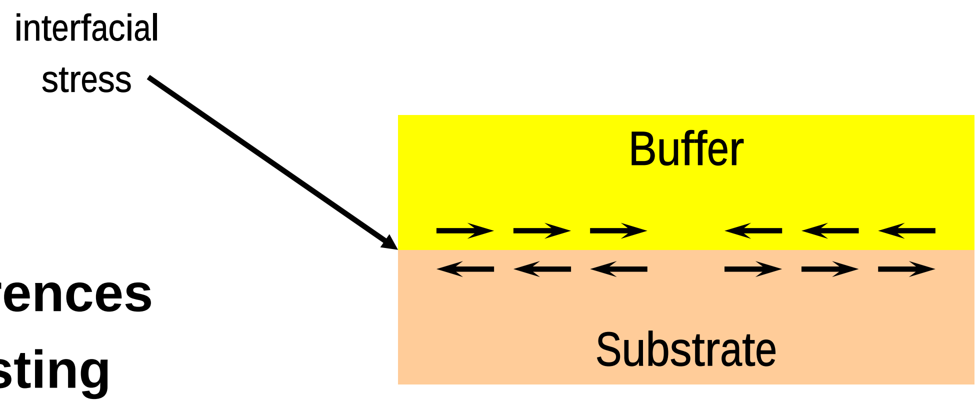
Delamination @ metal substrate (Auger)



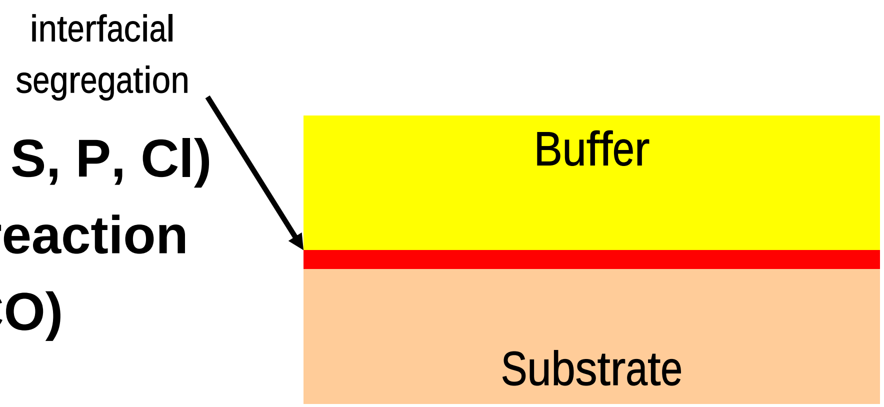


Potential causes for delamination are numerous

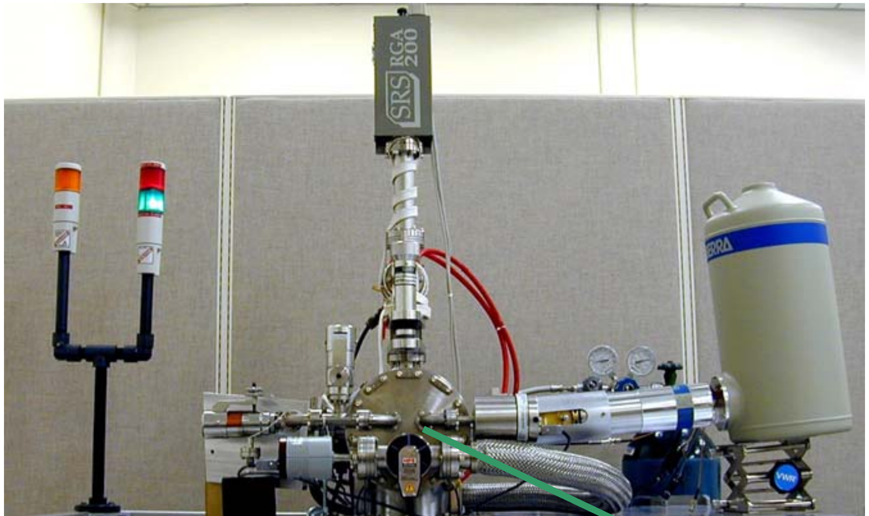
- **Film stress from:**
  - **epitaxial mismatches**
  - **thermal expansion differences**
  - **mechanical bending/twisting**



- **Interfacial degradation from:**
  - **interfacial segregation (e.g., S, P, Cl)**
  - **interfacial segregation and reaction (e.g., C segregation to form CO)**

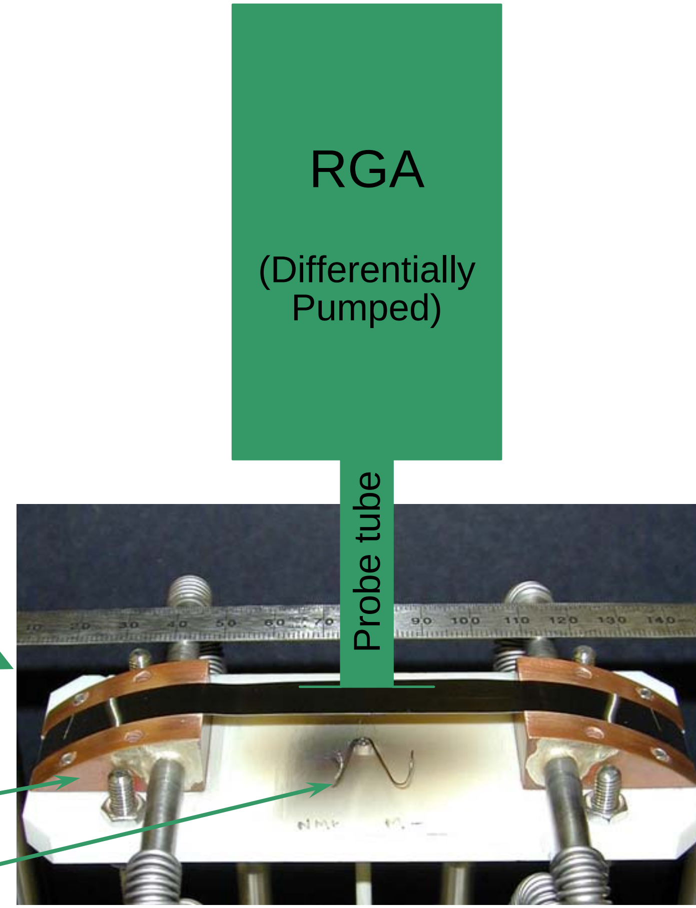


Thermal Desorption Spectroscopy has been used to study both RABiTS and IBAD substrates



