ORNL-AMSC Strategic Research

American Superconductor Corporation

U. Schoop, M. W. Rupich, D. Verebelyi, C. Thieme,
X. Li, T. Kodenkandath, W. Zhang, N. Nguyen and J. Scudiere

Oak Ridge National Laboratory

A. Goyal and M. Paranthaman

C. Cantoni, E. Hatfield, K. More, M. Fayek, R. Duckworth, L. Heatherly,
J. R. Thompson, E. Specht, S. Sathyamurthy, D. Lee, T. Aytug, P. M. Martin,
S. Cook, Mike Gouge

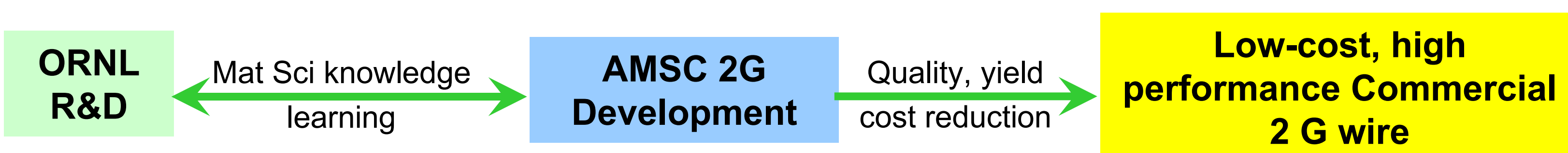
FY 2004 Funding: $ 0.9 million: DOE OETD, Matching Funds at AMSC

Objective: Assist AMSC's development of a low-cost, robust 2G wire based on RABiTS technology through R&D support

FY2004 Performance of CRADA

- Productive Collaboration over the last year
  - 3 All-hands meetings
  - Extensive sample exchange
  - Weekly telephone conferences

- Major achievements in all areas



FY2004 CRADA Goals

- **ORNL support of AMSC's 4 cm process scale up**

  Substrate Rolling in 4 cm width at ORNL facility

  Sample Characterization

- **Produce 20 meter lengths of 2G wire with an I_c of 250 A/cm from the 4cm wide manufacturing process**

  Demonstrated uniformity and reproducibility in 10 m lengths with I_c = 250-270 A/cm-w from 1 cm process – 4 cm process is in active development

- **Demonstrate feasibility of 10 cm wide substrate rolling**

  Uniform texture demonstrated in 10 cm x 80 m RABiTS substrates

More FY2004 CRADA Goals

- **Correlate "texture" to $J_{c.}$ Analyze the importance of out-of-plane alignment with respect to J_c.**
  - Improved product understanding will help focus development efforts
- **Optimize buffer layer stack for manufacturing of YBCO coated conductors**
  - Thickest buffer layer was reduced by 2.7 x with no loss of performance
- **MOD buffer development**
  - Analytical understanding of buffer requirements through in-depth study of diffusion and microstructure
  - Two layer all solution buffer stack demonstrated
- **Also planned: ac-loss characterization and development of non-magnetic template**

AMSC-ORNL CRADA Presentation

- FY 2004 Results

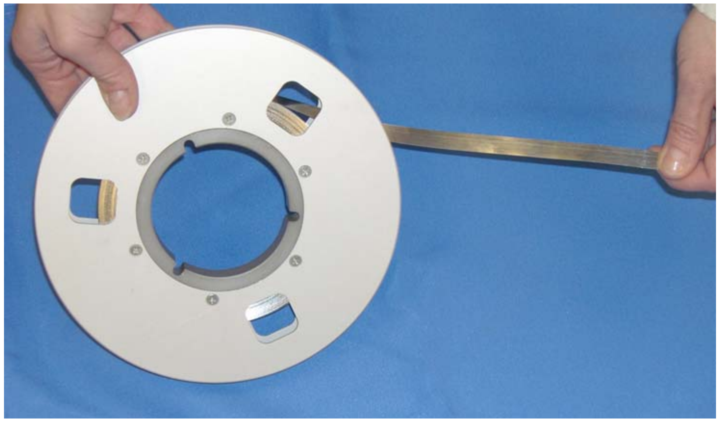
  2G Development (YBCO/RABiTS) at AMSC (Urs)
  2G wire manufacturing at AMSC
  2G wire characteristics

  Rolling and annealing of alloys (Amit)
  Correlation of texture to J_c
  Buffer layers: Methodology development and characterization
  AC Losses and stabilization

  Development of low-cost, solution buffer layers (Parans)

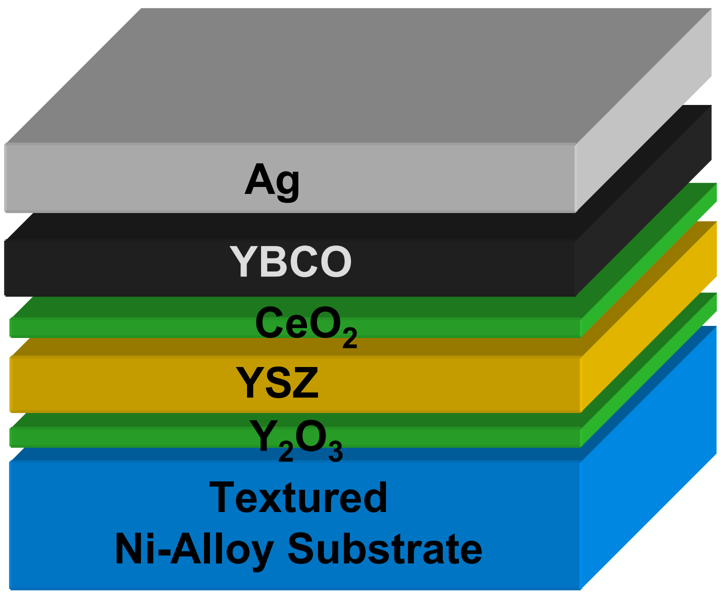
- FY 2004 Performance and FY 2005 Plans (Parans)
- Research Integration

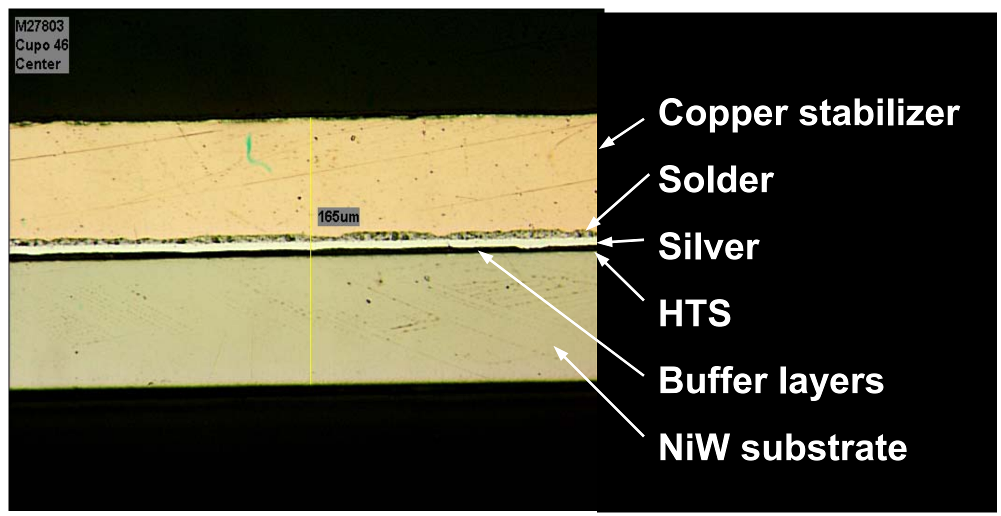
AMSC 2G Conductor Architecture



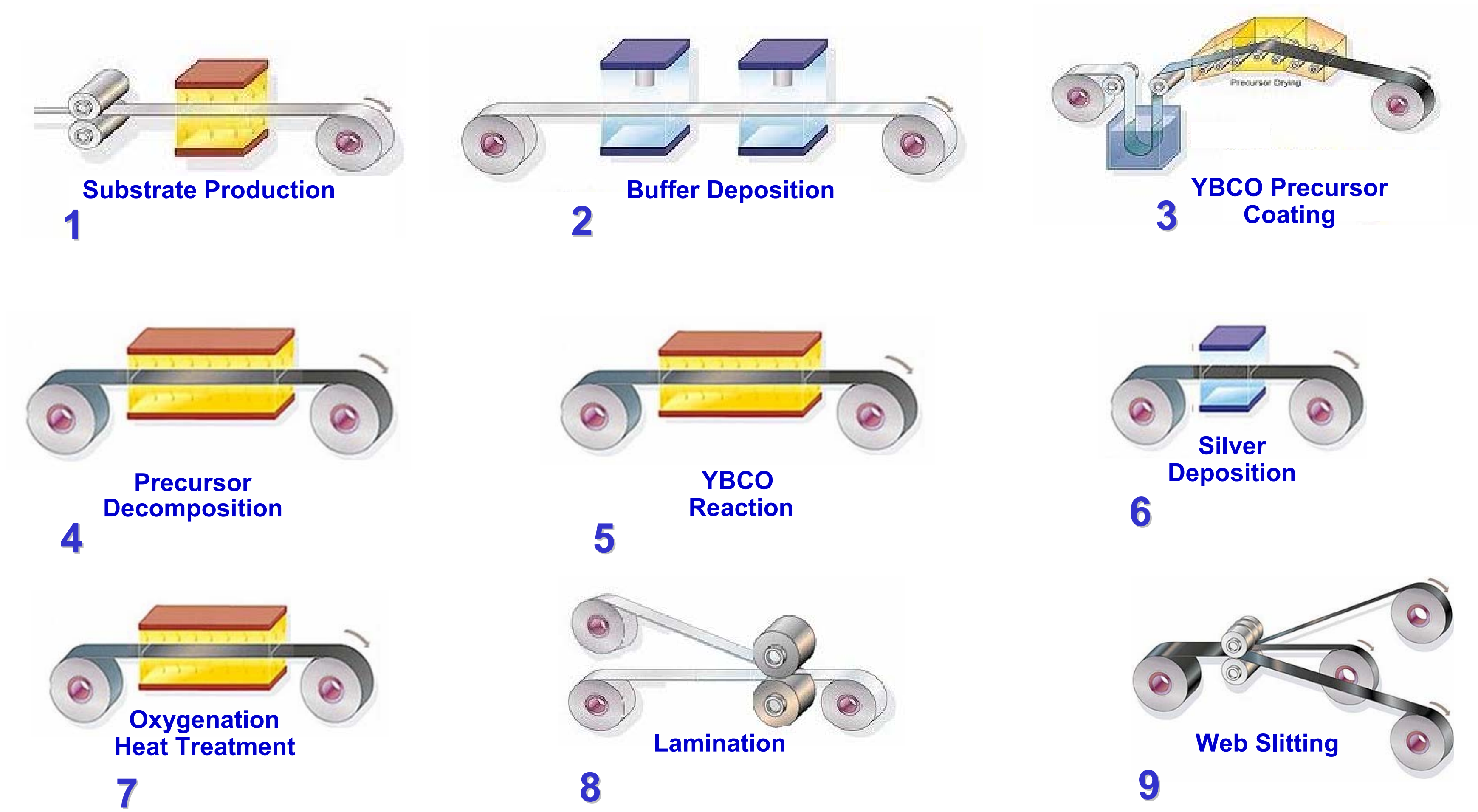
AMSC 2G conductor is based on:

- Ni5at%W RABiTS substrate
- Y_2O_3 / YSZ / CeO_2 buffer stack
- MOD YBCO
- Neutral Axis (NA) Conductor design





AMSC 2G Wire Manufacturing Process



ORNL AMSC CRADA supports development of initial steps of 2G process

Supporting Work at ORNL

Investigate routes that lead to long term improvements, including:

Fundamental research with the goal to:

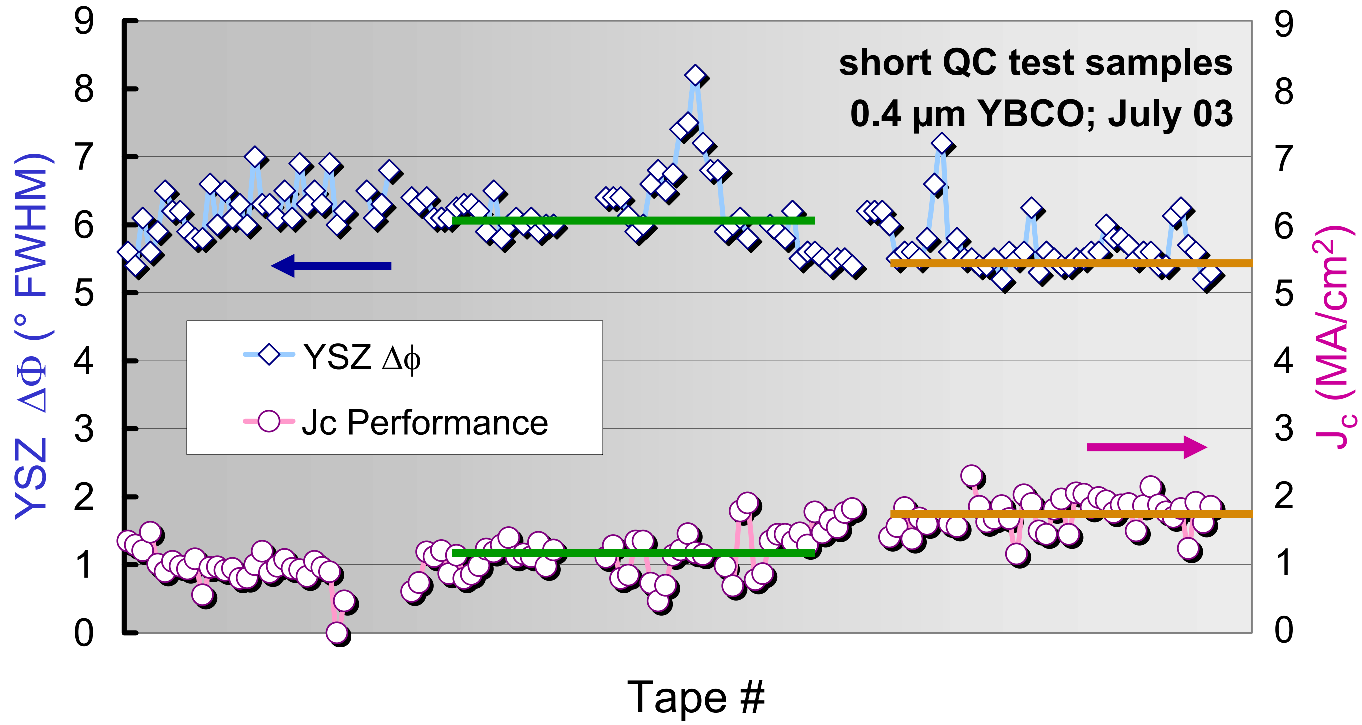
- Improve performance → I_c vs. texture relation
- Increase reliability (yield) → Analytical support
- Reduce cost → engineered buffers, mitigate scale up risk

High risk – high reward approaches:

- All solution buffer work
- Non-magnetic templates

ORNL is key player in supporting future process improvements

How is I_c Limited by Template Texture?

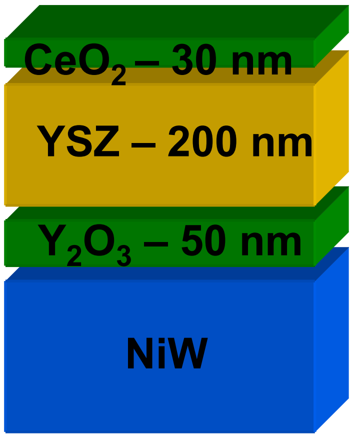


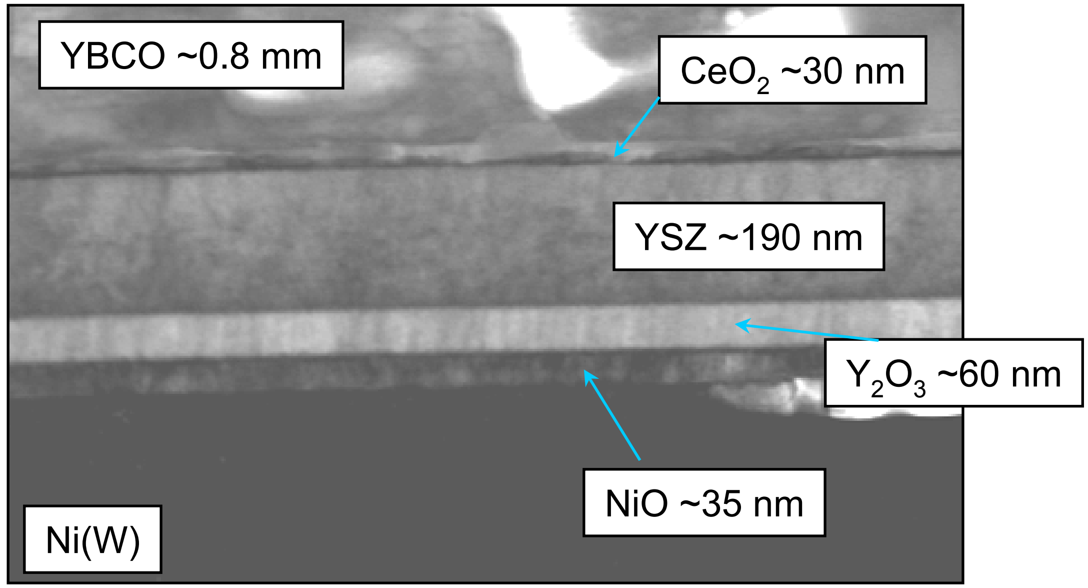
July 03: AMSC database suggests that I_c improvements are possible by further improving texture of template.

- How should the template texture be improved to increase I_c?

ORNL-AMSC CRADA focused on correlation of Ic vs. texture

Goal: Optimize Buffer Stack
AMSC Baseline Buffer Architecture – July 2003





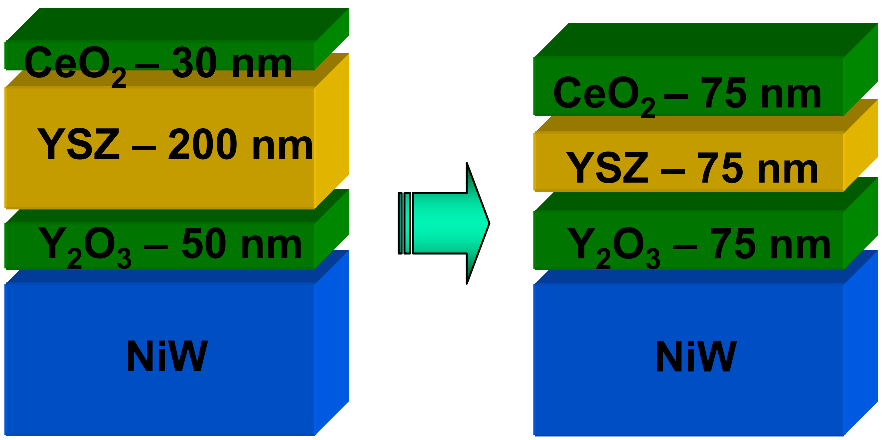
<u>Start:</u>
Establish diffusion properties of buffer stack for oxygen and metal diffusion in regime of YBCO growth.

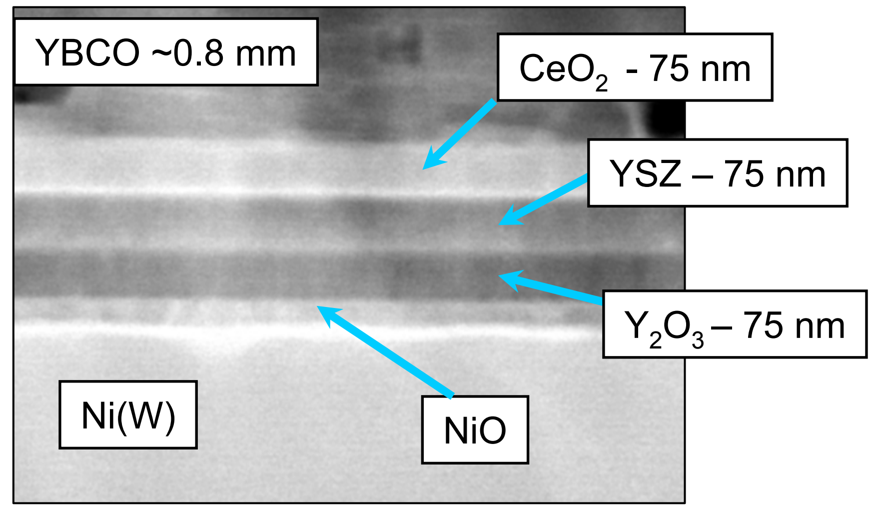
<u>Methods:</u>
XRD / X-SEM studies at AMSC
TEM / ^{18}O and SIMS studies at ORNL
^{18}O and SIMS studies at SNL

CRADA focused on engineering a robust, low cost buffer

Goal: Optimize Buffer Stack
AMSC Baseline Buffer Architecture – July 2004

☑ Result: Characterized diffusion properties of standard buffer layers
Optimized buffer stack maintaining full performance I_c = 280 A/cm-w





