Development of Buffer Layers for Copper-Based RABiTS

D. K. Christen, C. Cantoni, T. Aytug, H. Y. Zhai, A. Gapud, M. Verela, J. R. Thompson, A. Goyal, N. Rutter, E. D. Specht, and M. Paranthaman

Oak Ridge National Laboratory, Oak Ridge TN

INVITED PRESENTATION

DOE Wire Workshop
St. Petersburg, Florida
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Development of Buffer Layers for Copper-Based RABiTS

David Christen

C. Cantoni, T. Aytug, H.Y. Zhai, A. Gapud, M. Verela, J. R. Thompson
Condensed Matter Sciences Division

A. Goyal, N. Rutter, E. D. Specht
Metals & Ceramics Division

M. Paranthaman
Chemical and Analytical Sciences Division

Oak Ridge National Laboratory
U.S. Department of Energy

Motivation for Copper-Based RABiTS

- ***Excellent texture has been achieved***

  [<5° FWHM in pure copper]

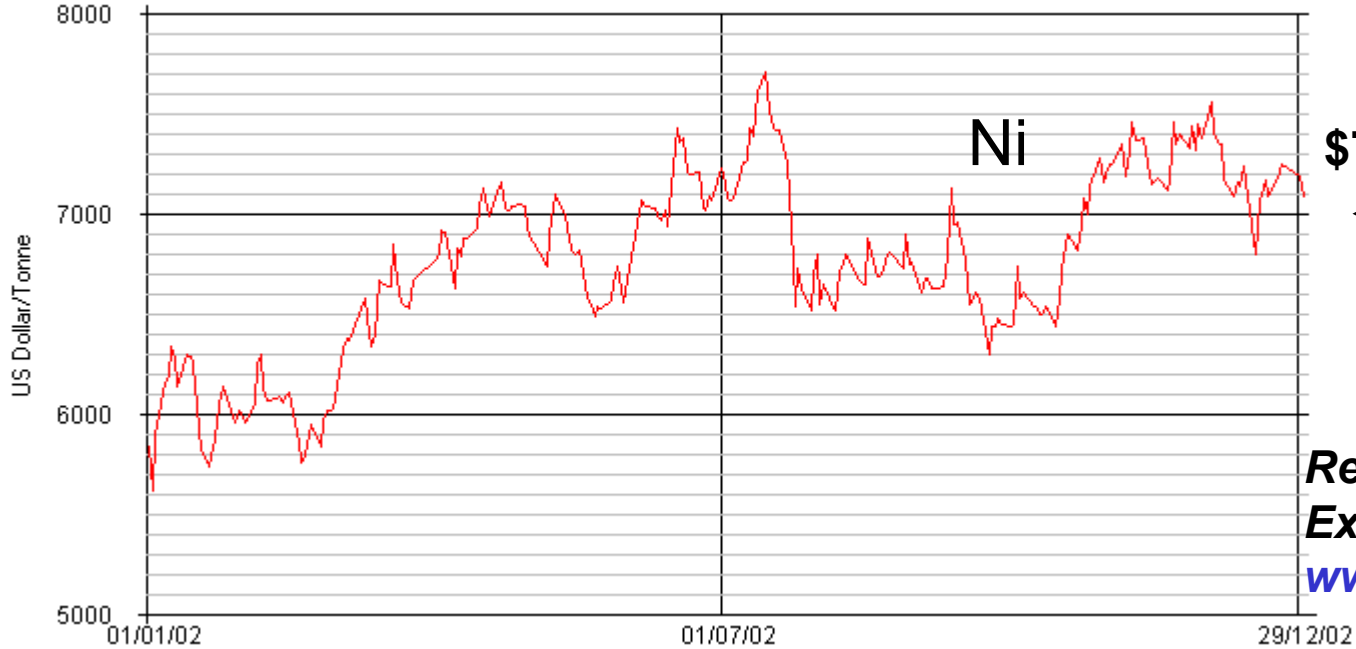
- ***Weakly diamagnetic***

  ⇒ no ferromagnetic contribution to hysteretic ac losses

- ***Inexpensive***

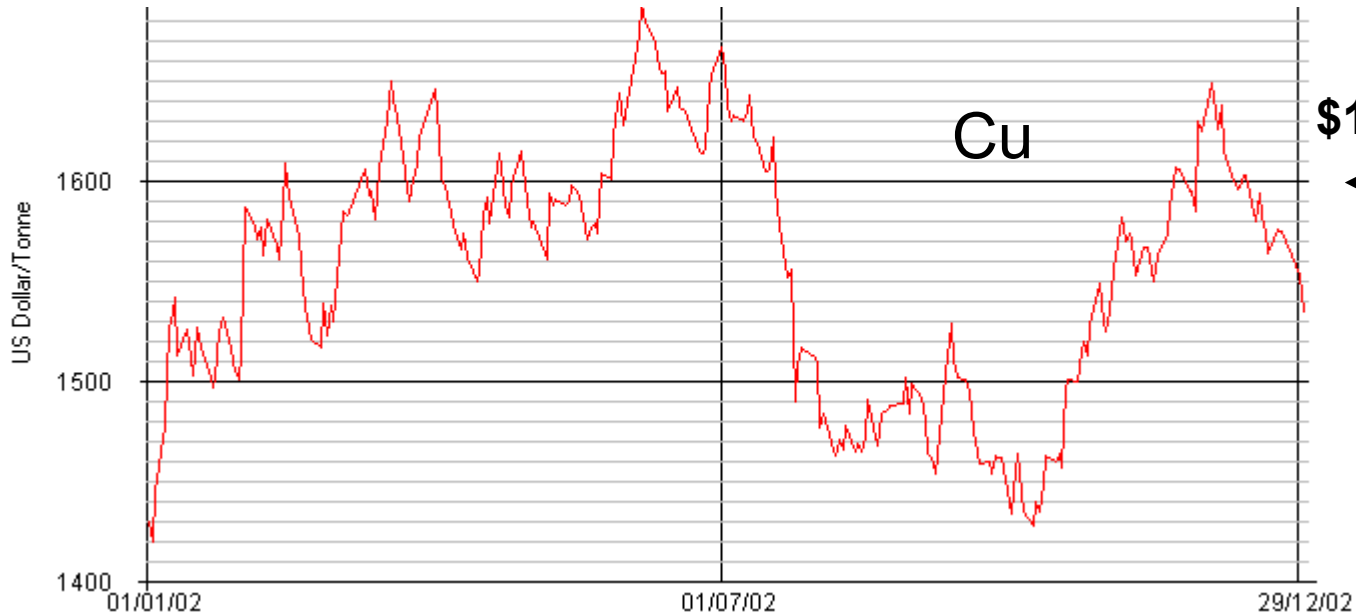
  [factor of 4 - 6 less than nickel (ref: London Metal Exchange, www.lme.co.uk)]

Metal Market Prices



$7k/metric ton

Ref: London Metal Exchange
www.lme.co.uk



$1.6k/metric ton

Jan '02

Dec '02

Motivation for Copper-Based RABiTS

- ***Excellent texture has been achieved***

  [<5° FWHM in pure copper]

- ***Weakly diamagnetic***

  ⇒ no contribution to hysteretic ac losses

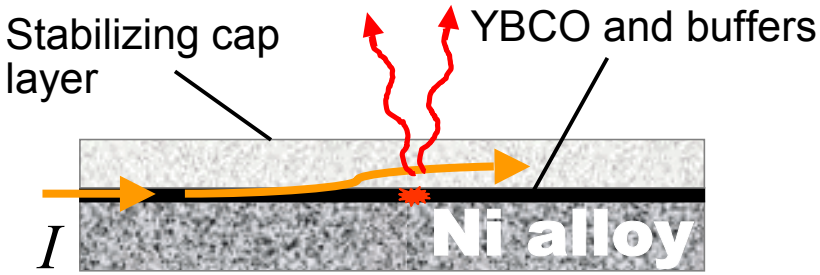
- ***Inexpensive***

  [factor of 4 - 6 less than nickel (ref: London Metal Exchange, www.lme.co.uk)]

- ***Highly conductive***

  [with conductive buffers, no need for additional stabilizer]