<u>TDS System</u>

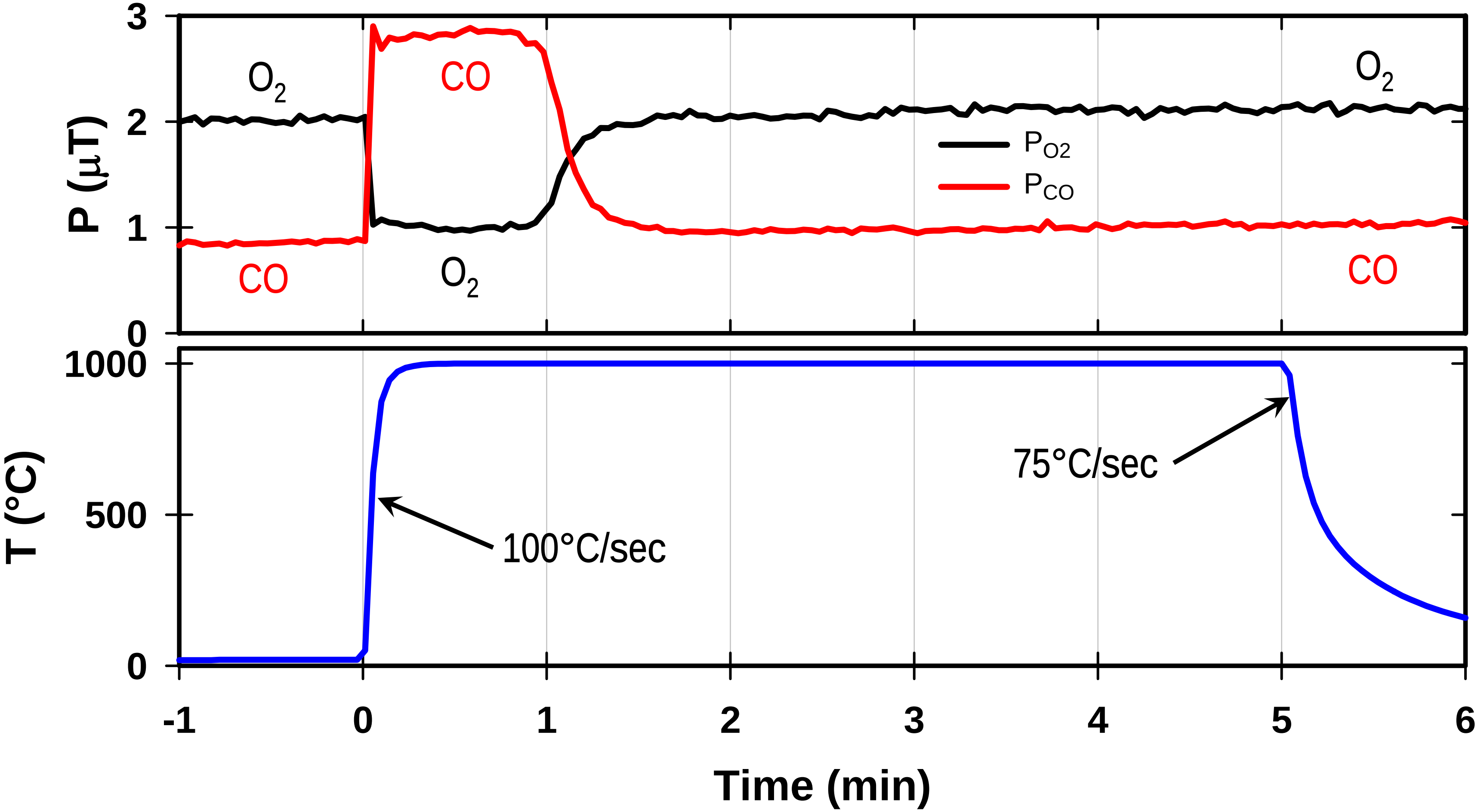
Base pressure: ~5 x 10^{-8} Torr
Simultaneous TDS & XRD
Sample Heating: Resistive
Gases: H_2O, O_2, H_2



Water-cooled copper electrode

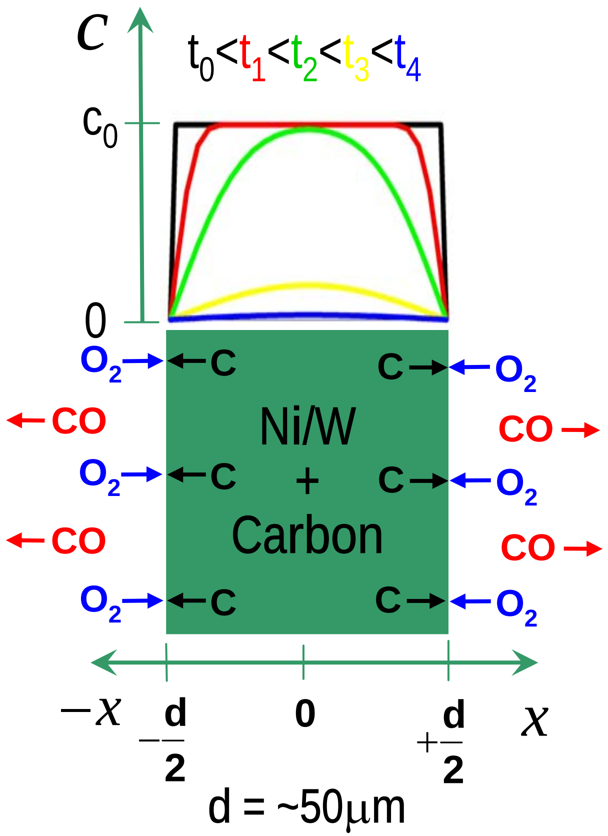
Thermocouple

Significant CO desorption occurs when ORNL Ni-3at%W tape is heated in oxygen



A simple 1-D diffusion model describes the observed CO desorption kinetics

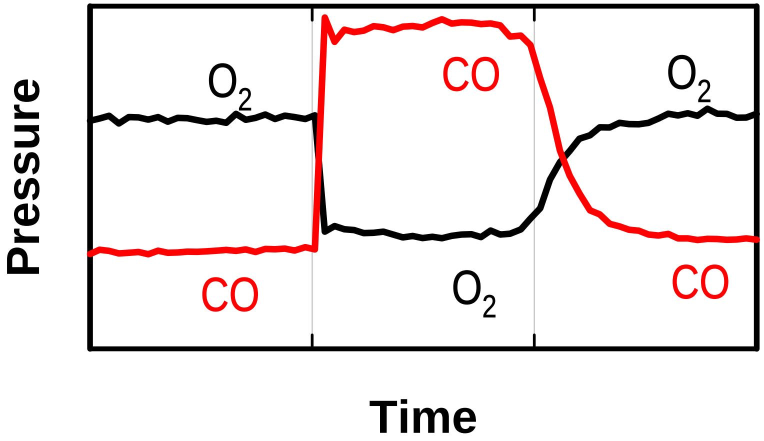
$$2\,C + O_2 \Rightarrow 2\,CO \uparrow$$



Carbon oxidation of ORNL Ni/3%W has been shown to reduce delamination

Bad RABiTS

+



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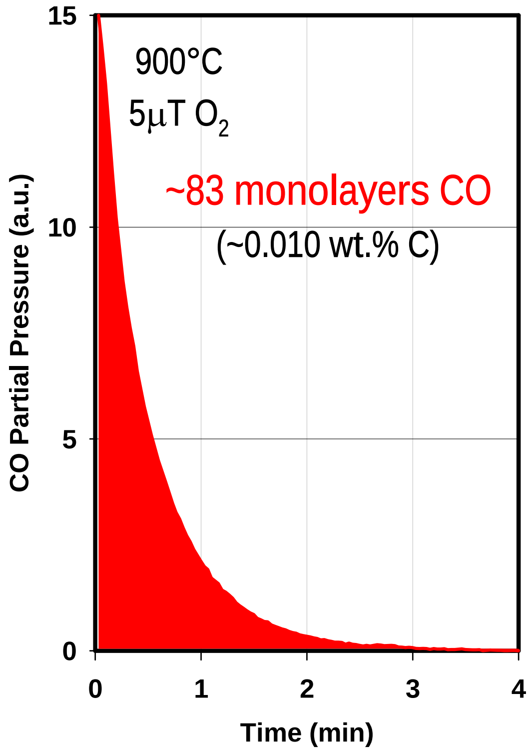
Good RABiTS

Does this apply to other Ni-based substrates?