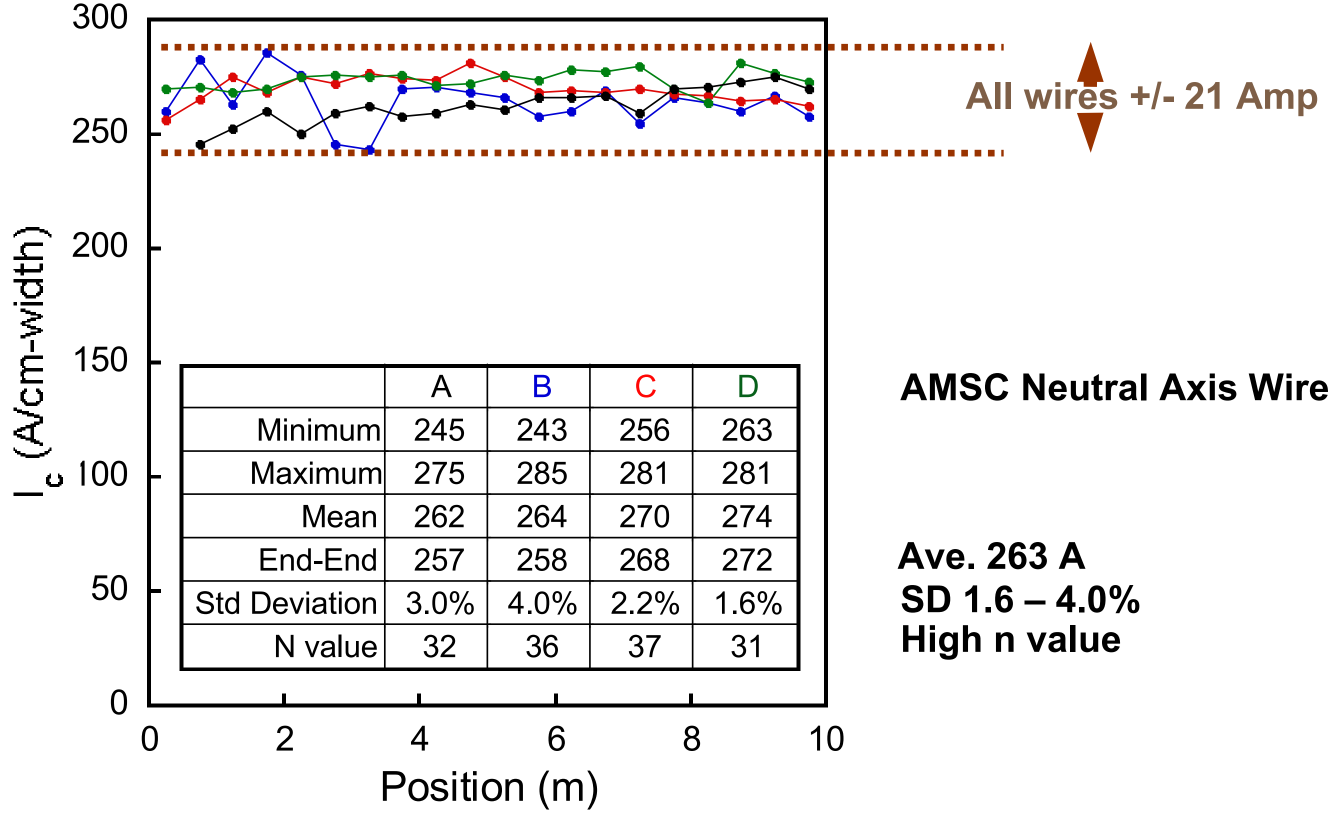
Benefits:

- Cost: reduction of deposition time – YSZ reduced by 2.7x
- Manufacturing: matched line speeds (equal thickness & rates)
- Process Integration: HTS process window maintained

Buffer architecture and deposition process engineered for robust manufacturing

Goal: Demonstrate > 250 A/cm-w in continuous process

☑ Result: RABiTS process capability demonstrated



	A	B	C	D
Minimum	245	243	256	263
Maximum	275	285	281	281
Mean	262	264	270	274
End-End	257	258	268	272
Std Deviation	3.0%	4.0%	2.2%	1.6%
N value	32	36	37	31

AMSC Neutral Axis Wire

Ave. 263 A
SD 1.6 – 4.0%
High n value

I_c close to commercial requirements of cable wire for AMSC NA wire.
Reproducibility and uniformity is a critical validation for scale-up

Focus of Current Activities at AMSC

AMSC has demonstrated that the current architecture is

- *technically viable,*
- *meets the customer specs for electrical and mechanical properties*
- *is cost effective.*

The current architecture will be the basis to:

- Scale to pre pilot production in 4 cm / 100 m
- Improve process knowledge and establish manufacturing methods
- Increase capacity by scaling width and length

AMSC identified path to scale up commercial conductor manufacturing

AMSC Scale up Plan

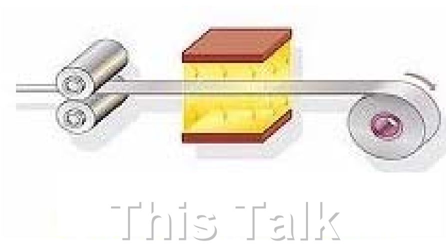
<u>Yielded Wire Capacity:</u>

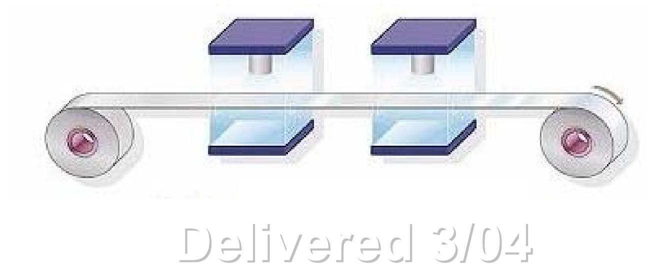
- Pre-pilot (4 cm x 100 m) ~ 10-20 km / yr
  - Spring 2005
  - Key pieces of new equipment and upgraded R&D systems
  - R&D systems capable 1 and 4 cm widths, 100 m length
  - Pilot Scale equipment capable of 4 and 10 cm widths, > 1 km length
- Pilot scale (10 cm x >1000m) ~ 300 km / yr
  - all systems pilot scale
- Initial Production multiple thousand km / yr

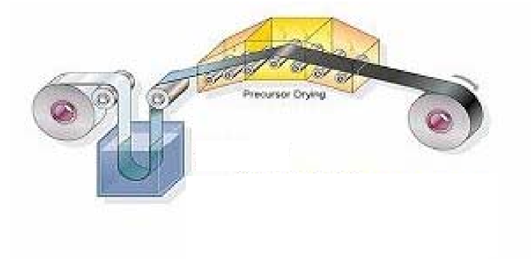
ORNL is assisting the scale up in:

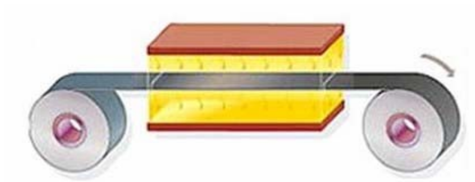
1. ***Rolling of pre-pilot substrates***
2. ***Optimize processes and develop new approaches***
3. ***Characterization of resulting wire***

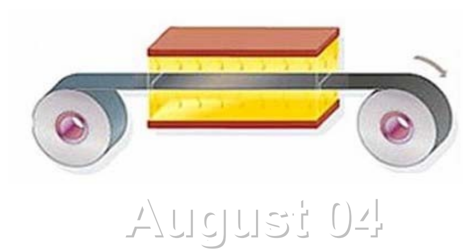
Goal: ORNL Assists in AMSC Scale up to Pre Pilot

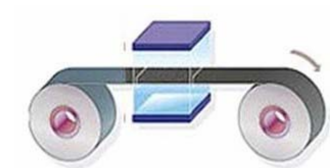












Upgrades for R&D equipment to 4 cm x 100 m:

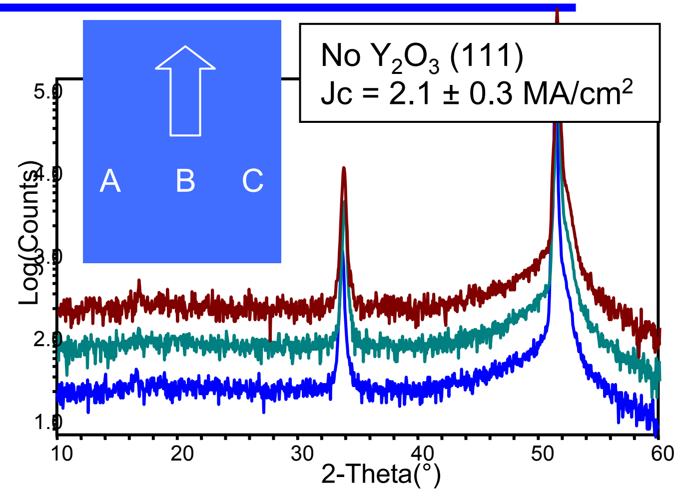
- Better web transport (alignment, tension, build up)
- Tighter control of parameters for process stability
- Increase of active zone width

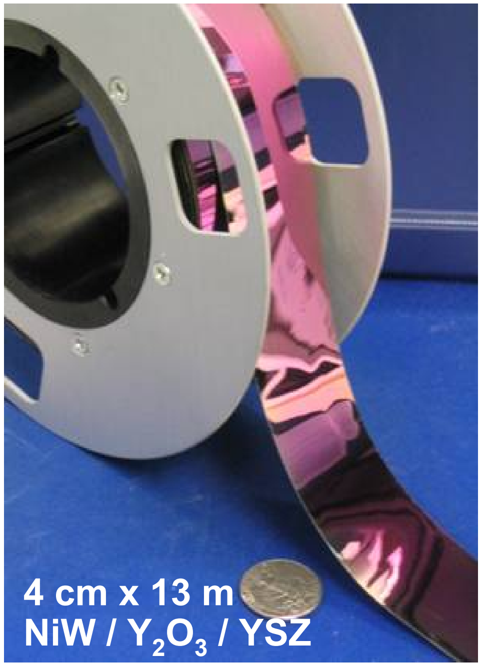
Verify Design Concept for Key Technology Concepts

AMSC Scale up to 4 cm width: PVD Process

Goals:
- Reactive high rate buffer process
- 4 cm width x 100 m length

☑ Result: 4 cm process development in progress





Long length efforts in 4 cm width:

- Y_2O_3 seed in converted R&D system – qualified
  - **100% (200) texture across 4 cm x 40 m demonstrated**
  - **I_c = 2.1 MA/cm² demonstrated (short QC YBCO, 0.4 µm)**
- YSZ barrier in pilot system (Zone A) – in qualification
  - **Deposition rate for throughput 50 m/hr**
  - **Uniformity (4cm width): +/- 3%**
  - **Uniformity (40 m length): +/- 3%**
  - **Demonstrated fully automated operation**
- CeO_2 cap in pilot system (Zone B) – next quarter

Major Equipment Assumptions and Design Innovations Confirmed

Goal: ORNL Assist in AMSC Process Scale up

Sample characterization is critical for development of robust manufacturing process

