Alternative Buffer Layer Architectures for YBCO Coated Conductors

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Industrial Licensees/Partners

- Microcoating Technologies, SuperPower, Inc., Neocera, Oxford Superconducting Technology, and American Superconductor Corporation

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PURPOSE: **To develop a basic understanding of and practical synthesis paths for epitaxial buffer layers on biaxially textured metal tapes for YBCO coated conductors.**

FY 2003 Objectives

- Research and develop faster, potentially lower cost, and simpler RABiTS buffer-layer architectures that are compatible with ex-situ YBCO processes
- Develop a viable high rate process to fabricate high quality buffer layers
- Collaborate with LANL and ANL to develop suitable buffer architectures on IBAD-MgO and ISD-MgO substrates for compatibility with ex situ YBCO
- Continue fundamental studies of epitaxial growth on textured non-magnetic substrates, including copper and copper alloys

FY2003 Performance/Outline

- **FY 2003 Results**

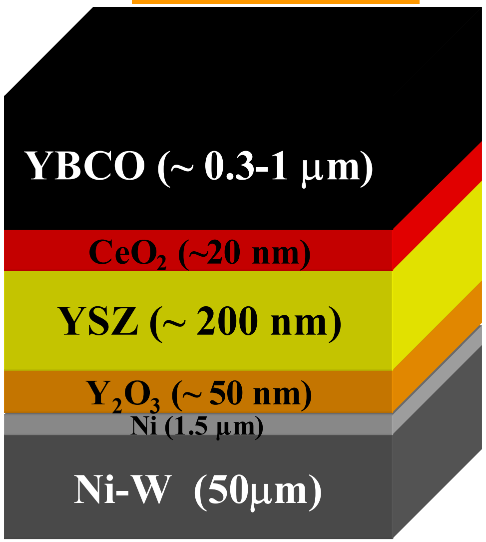
  Reactive sputtering of YSZ buffers **(Parans)**
  Solution buffer layer development for YBCO
  Compatible-buffer-layer development for MgO-based tapes (*LANL* IBAD MgO & ANL ISD MgO)

  Buffer layer development for Cu substrates **(Claudia)**

- **FY 2003 Performance and FY 2004 Plans** **(Claudia)**
- **Research Integration**

RABiTS Templates for YBCO Coated Conductors

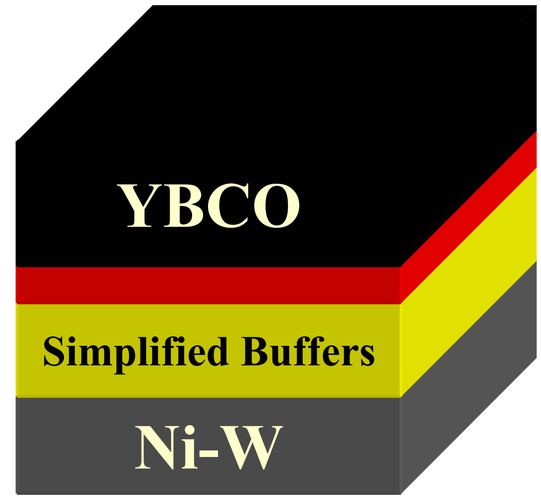
FY2002



Deposition Methods:

- YBCO: ex-situ BaF_2 process
- YSZ and CeO_2 : rf sputtering
- Y_2O_3: e-beam
- Ni: dc sputtering

FY2005



OBJECTIVE:

Research and develop faster, potentially lower cost, and simpler RABiTS buffer-layer architectures that are compatible with ex-situ YBCO processes

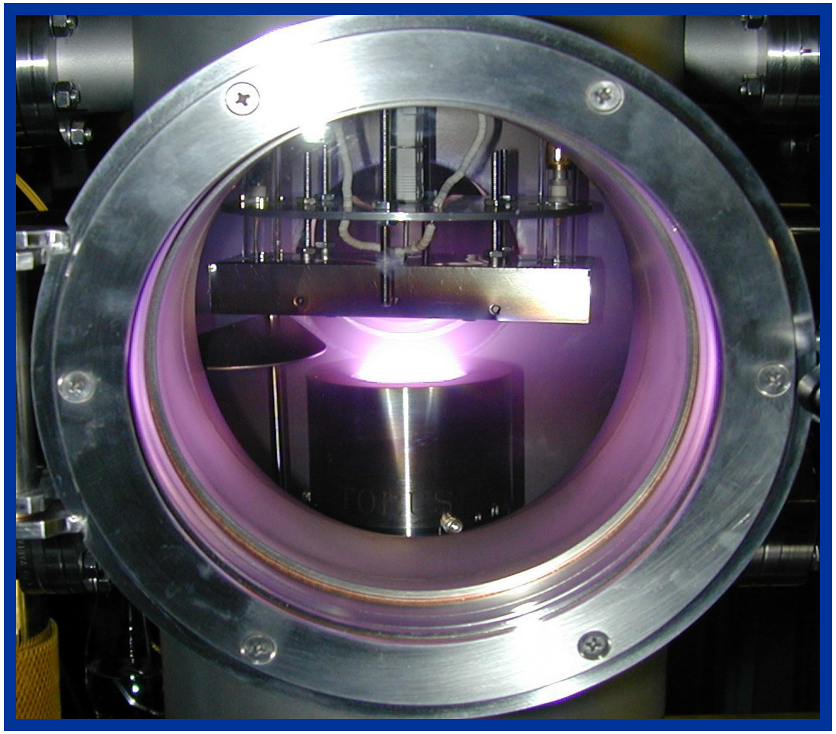
APPROACH:

Reactive sputtering of YSZ buffers

Metal-organic deposition (MOD) process

$La_2Zr_2O_7$ (LZO) (seed & barrier; alkoxide); CeO_2 (cap; acac)

High Rate Reactive Sputtering of YSZ Buffers for Standard RABiTS Templates

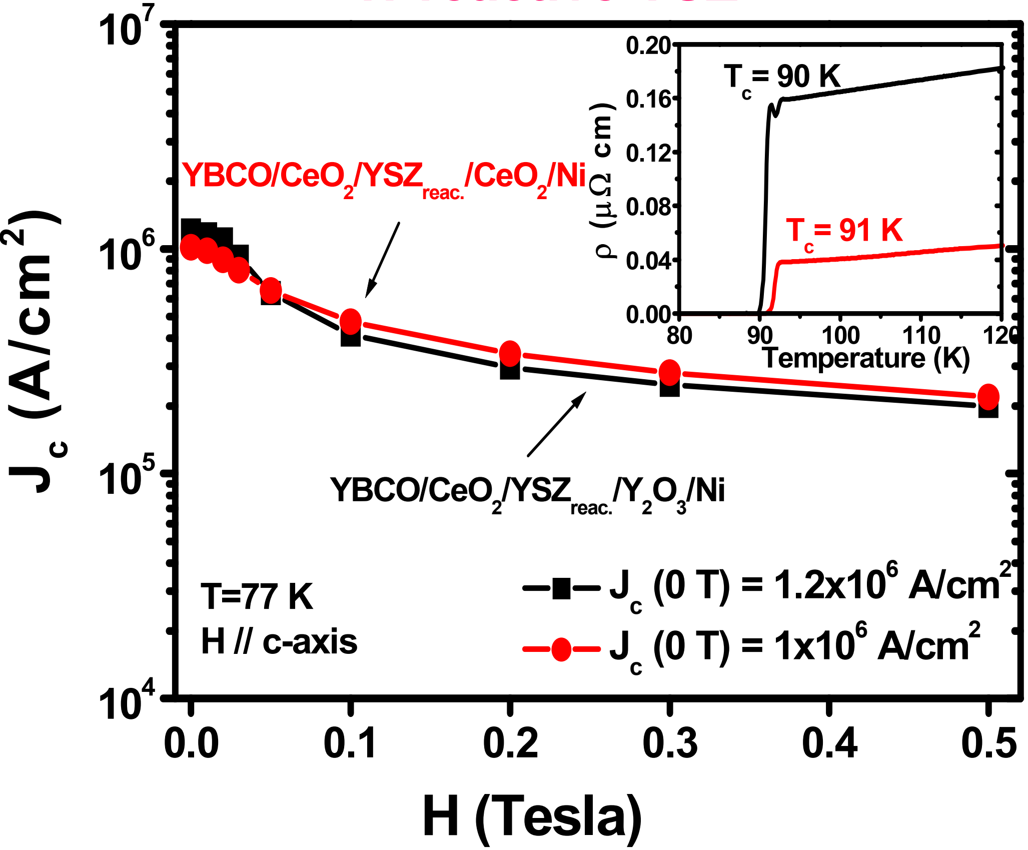


- 2" pulsed 1 kW dc/rf sputter system
- Differential pump RGA
- H_2O and O_2 (as reactive sources)

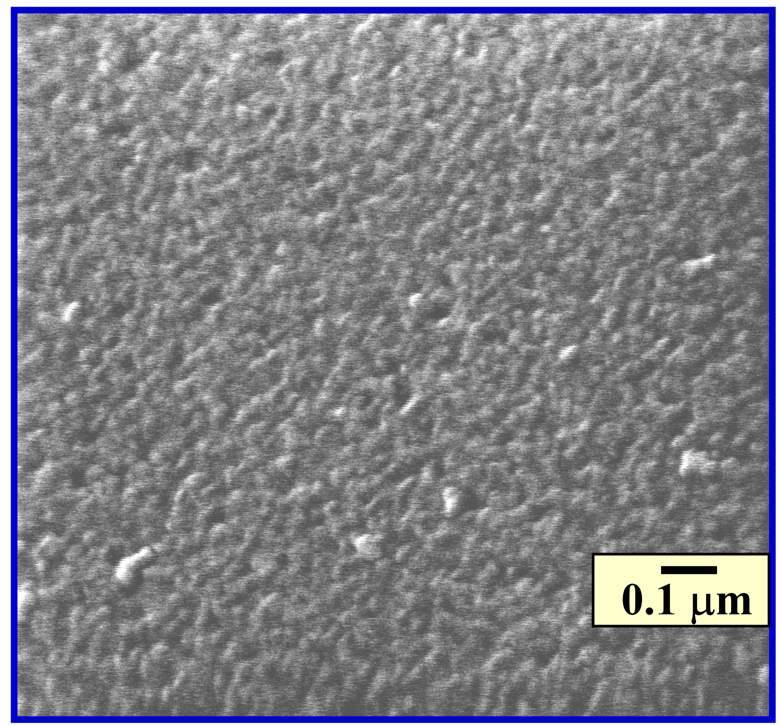
Reactive *YSZ* Buffer Layers by *rf*-sputtering

J_c > 1 MA/cm^2 on reactive YSZ demonstrated using an alloy target
Deposition rate = 2 - 2.5 Å/sec (4-5 times higher than rf-oxide)

J_c vs. H for YBCO on *rf*-reactive YSZ



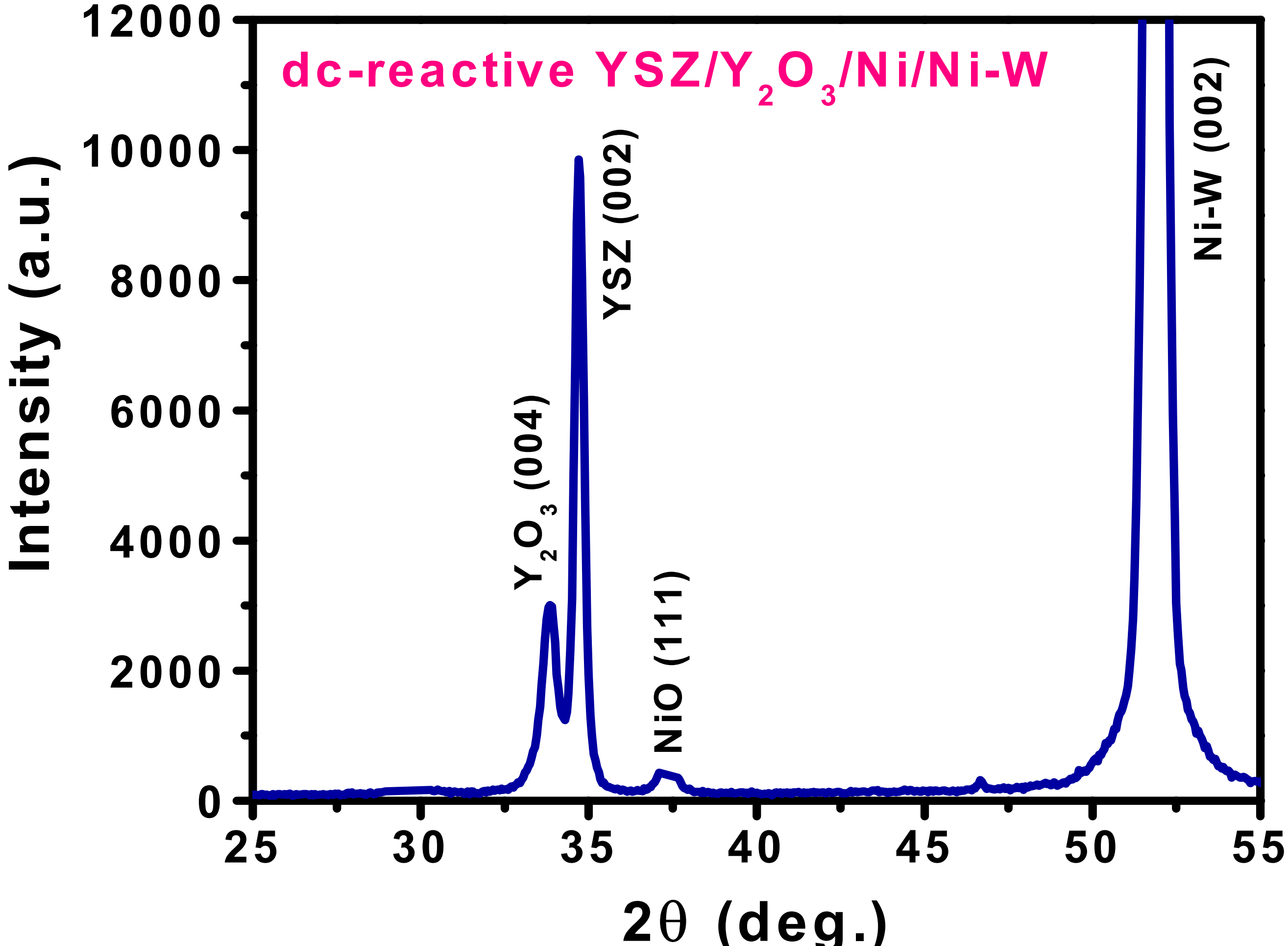
Surface morphology of *rf*-reactive YSZ



smooth & dense coating

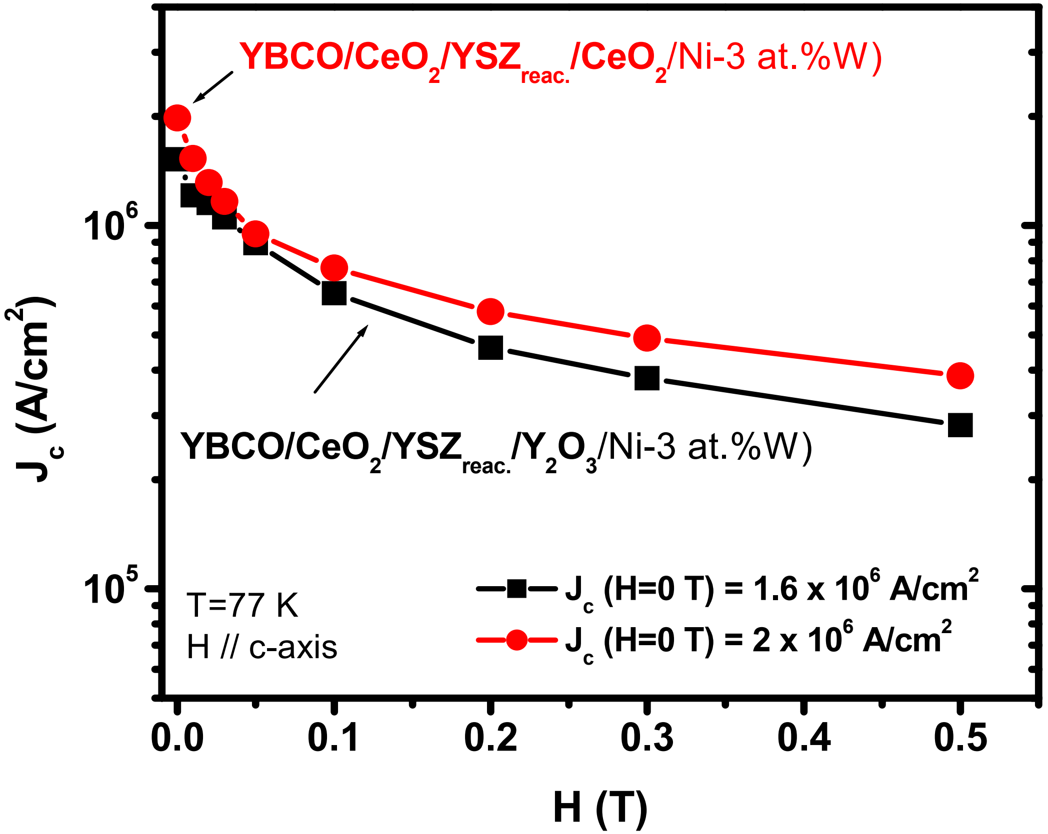
YSZ by *dc*-reactive sputtering on Y_2O_3 seeds

Dep. rate is 5-10 Å/sec
(10-20 times higher than rf-oxide sputtering)

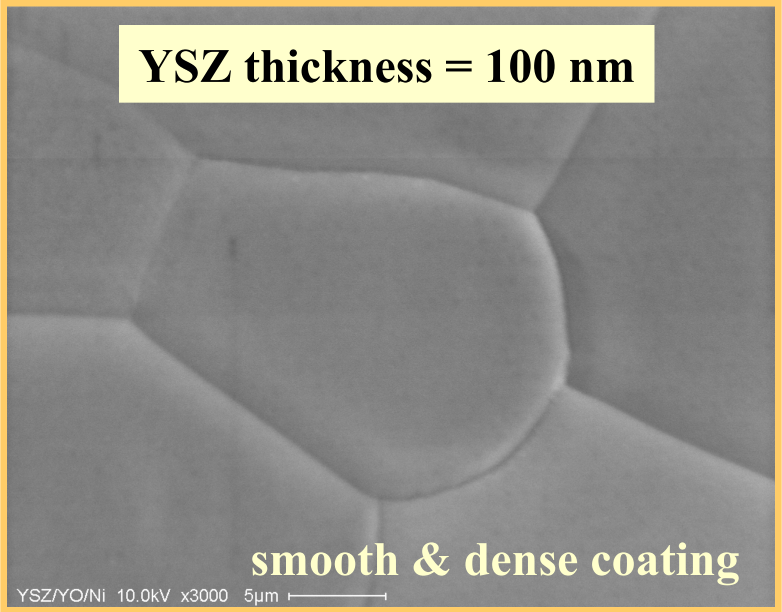


High-J_c on reactive *YSZ* Buffer Layers by *dc*-reactive sputtering (better texture templates)

J_c vs. H for YBCO on *dc*-reactive YSZ



Surface morphology of *dc*-reactive YSZ

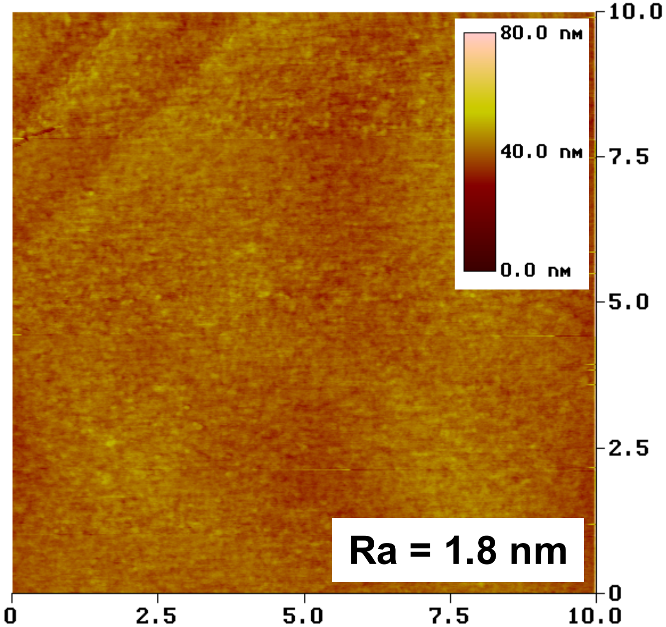


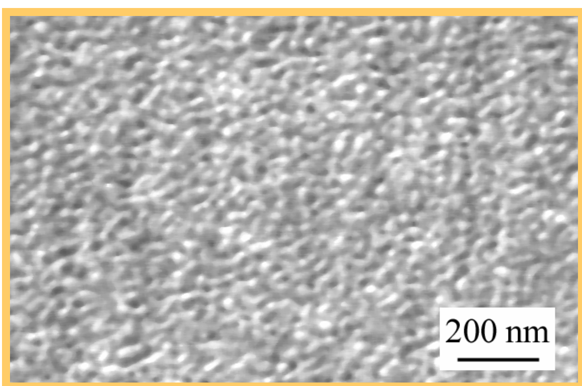
Dep. Rate is 10-20 times higher than rf-oxide sputtering