Over bare metal substrates, CO desorption is significant for both RABiTS Ni/3%W and IBAD Hastelloy

50 μm Ni/3%W

50 μm Hastelloy (C-276)



Ni/3%W

Typ. wt %

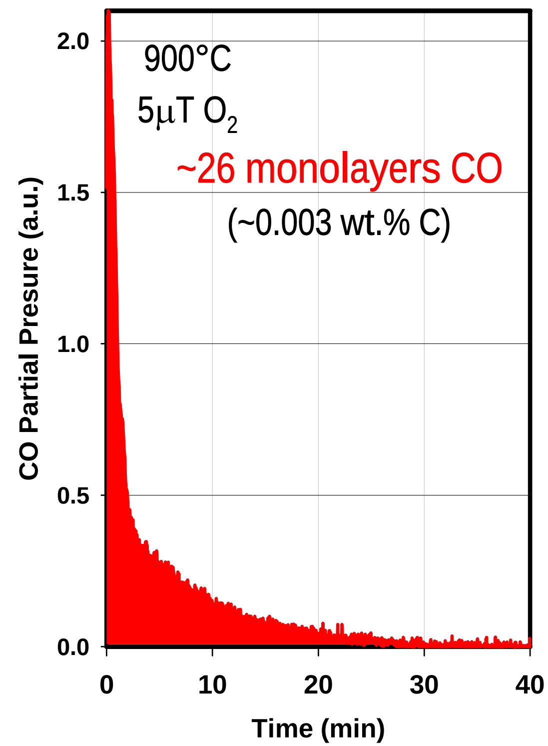
Ni – 95%

W – 5%

↓

C – 0.011%

⇐ Lots of CO ⇒



C-276

Typ. wt %

Ni – 57%

Mo – 16%

Cr – 16%

Fe – 6%

W – 4%

↓

C – 0.005%

Before treatment : 0.011 wt% C
After treatment : < 0.0004 wt% C

LECO
Carbon Analysis

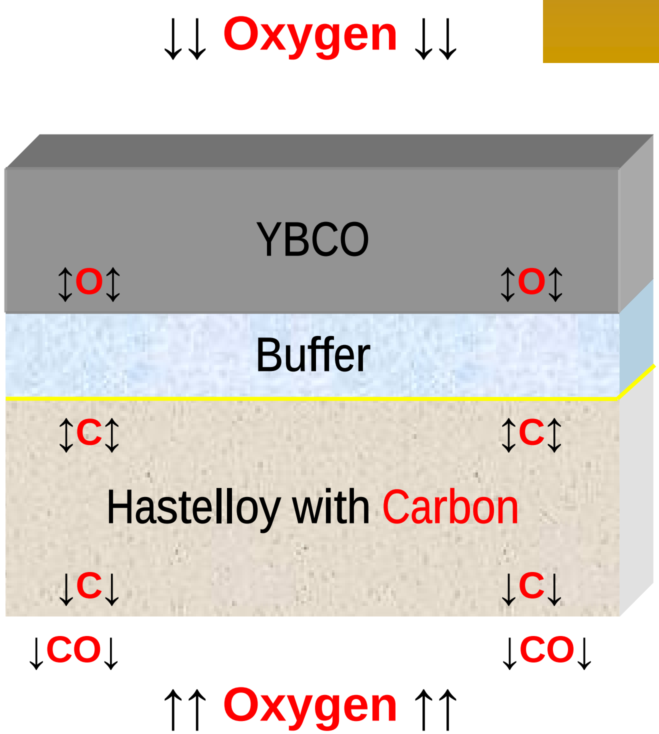
Before treatment : 0.005 wt% C
After treatment : 0.002 wt% C

For Hastelloy, however, carbon removal is slow and incomplete.

For Hastelloy, alternatives to carbon removal by oxidation must be considered

- Low carbon alloy substrates (< ~0.0005 wt%)
- Cr-free alloy substrates
- Better buffers

Implementation of some of these alternatives has led to significant improvements in SuperPower coated conductor.



Better buffer characteristics:

- **low diffusivity for O & C**
- **low porosity / high density**
- **thermodynamically stable with C**

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- FY 2005 Performance and FY 2006 Plans (Fred)

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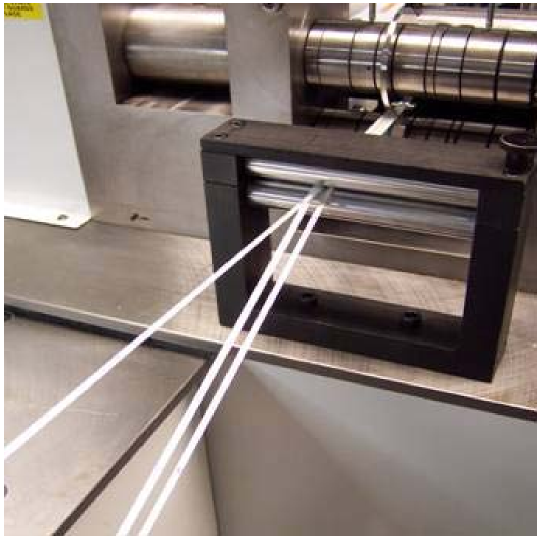
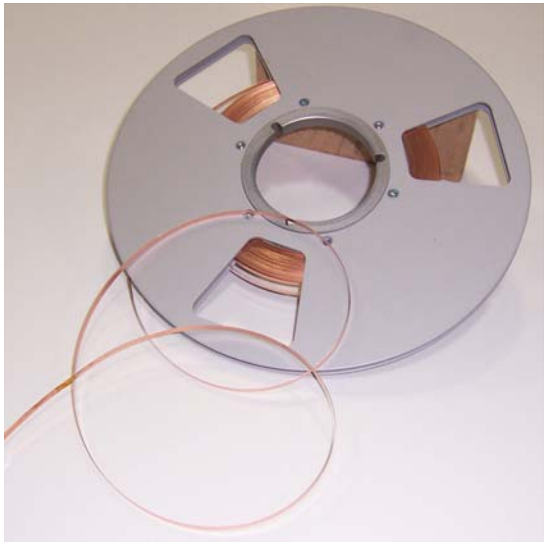
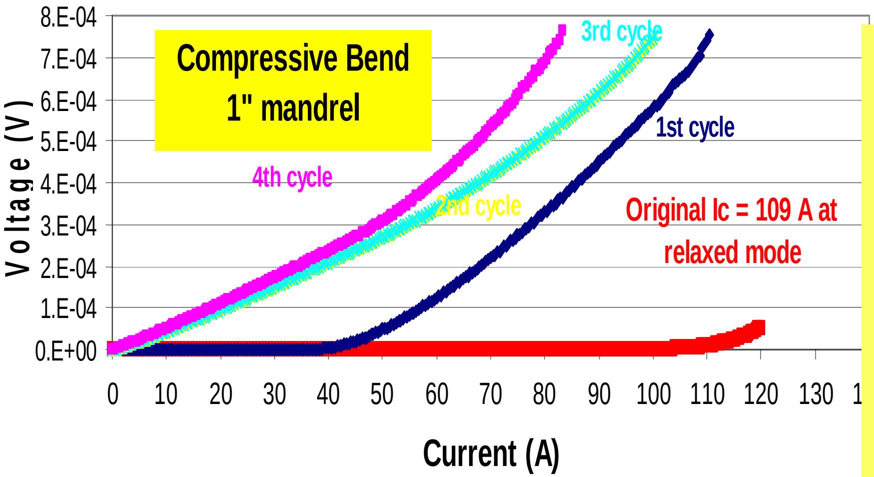
SuperPower has addressed delamination issues on a macro-scale