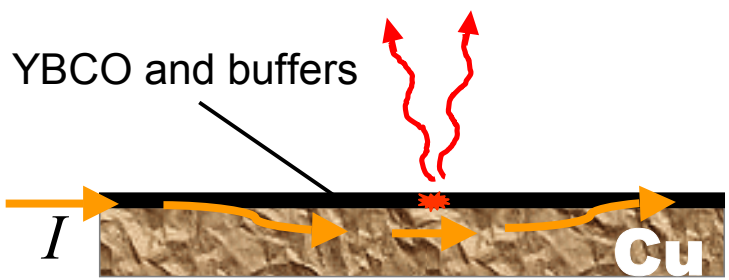
Conducting Buffers and Stability



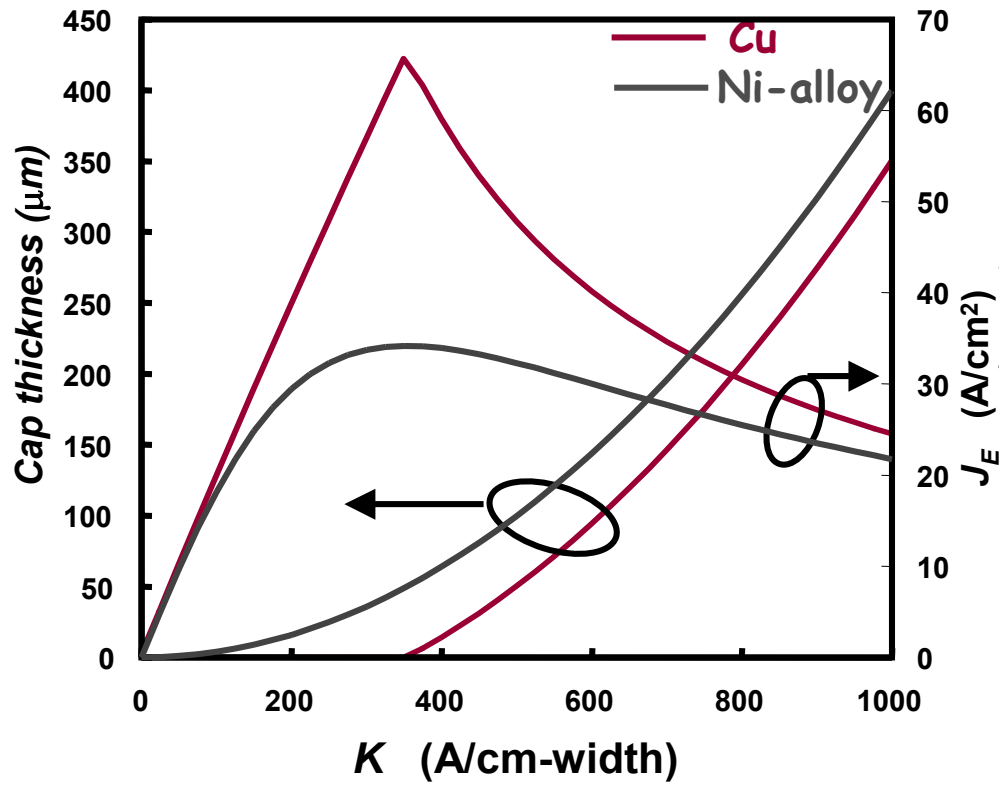
C. Cantoni et al., IEEE T APPL SUPERCON 11 (1) 2001

Y.Fu, et al., to be published in IEEE T APPL SUPERCON

- $J_E^{max} \approx 30 kA/cm^2$, $K^{max} \approx 400 A/cm$
  metal cap layer 50 μm thick



- $J_E^{max} \approx 65 kA/cm^2$, $K^{max} \approx 400 A/cm$
  No cap layer needed



Challenges/Issues for Copper-Based RABiTS

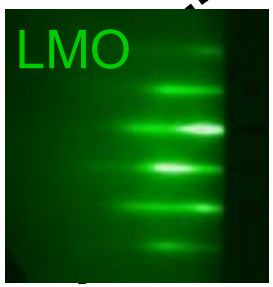
- ***Rapid copper diffusion through oxide buffer layers***
  [chemical contamination of HTS coating]

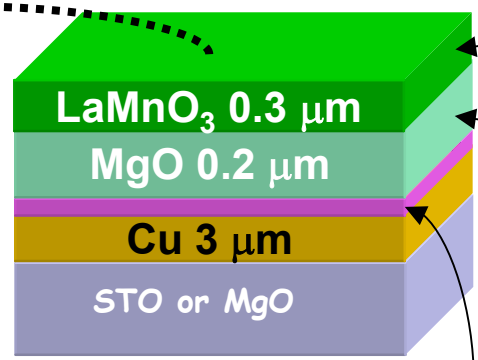
- ***Rapid formation of Cu-O [related to high Cu diffusivity through native oxides]***

- ***Low mechanical strength of pure copper***
  [strong alloys and dispersions possible?]

- ***Large thermal expansion***
  [compressive stresses on HTS coatings]