J_c of 2 MA/cm^2 on reactive YSZ demonstrated using an alloy target

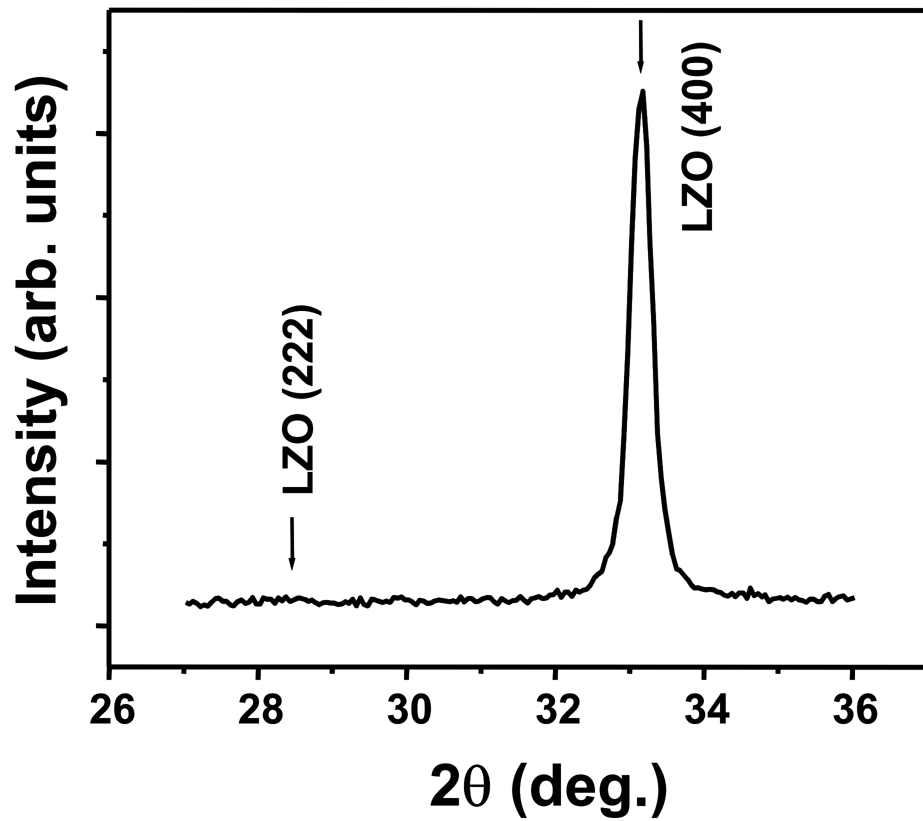
Solution Buffer Layer Development

AFM LZO surface



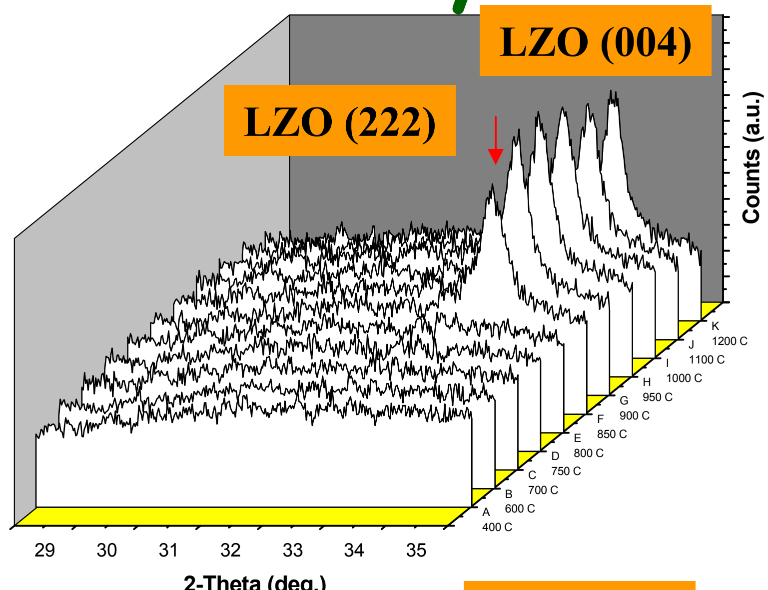


SEM LZO surface

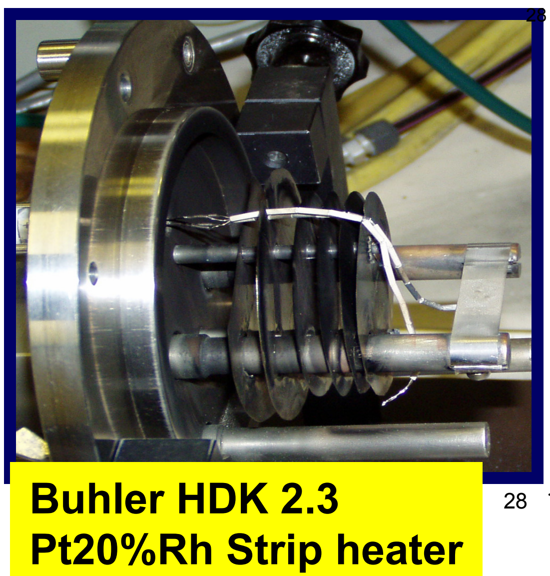


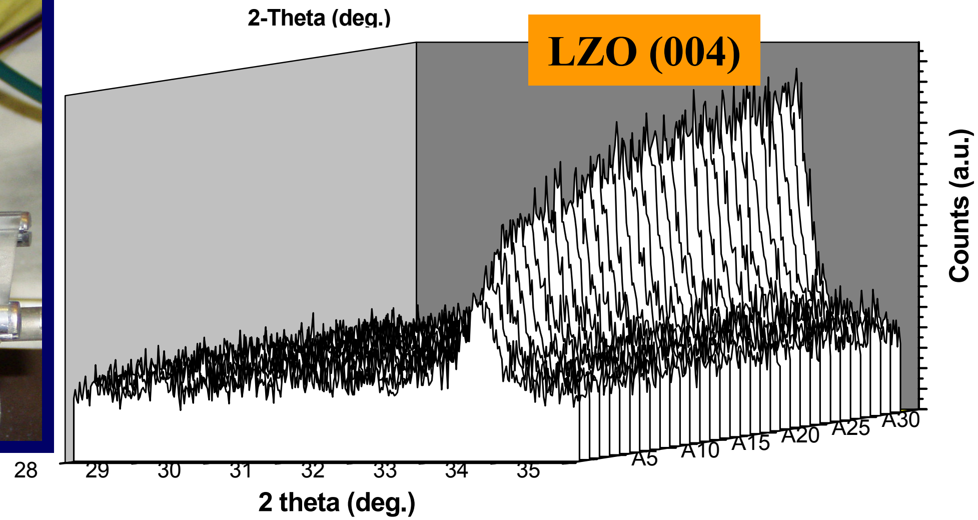
- Epitaxial LZO can be grown directly on textured Ni-W 3% substrates
- Pursued both reel-to-reel dip-coating
  - Double sided coating
- 20 nm/coat seeds; highly reproducible

High Temp. *in-situ* XRD Analysis of LZO Buffer Layer Growth



- XRD @ various T
- LZO *(00l)* starts to nucleate @ 850 °C
- No (222) peaks
- LZO thickness:20 nm

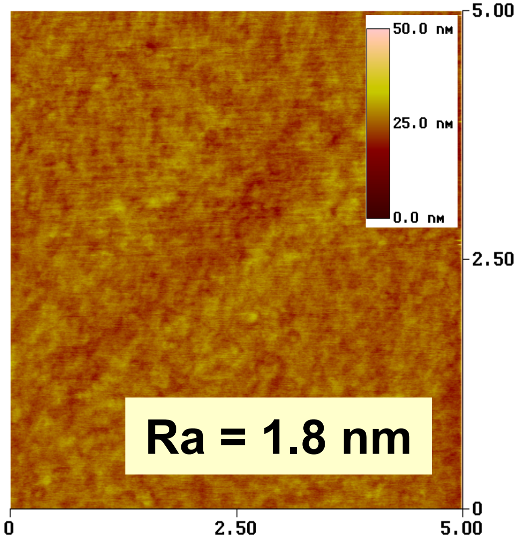




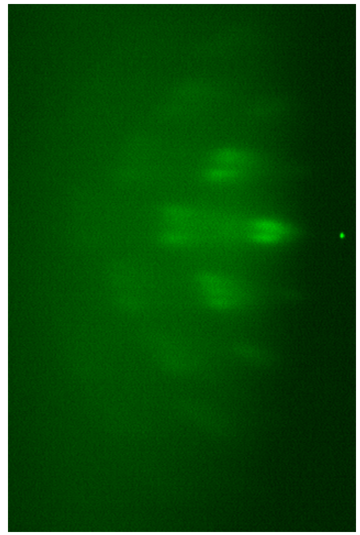
- XRD @ 1100 °C & different time
- LZO (002) peak saturates @6min
- (004) peak width constant after 6 min

MOD LZO Nucleation & Growth on Ni-3%W

LZO/Ni-W; 1100 °C; 6 min Q

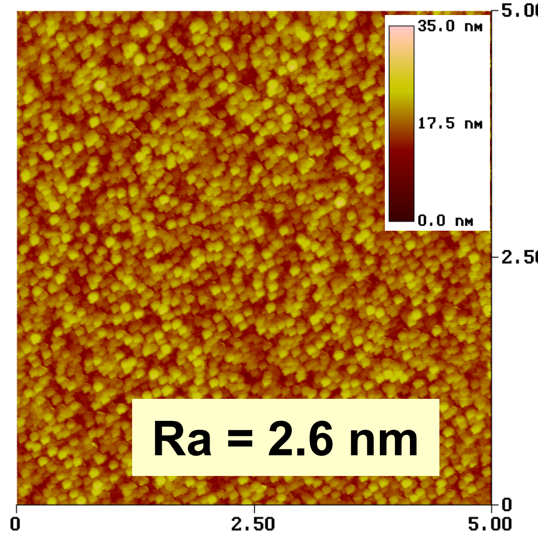


AFM LZO surface

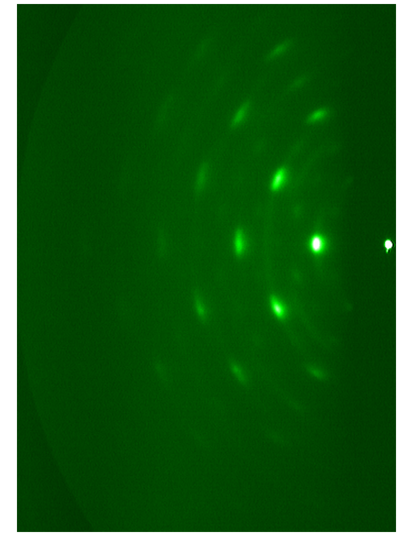


RHEED 600 °C

LZO/Ni-W; 1100 °C; 60 min Q



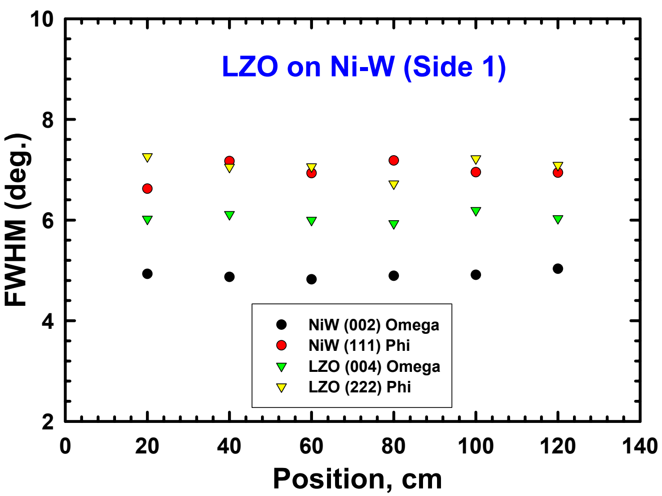
AFM LZO surface

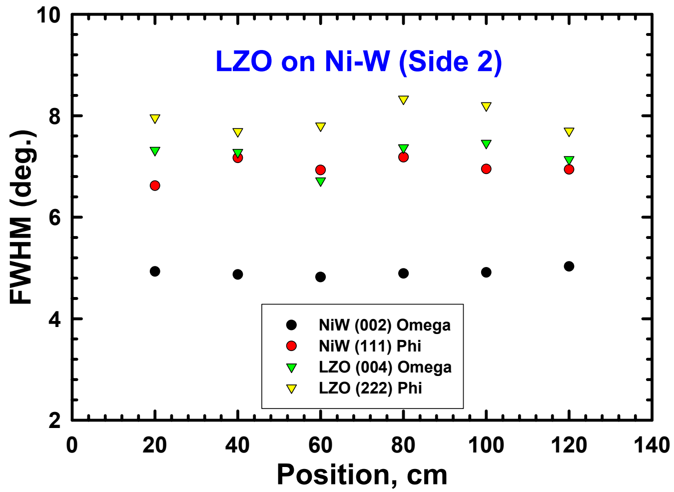


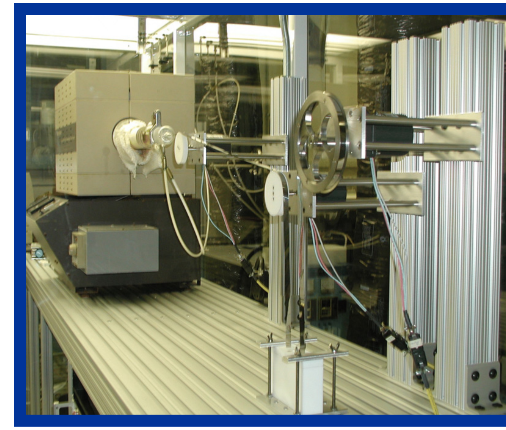
RHEED 600 °C

- LZO grows in 6 min at 1100 °C (key for scale-up efforts)
- Smooth MOD LZO layers were produced
- Surface roughness increases as the process time increases
- Polycrystalline LZO phases were not observed at both surfaces
- Successfully used RHEED as a tool to study the MOD surface

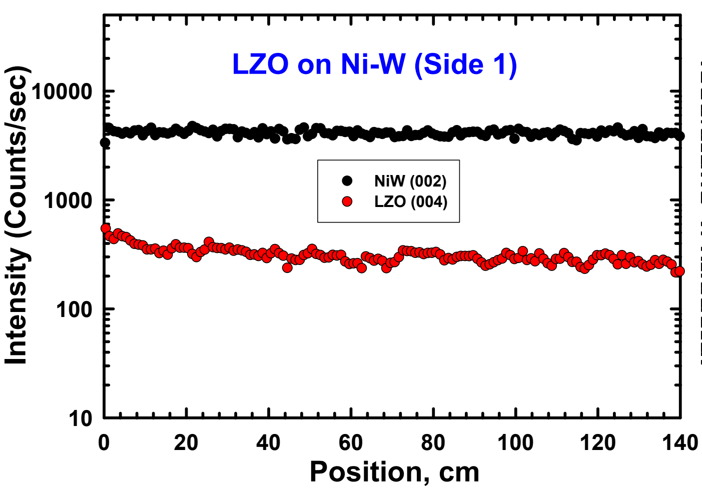
Over 1.4 meter long, double-sided, reel-to-reel dip-coated LZO seeds on textured Ni-W substrates with uniform texture were produced

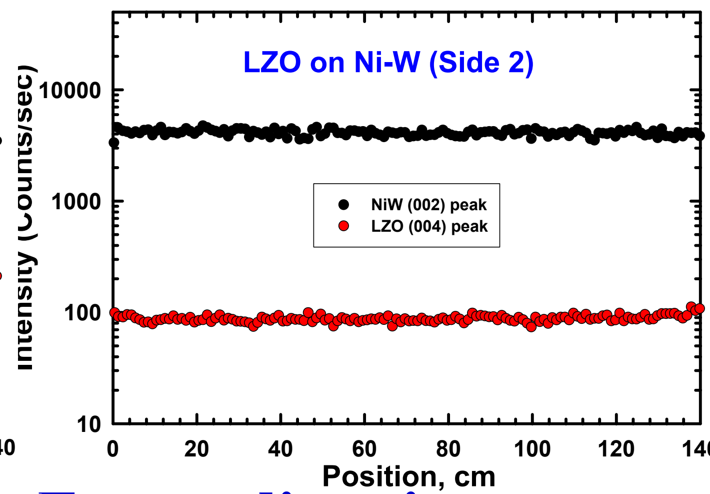






Dip-coating unit



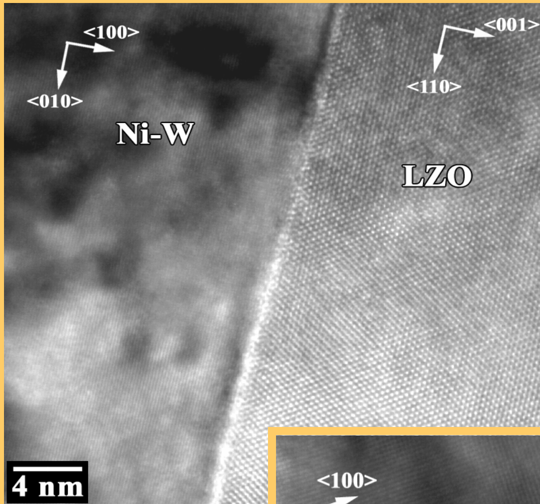


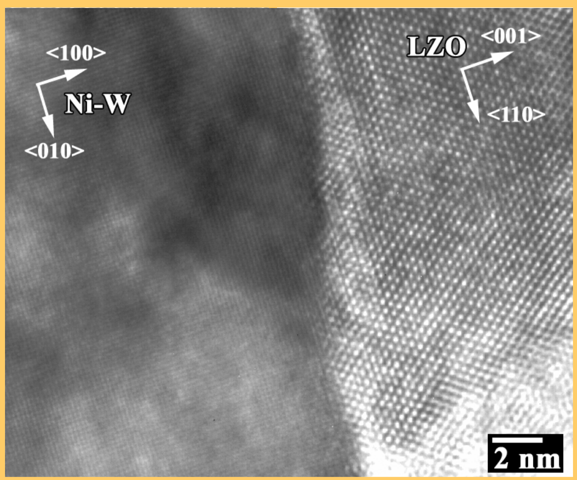
Future directions:

Two-sided coatings; wide substrates

LZO on Ni-W

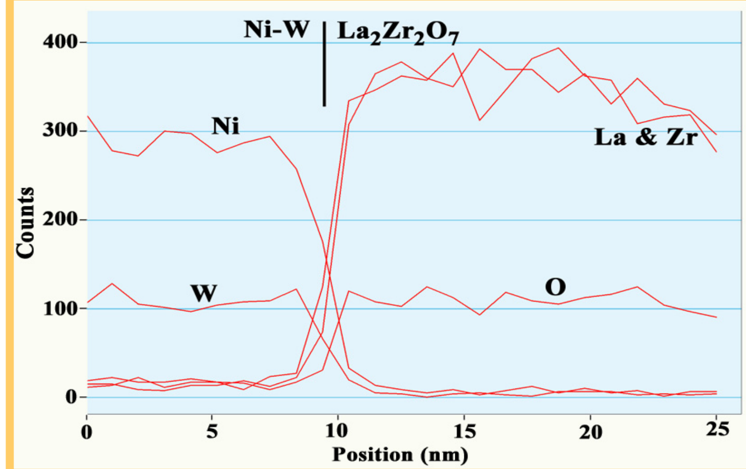
High resolution TEM images

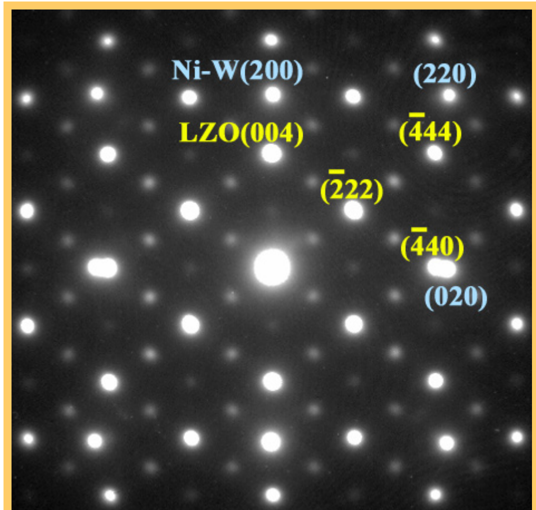




→LZO/Ni-W interface is clean and sharp

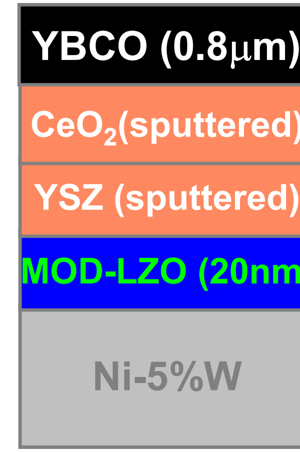
Line scale profile at LZO/Ni-W interface





SAD pattern of LZO/Ni-W indicates that LZO grows cube-on-cube texture on Ni-W

YBCO films with an I_c of 184 A/cm-w were grown on MOD LZO seeds



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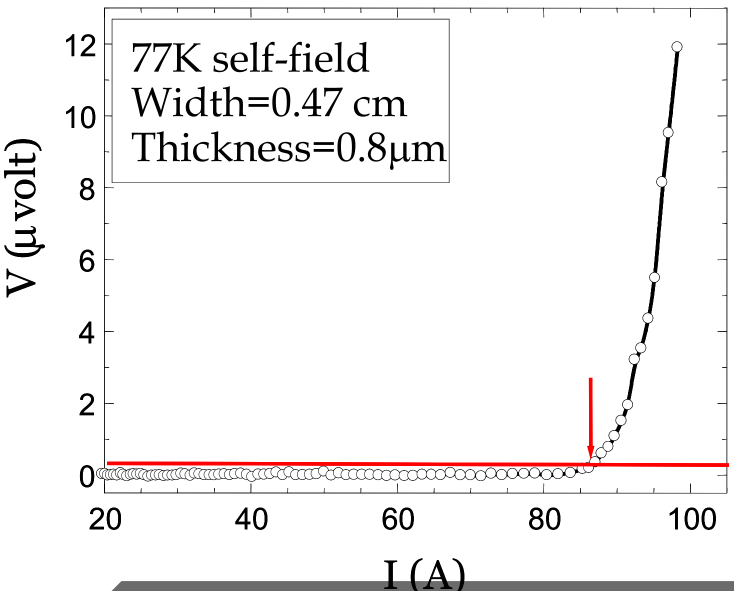
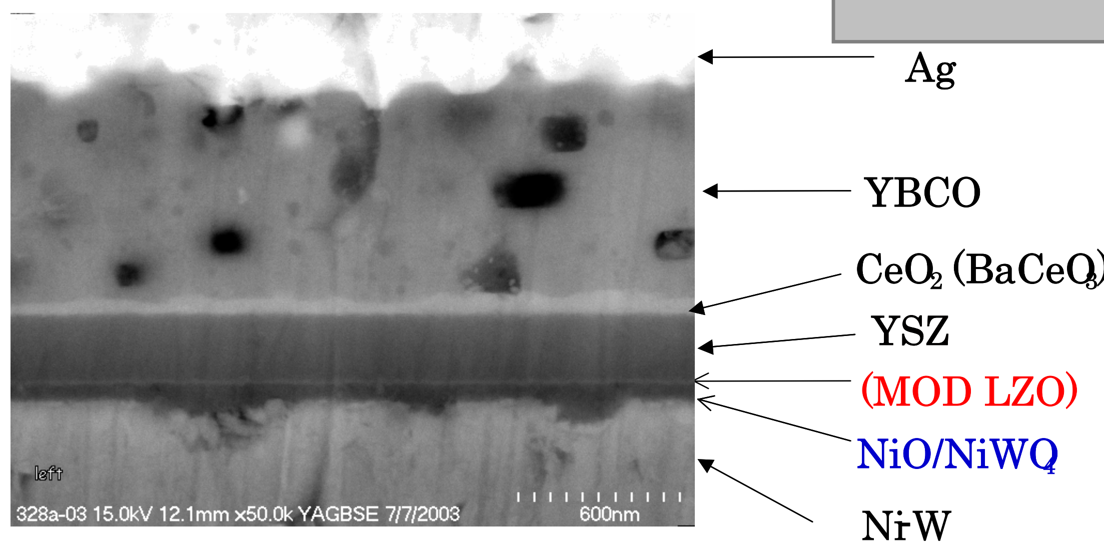
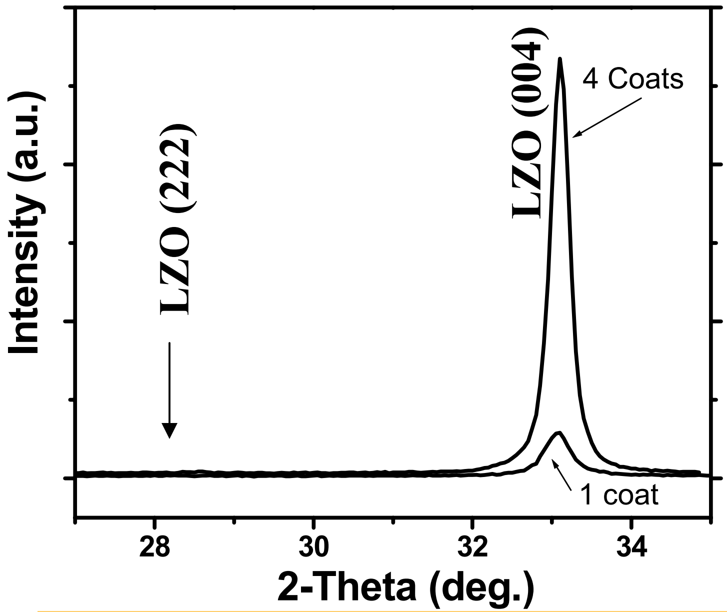