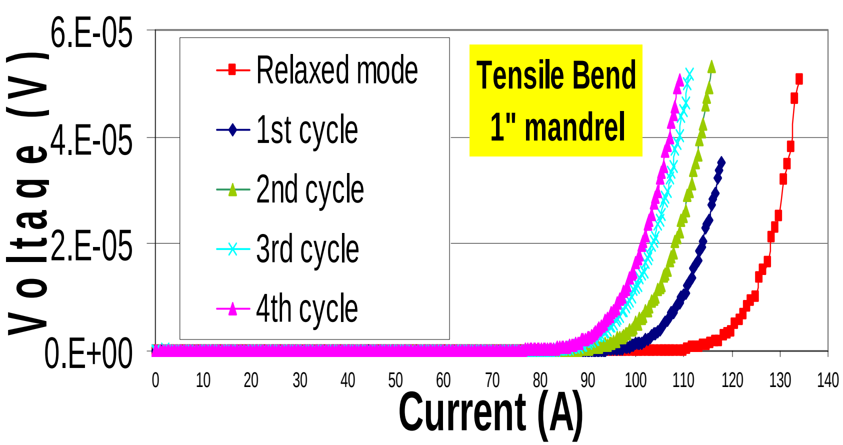
- **2G fabrication process at SuperPower was modified to eliminate delamination issues in long lengths.**
- **Problems with delamination may not be obvious until the conductor is subjected to slitting and copper stabilizer application.**
- **In several cases, delamination issues may not arise until the stage of coil testing.**
- **Thermal cycling tests (between room temperature and 77 K) on conductor in a *bent form* have been done to qualify the conductor prior to coil fabrication.**



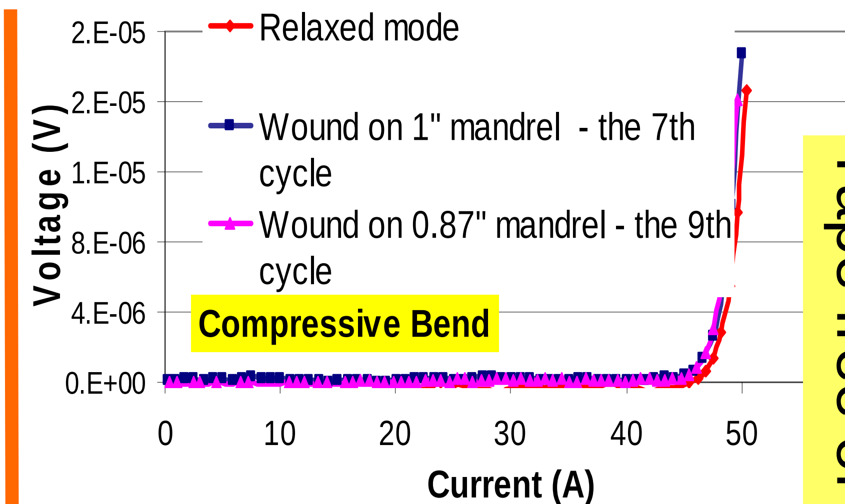


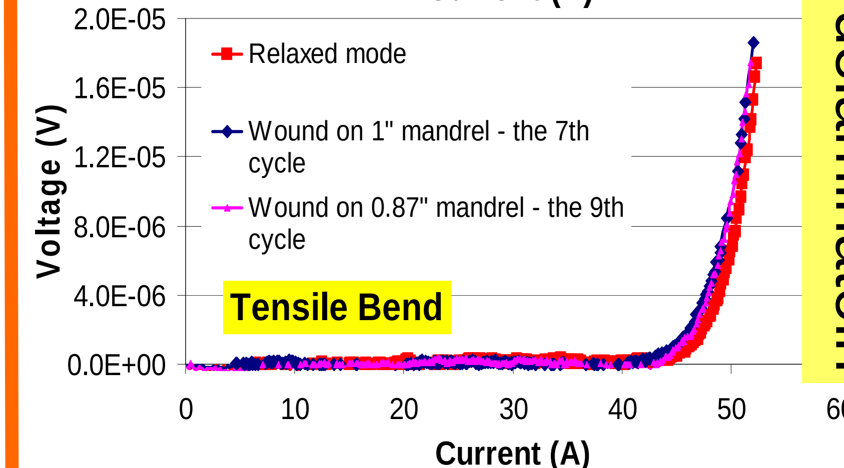
Substrate modifications at SuperPower have eliminated delamination issues in long lengths





Tape susceptible to delamination





Tape free of delaminatoin

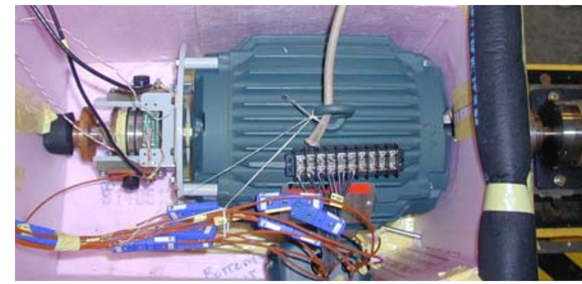
Delamination-free conductor is now routinely produced in long lengths.

ORNL/SuperPower CRADA has contributed to this success.

2G Coils for Rotating Machinery: Significant improvement in 2005

SuperPower Inc.