Oxygen Diffusion Barrier Needed for YBCO Deposition



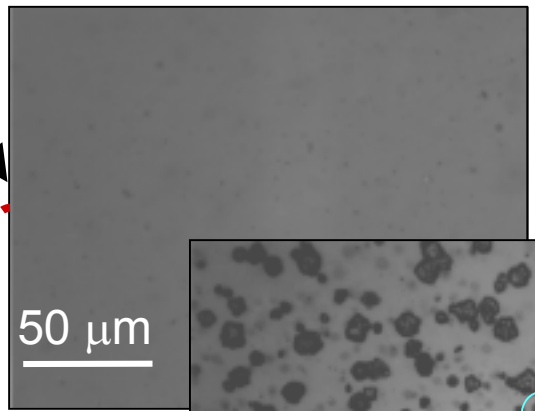


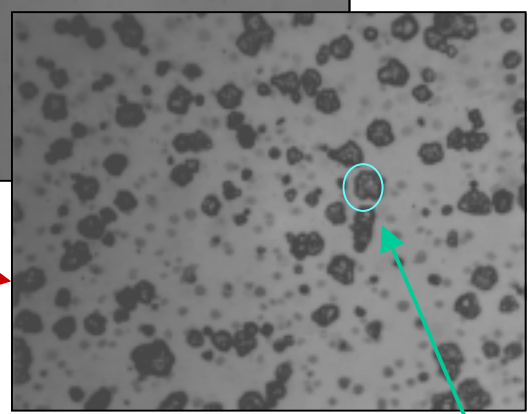
compatible with YBCO

Excellent oxygen diffusion barrier
$D \approx 10^{-20}$ cm^2/s @ 800 °C

STO
5 *nm*

Epitaxial template



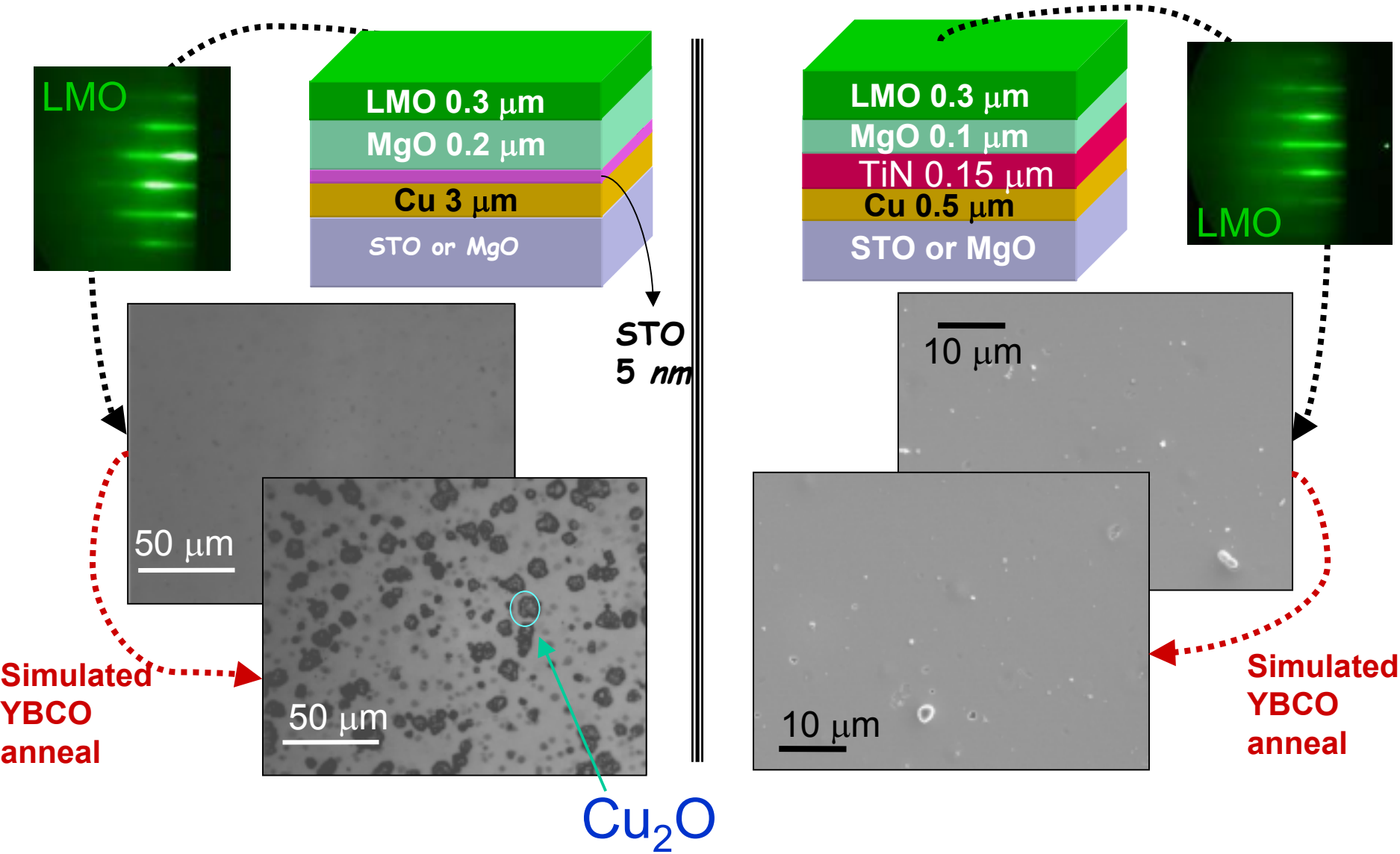


Simulated YBCO anneal

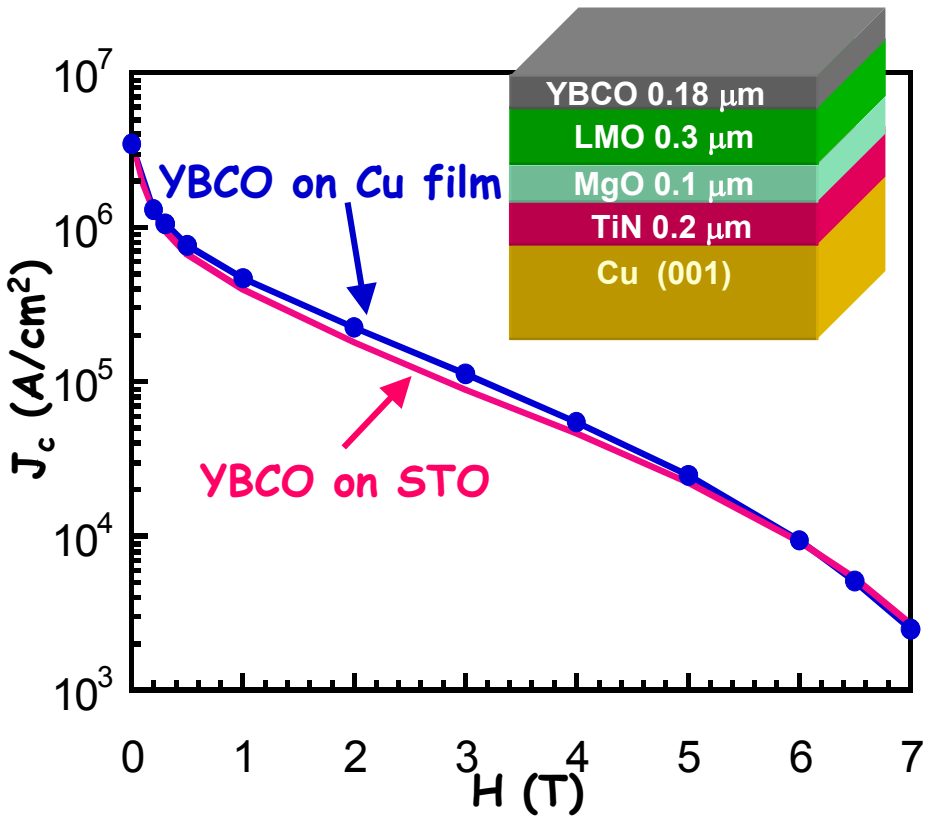
copper diffusion through buffer stack!

Cu_2O

Copper Diffusion Barrier Needed for YBCO Deposition



Results (PLD YBCO):



- J_c = 3.5 MA/cm^2 on Cu film on MgO
- $J_c \cong$ 2 MA/cm^2 on Cu bulk crystal (magnetization result)
- $J_c \cong$ 1 MA/cm^2 on textured Cu (magnetization result)

- **A number of analyses (TEM, XRD, RBS, SEM) performed to probe buffer layer quality and YBCO properties**

Challenges/Issues for Copper-Based RABiTS

- ✓ ***Rapid diffusion through oxide buffer layers***
  [chemical contamination of HTS coating]

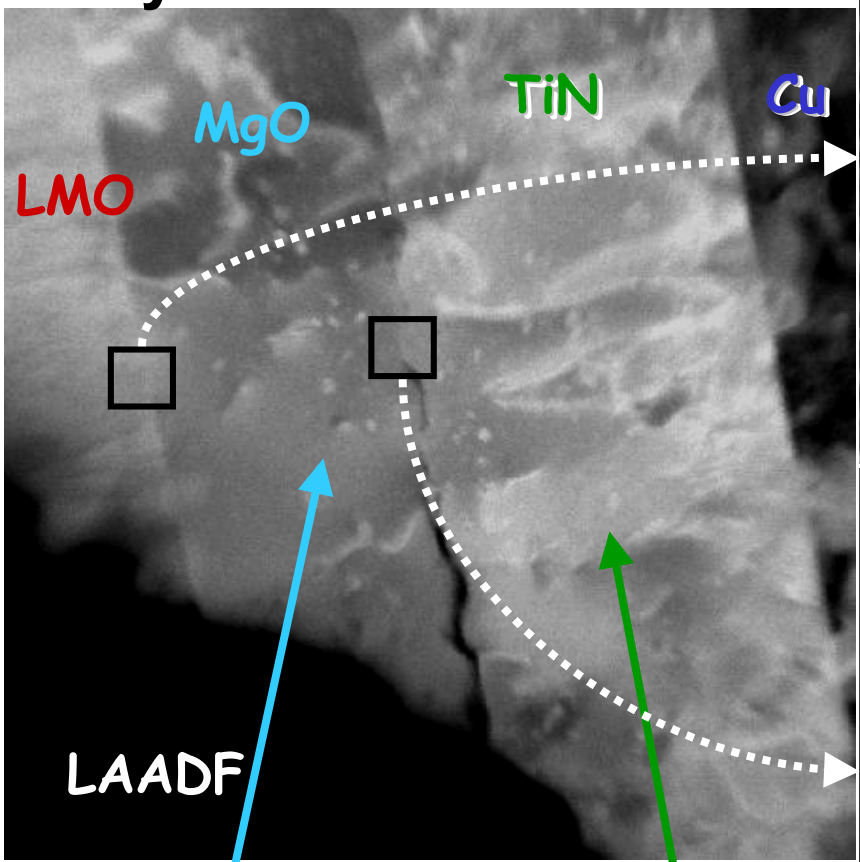
- ✓ ***Rapid formation of Cu-O [related to high Cu diffusivity through native oxides]***

- ***Low mechanical strength of pure copper***
  [strong alloys and dispersions possible?]