☑ Result: Ongoing analytical support from ORNL

- Labs have excellent analytical capabilities
- Outstanding resource for effective troubleshooting
- Leads to consequent improvements in process stability

- Analysis of all samples allows:
  - Identification and elimination of local defects
  - Understanding and optimization of process dynamics
  - Correlation of process interactions

Sample characterization beyond AMSC's resources

AMSC-ORNL CRADA Presentation

- **FY 2004 Results**

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  Rolling and annealing of alloys (Amit)
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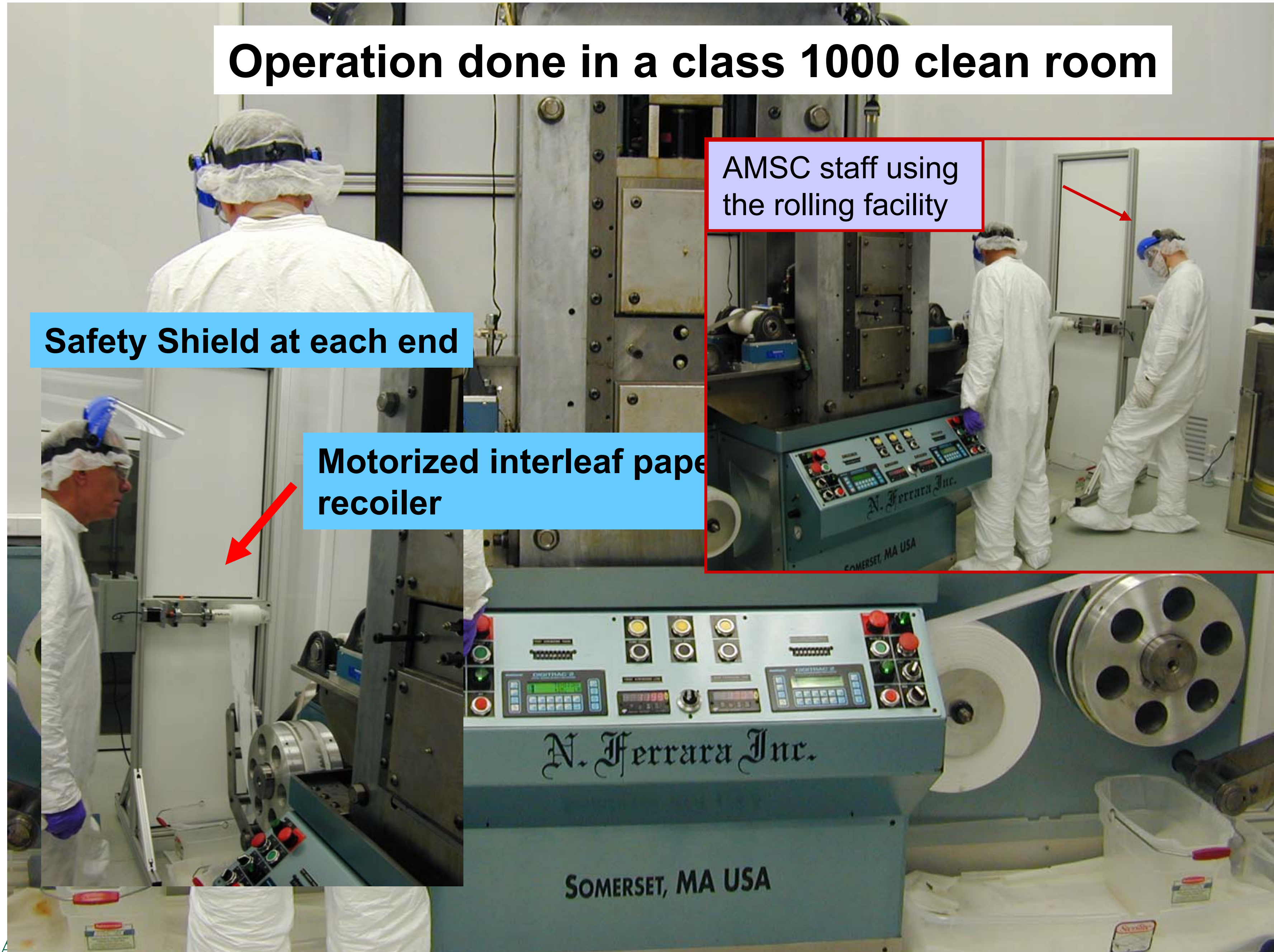
- FY 2004 Performance and FY 2005 Plans (Parans)
- Research Integration

Development of Rolling Mill Facility at ORNL

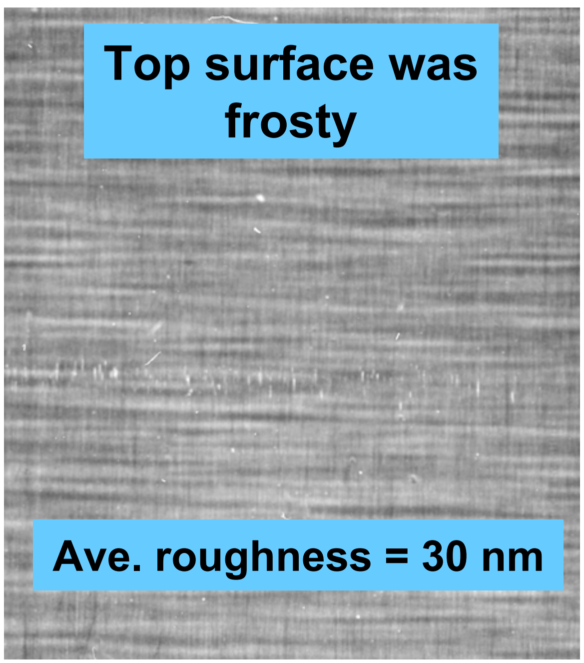
- Water sprinkler system on roof (very expensive)
- Installed a pressure differential sensor
- particle count detector, telephone inside clean room

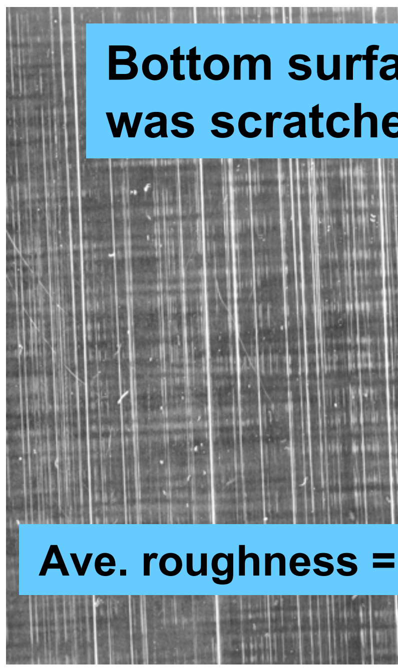
Operation done in a class 1000 clean room



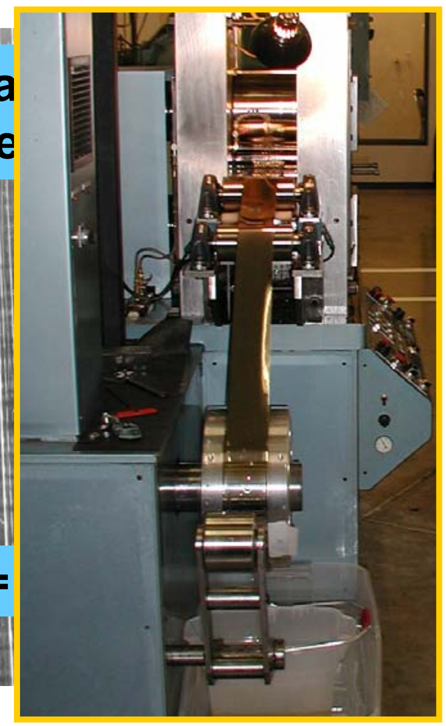
Goal was to fabricate wide substrates for AMSC

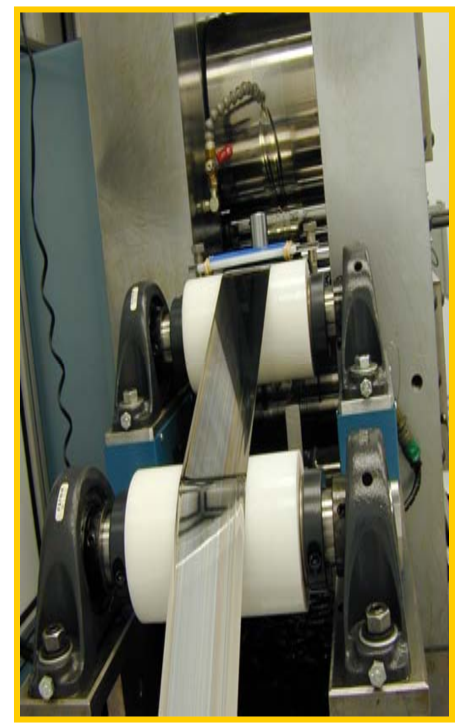
- AMSC interested in high rolling speeds for high throughput
- Significant problems were encountered initially



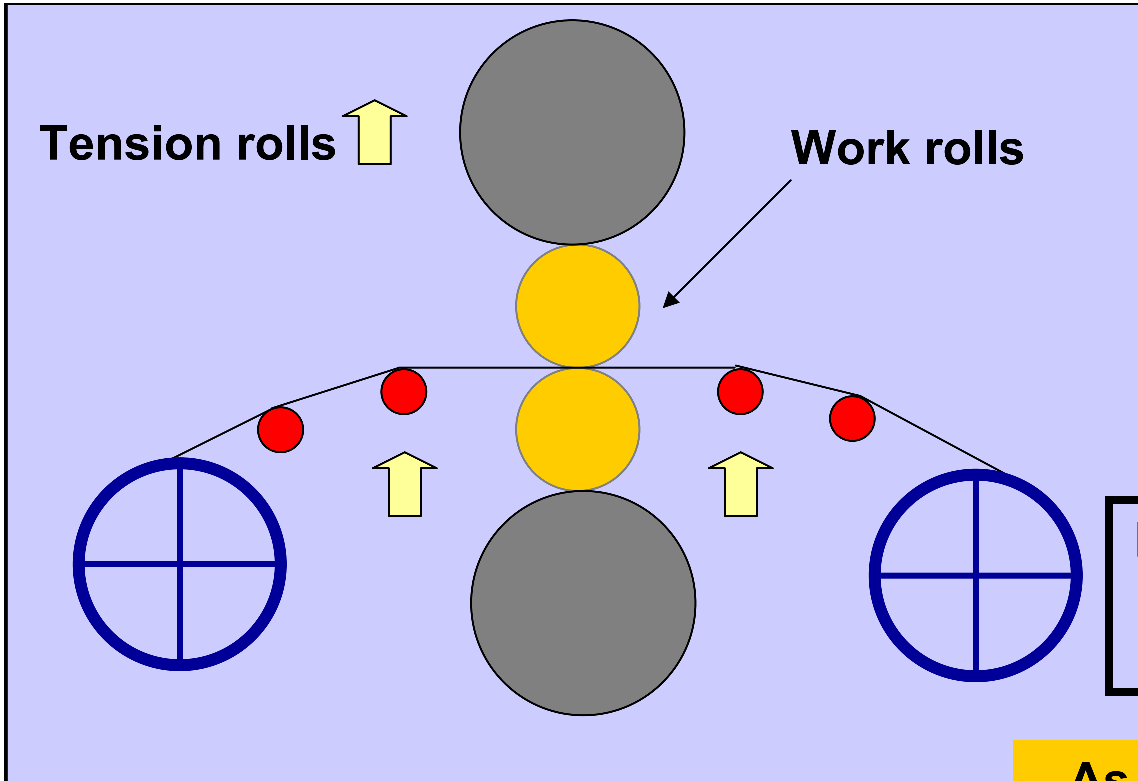


Fixing the bottom surface was easy





Modifications to the mill were made and lubricant viscosity was experimented with to obtain a smooth top surface