Four 2G Racetrack coils supplied to Rockwell in June 2004 & the world's first 2G-based rotating machine was constructed & tested



Motor tested at 1800 rpm, 1.2 hp
800 Amp-turns/coil @ 82 K in June 2004

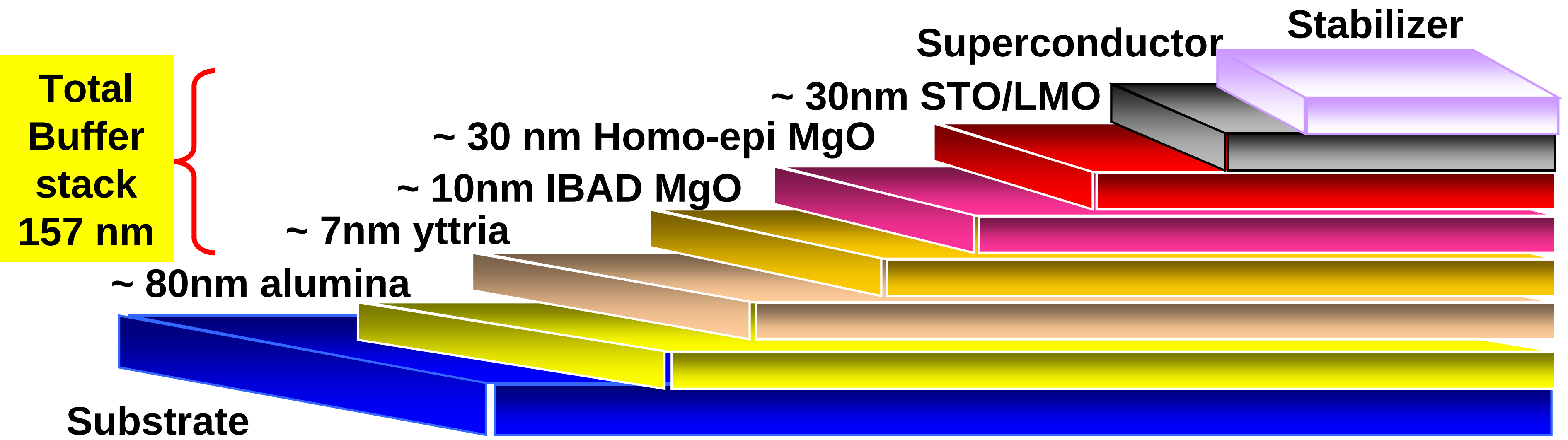
4 new race track coils provided to Rockwell in 2005 – with better performing conductor and improved coil design

Motor tested at <u>6 times</u> higher power: 7.5 hp with new coils at 1800 rpm

7.5 hp achieved with 2G HTS coils in a 5 hp conventional motor frame

Rockwell Automation

A major objective at SuperPower in FY'05 was to integrate IBAD MgO with MOCVD



SuperPower is scaling up 2G conductors based on high throughput processes, IBAD MgO and MOCVD.

Alumina --- diffusion barrier

Yttria - Nucleation layer

IBAD MgO - Template layer

Homo-epi MgO - Texture improvement layer

STO/LMO - Lattice match cap layer

ORNL-SuperPower CRADA: An important goal in FY'05 was to process epitaxial buffer layers on IBAD MgO at a fast rate so as to enable manufacturing of long lengths

Issues with High throughput processing of buffers on IBAD MgO

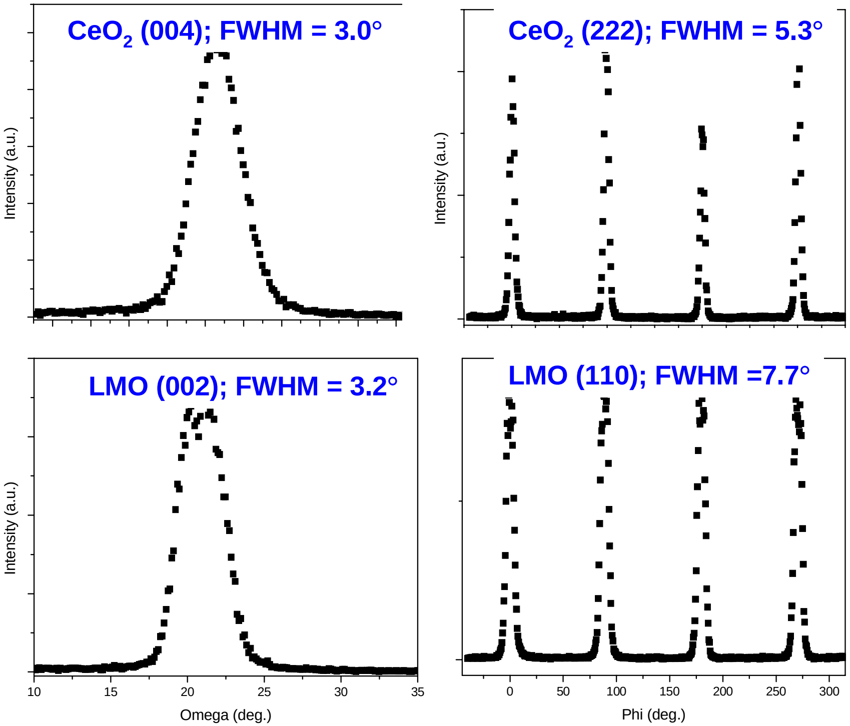
- **Reactive sputtering of all layers in IBAD MgO structure is preferred for high throughput.**
- **SuperPower already established reactive sputtering process for homo-epi MgO.**
- **Reactive sputtering of STO was not possible because of the unavailability of Sr-Ti alloy targets.**
- **RF Sputtering of STO was the next choice on reactively sputtered MgO & yielded good results with MOCVD (200 A/cm in short samples & 139 A/cm over 10 m).**
- **But, this structure posed problems and the solutions developed for RF sputtered STO were not manufacturing friendly.**
- **So, SuperPower sought the support of ORNL for an alternate to STO.**

ORNL provided a solution in LMO

Objective: Development of LMO buffers at ORNL on SuperPower's templates of IBAD-MgO and test it with SP's high-rate MOCVD process

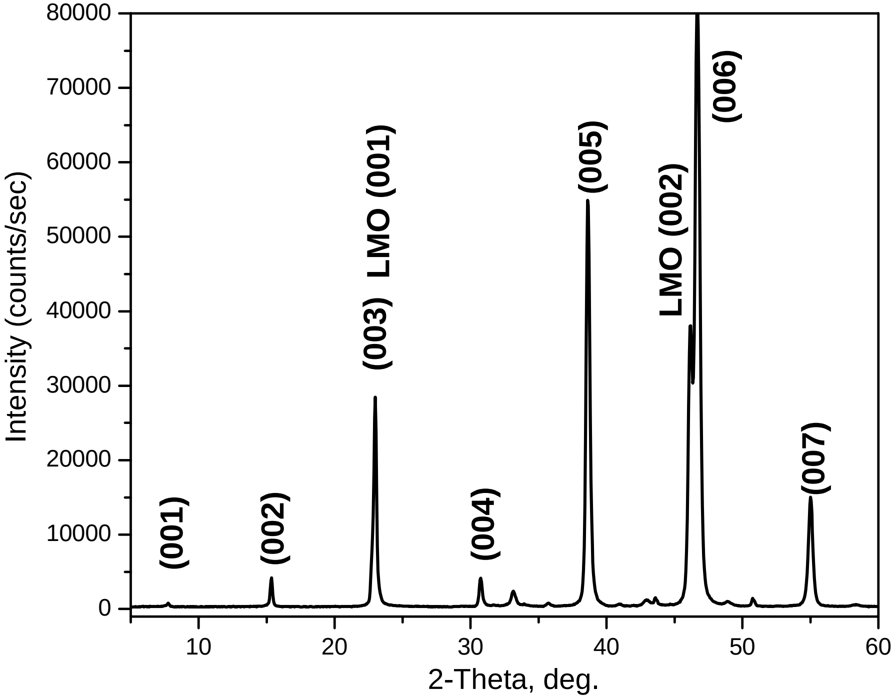
Approach :