- ➡ ***Large thermal expansion***
  [compressive stresses on HTS coatings]

All interfaces are clean and well defined

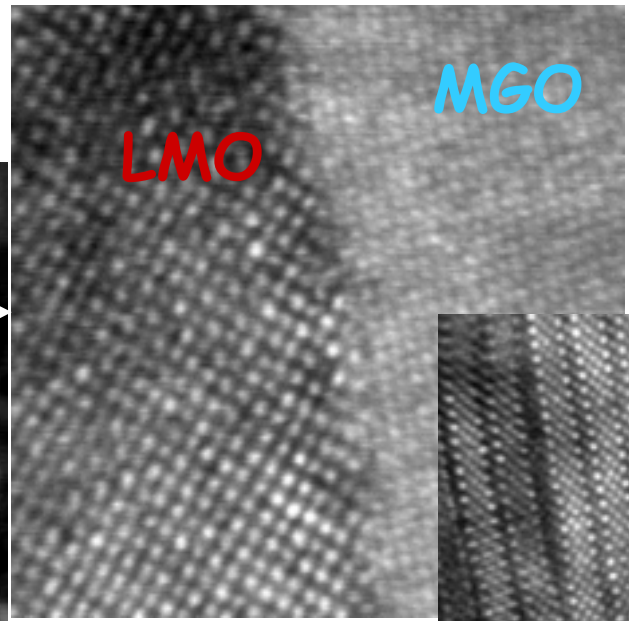
- **MgO/TiN optimal barrier layer**

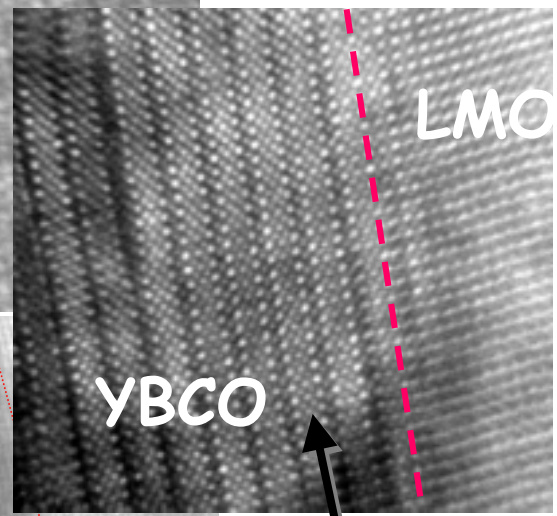


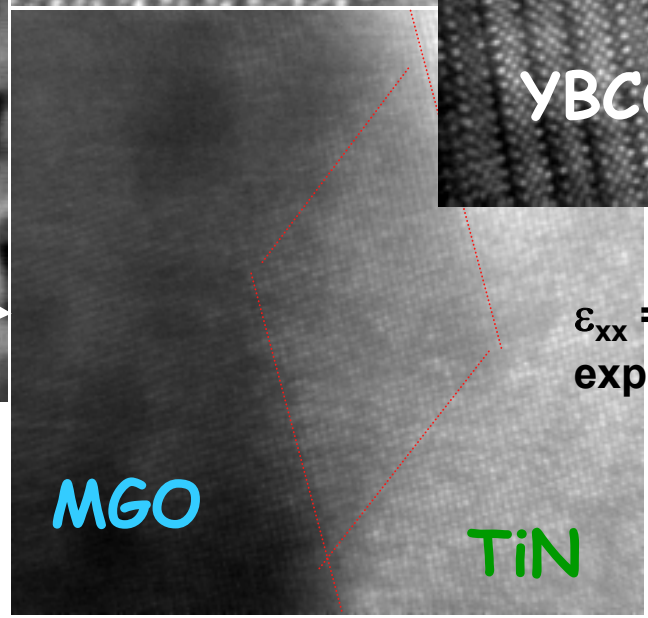
$\varepsilon_{xx} = \varepsilon_{yy} = 0.35\%$

XRD

$\varepsilon_{xx} = \varepsilon_{yy} = 0.8\%$



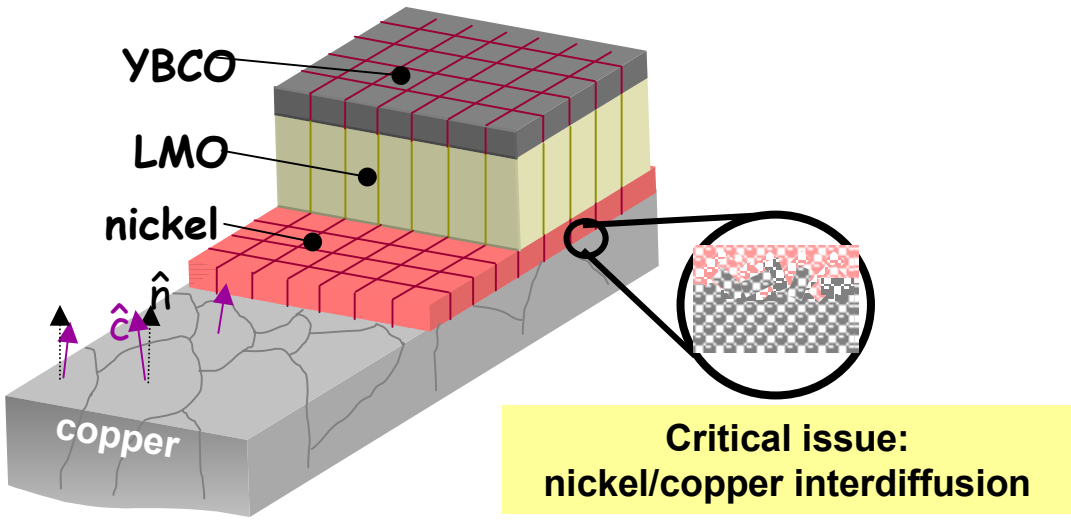




$\varepsilon_{xx} = \varepsilon_{yy} = 0.2\%$

expected $\varepsilon_{xx} = 0.45\%$

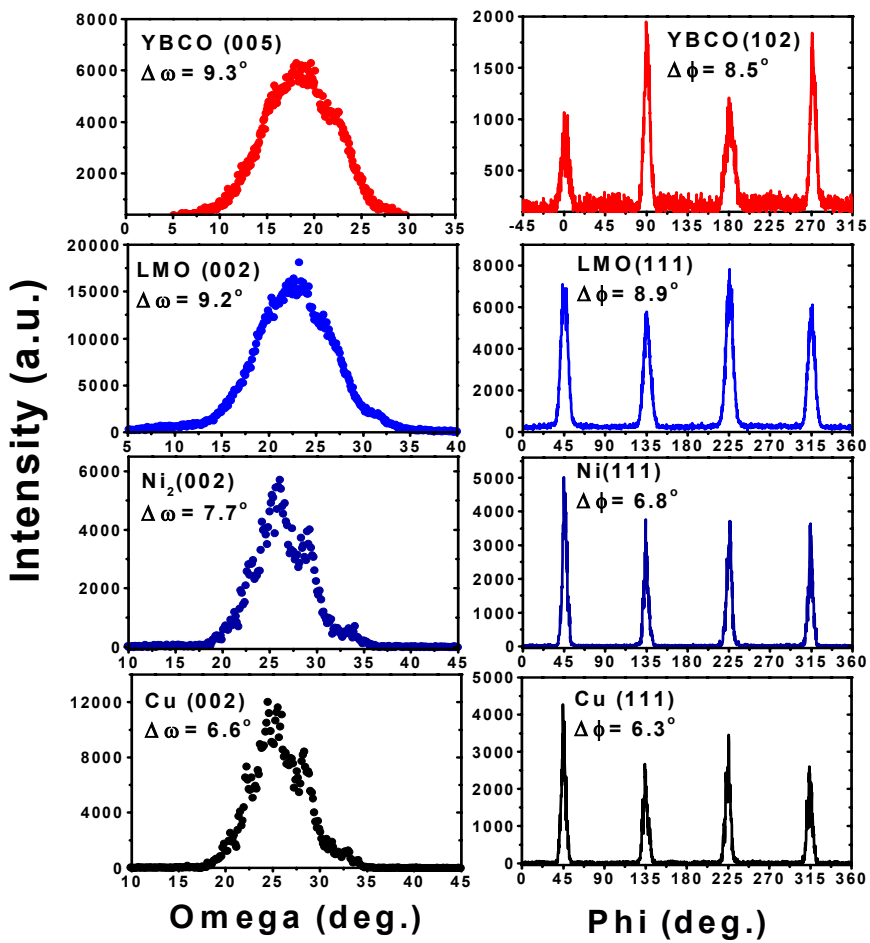
Alternative approach: nickel buffer layer