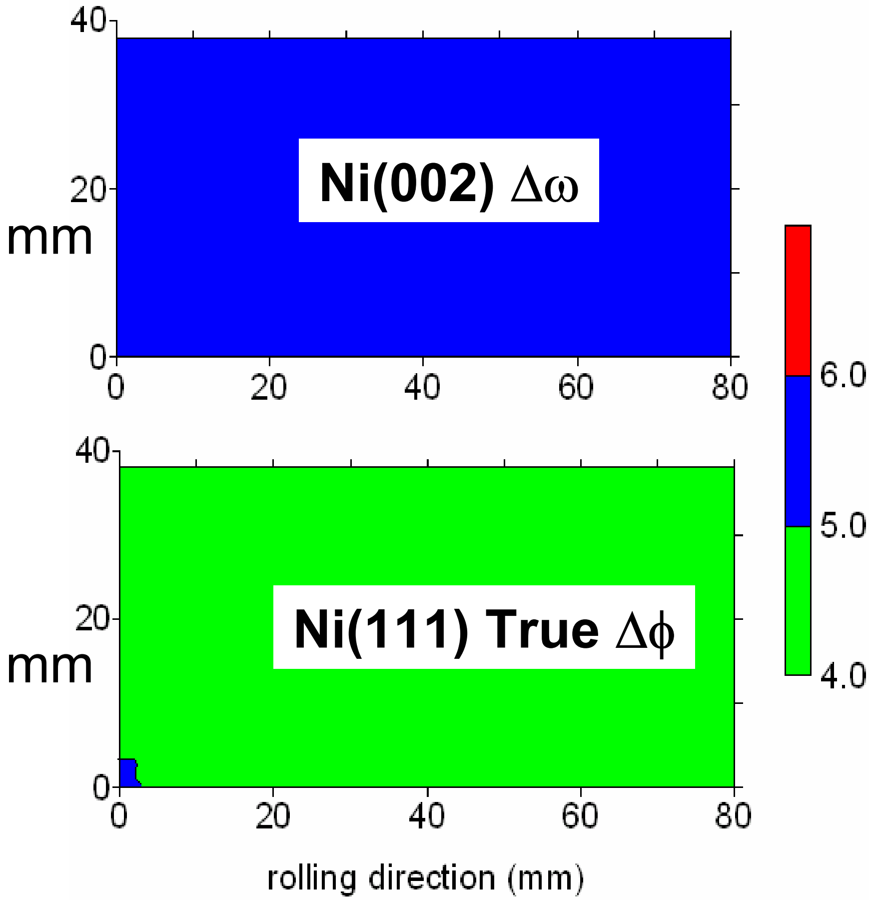


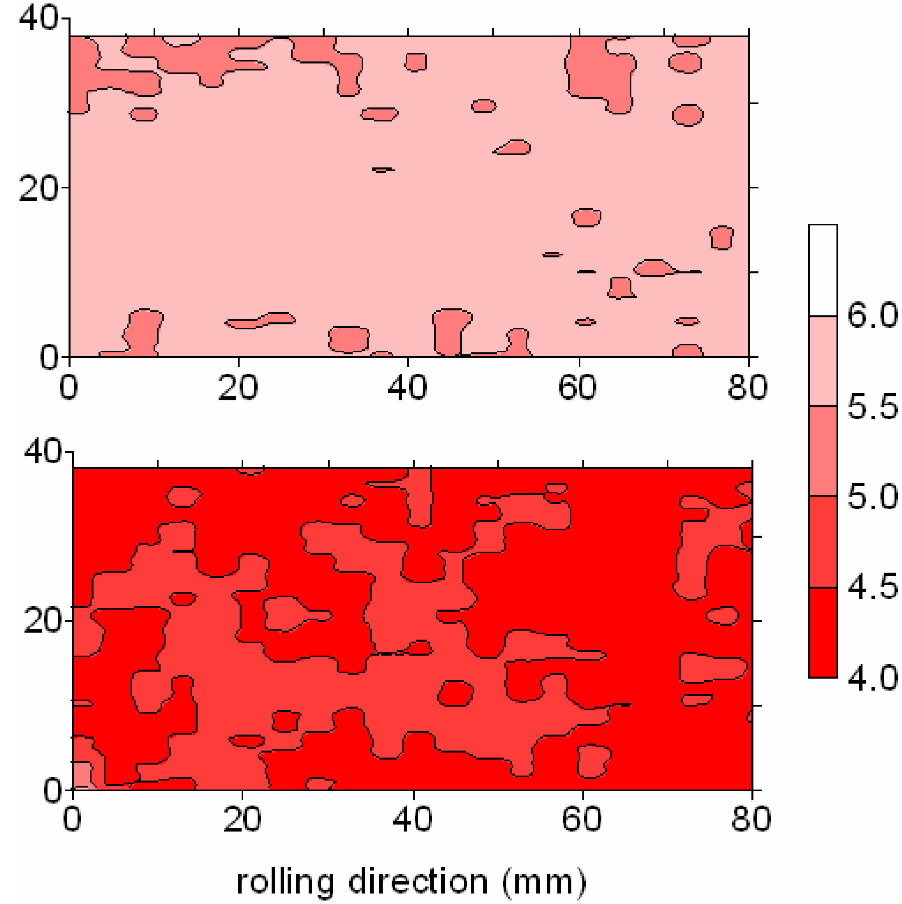
Experiments with changing lubricant viscosity were done

As rolled surfaces are smooth and require no polishing (8-10nm surface roughness)

AMSC personnel visit ORNL on a regular basis to roll wide area NiW substrates for scale-up efforts and this has been the primary activity of the mill this year.

Goal: ORNL support AMSC 4cm process scale-up

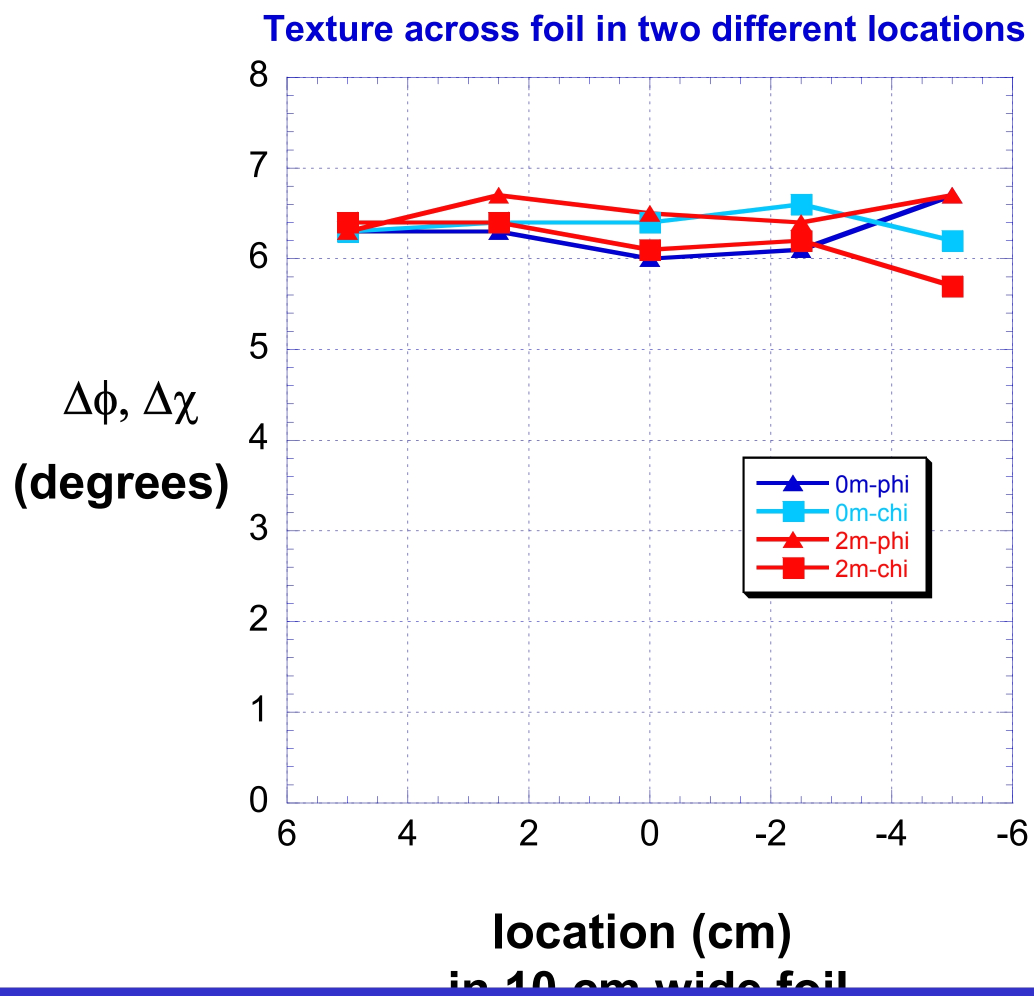




AMSC substrate rolling in 4cm widths routinely performed at ORNL facility

Wide foils have homogeneous texture

First run on 10cm wide substrate



10 cm wide substrates with homogeneous and sharp texture are viable

Goal: Correlation of texture and grain boundary networks to J_c

A True Phi of ~5° in-plane FWHM supports 80% of single crystal J_c for YBCO Films on RABiTS

April, 2004

YBCO on $CeO_2/YSZ/Y_2O_3/NiW$

	Sample 1	Sample 2
	J_c = 3.3 MA/cm^2 I_c = 260 A	J_c = 3.4 MA/cm^2 I_c = 270 A
YBCO	$\Delta\phi$ = 4.9° $\Delta\omega$ = 4.0°; 5.1°	$\Delta\phi$ = 4.8° $\Delta\omega$ = 4.0°; 5.2°
Buffer	$\Delta\phi$ = 3.9° $\Delta\omega$ = 4.7°; 7.0°	$\Delta\phi$ = 4.0° $\Delta\omega$ = 4.77°; 7.3°
NiW	$\Delta\phi$ = 4.3° $\Delta\omega$ = 5.29°; 8.37°	$\Delta\phi$ = 4.5° $\Delta\omega$ = 5.37°; 8.26°