77K, sf J_c=2.3 MA/cm^2, I_c=184 A/cm-w; T_c=89.2 K, ΔT_c=1 K

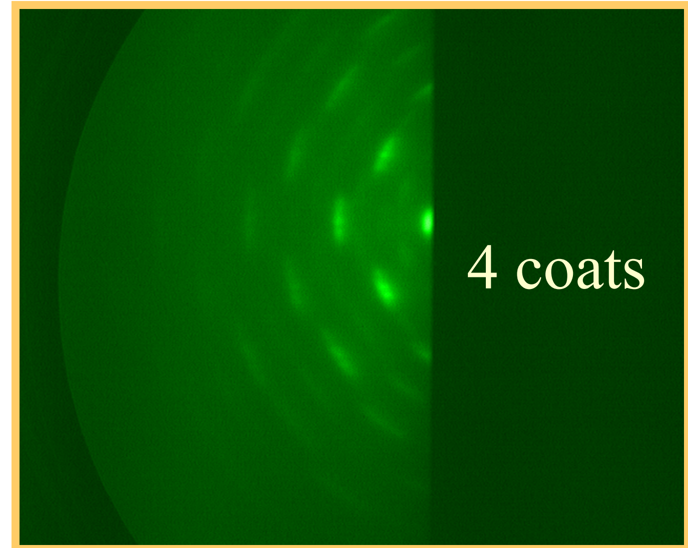
Successfully replaced e-beam Y_2O_3 seed with MOD LZO seed

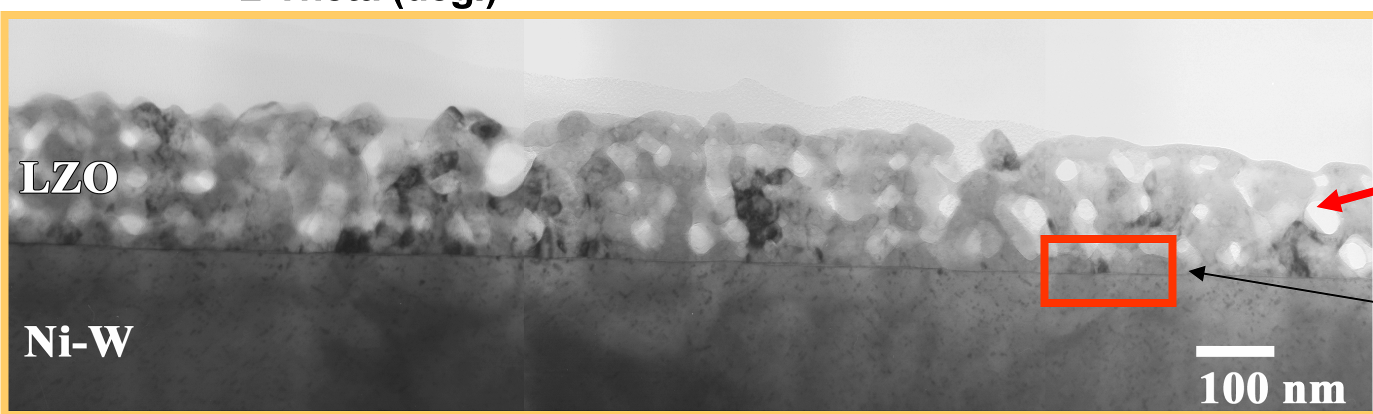
MOD LZO as Barrier Layer



→Multiple coating to produce thick buffers (80-100 nm)

→RHEED: no evidence of polycrystalline LZO at the surface





Pores but not connected

Interface is very clean

MOD LZO (4-coats)/Ni-W cross-sectional TEM image

MOD LZO as Seed and Barrier Layer

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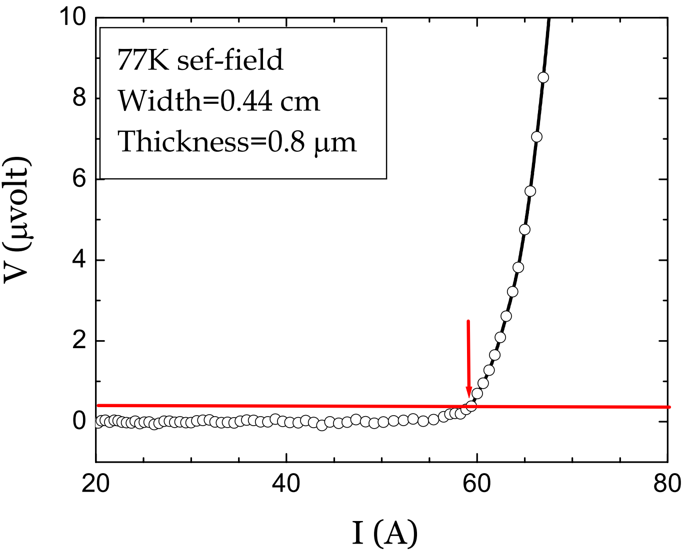
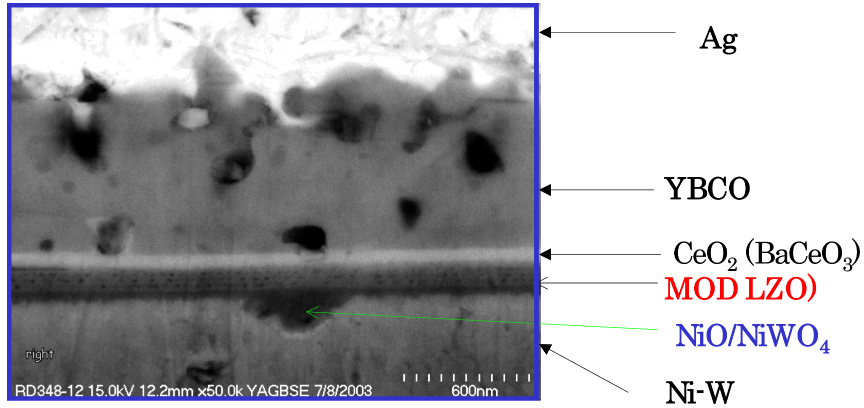
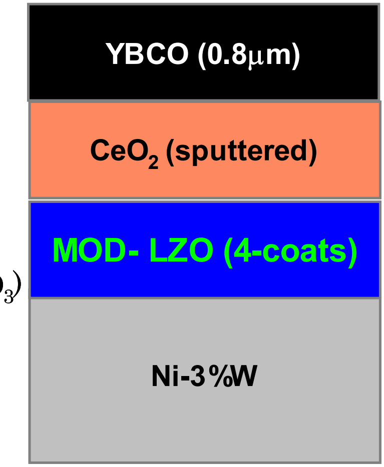




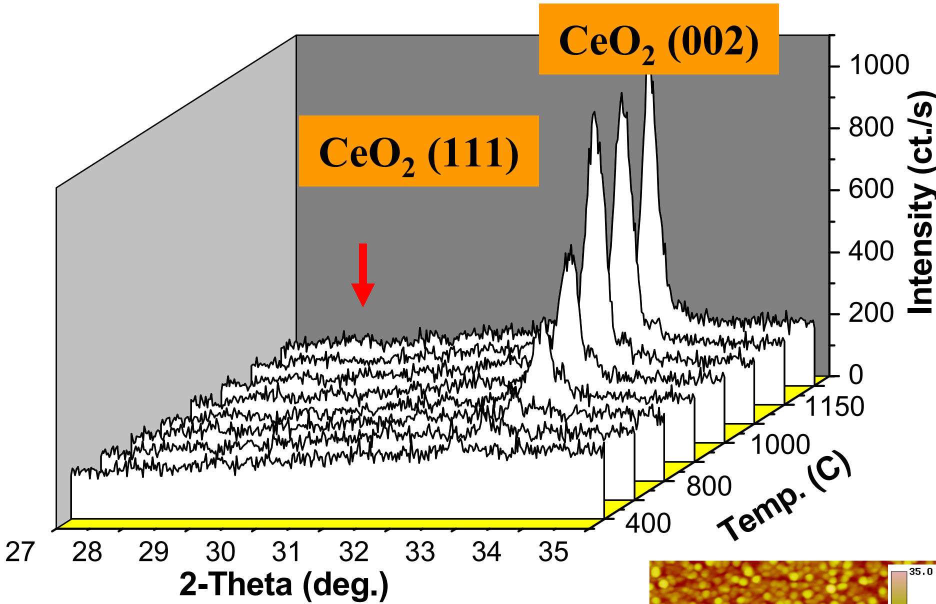


YBCO films with an I_c of 135 A/cm-w were grown on MOD LZO seed/barrier

77K, SF: J_c=1.68 MA/cm^2, I_c=135 A/cm-w; T_c=90.5 K, ΔT_c=1 K

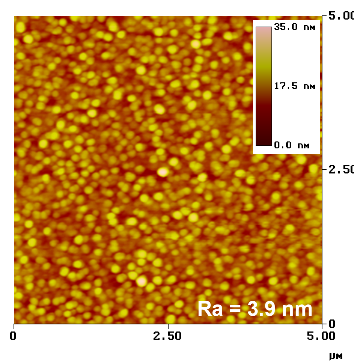
Successfully replaced both e-beam Y_2O_3 seed and sputtered YSZ with MOD LZO

MOD CeO_2 Nucleation & Growth (HT *in-situ* XRD)

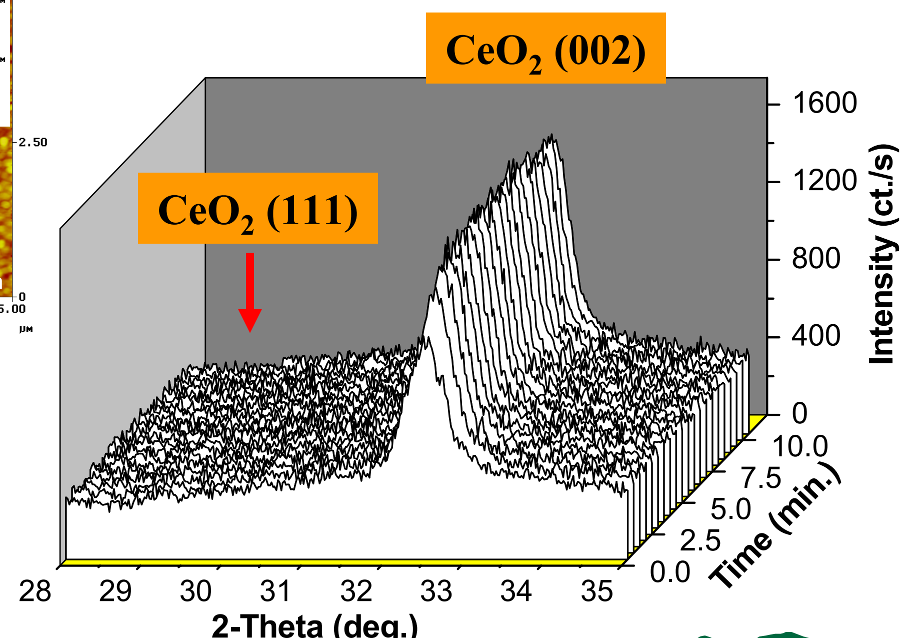


- CeO_2 nucleation studies
- XRD @ various T
- CeO_2 *(00l)* starts to nucleate @ 600 °C
- No (111) peaks observed
- CeO_2 thickness : 20 nm

AFM CeO_2 surface →



- CeO_2 growth studies
- XRD @ 1100 °C & different time
- CeO_2 (002) peak saturates @ 5 min
- (002) peak width constant after 5 min



UT-BATTELLE

YBCO films with an I_c of 141 A/cm-w were grown on MOD CeO_2 cap

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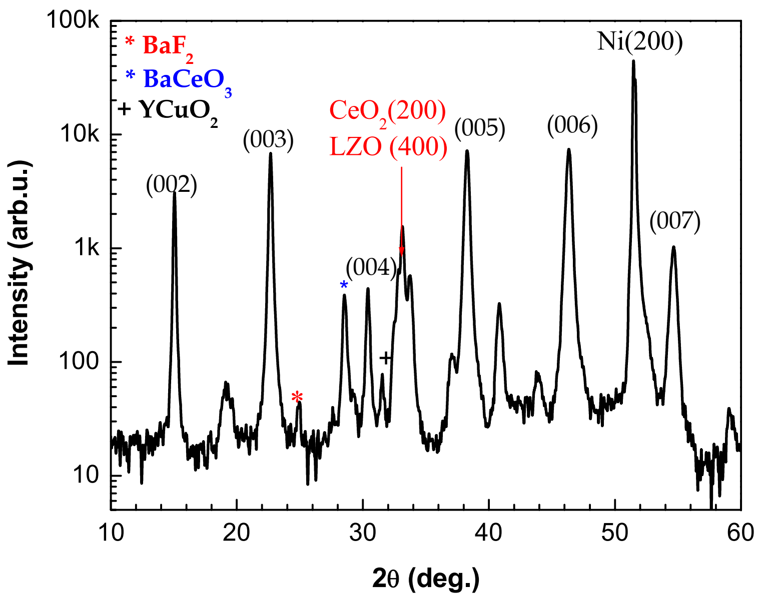
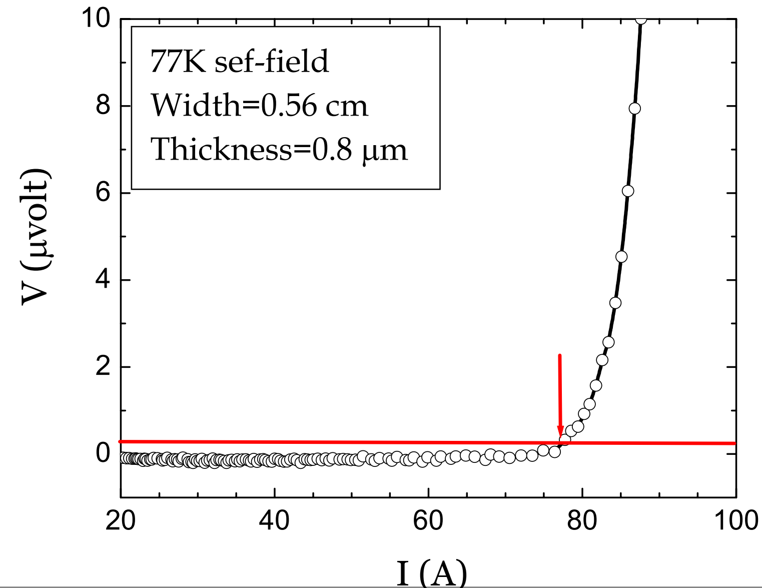
Good c-axis YBCO Epitaxial Growth

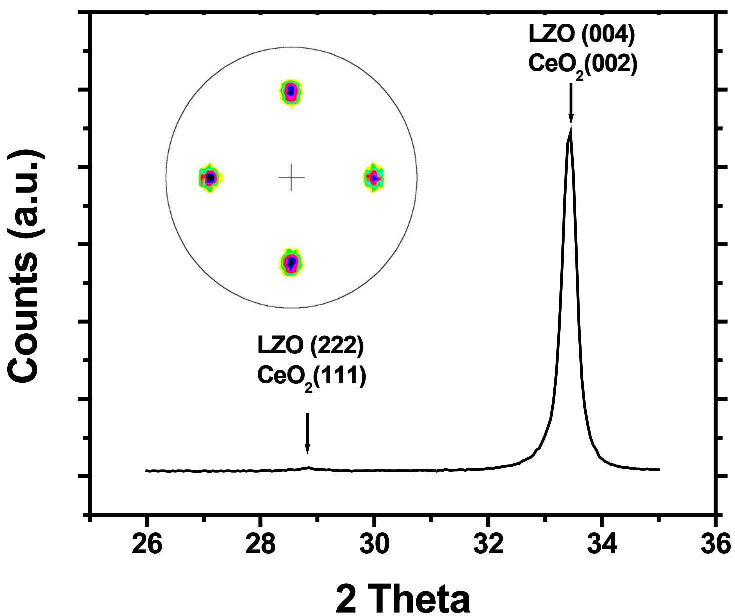




77K, SF: J_c=1.76 MA/cm², I_c=141 A/cm-w; T_c=88.4 K, ΔT_c=1.2 K

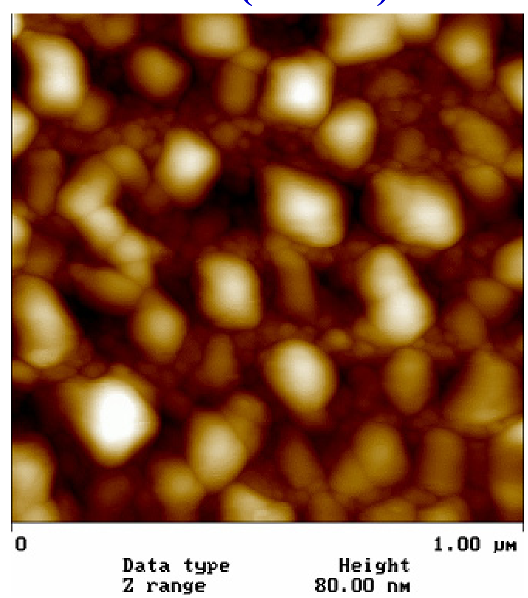
This demonstration shows that MOD CeO_2 cap is compatible with MOD YBCO

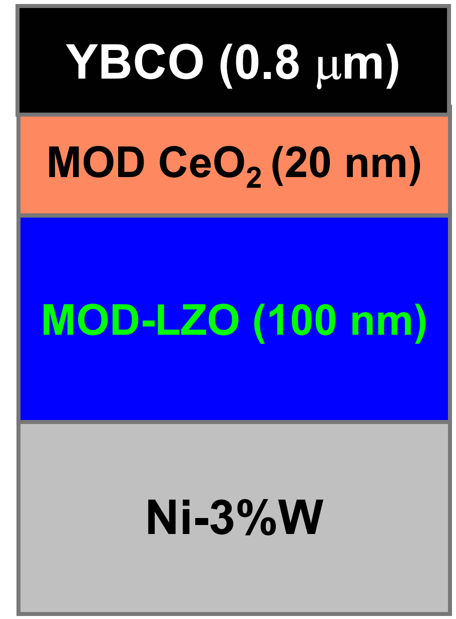
All MOD buffers with CeO_2/LZO/Ni-3%W substrates



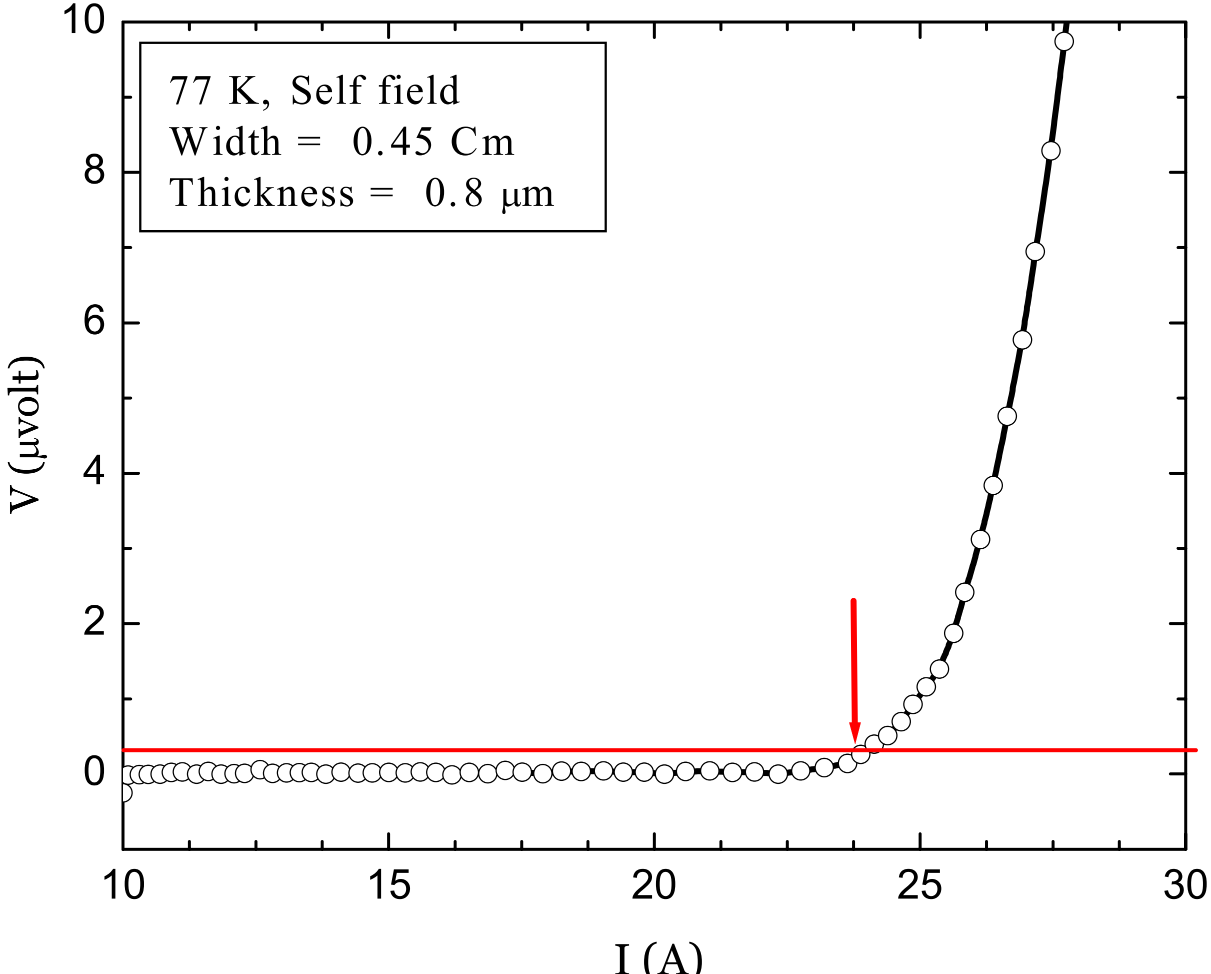
X-ray data on CeO_2/LZO/Ni-W

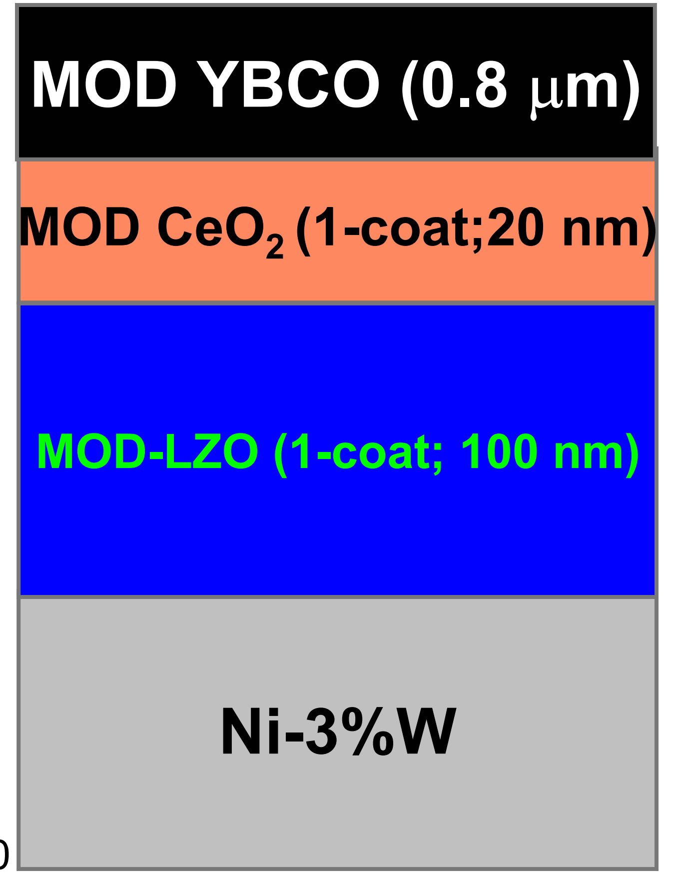
AFM of MOD CeO_2 surface on MOD LZO (2 coats)/Ni-3%W