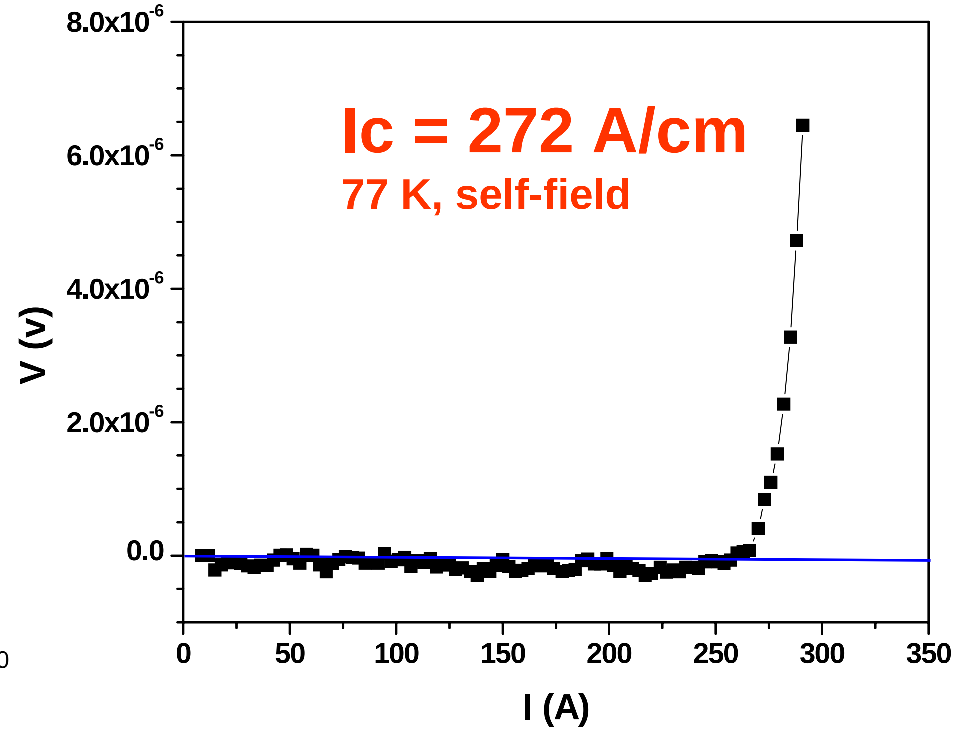
- **SuperPower provided homo-epi MgO buffered IBAD MgO substrates to ORNL**
- **ORNL optimized LMO deposition process on these substrates**
- **SuperPower deposited YBCO by MOCVD on ORNL LMO buffers.**



Close collaboration with ORNL enabled SuperPower to expedite the evaluation of LMO for IBAD MgO-MOCVD based conductors

High Performance YBCO with ORNL buffers using SuperPower's high rate MOCVD process



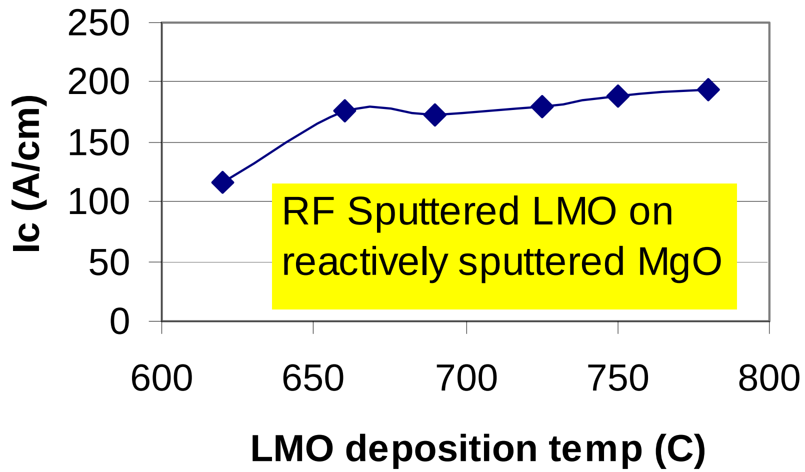


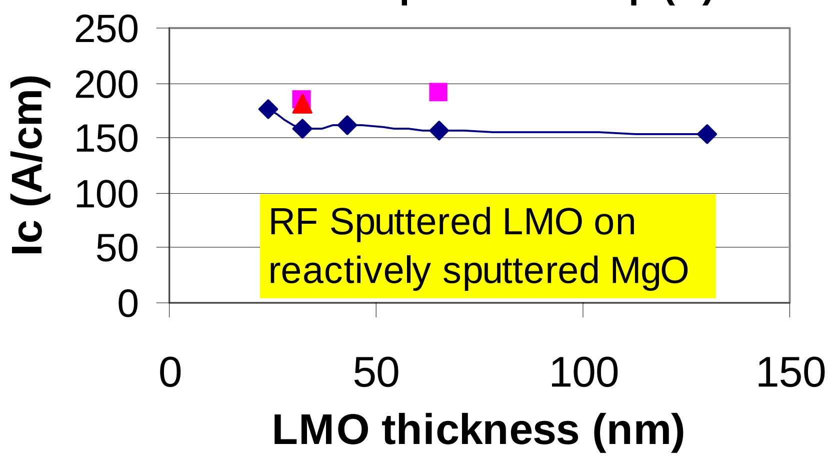
MOCVD YBCO films grown on IBAD-MgO templates with ORNL buffers showed good texture and high critical currents.

Ic of 272 A/cm is the highest current SuperPower has achieved with MOCVD on any 2G template in our standard 1.1 micron thick YBCO films

LMO buffers provide several advantages

- **Lower deposition temperature and larger temperature window than STO**
- **Higher deposition rate enables high speeds even with RF sputtering :** 177 A/cm* with 24 nm LMO @ 10 m/h
- **Higher Ic than STO (~ 40 A/cm higher) - Bonus !**
- **La-Mn alloy targets are available for reactive sputtering whereas Sr-Ti alloys are not available.**
- Critical current* over 200 A/cm achieved with tape speeds of 10 m/h in reactive sputtering of BOTH LMO and MgO





***MOCVD films are 1.1 microns thick**

LMO is an excellent alternative to STO especially in combination with MOCVD YBCO and reactively sputtered MgO