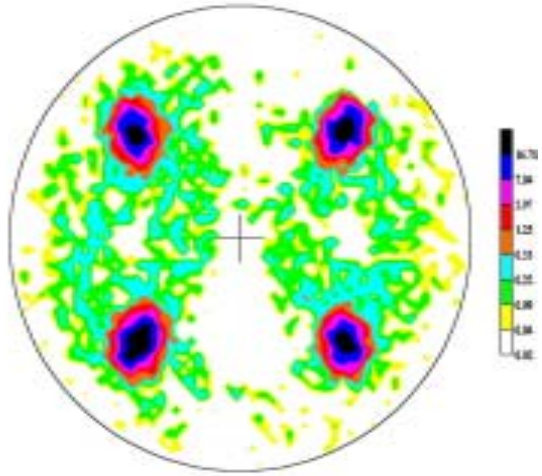


- ***Existing techniques for simple, sputtered buffer on nickel surface [e.g., $LaMnO_3$ as single buffer]***
- ***Process limited by rate of copper-nickel interdiffusion for an excessively thin Ni layer,***
- ***and/or the magnetic hysteretic losses for an excessively thick Ni layer***

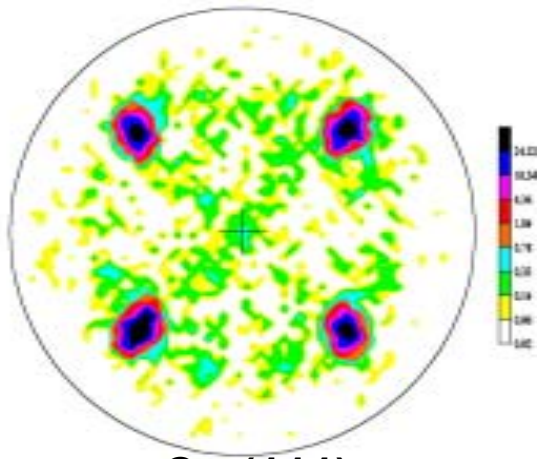
Epitaxial architecture achieved

PLD YBCO coating 0.2 μm thick
Ni layer 1.6 μm





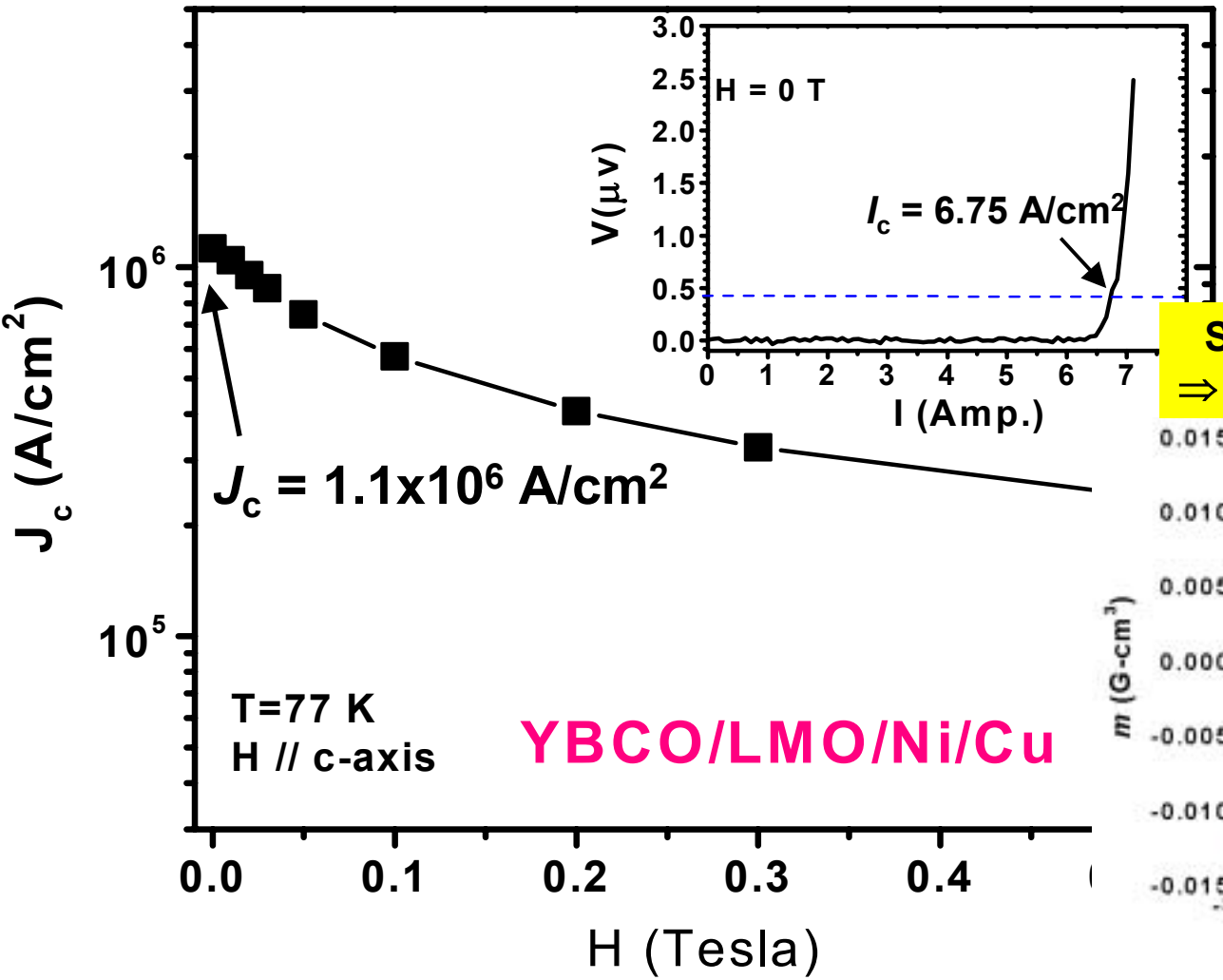
LMO (111)



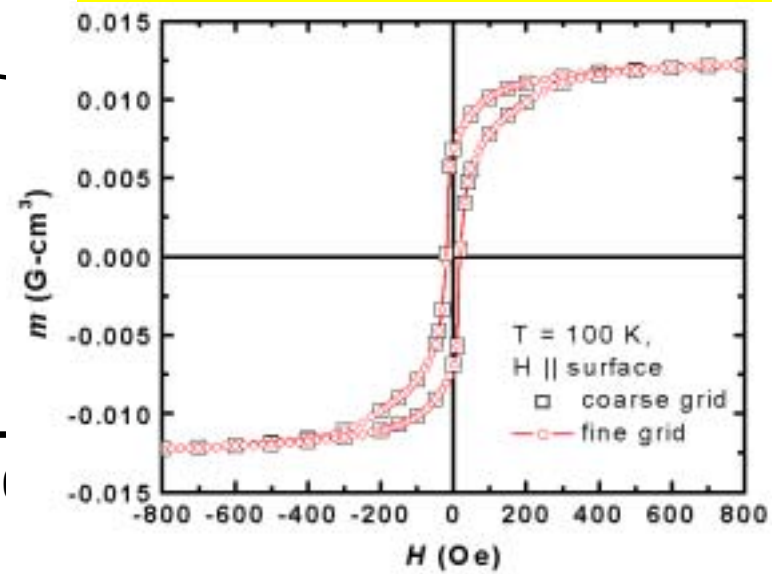
Cu (111)