A J_c of 600,000 A/cm^2 was achieved on on all MOD buffers and YBCO conductors





77K, SF: J_c =0.6 MA/cm^2, I_c=45 A/cm-w

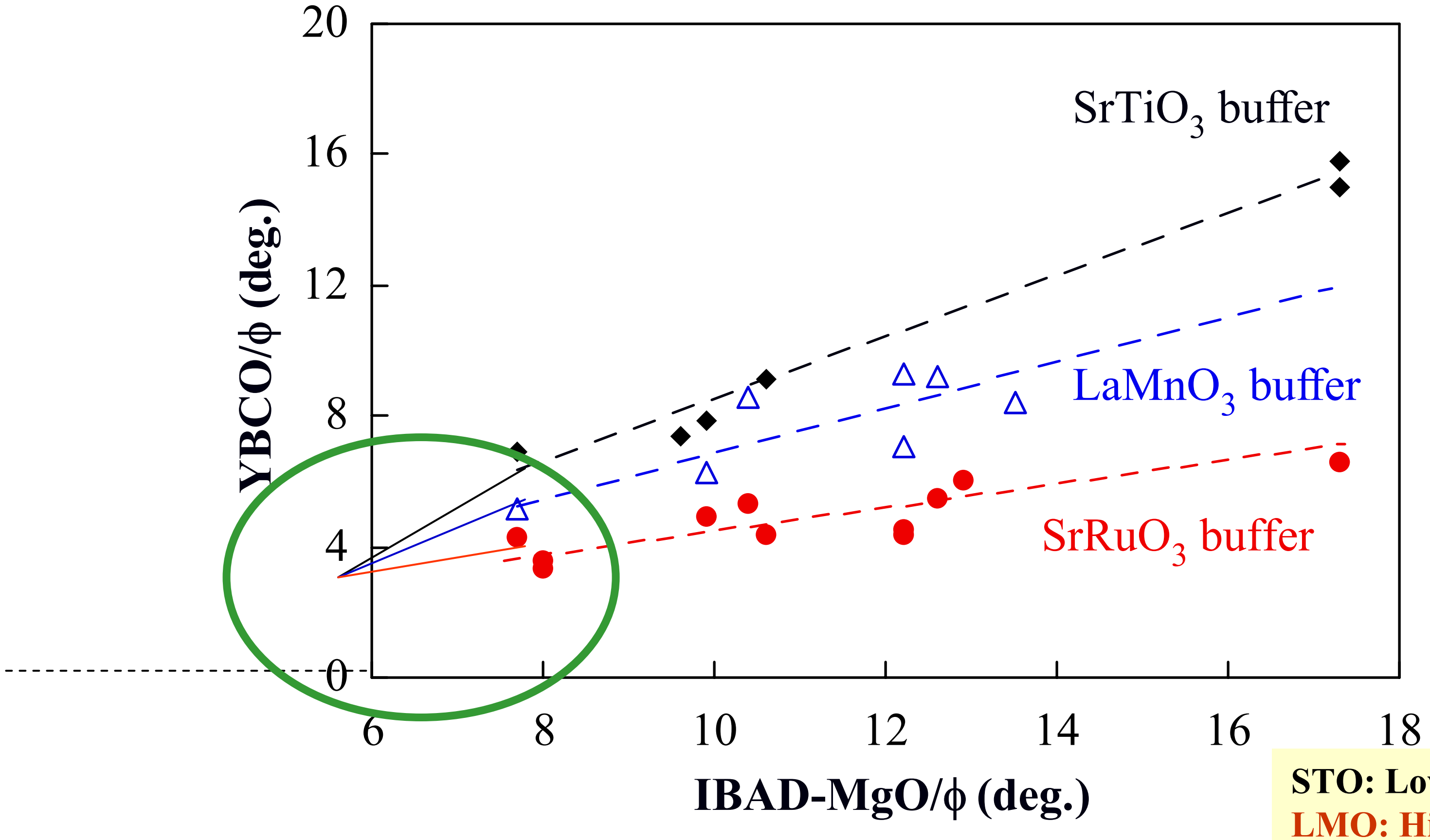
Summary

- Successfully developed methods to produce LZO seed and barrier layers and CeO_2 cap layers
- Successfully replaced Y_2O_3 and YSZ with MOD LZO
- MOD YBCO films were grown on solution buffers
  - Ic 184 A/cm-w CeO_2/YSZ/MOD LZO/Ni-W
  - Ic 135 A/cm-w CeO_2/MOD LZO/Ni-W
  - Ic 141 A/cm-w MOD CeO_2 cap/std. RABiTS
- J_c of 600,000 A/cm^2 on all solution YBCO and buffers was achieved

Developed $LaMnO_3$ Buffers for MgO-IBAD & MgO-ISD Substrates

- IBAD-MgO (LANL)
  - $LaMnO_3$ buffers are highly compatible
  - High I_c YBCO films were grown on $LaMnO_3$ buffers
    - Both PLD YBCO and Ex-situ MOD YBCO (with CeO_2 cap)
- ISD-MgO (ANL)
  - $LaMnO_3$ grows cube-on-cube
  - PLD YBCO films are tilted; J_c of 250,000 A/cm^2 at 77 K so far
  - PLD YBCO films are c-axis aligned (ANL) on CeO_2 layers; Developing the CeO_2 cap layers for $LaMnO_3$/ISD-MgO (in progress)

$SrTiO_3$, $LaMnO_3$, and $SrRuO_3$ buffers for IBAD-MgO substrates



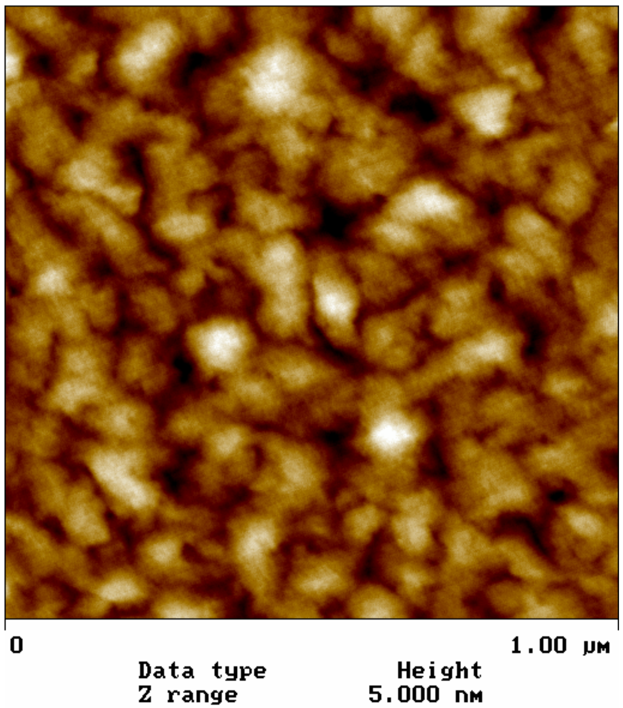
Jia *et al*., Appl. Phys. Lett. **81**, 4571 (2002).

STO: Low deposition rate
LMO: High deposition rate
SRO: Expensive & target preparation is difficult

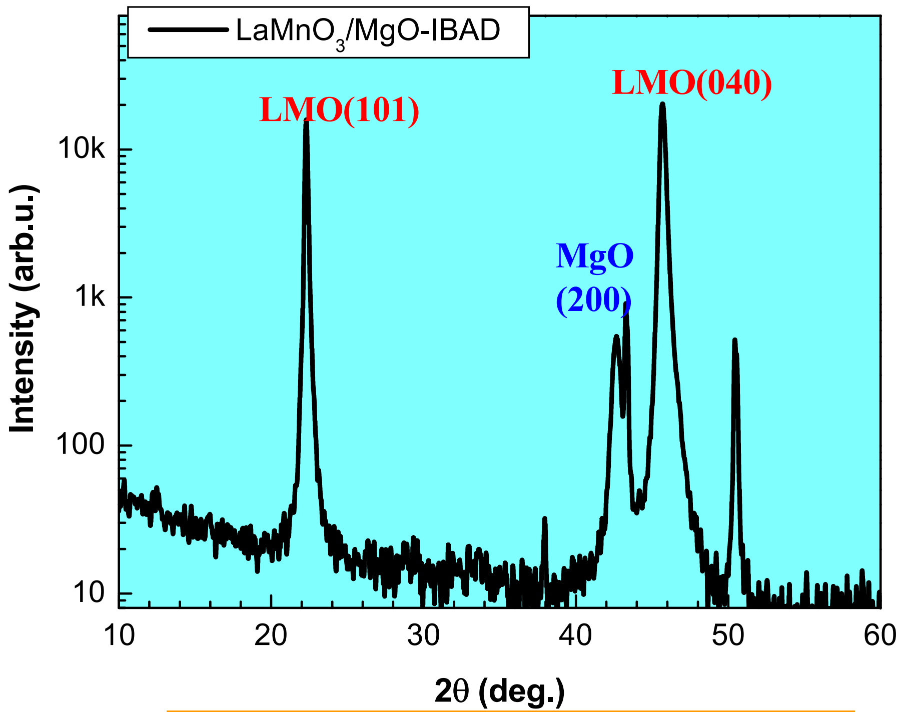
Highly textured and smooth $LaMnO_3$ buffers on IBAD-MgO

$LaMnO_3$/MgO-IBAD: Surface and Texture

- rf sputtered LMO: H_2O/Ar, T=650-750 ° C, t ~250 nm



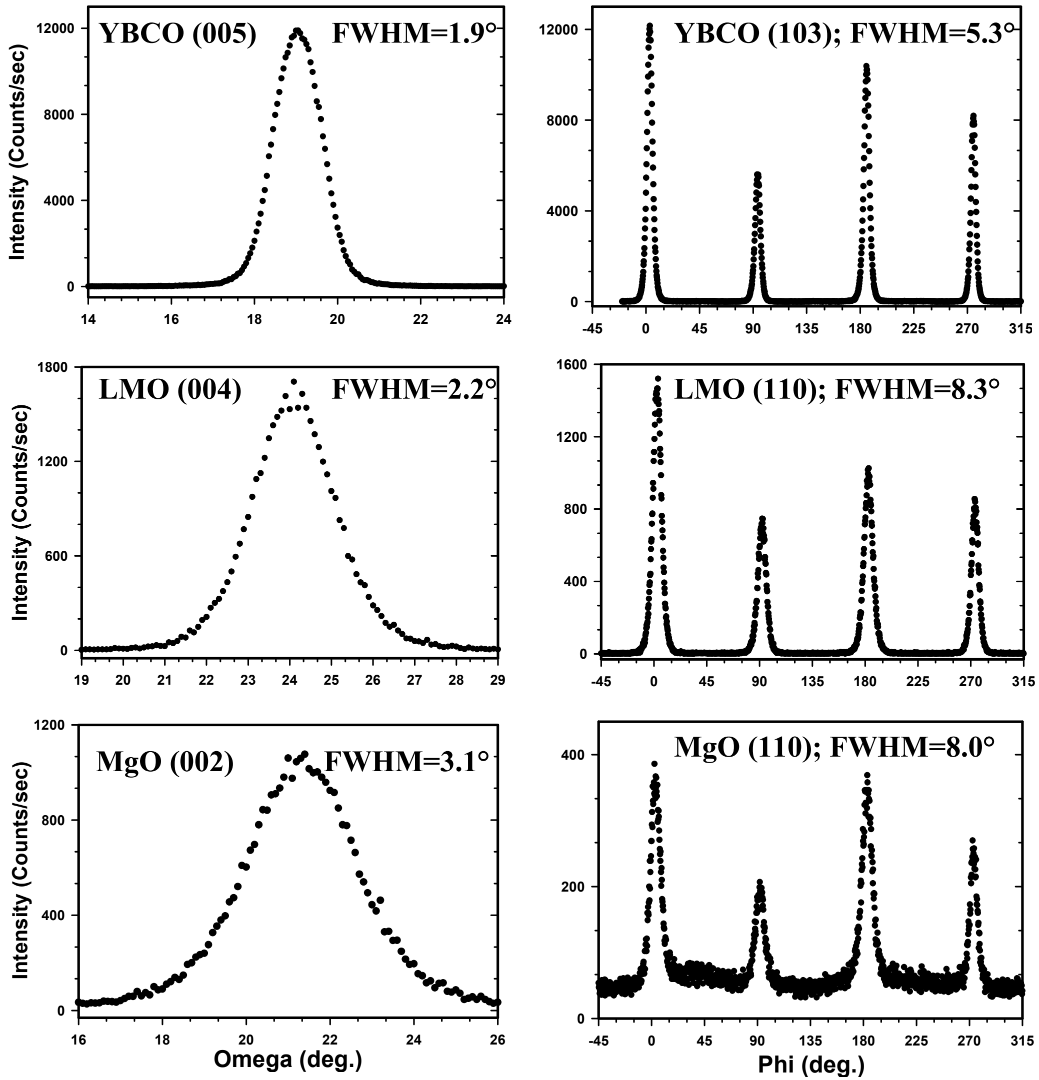
RMS = 0.75 nm

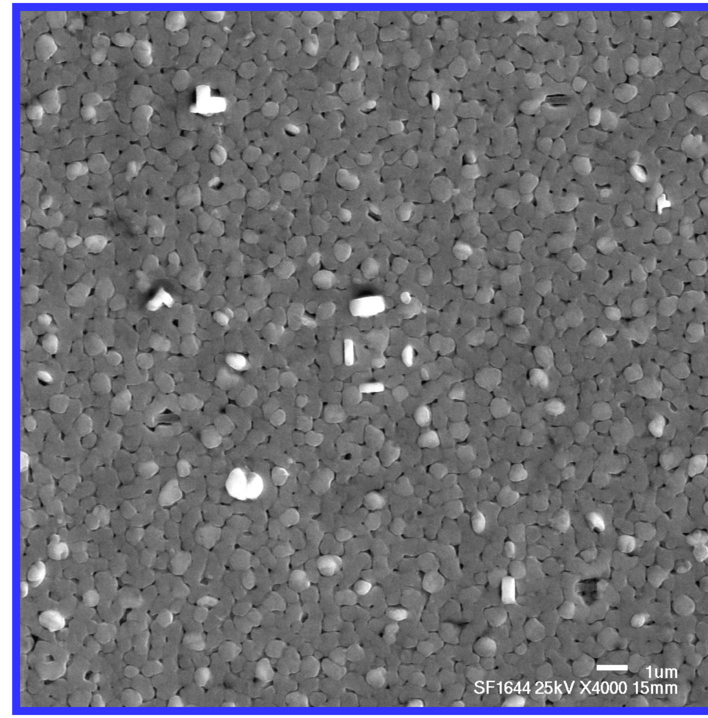


$\Delta\phi_{LMO(112)}$ =6.5°

$\Delta\omega_{LMO(004)}$ =2°

High Ic of over 230 A/cm achieved on PLD YBCO films deposited at LANL on LMO buffered IBAD-MgO substrates





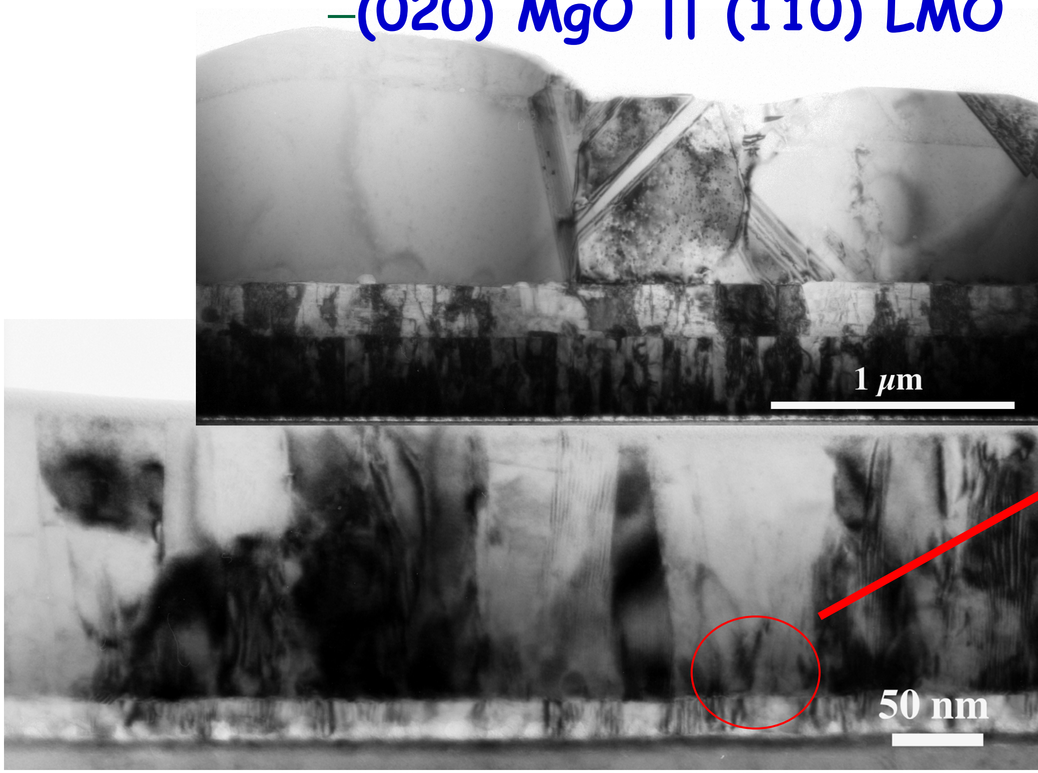
Thick YBCO films with dense microstructures were produced using PLD

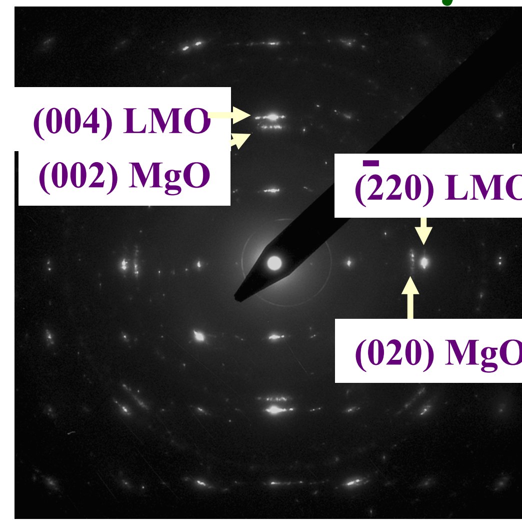
Steve Foltyn

M. Paranthaman et al. JMR (in press)

YBCO / $LaMnO_3$ / Homoepi MgO / IBAD MgO / amorphous Y_2O_3 seed / Al_2O_3 barrier / Ni-alloy

- Alignment of $LaMnO_3$ on IBAD MgO
  - [100] MgO || [110] LMO
  - (020) MgO || (110) LMO



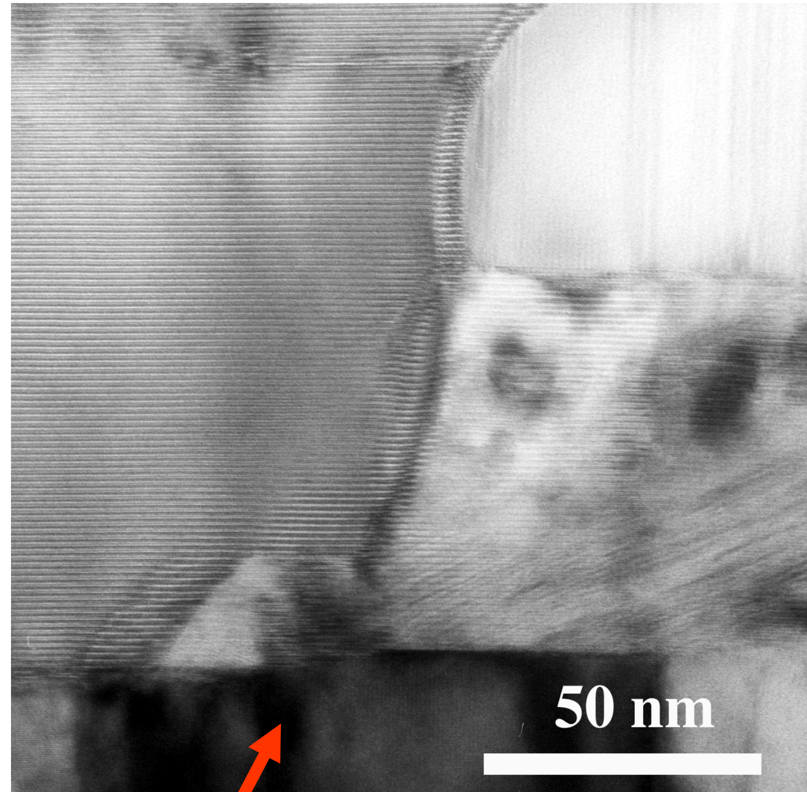


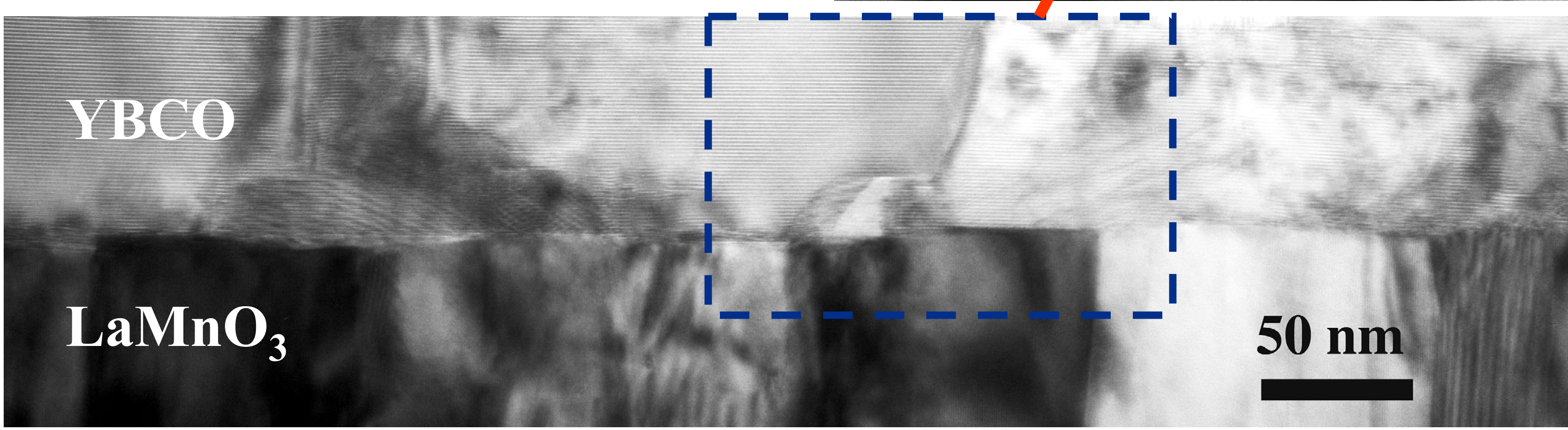
→Clean interface between the PLD YBCO and $LaMnO_3$ buffer layer