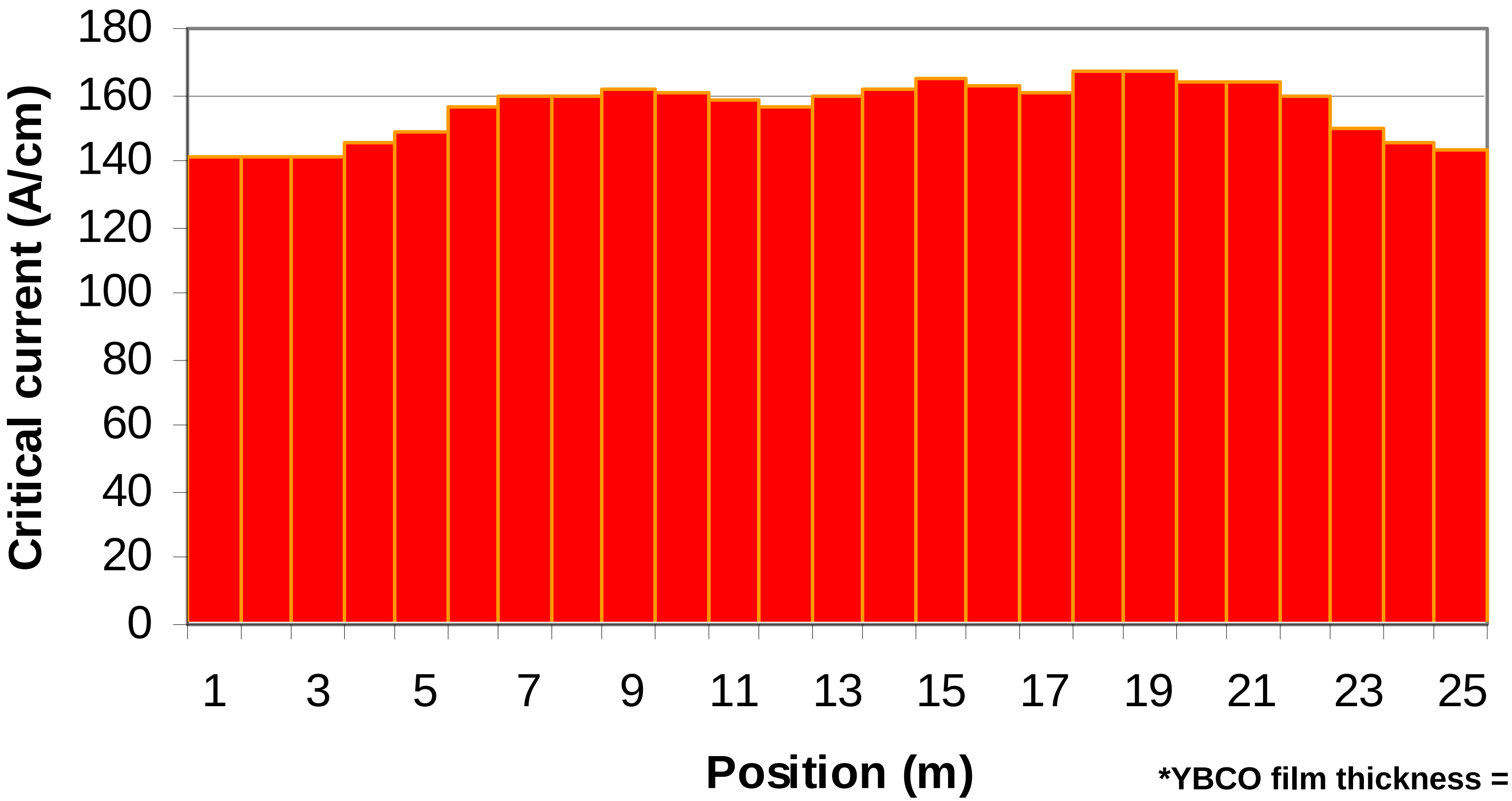
25 m MOCVD tape demonstrated with LMO buffered IBAD MgO

•IBAD MgO @ 10 m/h

•Reactively sputtered MgO @ 10 m/h

RF Sputtered LMO @ 10 m/h

MOCVD @ 10 m/h × 2 passes

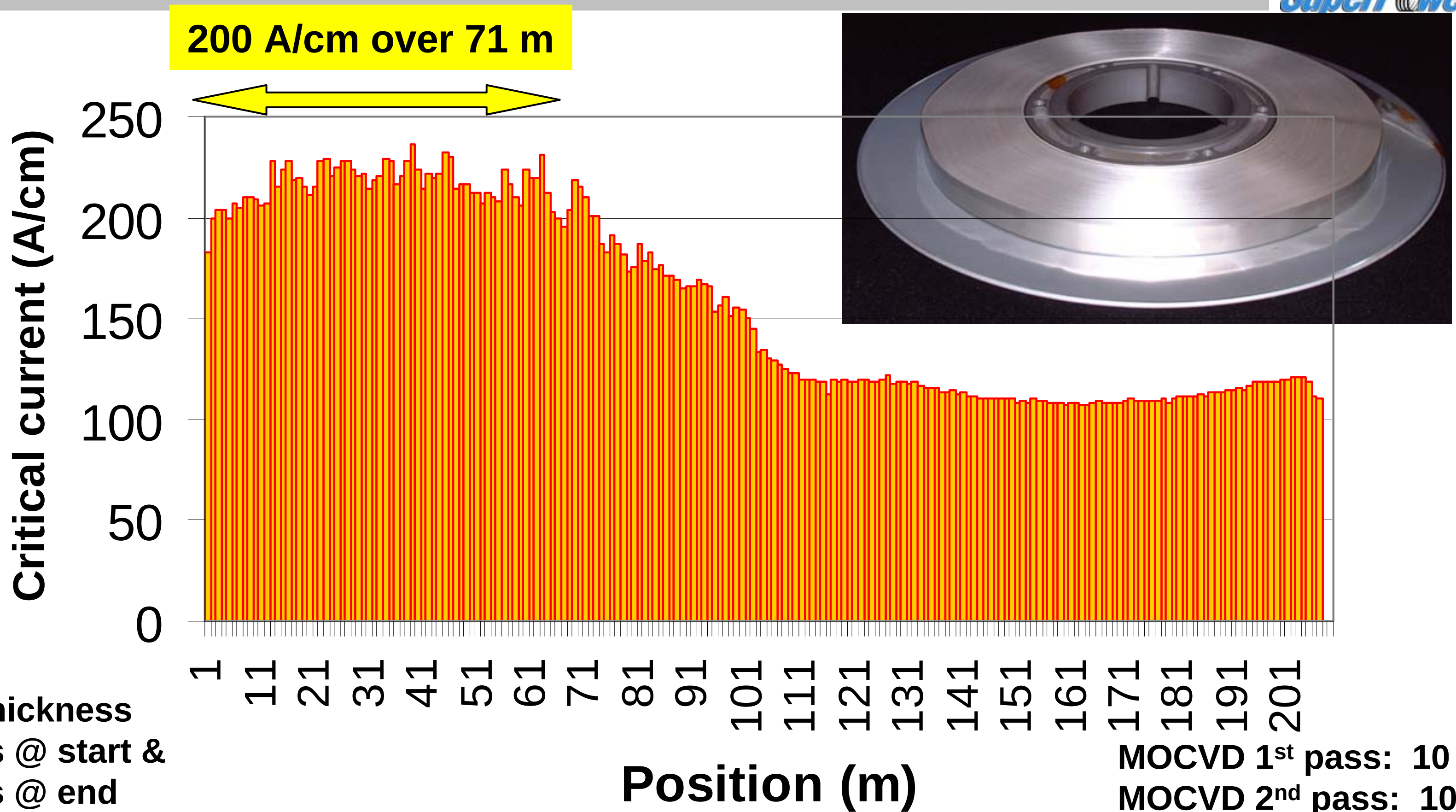


*YBCO film thickness = 1.1 microns

Ic* of 142 A/cm over 25 m MOCVD tape with all high throughput buffers

200 m long 2G conductor by MOCVD

SuperPower Inc.