Good Superconducting Properties

but, magnetic losses due to nickel



Substrate magnetic hysteresis
⇒ *AC losses ~ Ni5%W alloy tape*



Aytug *et al.*, JMR Rapid Commun. (in press)
Thompson *et al.*, Physica C **370** (2002)

Summary and Future Directions

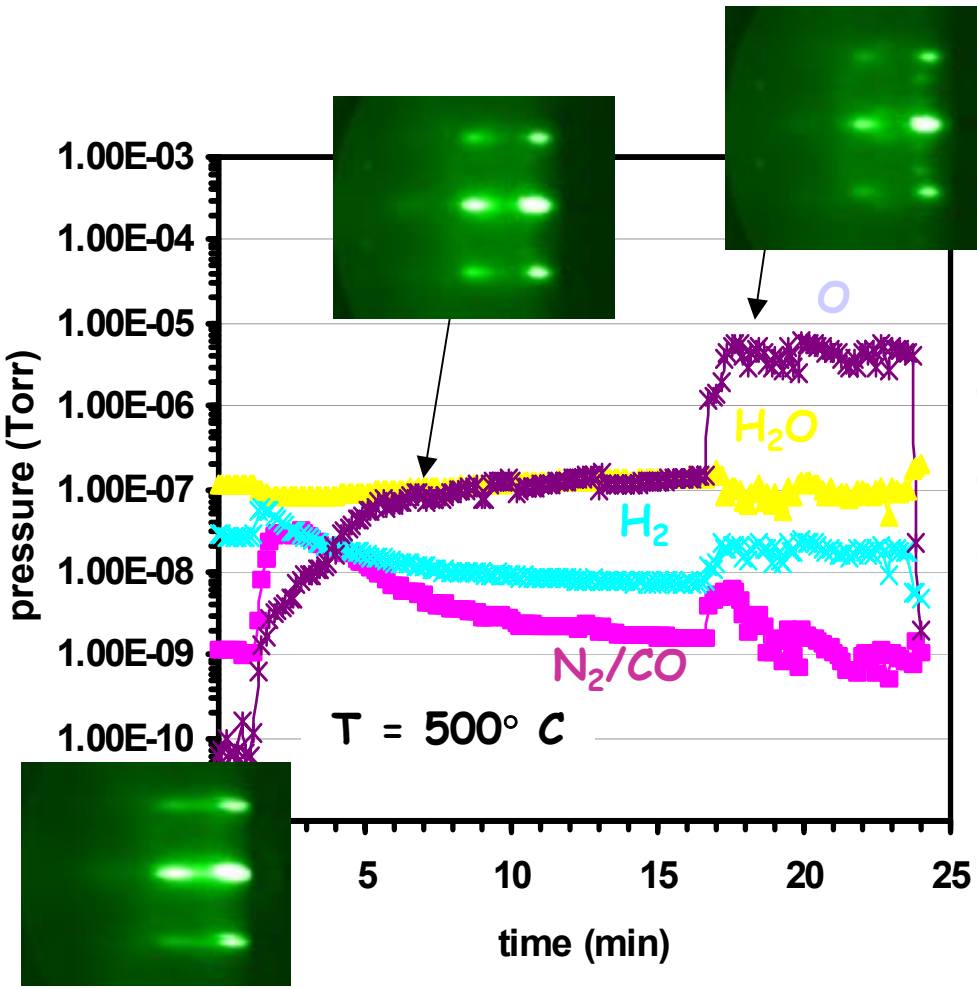
- ***Optimize buffer architectures for both oxygen and copper diffusion resistance***
  - *MgO/TiN provides oxygen/copper diffusion barrier for insulating buffer structure*
  - *Conductive buffers may require:*
    nitride barriers that form less stable oxides: WN_x, VN, TaN,…
    or, transient metal protection layer

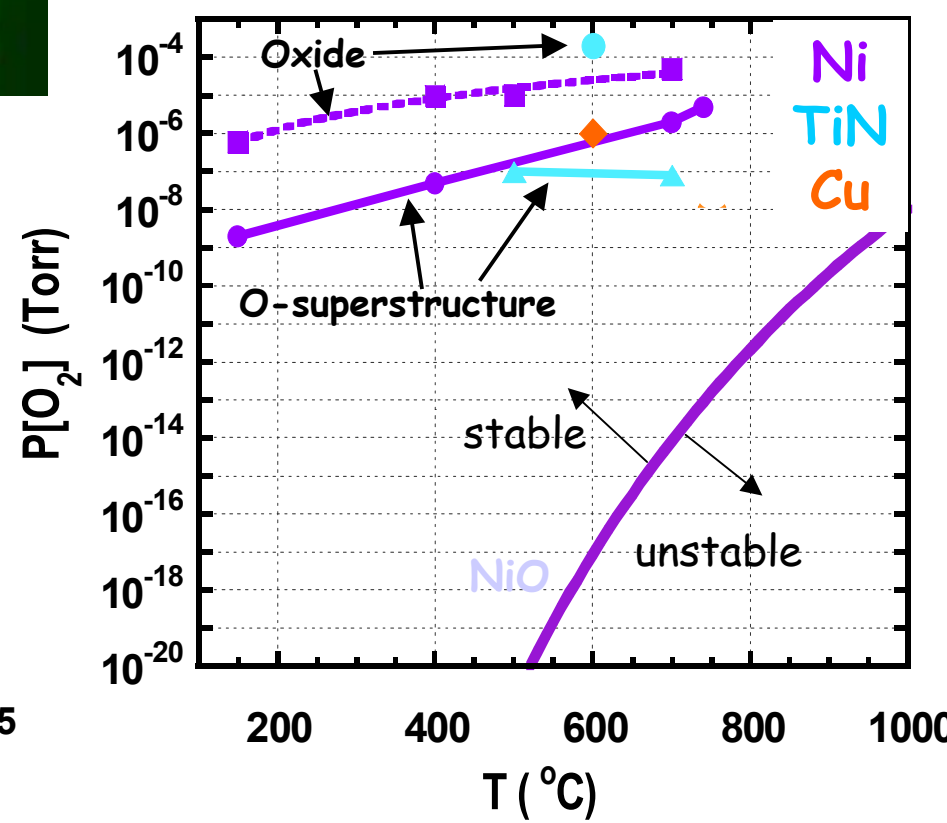
- ***Develop combination of texture, strength, and conductivity in copper alloy tapes***