$YBCO/LaMnO_3$/IBAD-MgO/Ni-alloy

PLD YBCO

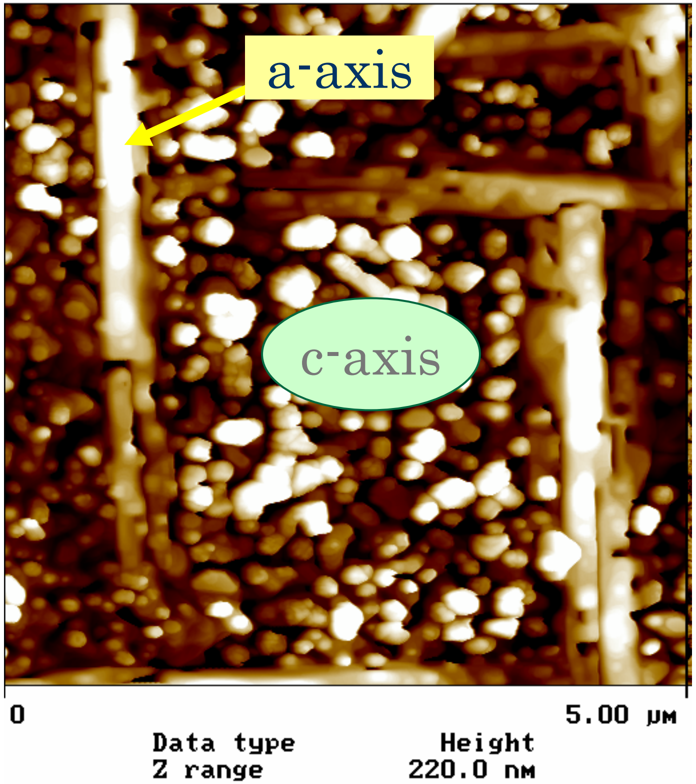
Sputtered $LaMnO_3$

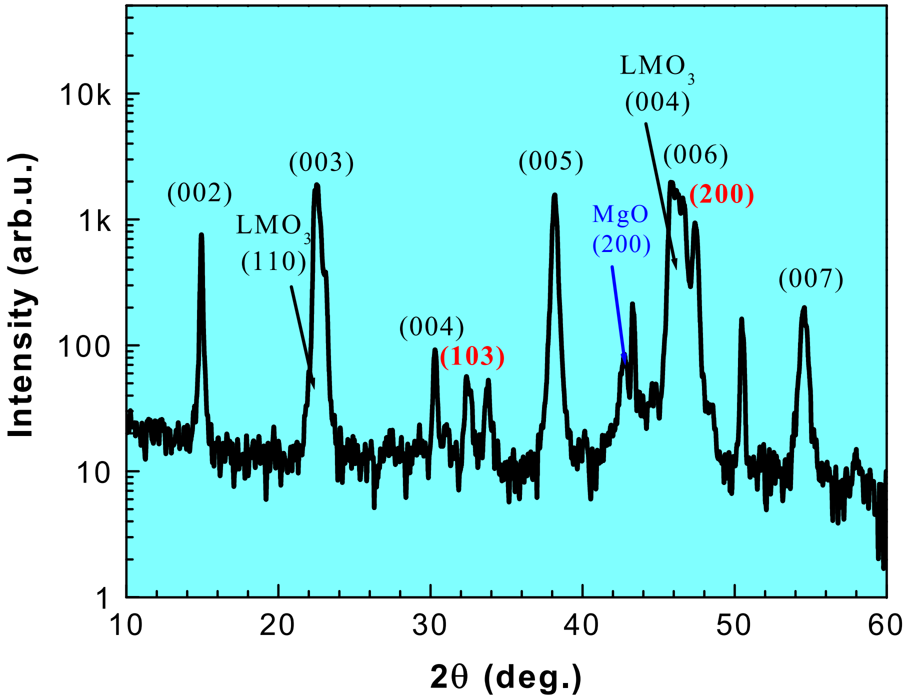




Terry Holesinger

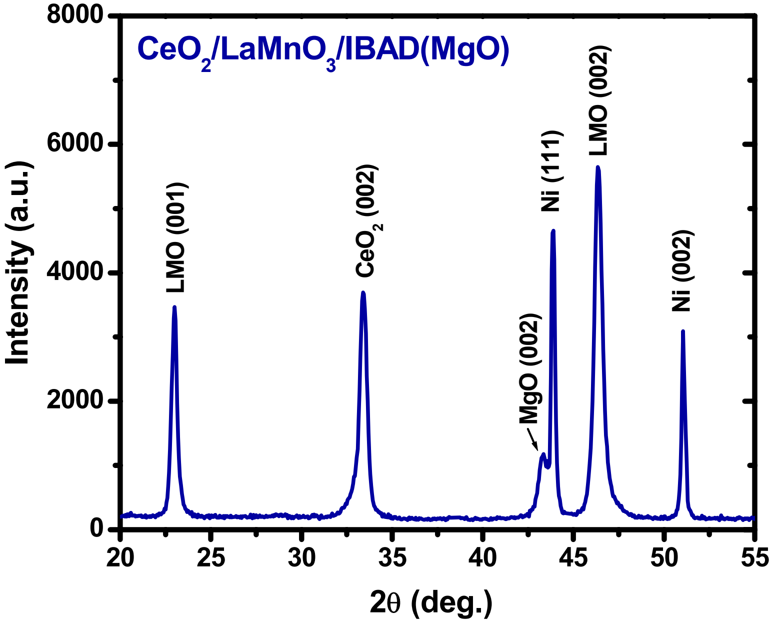
MOD-YBCO/$LaMnO_3$/MgO-IBAD: *a-axis YBCO*

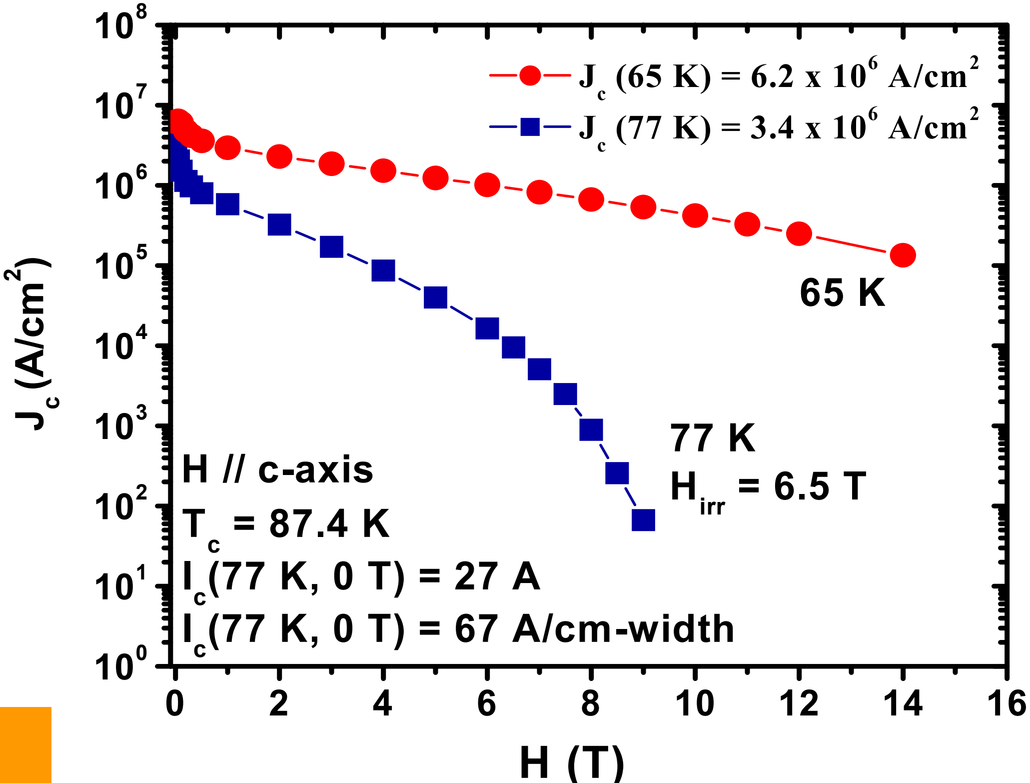


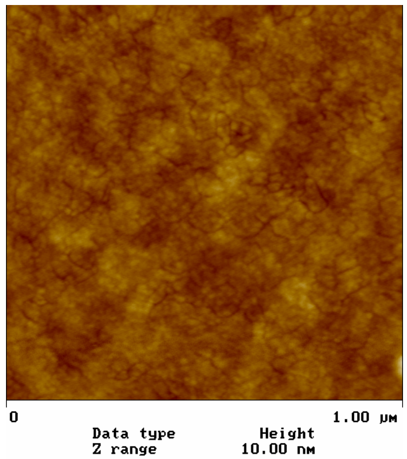


Mixture of a-axis and c-axis grains of YBCO on LMO/MgO-IBAD using TFA-MOD conversion

Sputtered CeO_2 cap layers were developed







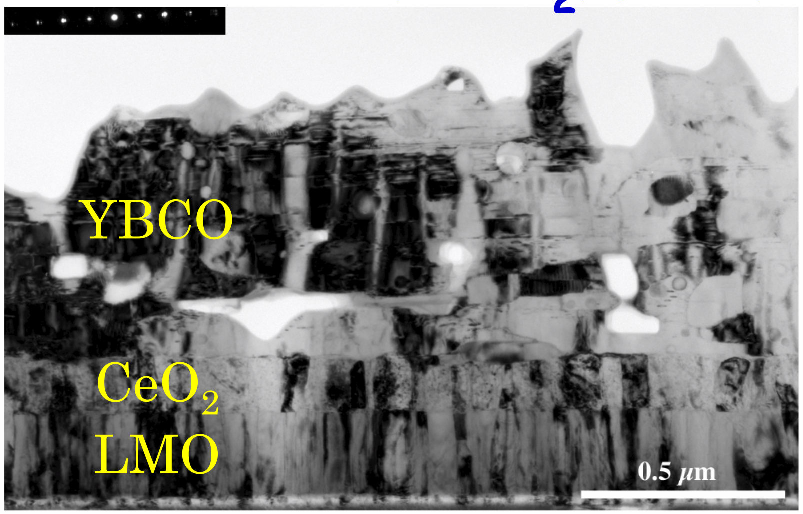
$\Delta\phi_{111}$~5.5°
$\Delta\omega_{002}$~1.8°

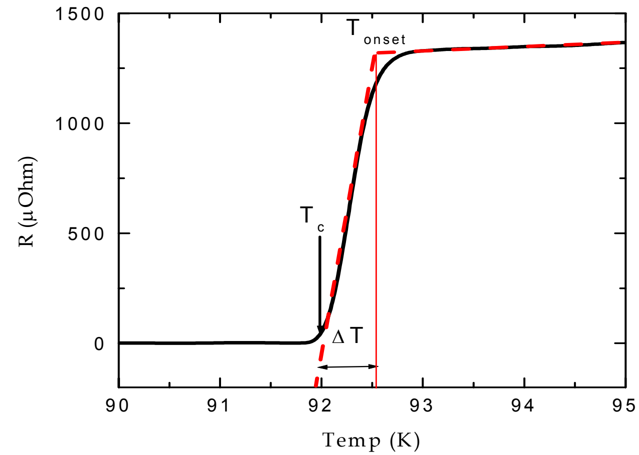
CeO_2/LMO
RMS=0.45 nm

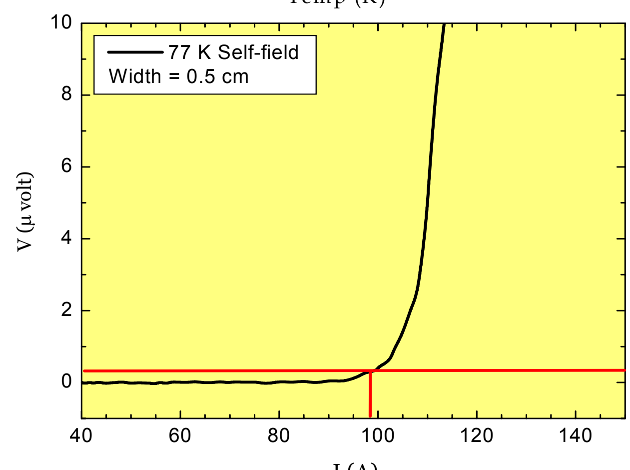
- Smooth CeO_2 layers were deposited on LMO buffered MgO-IBAD
- Achieved a J_c of 3.4 MA/cm^2 on CeO_2 cap (PLD YBCO)

Achieved High I_c MOD YBCO Films on CeO_2/LMO Buffers

YBCO/CeO_2/LMO/MgO-IBAD







Texture evolution

YBCO: $\Delta\phi_{103}$= 2.5° ; $\Delta\omega_{005}$= 2.5°

CeO_2: $\Delta\phi_{111}$ = 5.5° ; $\Delta\omega_{002}$ = 1.8°

LMO: $\Delta\phi_{110}$ = 6.5° ; $\Delta\kappa_{004}$ = 2°

J_c (77K) = 2.2 MA/cm², I_c=194 A/cm-w, T_c=92K, ΔT_c=0.5K

FY2003 Performance/Outline

- **FY 2003 Results**

  Reactive sputtering of YSZ buffers (Parans)
  Solution buffer layer development for YBCO
  Compatible-buffer-layer development for MgO-based tapes (*LANL* IBAD MgO & ANL ISD MgO)

  Buffer layer development for Cu substrates (Claudia)

- **FY 2003 Performance and FY 2004 Plans (Claudia)**
- **Research Integration**

Development of suitable buffer layers for Cu-based RABiTS

C. Cantoni, T. Aytug, J. R. Thompson, M. Varela, H.Y. Zhai,
A. A. Gapud, D. K. Christen *(ORNL,CMSD)*
A. Goyal, E. D. Specht, S. Kang, Y. Xu *(ORNL,M&C)*
M. Paranthaman *(ORNL, CSD)*

Collaborations:

K. Kim, D. P. Norton *University of Florida*
C. Thieme, U. Schoop *AMSC Crada* **NEW !**

Project Objectives

- Reduce costs of CC's
  - less expensive metal substrate (40% of total CC cost)
- Improve performance in ac field
  - non-hysteretic substrate
- Improve J_E
  - electrical coupling between buffer and low-resistivity substrate

Approach

- identify issues (e.g.: poor Cu oxidation resistance, sulfur-mediated epitaxy, etc.)
- use controlled experiments and high quality characterization to single out and solve specific problems (eg.: rapid Cu diffusion, high Cu thermal expansion, role of GB's, interfacial reactions)
- work on textured tapes to address specific substrate requirements
- address requirements for all-conductive architectures and FM losses

Project milestones

✓ high J_c and clean interfaces on prototype single-crystal samples (2002)

✓ high J_c on textured pure Cu tapes (2003)

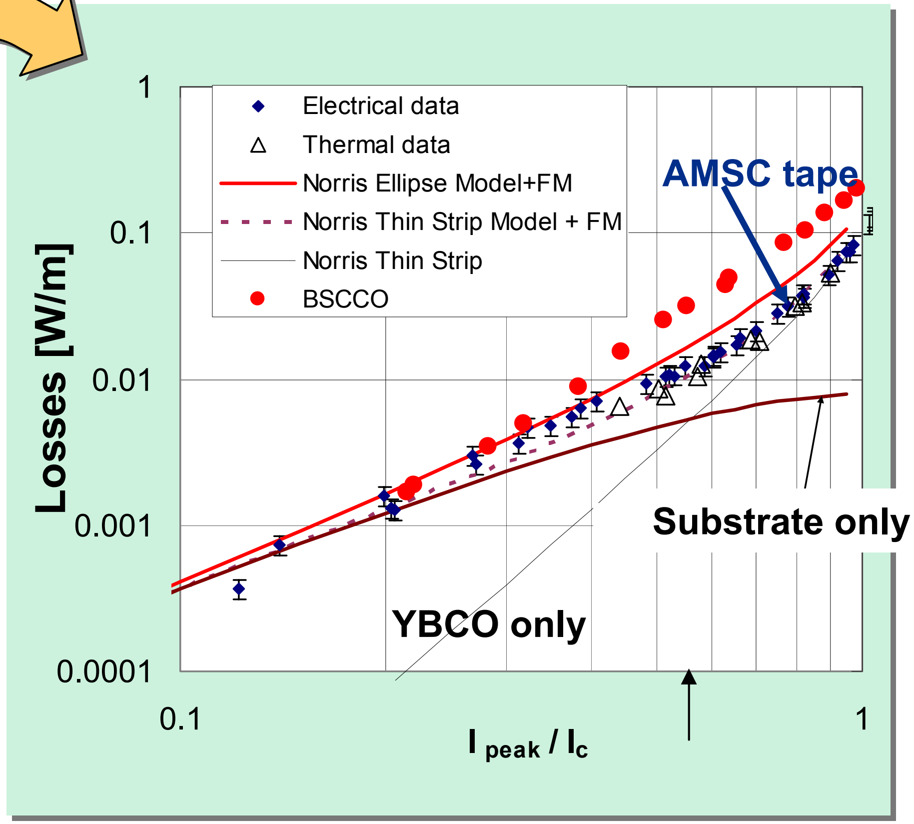
✓ high J_c on textured Cu alloys (2003)

- high I_c on 1μ-thick YBCO on Cu or Cu-alloy (2004)
- all-conductive structure with low interfacial resistivity (2005)

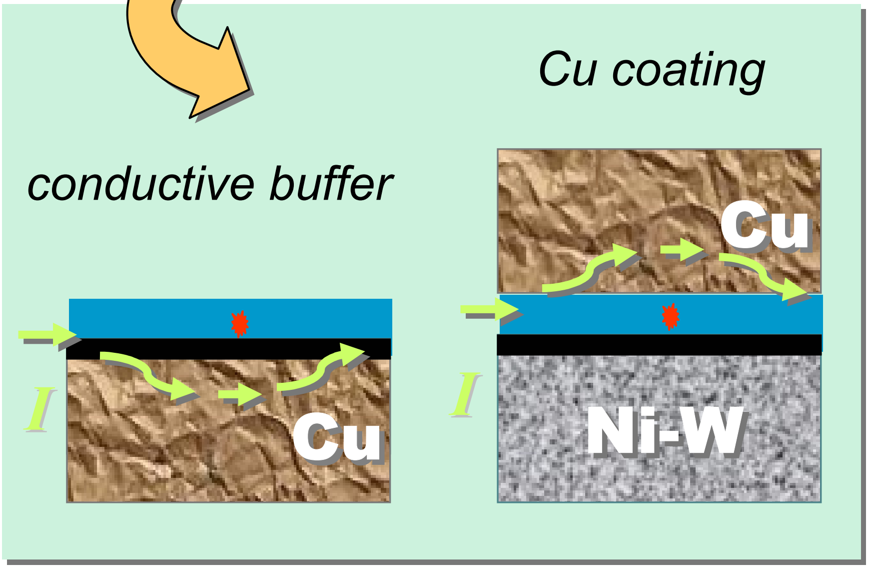
Motivation for Cu-based RABiTS:

advantages

- ✓ **No ferromagnetic losses**
- ✓ **less expensive** (up to 6 time for a commercial alloy)
- ✓ **high thermal conductivity**
- ✓ **high electrical conductivity**

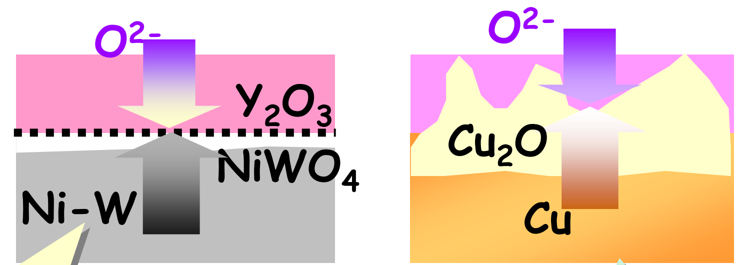


Duckworth, MURI Review, June 2003



UT-BATTELLE

Challenges



Ni diffusion barrier limits NiO growth

High Cu diffusion leads to detrimental Cu-O growth

☹ **rapid oxidation**

☹ **high ionic diffusion**

- *residual strain in buffers and YBCO*
- *substrate bowing*
- *strengthening by alloying/precipitates*

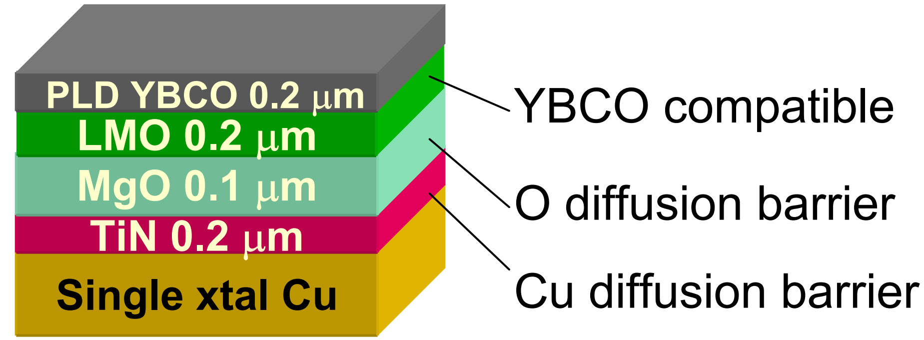
☹ **high thermal expansion**

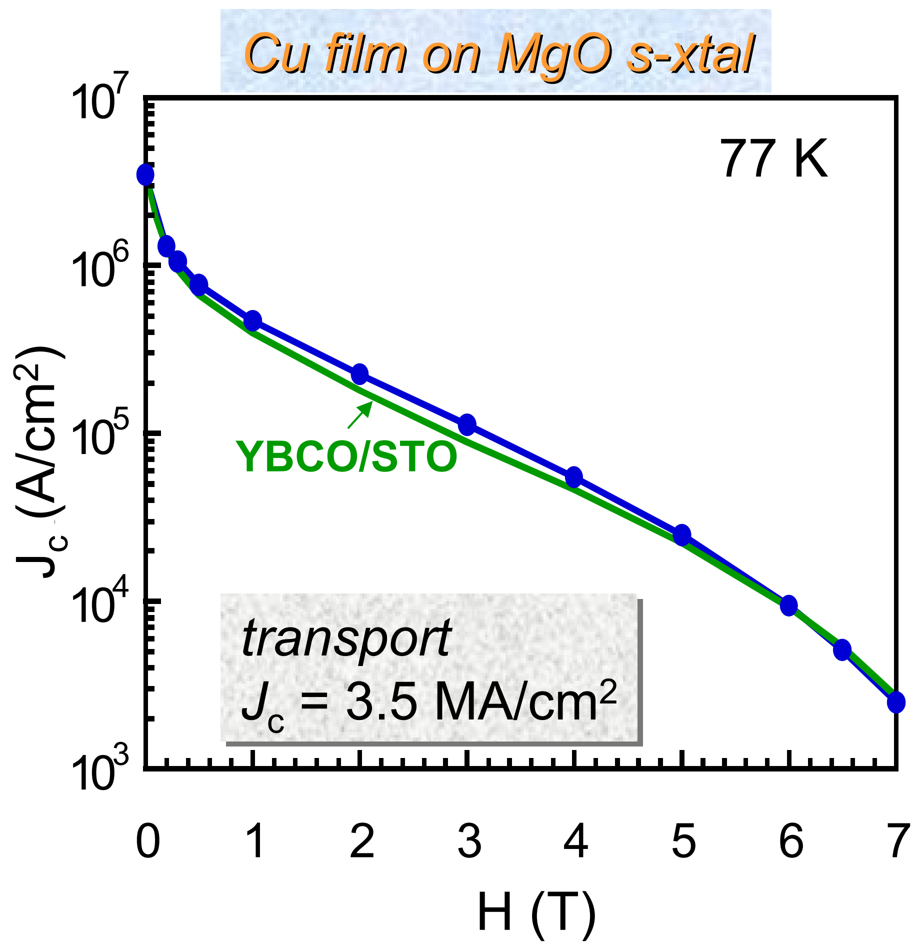
☹ **soft**

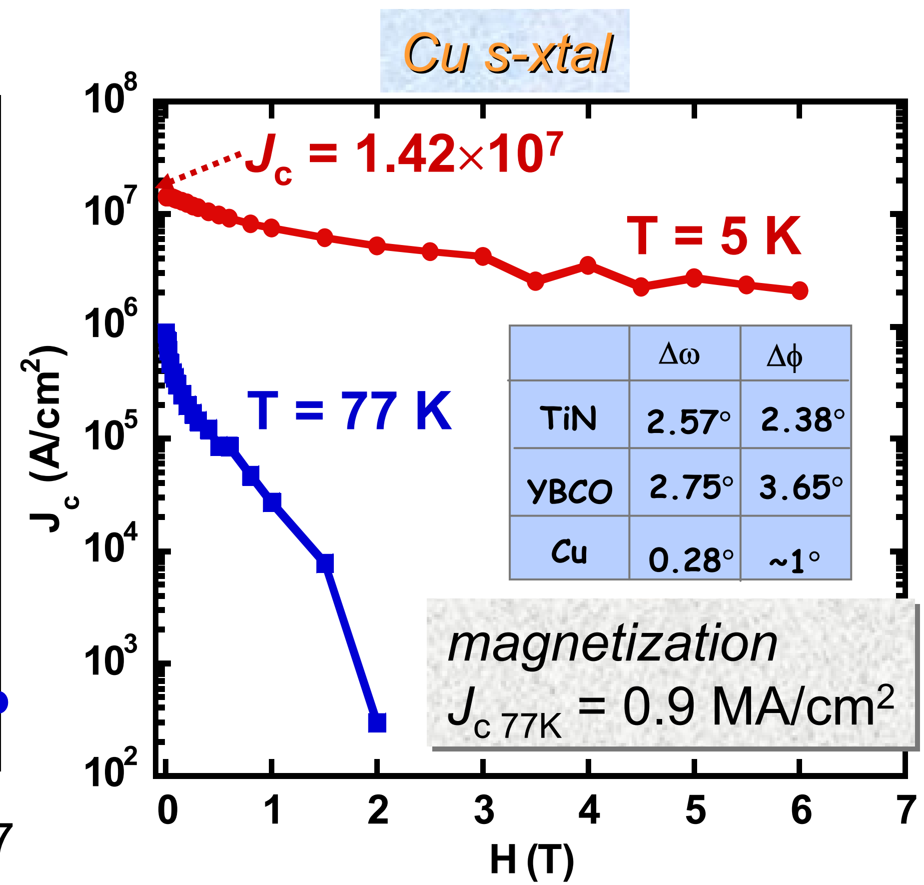
☹ **direct epitaxy only with NaCl type structure on clean surface (TiN, MgO)**