$YBCO/CeO_2$/SC YSZ

J_c = 4.3 MA/cm^2
I_c = 344 A

FWHM of $\Delta\omega$ ~ 1-2°
FWHM of $\Delta\phi$ ~ 1-2°

YBCO

CeO_2

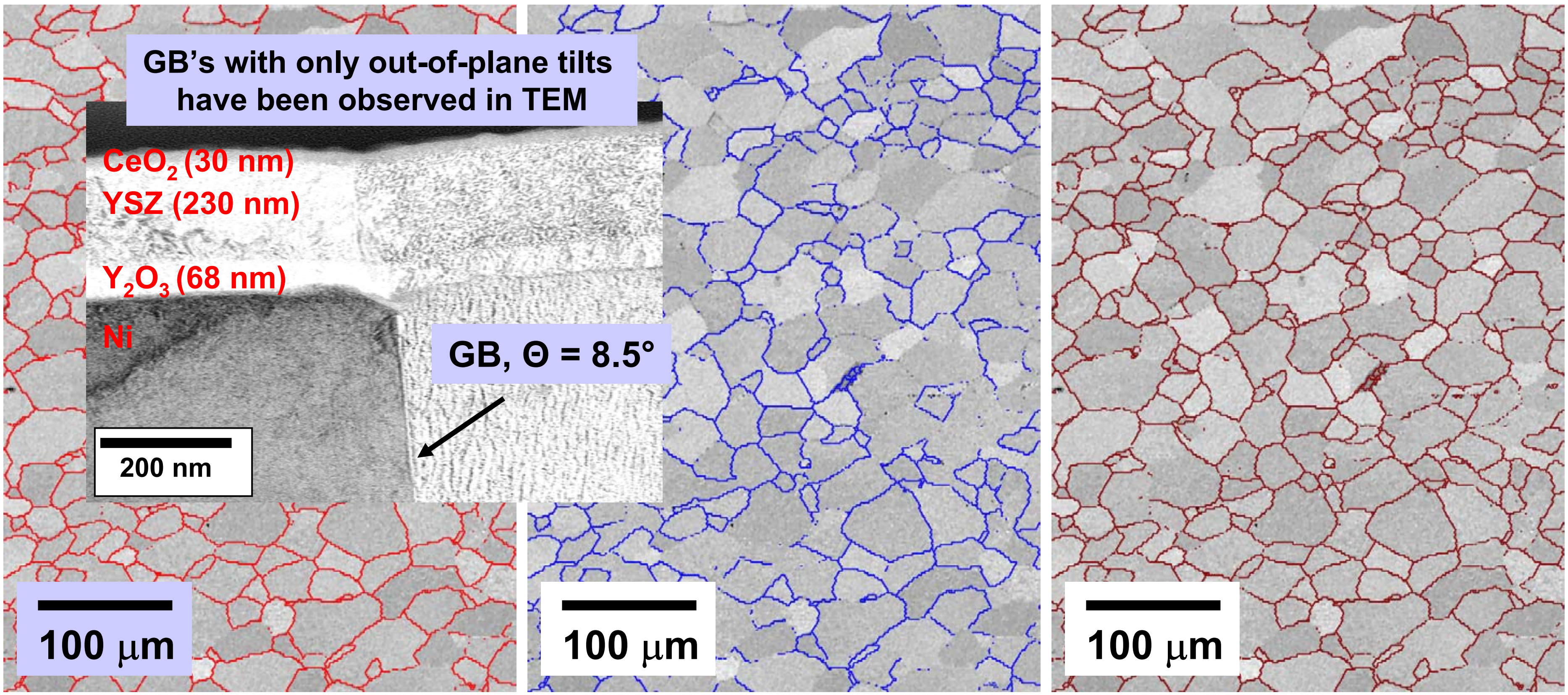
Single crystal YSZ

What is the nature of grain boundaries in RABiTS which support 70-80% of SC J_c?

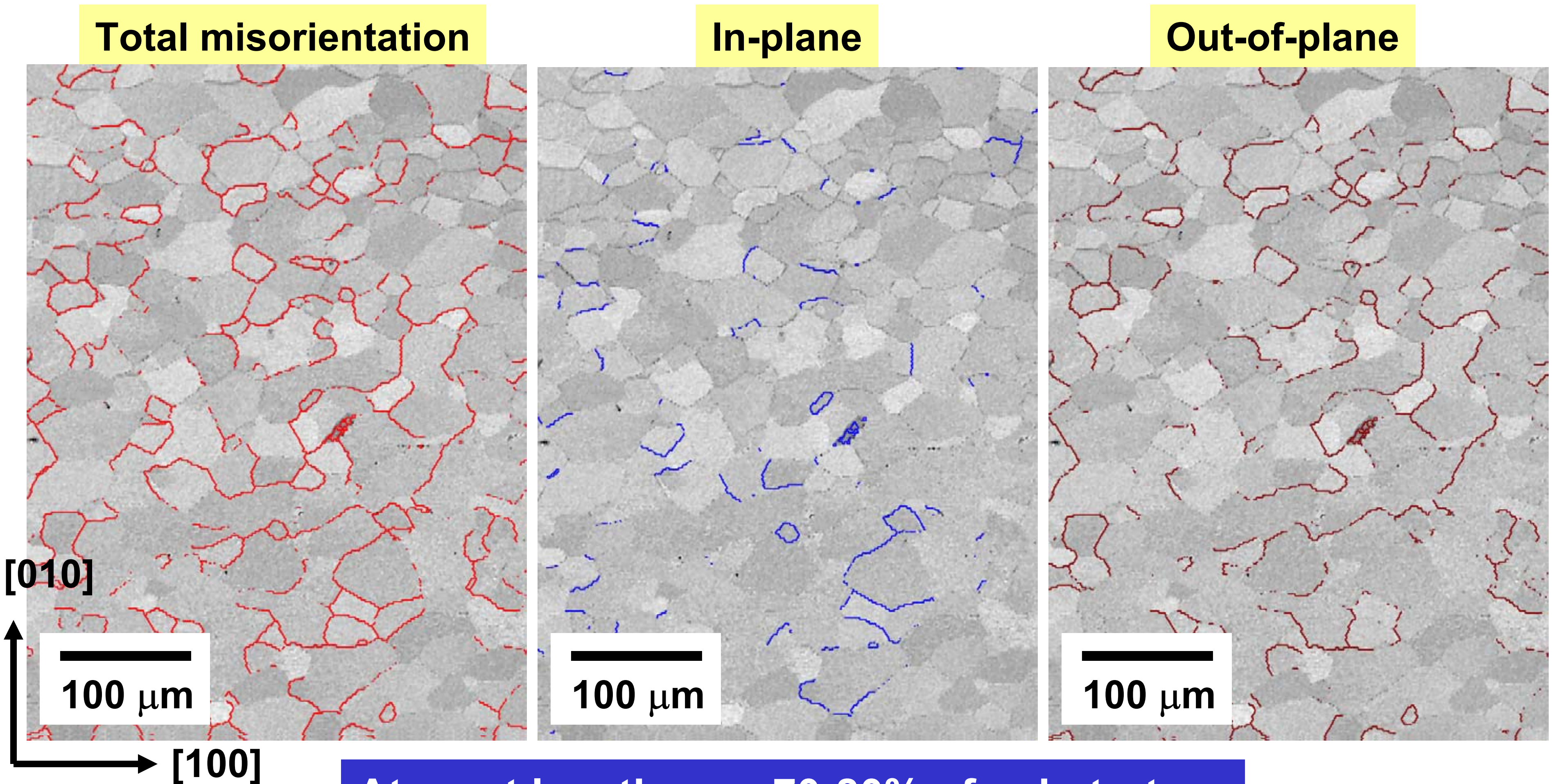
Total grain boundary misorientation was separated into in-plane and out-of-plane contributions using manipulations in Rodrigues space

EBKP data from the CeO_2 layer and all GB's greater than 1° shown

Total misorientation | **In-plane** | **Out-of-plane**



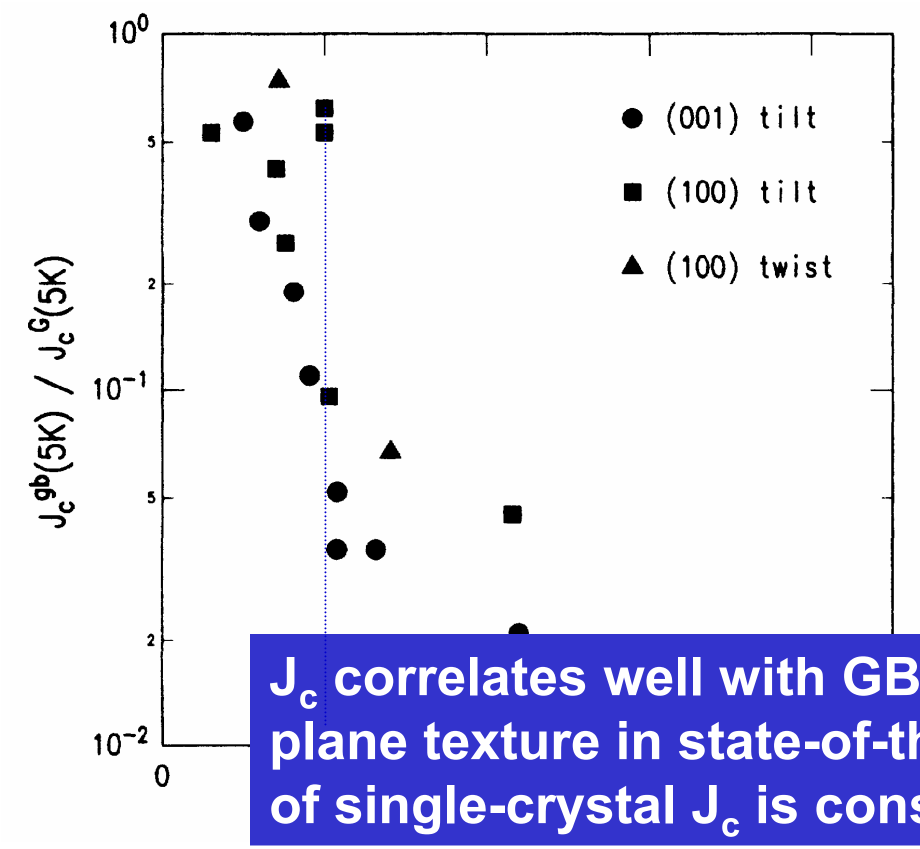
Grain boundary maps drawn with all GB's greater than 4° show that in-plane misorientation is determining J_c