END

Challenges for totally conducting buffer layer architectures

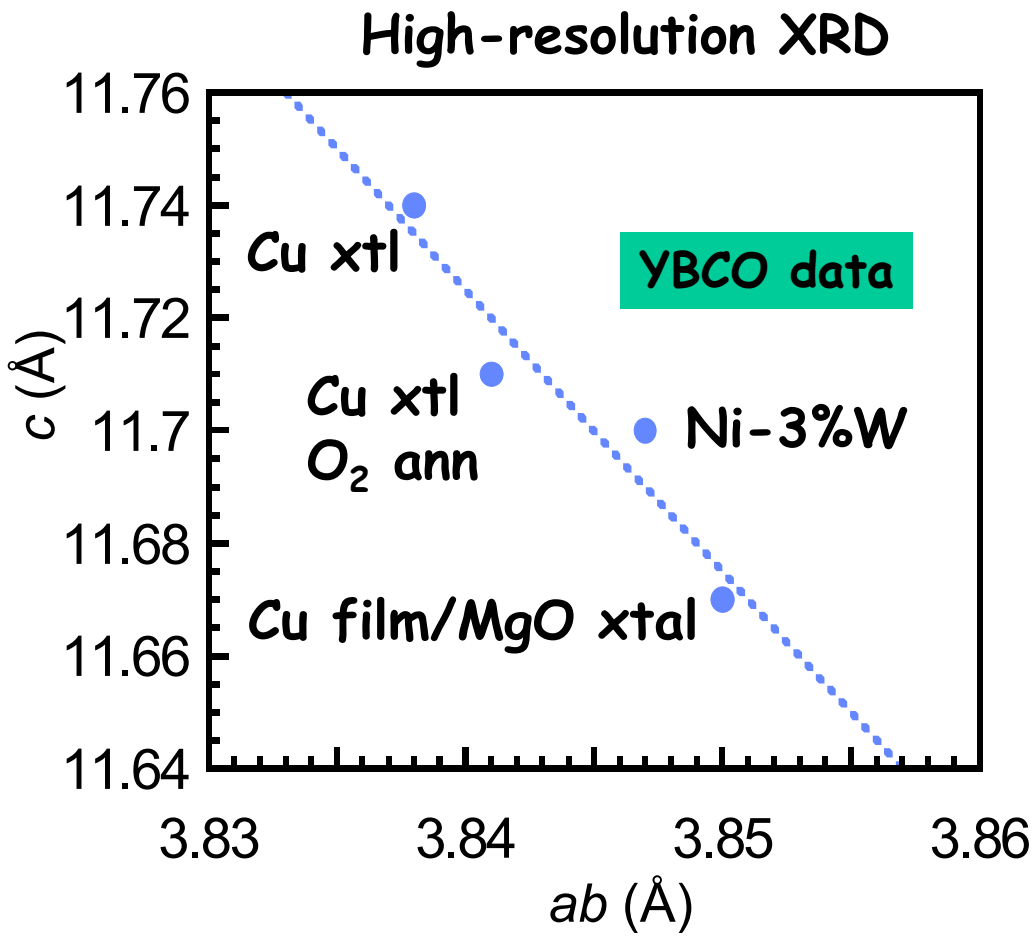
Stability of TiN in Oxygen



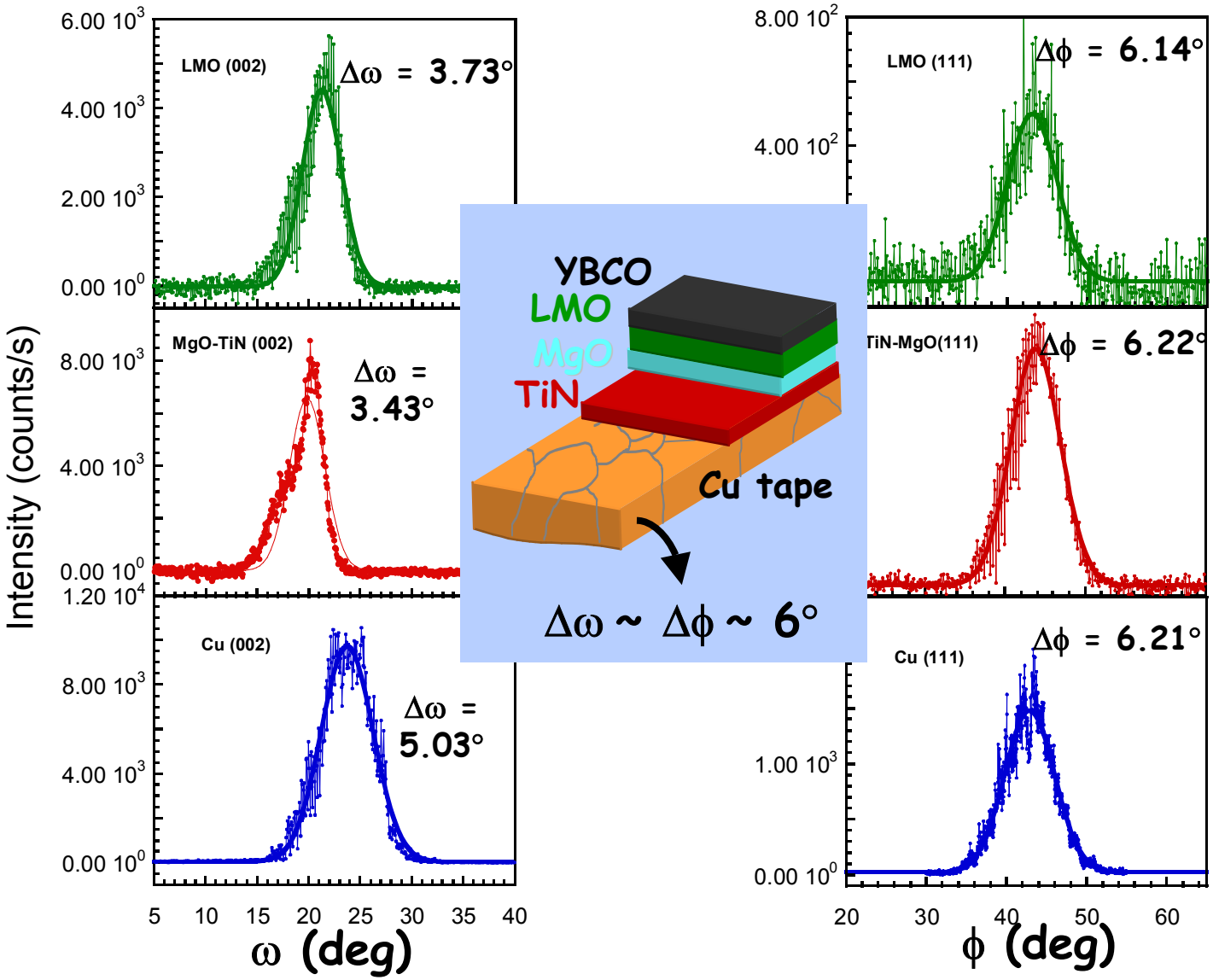


Comparison of strain in YBCO

- $a_{Cu} = 18 \times 10^{-6}\ K^{-1}$;
  $a_{YBCO} = 12 \times 10^{-6}\ K^{-1}$;
  $a_{Ni} = 16 \times 10^{-6}\ K^{-1}$
- Expected YBCO strain ~ 0.45%
- Measured YBCO strain = 0.2%
  (on 1.5 mm thick bulk Cu)



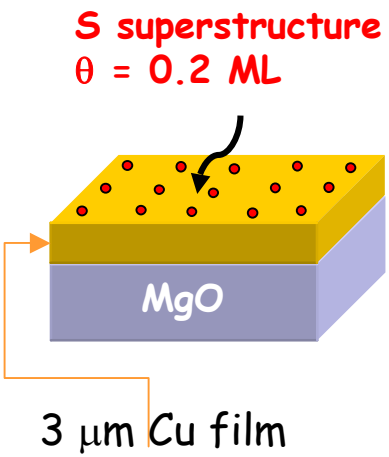
Also viable buffer layer structure on Cu tape

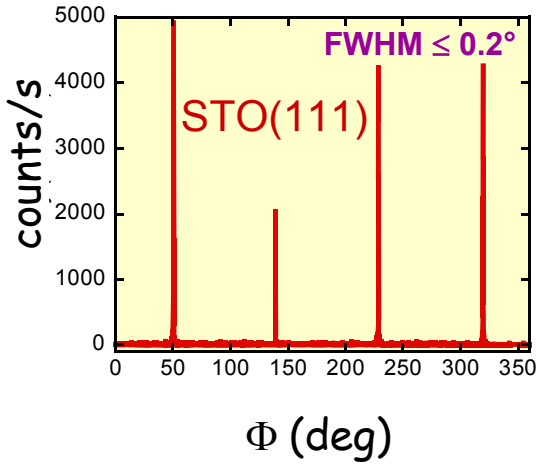


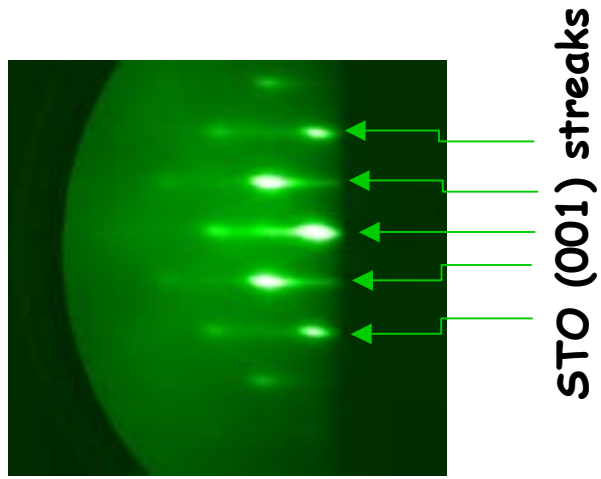
material	Unit cell	D_{ox} (800 °C) Oxygen Diffusion Coefficient
MgO	4.21 Å	1×10^{-20} cm^2/s
$CaTiO_3$	3.82 Å (orth)	1×10^{-15} cm^2/s
$SrTiO_3$	3.91 Å	2×10^{-12} cm^2/s
CeO_2	3.82 Å	1×10^{-5} cm^2/s
Ho_2O_3	3.75 Å	1×10^{-3} cm^2/s
YSZ	3.63 Å	1×10^{-7} cm^2/s