- *Alternative approach: metal overlayers*

Last year results

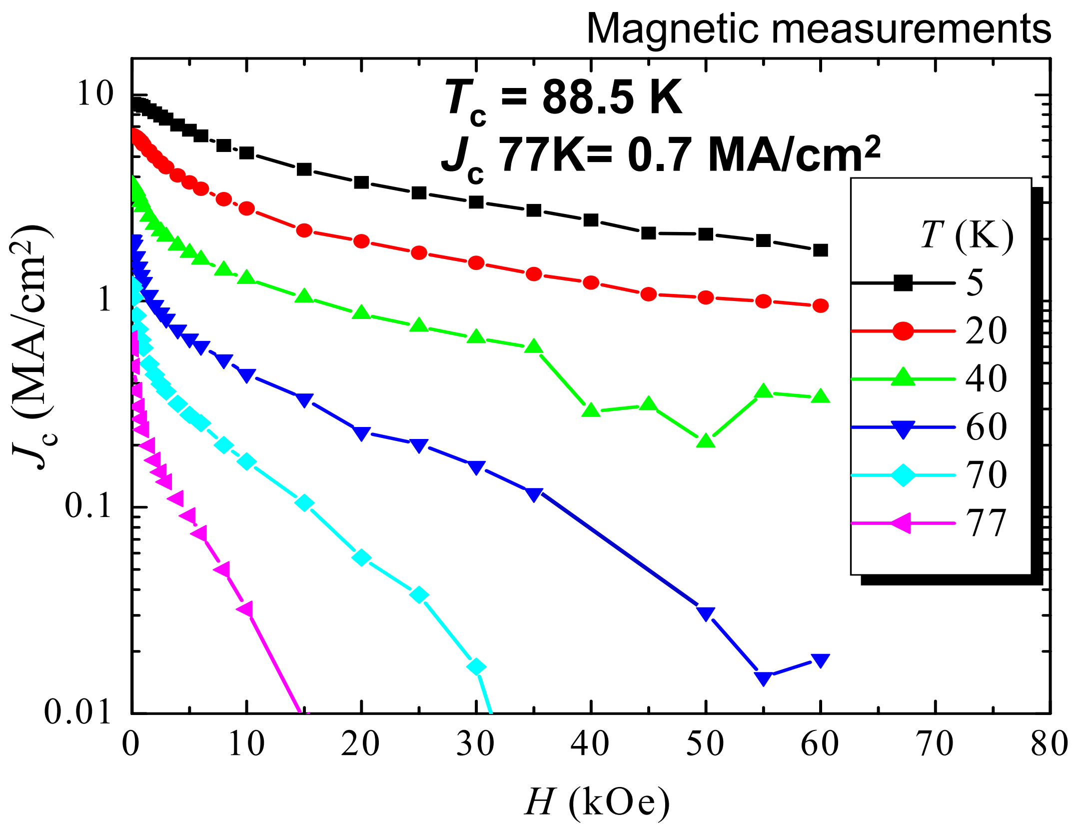


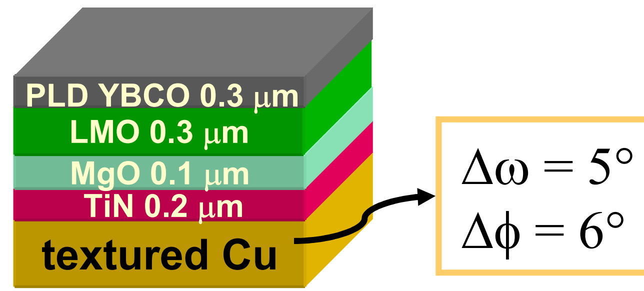


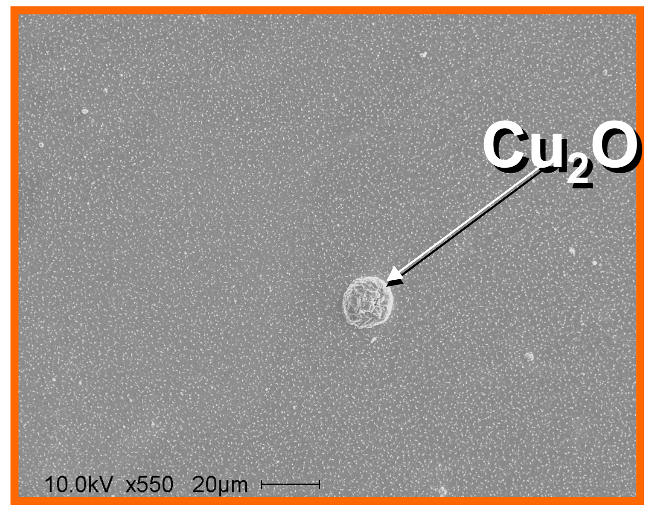


	Δω	Δϕ
TiN	2.57°	2.38°
YBCO	2.75°	3.65°
Cu	0.28°	~1°

2003 Results on pure textured Cu tape







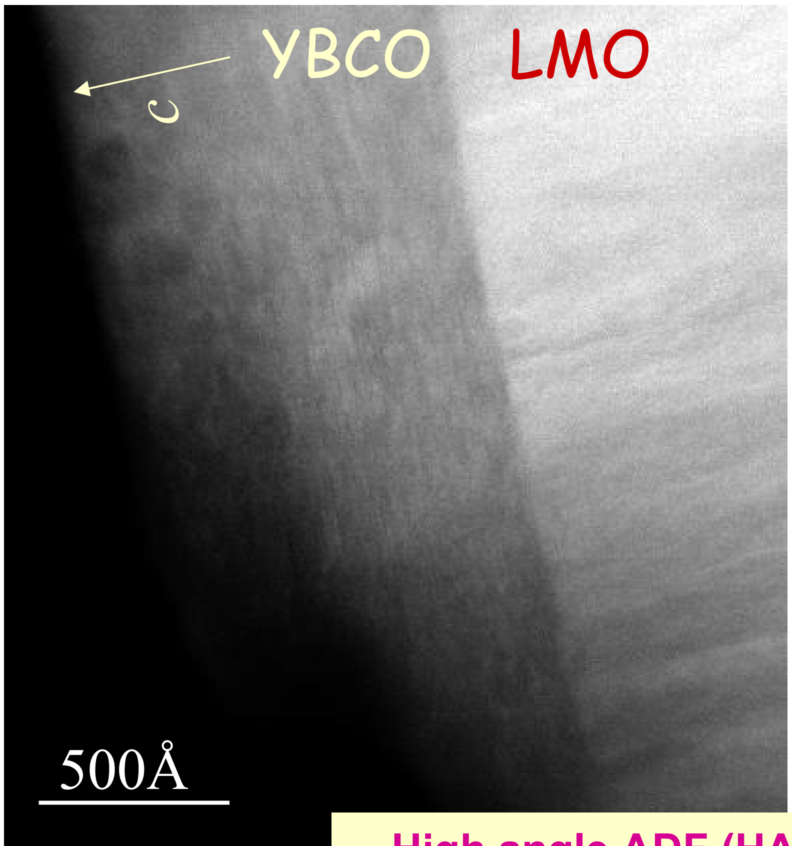
non-optimal transport properties due to:

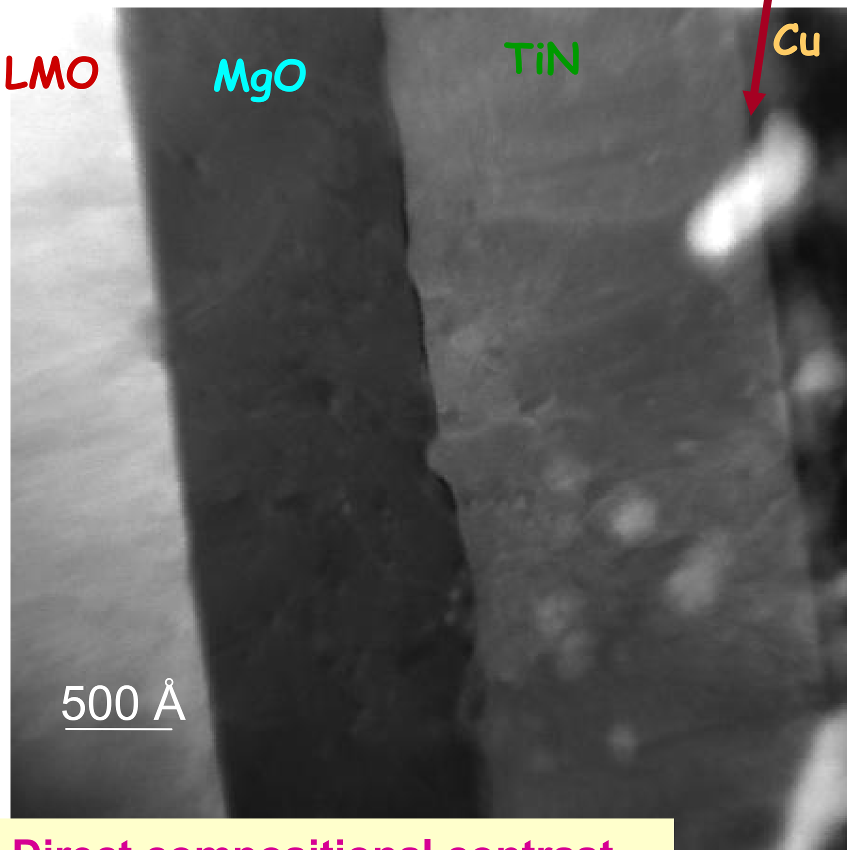
- *Buffers are not sufficient barrier to Cu and O diffusion?*
- *Strain in YBCO?*
- *Structure/morphology problems in buffers?*
- *Cu preferential diffusion through GB's?*

What can be learned from single crystals experiments

EELS detects no O

Interfaces are clean: no unwanted oxides or interdiffusion

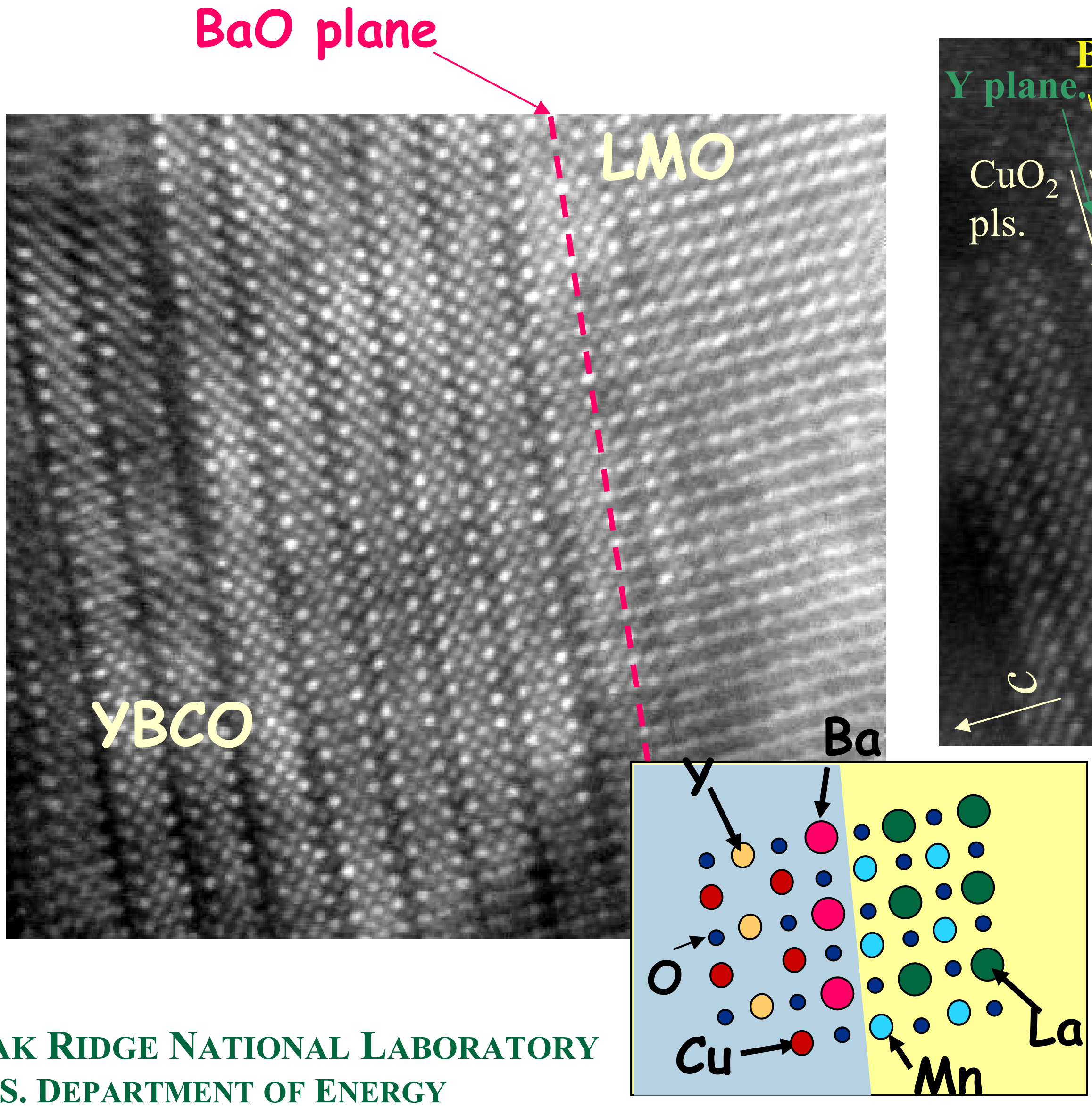


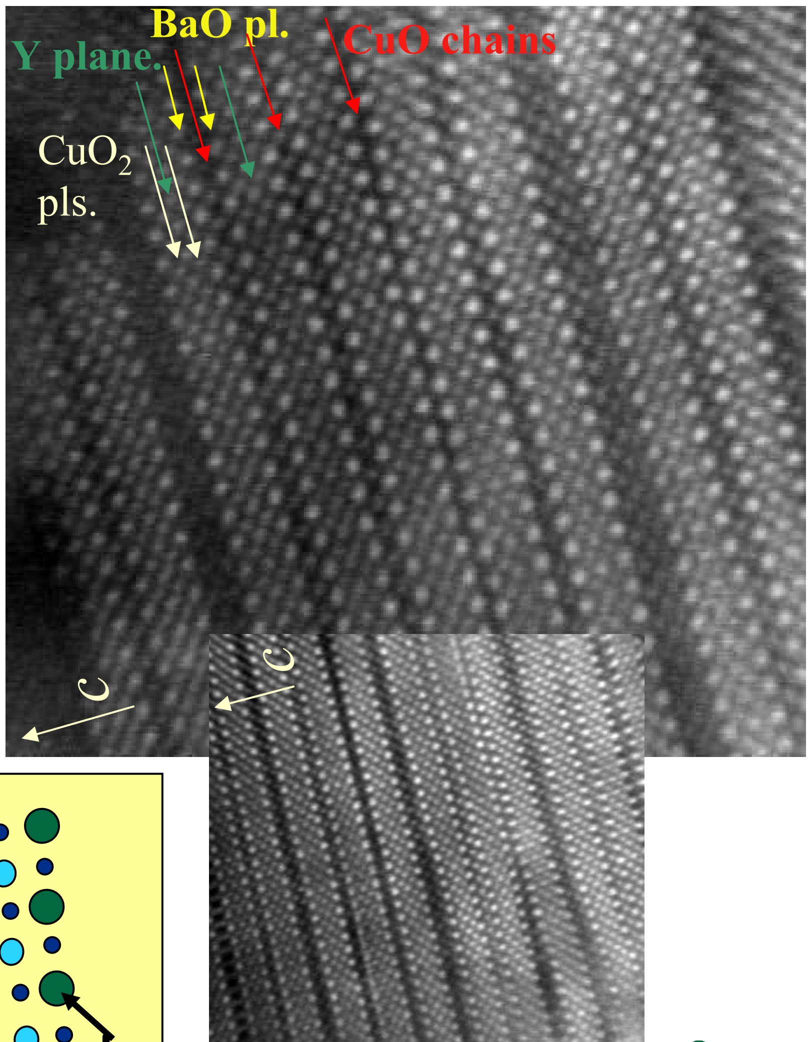


High angle ADF (HAADF): Direct compositional contrast
The heavier the atom, the brighter it appears

C. Cantoni et. al., JMR, in press

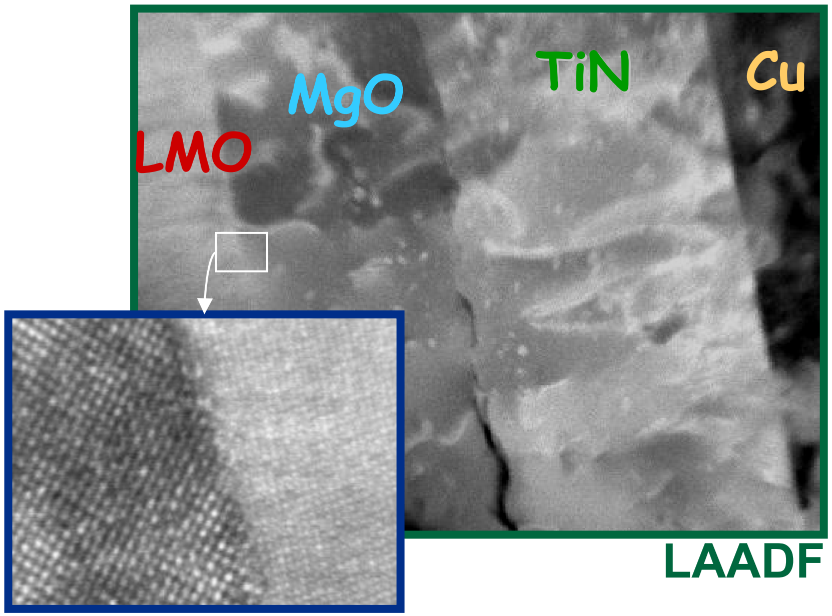
YBCO/LMO interface is straight and coherent

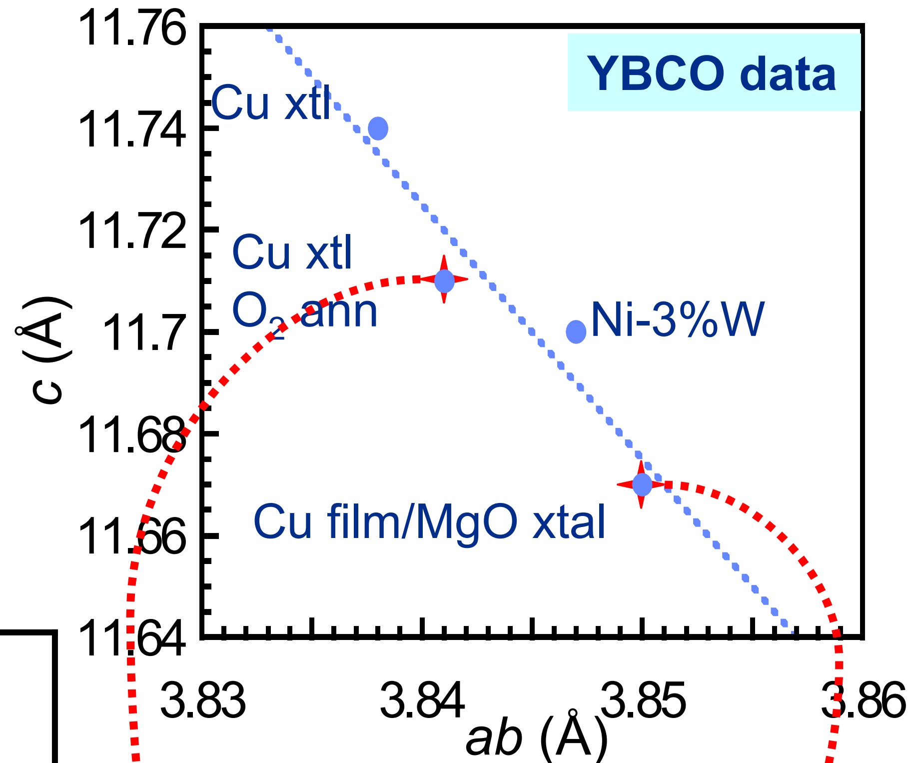




Strain analysis in buffer layers by high resolution XRD

- *Lattice strain is progressively relieved along the c-axis*
- *Small compressive residual strain in YBCO*