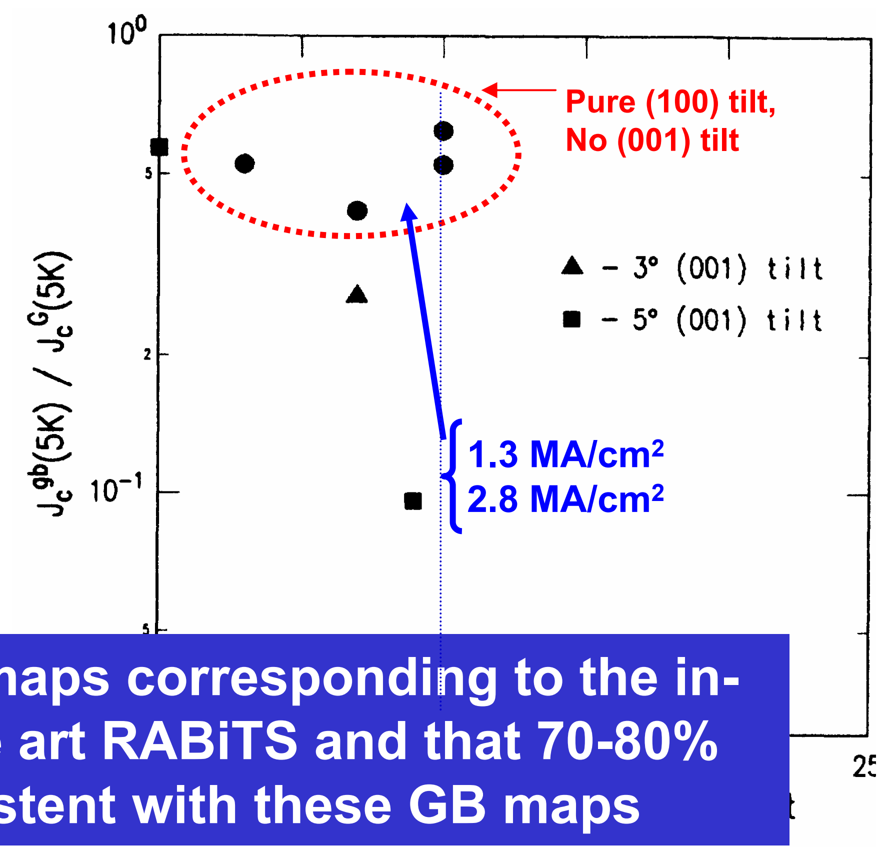


At most locations ~ 70-80% of substrate is single crystal-like w.r.t. in-plane texture

Observations are consistent with Dimos et al.'s work

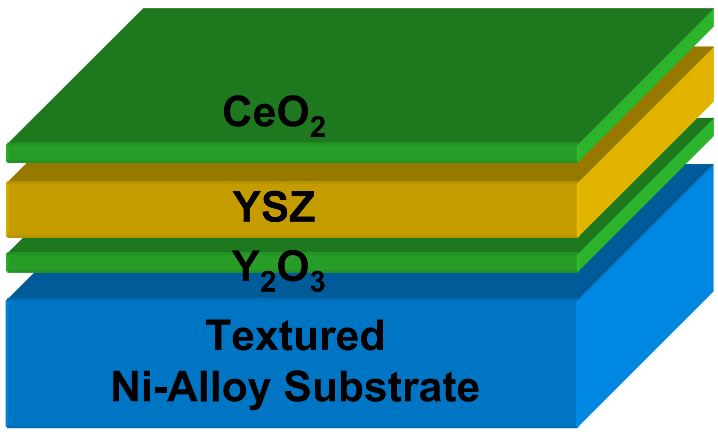
Ref: Dimos et al., Phys. Rev.B, 41, 4038 (1990)





J_c correlates well with GB maps corresponding to the in-plane texture in state-of-the art RABiTS and that 70-80% of single-crystal J_c is consistent with these GB maps

AMSC RABiTS™ Architecture: *Understanding buffer layer characteristics*



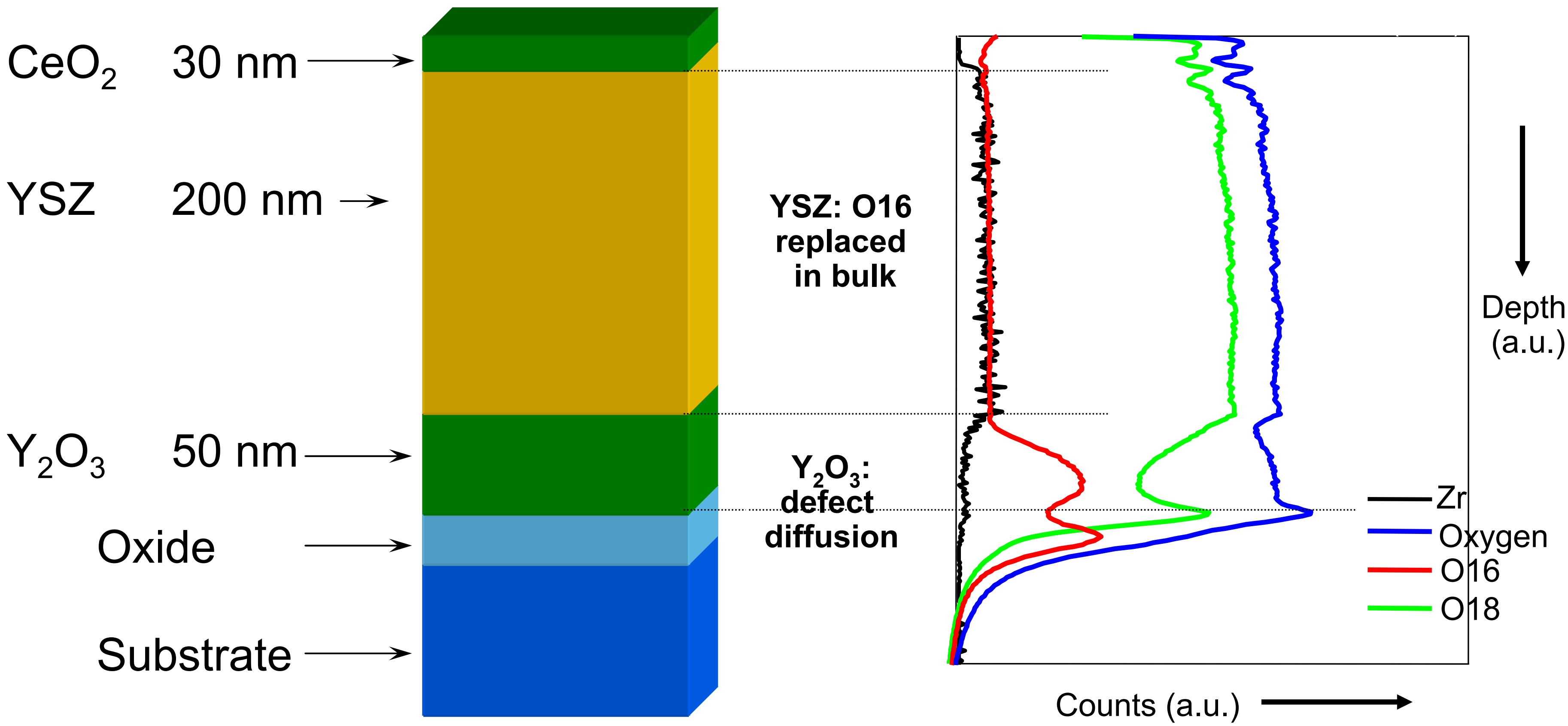
Objectives:

- Determine roles of various buffer layers comprising the stack
- Establish differences between GB's and intragranular regions
- Characterize the metal/oxide interface
- Engineer cost/performance of the buffer stack (thickness, rate of depn.)

Microscopy techniques and X-ray diffraction studies were performed at ORNL to further the materials understanding of buffer properties which is being applied to AMSC 2G wire process

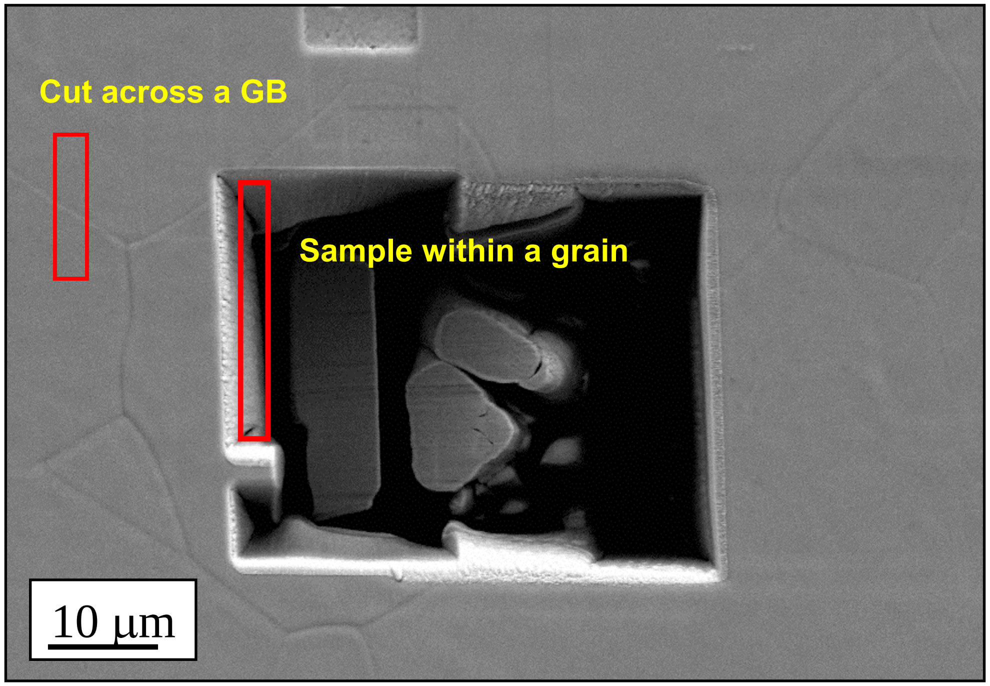
SIMS studies by SANDIA (FY03)

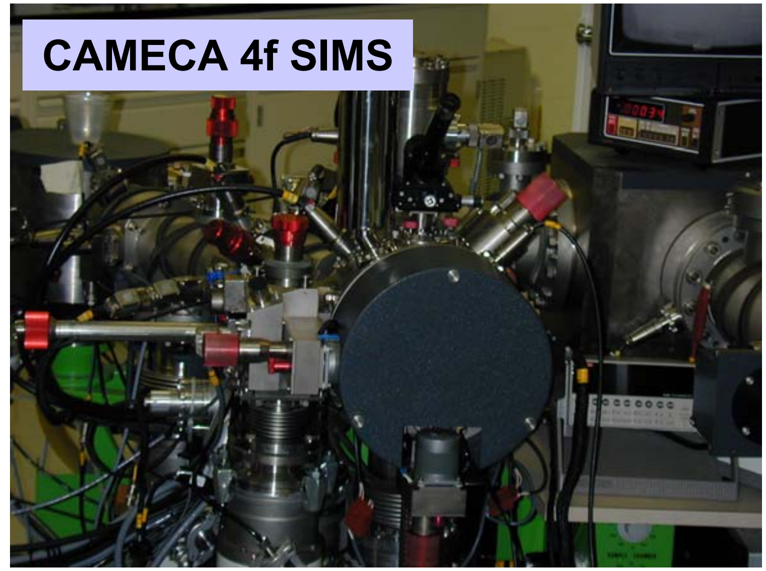
Sandia National Laboratories



Experimental methodology: TEM and SIMS

For TEM analysis, either a GB is isolated or a region within a grain is chosen using a FIB