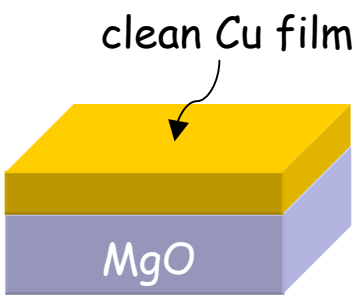
S Superstructures on (001) Cu

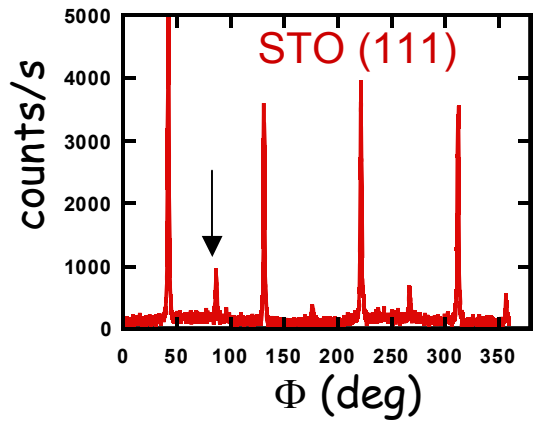
- S forms only a $p(2\times2)$ superstructure on Cu
- Epitaxy of STO and CeO_2 requires S superstructure

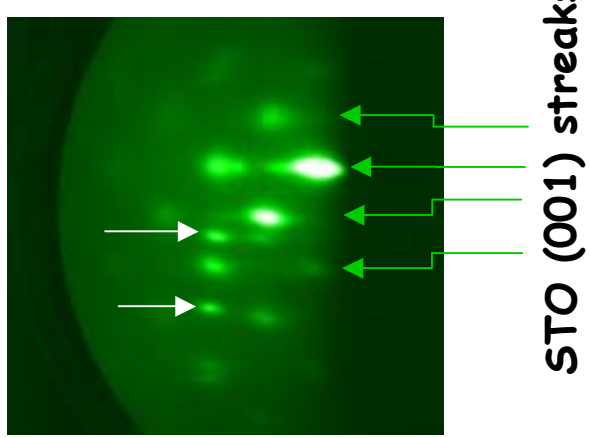




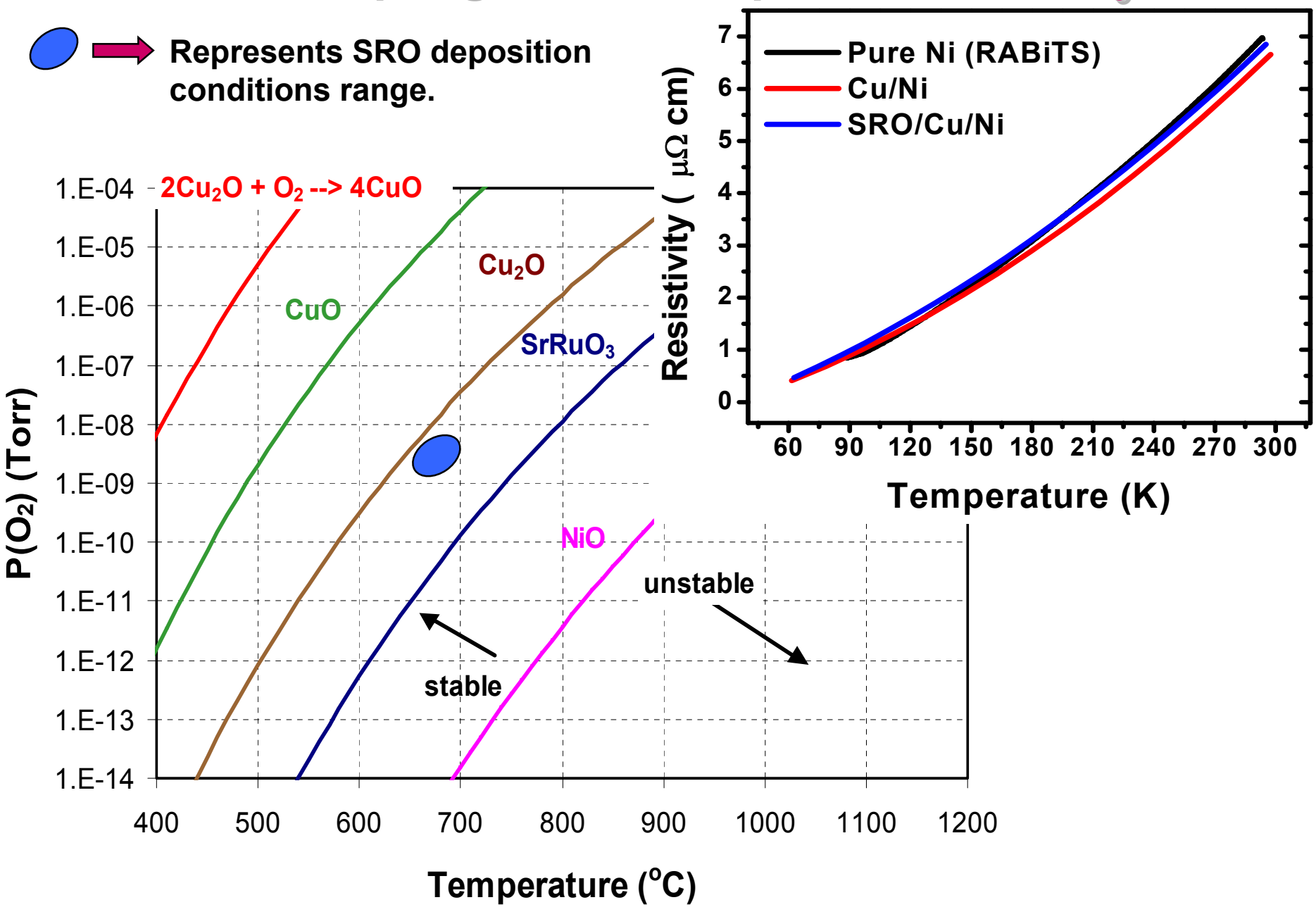








Electrical Coupling Between Sputtered $SrRuO_3$/Cu/Ni



http://www.amcpmc.com/metal_prices.html

Yesterday's AM Close

London Metal Exchange 3/28/2002								
MetalPrices.Com	Official Morning Price USD/Lb						Cash Averages	
by	Cash			3 Month			Month	
10 am EST	3/28	3/27	+/-	3/28	3/27	+/-	Feb	Mar
Al	.629	.626	.003	.636	.634	.002	.621	.637
Al Alloy	.581	.585	(.004)	.590	.590	.000	.532	.567
NASAA	NA	NA	NA	.703	.701	.002	NA	NA
Cu	.736	.730	.006	.745	.741	.004	.708	.728
Pb	.220	.222	(.002)	.226	.227	(.001)	.218	.218
Ni	3.044	3.037	.007	3.039	3.037	.002	2.736	2.967
Sn	1.778	1.780	(.002)	1.794	1.794	.000	1.692	1.743
Zn	.374	.377	(.003)	.384	.386	(.002)	.350	.372

Yesterday's Average Prices

LME Cash Price - Moving Averages -USD/Lb				
3/28/2002 MetalPrices.Com	Number Of Trading Days 10	20	30	2/26/2002 - 3/28/2002
Al	.636	.637	.631	.636
Al Alloy	.577	.567	.557	.565
Cu	.735	.728	.719	.725
Ni	3.026	2.967	2.877	2.946
Pb	.219	.218	.217	.218
Sn	1.751	1.743	1.718	1.739
Zn	.375	.372	.364	.370