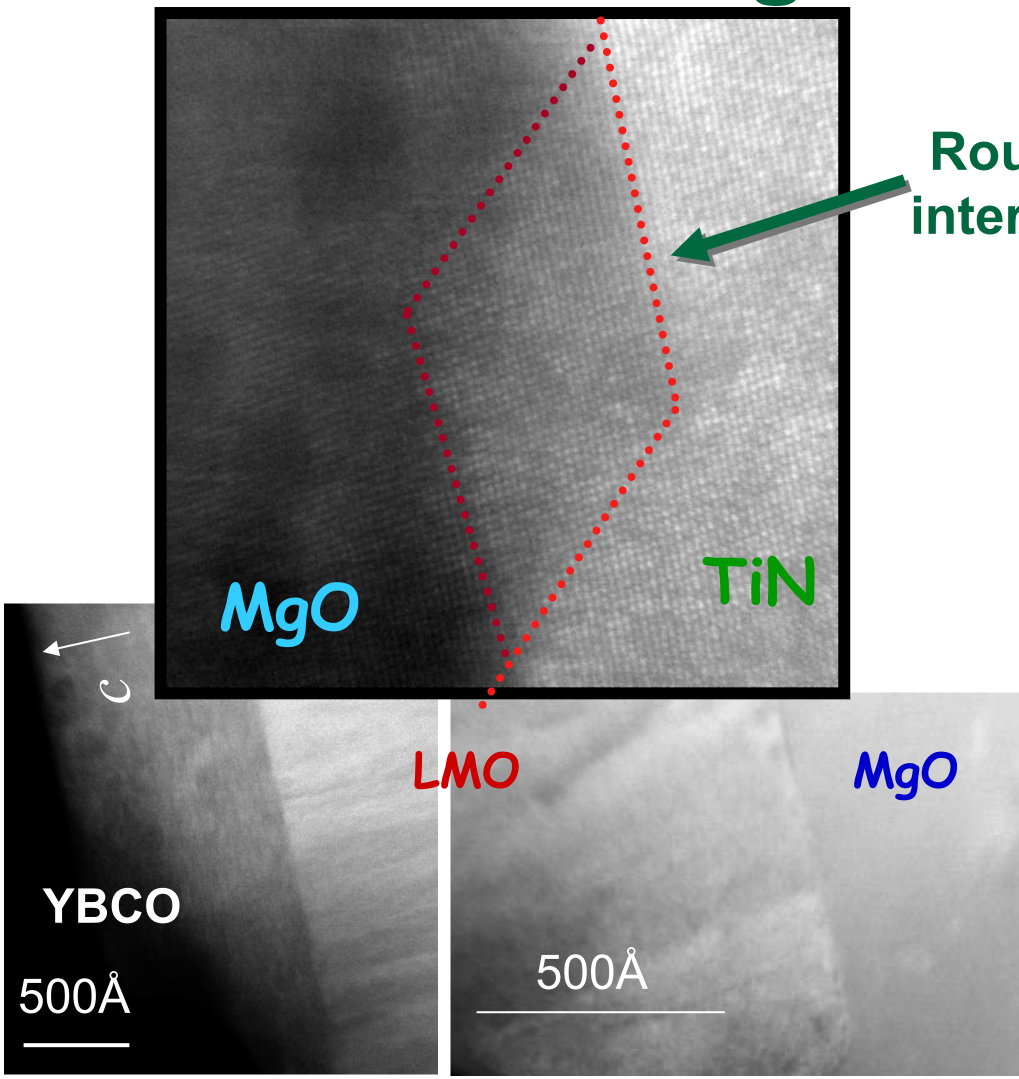


Substrate	TiN $(a-c)/a$	MgO $(a-c)/a$
Cu/MgO	- 0.66 %	1.01 %
1.5 mm-thick Cu crystal	-1.31 %	0.04 %

No lattice strain

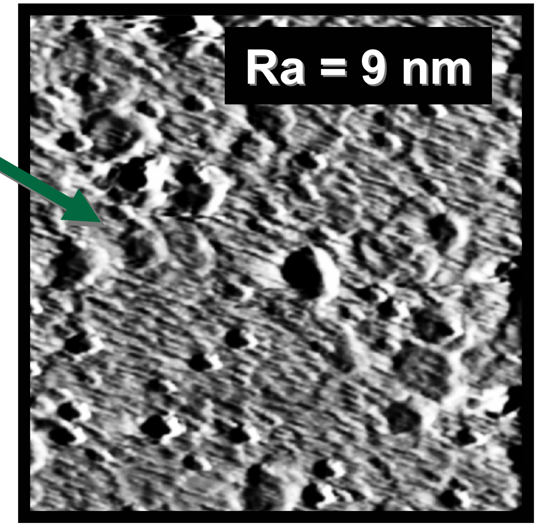
ε_{zz} = 0.25% vs. ε_{zz} = 0.45%

Structure and morphology of buffers on single-xtal



Rough interface

Cu film



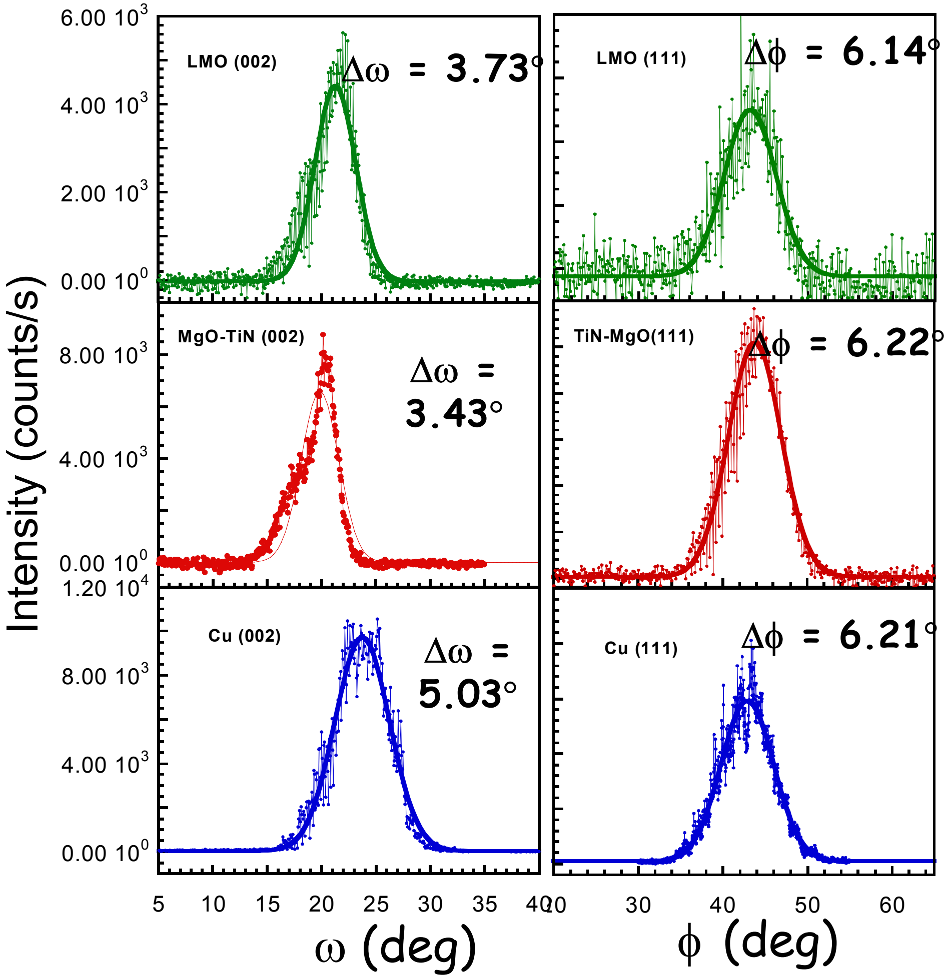
12 µm

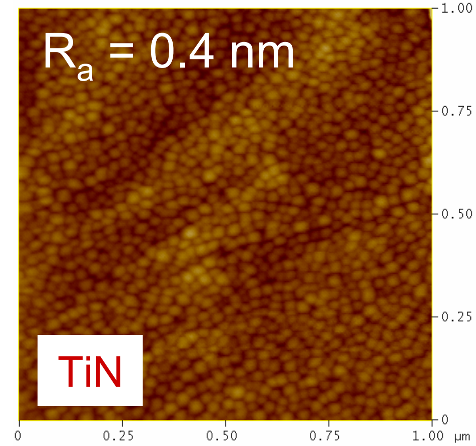
12 µm

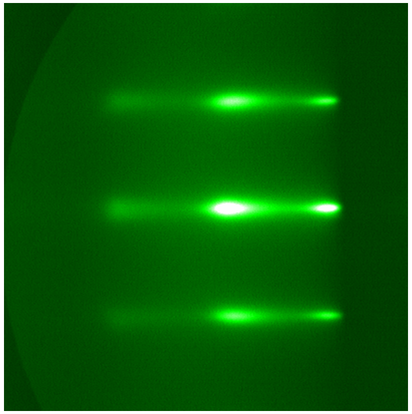
layer	Δω	Δϕ
Cu	0.184°	0.227°
LMO	1.47°	2.56°
YBCO	1.03°	2.54°

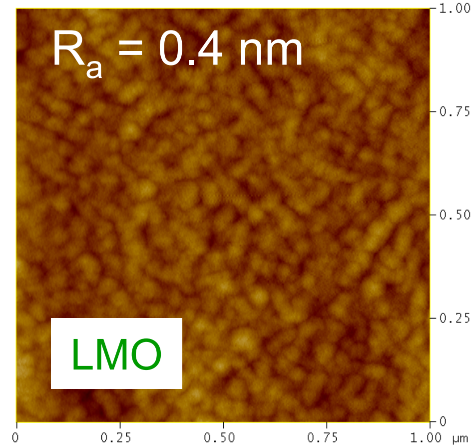
Excellent epitaxy and smooth surfaces on Cu tapes

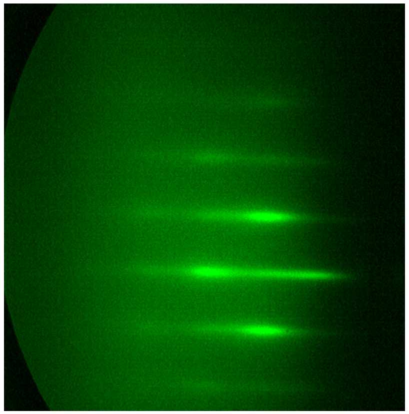
- *sharper out-of –plane texture*
- *substrate and buffers roughness are comparable*











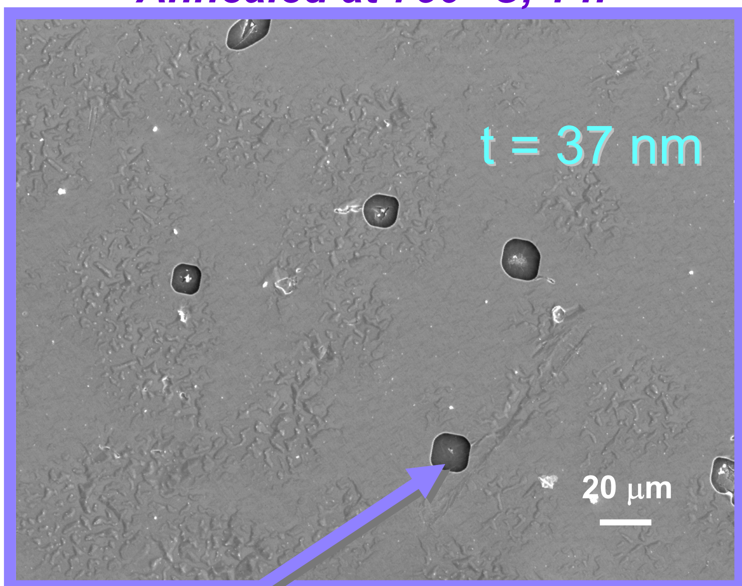
Cu Diffusion studies on TiN/Cu

150-nm thick TiN film blocks Cu diffusion in long, high temperature processing

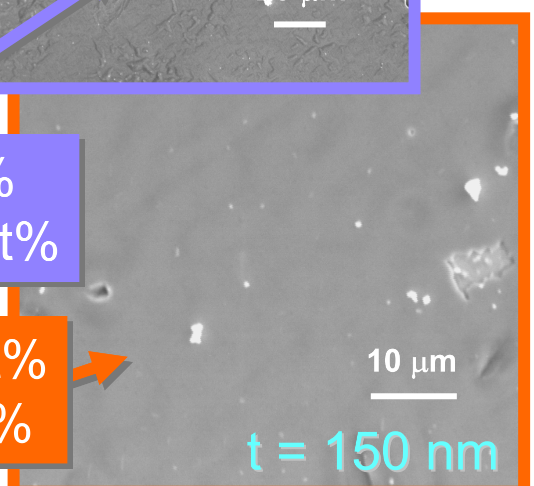
t = 37, 75, 150, 370, 600 nm

single-crystal

Annealed at 750 °C, 1 h



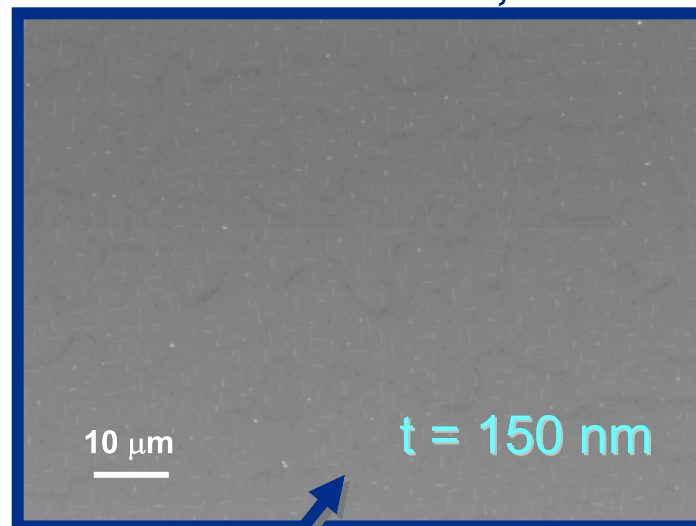
TiN = 0 at%
Cu = 100 at%



TiN = 21 at%
Cu = 30 at%

7° bi-crystal

Annealed at 750 °C, 1.5 h



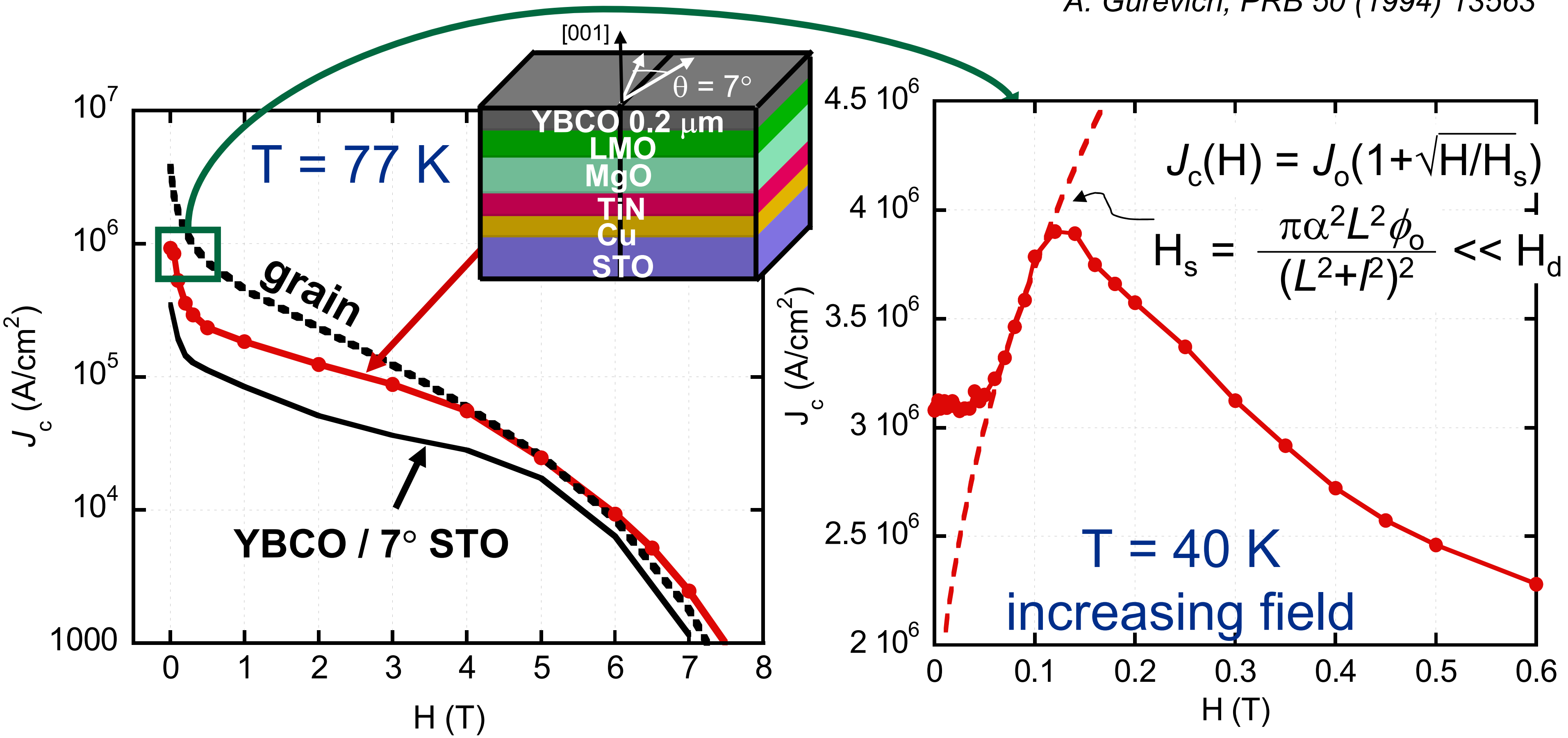
TiN = 20 at%
Cu = 29 at%

as grown 150-nm film
TiN = 22 ± 1 at%
Cu = 29 ± 2 at%

Transport J_c data on Cu 7° bi-crystal

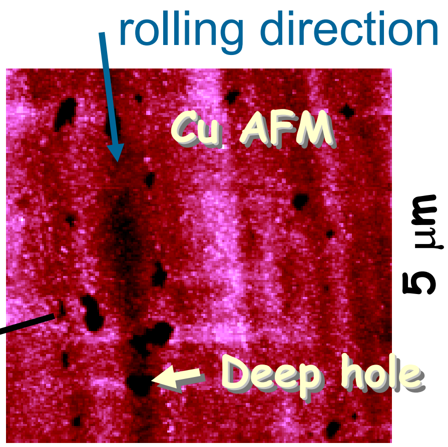
- Very high J_c across GB ⇒ GB's are o.k. in Cu tape
- First observation of non-monotonic J_c predicted by AJ vortices pinning

A. Gurevich, PRB 50 (1994) 13563



YBCO grain mosaic spread:
$\Delta\omega = 1°$, $\Delta\phi = 2°$

Conclusions:

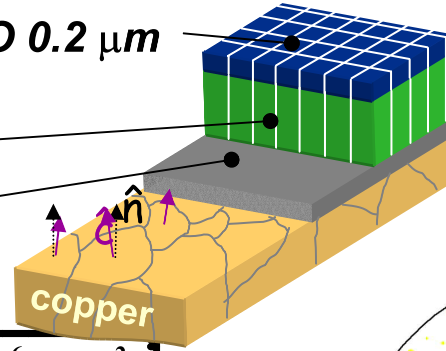


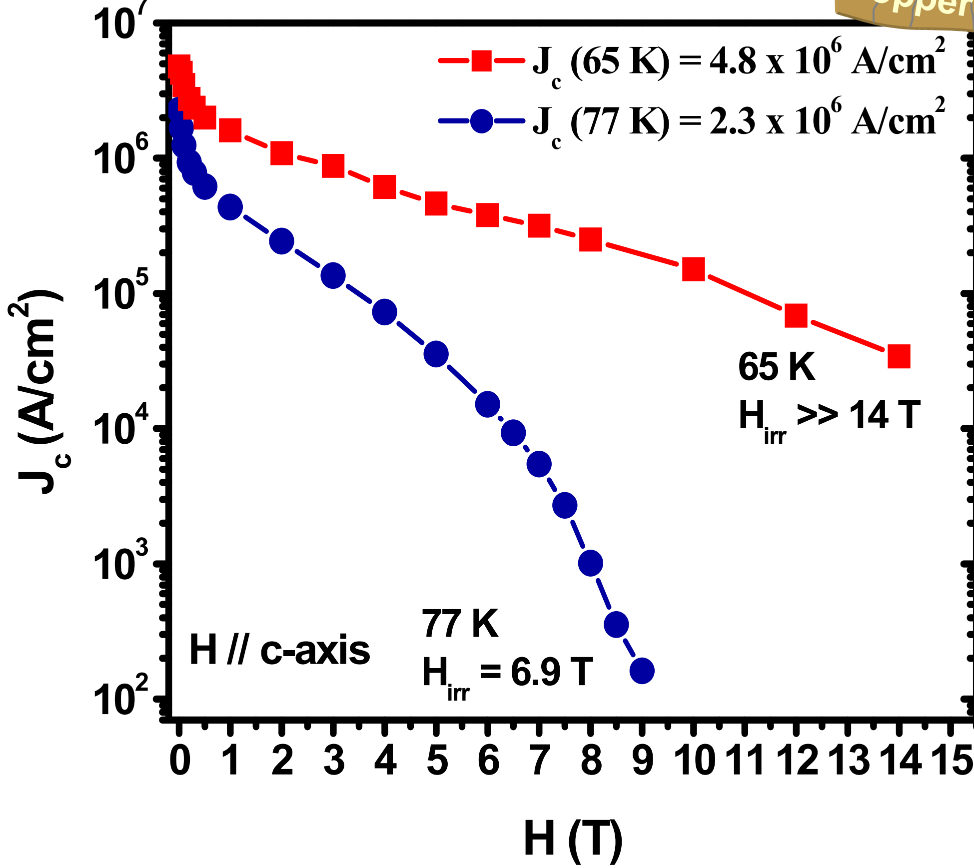
- Fast Cu oxidation likely occurs starting at exposed back side and edges, causing stress and eruptions in the YBCO
- Rolling defects in tape are critical regions (clean room being installed)

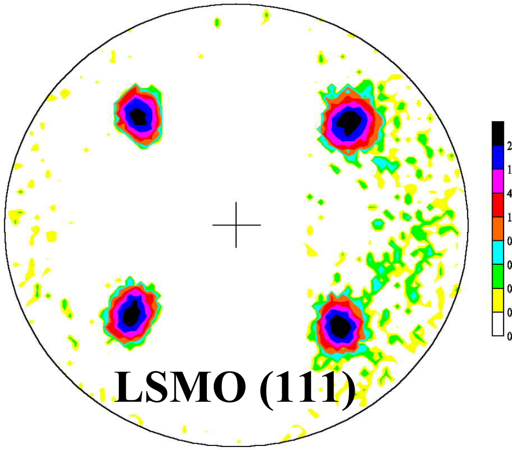
Solutions:

- Metal Ni overlayer on textured pure Cu
  - ↑ oxidation rate limited by NiO; very sharp texture ~ 4°
  - ↓ ferromagnetic contribution; soft
- Alloy Cu with a more oxidation resistant metal
  - ↑ stronger, non-magnetic, more oxidation resistant
  - ↓ resistivity is high unless particle dispersion is used