YBCO film thickness
1.47 microns @ start &
1.32 microns @ end

MOCVD 1st pass: 10 m/h
MOCVD 2nd pass: 10 m/h

Minimum Ic of 106.7 A/cm over 206.7 m (22,030 A-m)

71 m with Ic of 200 A/cm with standard deviation of 4.3%
Standard deviation of 4.3% over the last 100 m

FY 2006 Plans (ORNL-SuperPower CRADA)

- **Extend studies on understanding microstructural limitations in J_c of MOCVD-based 2G conductors in standard 1 micron thick films as well as in thicker films (up to 5 microns). Modify MOCVD process accordingly for higher J_c.**
- **Improve pinning in MOCVD-based YBCO films on IBAD substrates.**
- **Simplify buffer structure for IBAD MgO (in conjunction with LANL CRADA) suitable for MOCVD. Demonstrate an Ic of > 300 A/cm on LMO type buffers.**
- **Examine alloys alternate to Hastelloy that are suitable for IBAD MgO- MOCVD with less issues with diffusion, delamination etc (in conjunction with LANL CRADA).**

CRADA with ORNL has enabled SuperPower to significantly improve our 2G conductor in a short time frame (Nov'04 - July'05).

ORNL's support in fundamental understanding of SuperPower's 2G conductor issues will be extremely valuable in our scale up effort.

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- FY 2005 Performance and FY 2006 Plans (Fred)

- Research Integration

FY 2005 Plans and Performance

FY2005 Plans

- Extend work to incorporate self-aligned nanodots and nanorods in PLD YBCO films on RABiTS from 0.2-µm-thick to thicker films. Fabricate REBCO films on RABiTS.

FY2005 Performance

- ✓ It was shown that this method can be used to incorporate self-aligned nanodots and nanorods of other materials besides just BZO
- ✓ Microstructural modifications were shown to result in both columnar and planar defects in 1µm films. This results in significant enhancements in the transport properties
- ✓ Single layer, 3 µm thick, 2 vol% BZO added YBCO film was fabricated with an I_c of 389 A/cm, 77K, sf. This film had excellent performance in applied fields at 77, 65 and 40K.

FY 2005 Plans and Performance

FY2005 Plans (cont'd)

- **Conduct microstructure and texture characterization of YBCO tapes produced via high rate in-situ MOCVD of REBCO films. Characterize transport properties of tapes and correlate to microstructure.**

FY2005 Performance

- ✓ **SuperPower's standard MOCVD (Y,Sm)BCO/IBAD tape was characterized by transport, X-Ray diffraction and TEM measurements and key defects in the film were identified and correlated to transport properties.**

- ✓ **SuperPower's highest I_c MOCVD (Y,Sm)BCO/IBAD tape was also characterized via cross-section electron microscopy and X-ray diffraction and key defects in the film were identified.**

FY 2005 Plans and Performance

FY2005 Plans (cont'd)

- Investigate improvement in flux-pinning via defects generated by substrate surface modifications.

FY2005 Performance

- ✓ Substrate surface modification using both PVD and solution methods was demonstrated.
- ✓ In-field J_c enhancements of ~50-60% have been found.
- ✓ Improved pinning and J_c performance has been demonstrated for coated conductors & thick YBCO films.
- ✓ Pinning force density $F_P(B,T)$ scaling provides insight into underlying pinning mechanisms & practical predictive analysis

FY 2005 Plans and Performance

FY2005 Plans (cont'd)

- *Extend analysis by thermal desorption spectroscopy and Auger Spectroscopy to minimize delamination effects in IBAD substrates.*

FY2005 Performance

- ✓ **Strategies to reduce delamination IBAD substrates have been identified and successfully implemented.**
- ✓ **Delamination-free conductor is now routinely produced in long lengths at SuperPower.**

FY 2005 Plans and Performance

FY2005 Plans (cont'd)

- **Develop a robust buffer layer stack that is compatible with IBAD templates for use in subsequent YBCO deposition via MOCVD.**

FY2005 Performance

- ✓ **An IBAD-compatible, LMO buffer layer has been developed at ORNL.**
- ✓ **A 25-m length of 142A MOCVD coated conductor has been demonstrated using a high-rate (10m/h) LMO buffer. SuperPower has decided to use this buffer layer for scale-up work.**

FY 2006 Plans (ORNL-SuperPower CRADA)

- **Extend studies on understanding microstructural limitations in J_c of MOCVD-based 2G conductors in standard 1 micron thick films as well as in thicker films (up to 5 microns). Modify MOCVD process accordingly for higher J_c.**
- **Improve pinning in MOCVD-based YBCO films on IBAD substrates.**
- **Simplify buffer structure for IBAD MgO (in conjunction with LANL CRADA) suitable for MOCVD. Demonstrate an Ic of > 300 A/cm on LMO type buffers.**
- **Examine alloys alternate to Hastelloy that are suitable for IBAD MgO- MOCVD with less issues with diffusion, delamination etc (in conjunction with LANL CRADA).**
- **Quantifiy stability and dielectric properties of SuperPower's conductors**

FY 2006 Plans (Strategic base program)

- Further develop nanoparticle additions in the appropriate volume fractions to optimize pinning properties at different temperatures (i.e., 77K, 65K, 40K).
- Fabricate films with minor amounts of site substitution in the Y, Ba and Cu sites without significant reduction in T_c and determine effects on pinning properties.
- Fabricate films of REBCO with and without nanoparticle additions and compare pinning characteristics with YBCO with nanoparticle additions.
- Continue optimizing nanoparticle substrate surface modifications for flux-pinning in thick *in situ* and *ex situ* YBCO on RABiTS, and extend to YBCO on IBAD templates
- Introduce artificial pinning centers in MOD YBCO films by incorporating pre-formed oxide nanoparticles to solution precursors

Research Integration:

Interactions with Companies and Universities

- **SuperPower**
  - **Initiated the CRADA with SuperPower in FY05 and work on issues such as substrate development, buffer delamination, and simplified buffer development for IBAD templates, pinning studies and MOCVD YBCO characterizations**

- **University of Houston:** R. Meng, I. Rusakova
- **University of Oslo, Norway:** T.H. Johansen
- **ORISE:** S. Kang, J. Li, A.A. Gapud
- **University of Tennessee:** T. Aytug, J.R. Thompson, S. Sathyamurthy
- **University of Columbia:** Sui-Wai Chan
- **North Carolina A& T University:** D. Kumar

Communications:

- **Many publications**
- **Numerous presentations**
- **Patents issued and filed disclosures**
- **Information also dispersed via regular CRADA teleconferences/meetings/ annual reports/ ORNL websites: http://www.ornl.gov/sci/htsc/publications.htm**