High J_c on conductive *YBCO/LSMO/Ni/Cu*







Cube % = 98.4

Texture

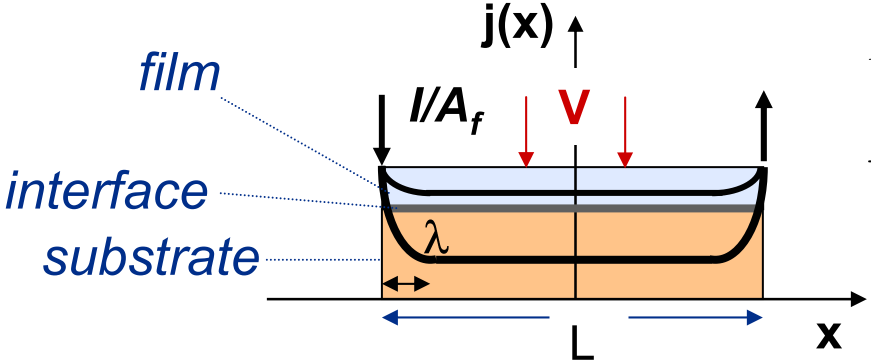
YBCO: $\Delta\omega = 6.5^o$, $\Delta\phi = 7.1^o$

Cu: $\Delta\omega = 5^o$, $\Delta\phi = 6^o$

T. Aytug et. al., JMR 18 (4) 872 (2003).

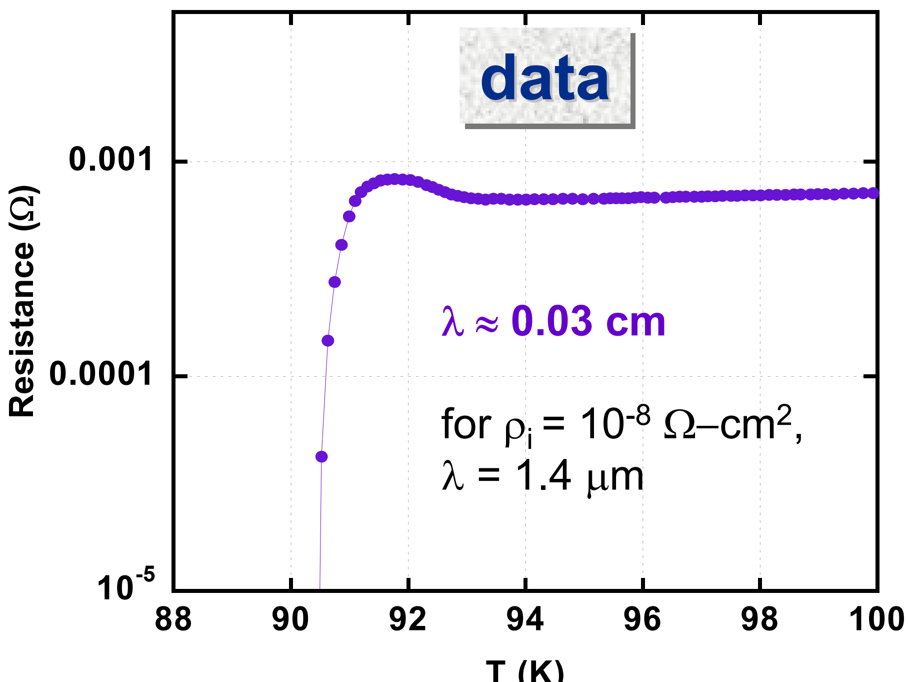
Electrical connectivity in *YBCO/LSMO/Ni/Cu*

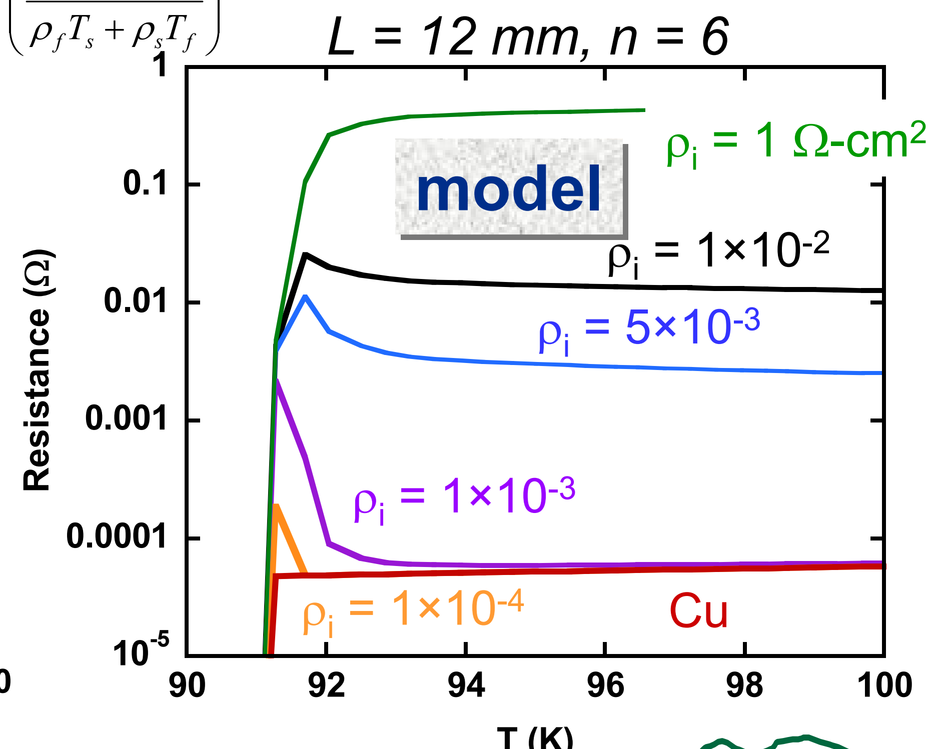
Formation of NiO during YBCO deposition causes poor interfacial resistivity



$$R_{meas}(L/n) = \frac{2LT_f\rho_s\rho_f}{nA_f(\rho_f T_s + \rho_s T_f)} + \frac{2\rho_f^2 T_s \lambda}{A_f(\rho_f T_s + \rho_s T_f)} \frac{(e^{L/n\lambda} - e^{-L/n\lambda})}{(e^{L/2\lambda} + e^{-L/2\lambda})}$$

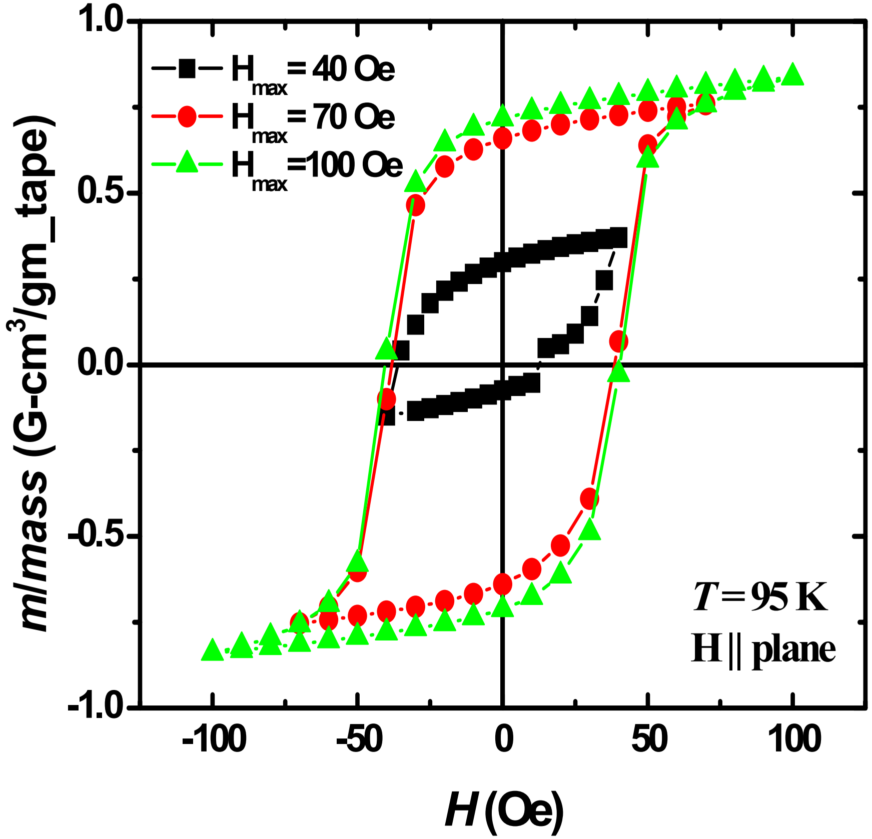
$$\lambda = \left(\frac{\rho_i T_s T_f}{\rho_f T_s + \rho_s T_f}\right)^{1/2}$$

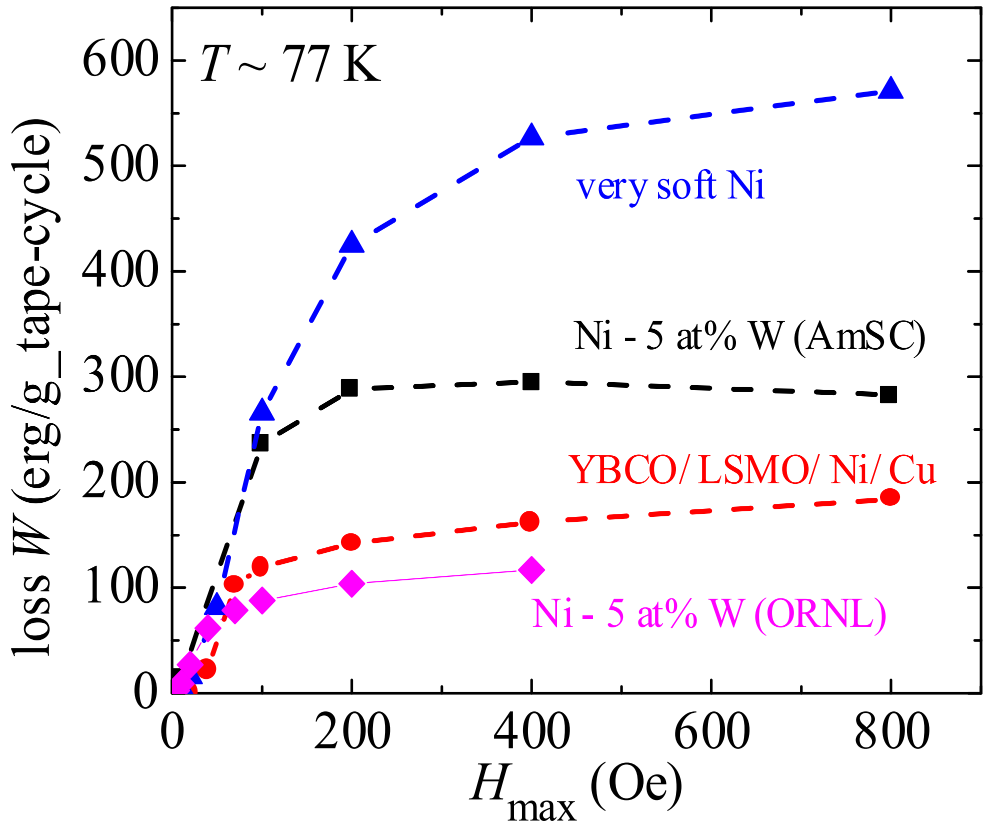




Ferromagnetic loss from *M*(*H*) loop area

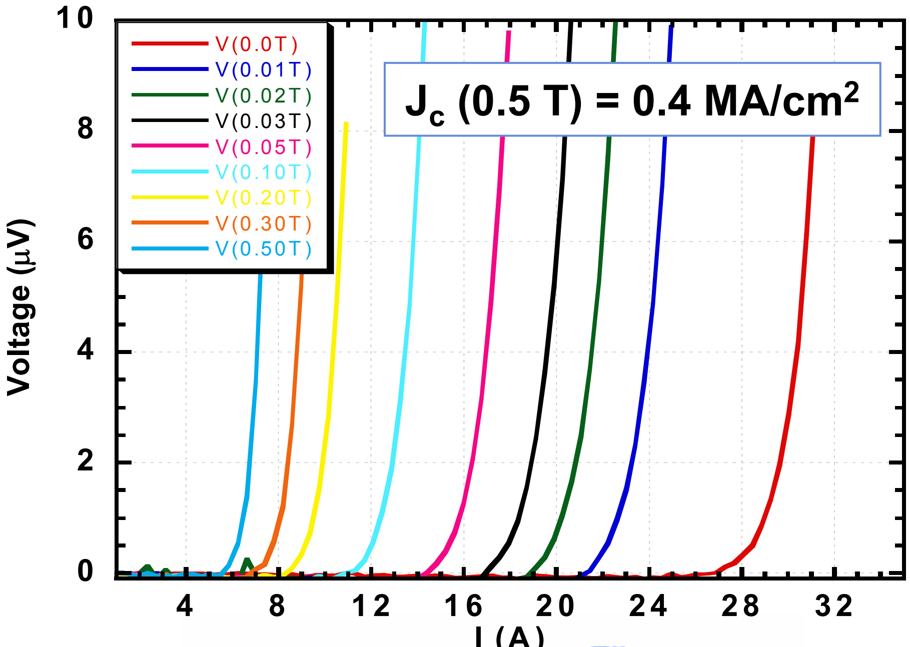
Ni-film losses are comparable with ORNL Ni-5%W



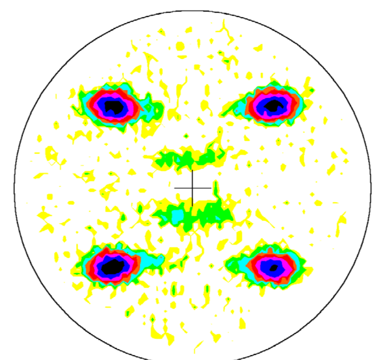


J_c = 2MA/cm^2 on AMSC Cu-Ni-Al alloy

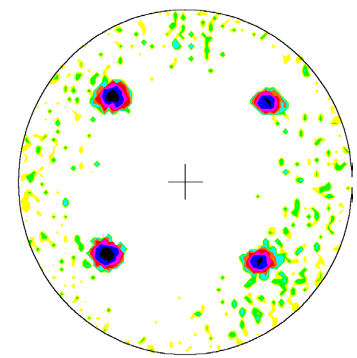
- ***Composition: Cu-Ni48% with 1-1.5%Al, Yield Stress = 130 MPa***
- ***Substantial $\Delta\omega$ improvement occurs in TiN***
- ***PLD YBCO 0.3 μm thick***



	$\Delta\omega$,t	$\Delta\omega$,r	$\Delta\phi$
alloy	10.73	6.52	8.05
TiN	3.01	2.57	5.72
MgO	2.99	2.74	5.54
LMO	4.01	3.30	6.48
YBCO	4.00	2.81	6.45

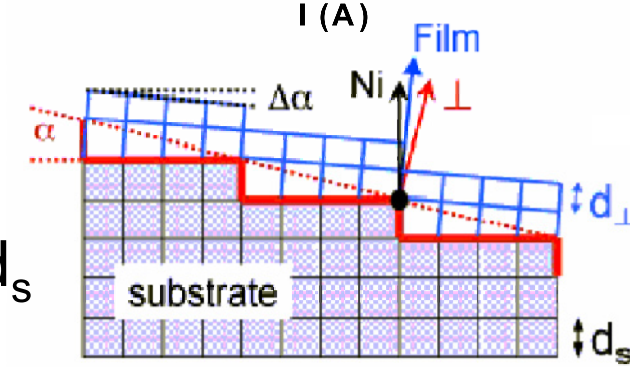


Substrate (111)
98.6% cube



TiN (111)
98.9% cube

$d_f < d_s$

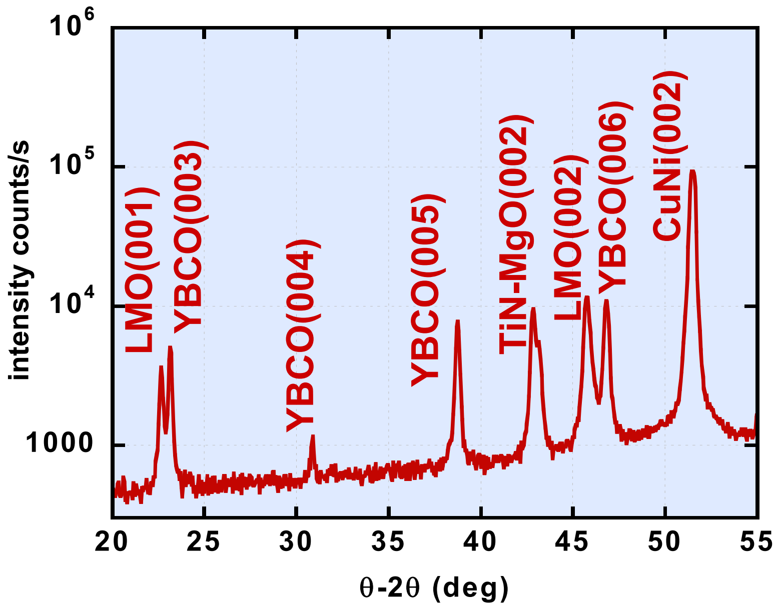


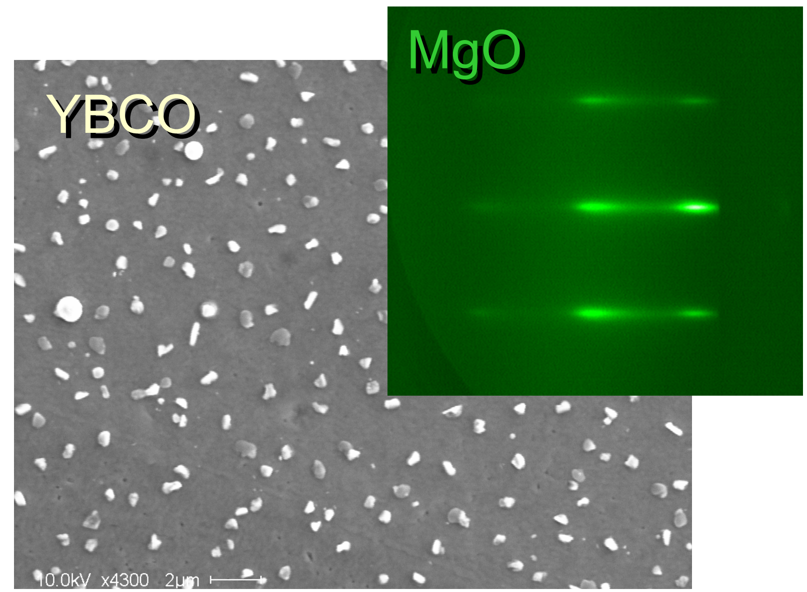
For TiN/Cu:
d_f = 2.11 Å > d_s = 1.82 Å !

J. Budai, Nature Materials (2003)

Buffers prevent Cu-alloy oxidation during YBCO deposition

- External oxidation forms γ-alumina, very reactive
- No sign of Al-O, Ti-O, Cu-O or Ni-O in x-ray scan





- Initial Al-O was removed by chemical etching or ion-sputtering
- To prevent Al-O formation a nucleation layer of TiN was deposited at 400 °C using enhancement of epitaxy by ion-sputtering (Ar^+, 400 eV)

Summary

- LMO/MgO/TiN is a suitable barrier for 0.3 μm PLD YBCO on Cu
- Results on textured tapes are limited by softness, oxidation from unprotected side, and rolling pits
- J_c = 2.3MA/cm^2 on Ni/Cu
- FM Losses from a Ni overlayer are comparable to those of Ni-5%W
- J_c=2MA/cm^2 on CuNiAl
- Need a stronger, low resistivity Cu substrate

FY 2003 Performance

FY2003 Plans

- Research and develop faster, potentially lower cost, and simpler RABiTS buffer-layer architectures that are compatible with ex-situ YBCO processes

FY2003 Performance

- ✓ Used Metal-organic deposition (MOD) process for buffers
- ✓ High quality LZO seeds were produced in meter lengths
- ✓ In-situ XRD of nucleation and growth of MOD LZO and CeO_2
- ✓ Successfully replaced PVD Y_2O_3 and YSZ with MOD LZO
- ✓ High quality MOD-YBCO on MOD buffers
  - High I_c of 184 A/cm-w on LZO seeds
  - High I_c of 135 A/cm-w on LZO seed & barrier
  - High I_c of 141 A/cm-w on MOD CeO_2 cap
  - I_c of 45 A/cm-w on all MOD

FY 2003 Performance Cont'd.

FY2003 Plans (cont'd)	FY2003 Performance
• Develop a viable high rate process to fabricate high quality buffer layers	✓ Increased the deposition rate of YSZ by 10-20 times using reactive sputtering of metal alloy targets ✓ YBCO films with a J_c of 2 MA/cm^2 have been achieved on reactively sputtered YSZ barriers
• Collaborate with LANL and ANL to develop suitable buffer architectures on IBAD-MgO and ISD-MgO substrates for compatibility with ex situ YBCO	✓ Developed $CeO_2/LaMnO_3$ buffers for IBAD-MgO substrates ✓ MOD-YBCO films with an I_c of 194 A/cm-w have been achieved on CeO_2/LMO/IBAD-MgO substrates in collaboration with AMSC ✓ $CeO_2/LaMnO_3$ buffer for ISD-MgO substrates (with ANL; in progress)

FY 2003 Performance Cont'd.

FY2003 Plans (cont'd)

- Continue fundamental studies of epitaxial growth on textured non-magnetic substrates, including copper and copper alloys

FY2003 Performance

✓ Base line developments
  - TiN/MgO buffers block Cu and Oxygen during annealing at 750 °C
  - Cu bi-crystal studies established adequate grain boundary passivation

✓ High J_c of 2 MA/cm^2 have been achieved on AMSC's Cu-Ni-Al alloys with an architecture of LMO/MgO/TiN/Cu-alloy

✓ Feasibility studies of all conducting buffers on Cu have been initiated
  - High J_c of 2.3 MA/cm^2 have been achieved on LSMO/Ni/Cu

FY 2004 Plans

- Develop all solution buffer architectures that are compatible with MOD TFA processes
  - Achieve over 200 A/cm-w on solution LZO seeds
  - Develop two-sided LZO layers
  - Extend to 4 cm wide substrates

- Continue the collaboration with LANL and ANL to develop suitable buffer layer architectures for IBAD-MgO and ISD-MgO templates

- Continue research and develop robust and simpler RABiTS buffer-layer architectures that are compatible with ex-situ YBCO processes

- Focus on processing high I_c (approaching 200 A/cm-width) YBCO films on Cu or Cu-alloy by in-situ or ex-situ approach

- Continue fundamental studies of epitaxial growth of both PVD and solution buffers on textured non-magnetic substrates, including copper and copper alloys
  - Strengthened, more oxidation resistant, and low-resistivity Cu-alloy
  - Conductive architecture

Research Integration

- ORNL – AMSC CRADA: YBCO on Cu-alloy substrates; MOD YBCO on Solution Buffers
- ORNL – University Student Interactions
  - Resident students from Houston, Florida & Tennessee supported through AFSOR program (H. Weinstock)
- ORNL – LANL – AMSC collaboration: Demonstrated high I_c MOD YBCO films CeO_2/LMO/IBAD-MgO substrates
- ORNL – ANL Collaboration: Buffers for ISD-MgO
- Transferred all the strategic buffer layer technology to all of our CRADA partners
- Published over 10 journal articles based on this work during FY 03; Posted our annual reports on the Web; 2 patents have been filed; Several invited talks; Organized MRS and DOE workshops; Editorial board: Supercond. Sci. & Tech.; Technical Editor: ASC 2002