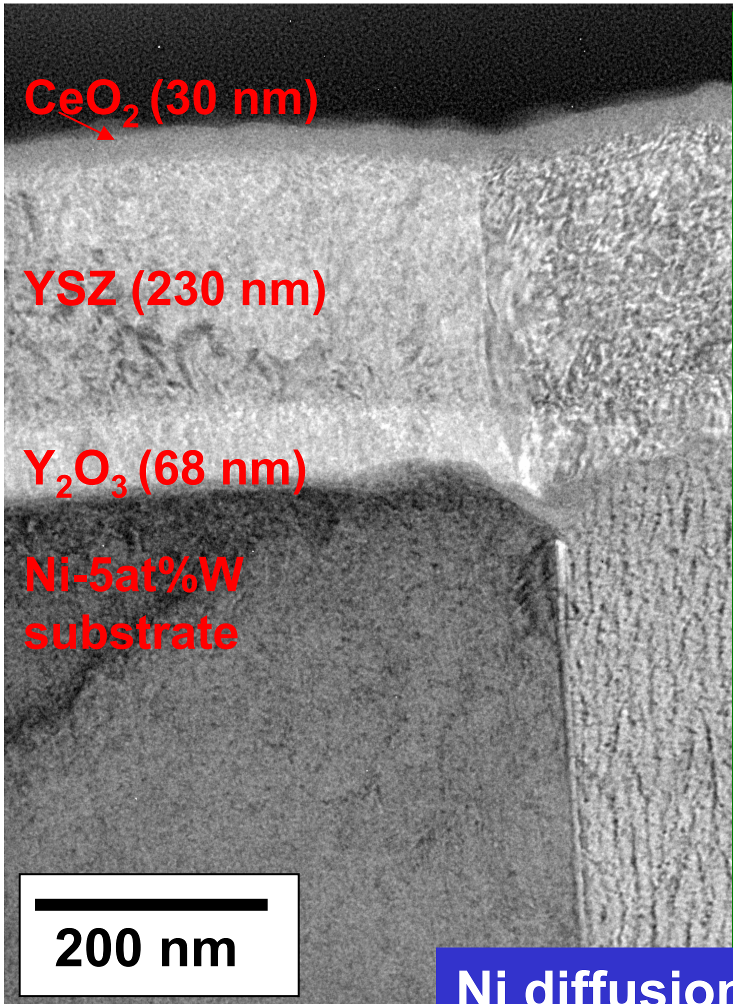


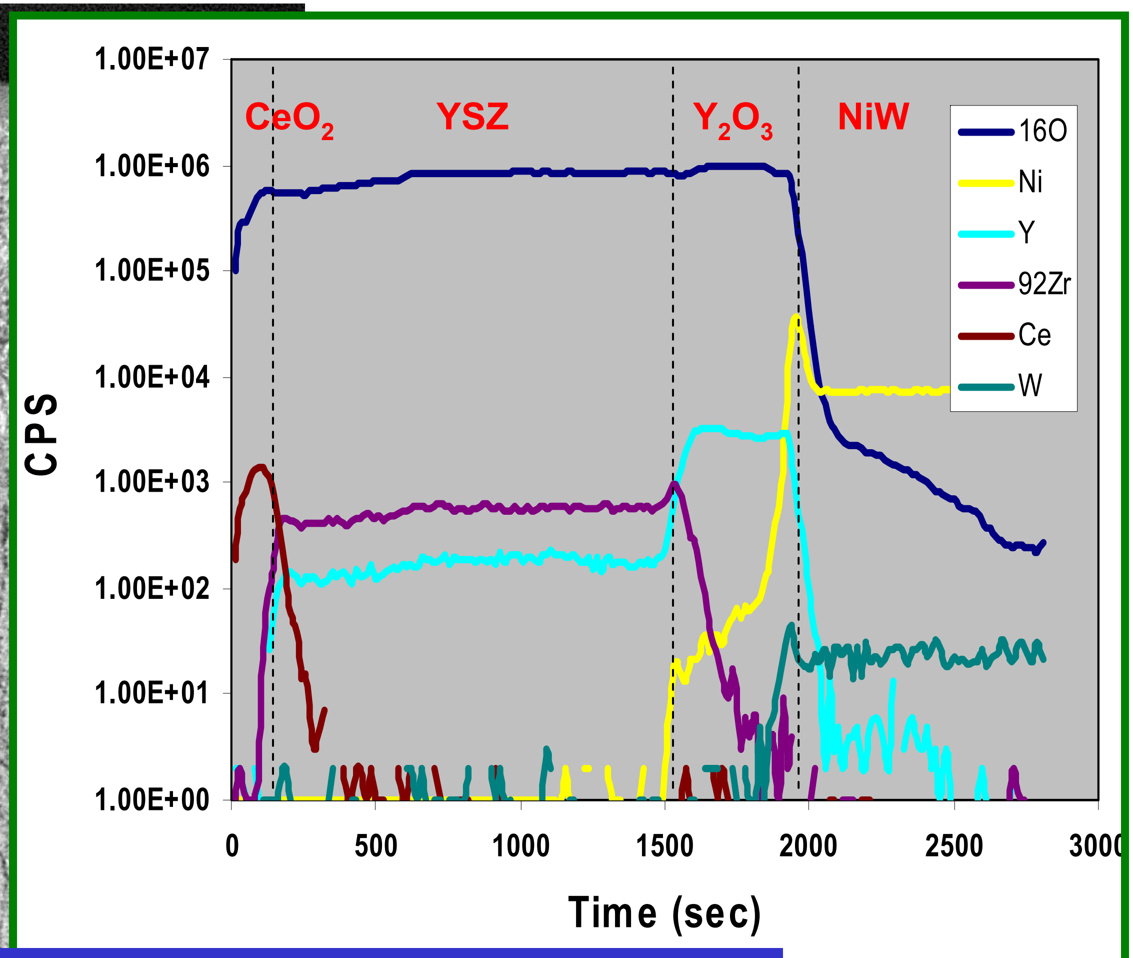


Key attributes of CAMECA 4f SIMS

- A magnetic sector for superior mass resolving power & extreme energy filtering capabilities, which reduce or eliminate spectral interferences.
- Two primary ion sources; a duoplasmatron source capable of producing O2+ or O- ions, and a Cs+ ion source for enhanced secondary ionization efficiency.
- Low detection limit and excellent charge neutralization.

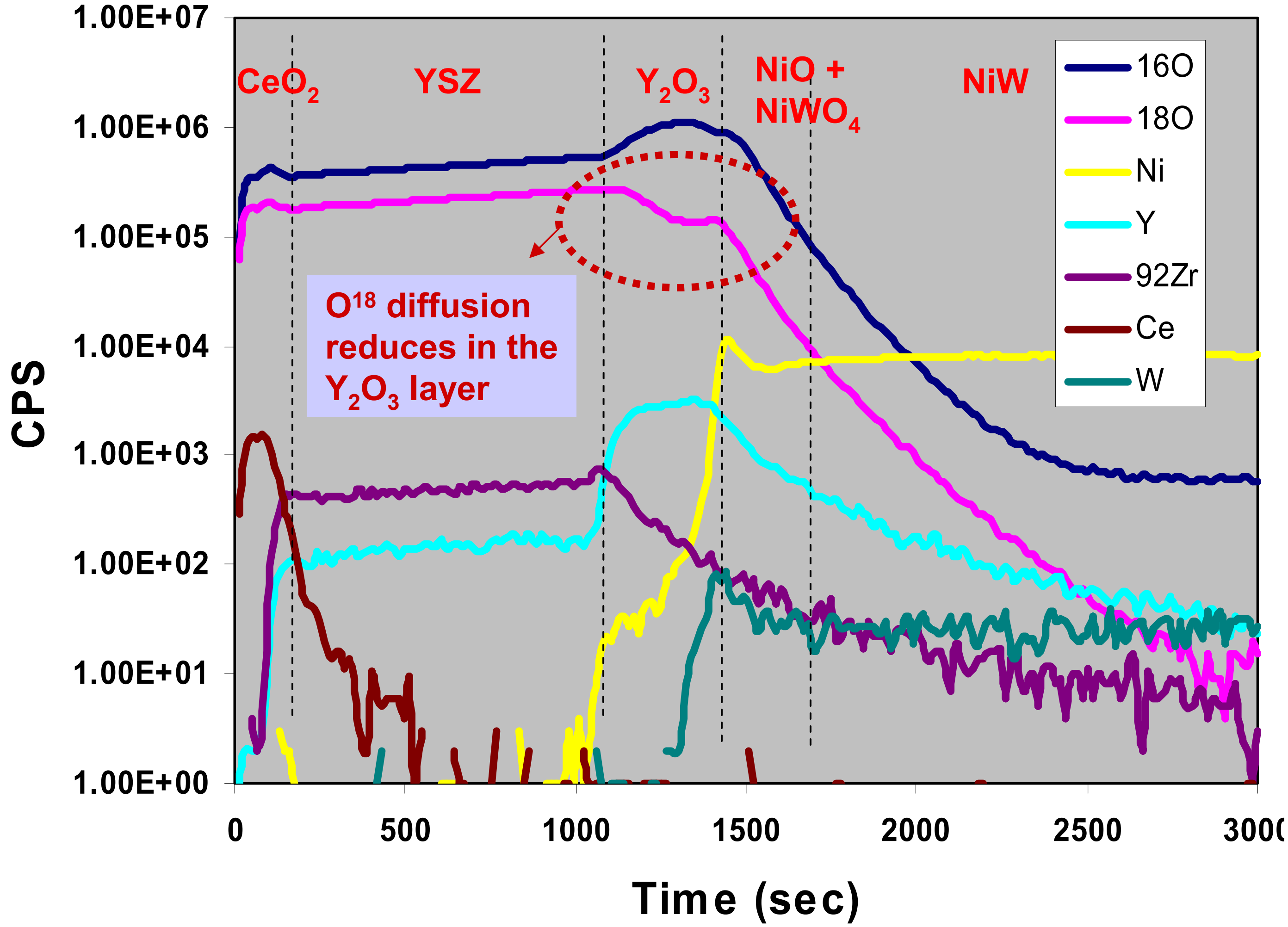
A combination of X-ray diffraction, TEM and SIMS is powerful in study of buffer layer characteristics



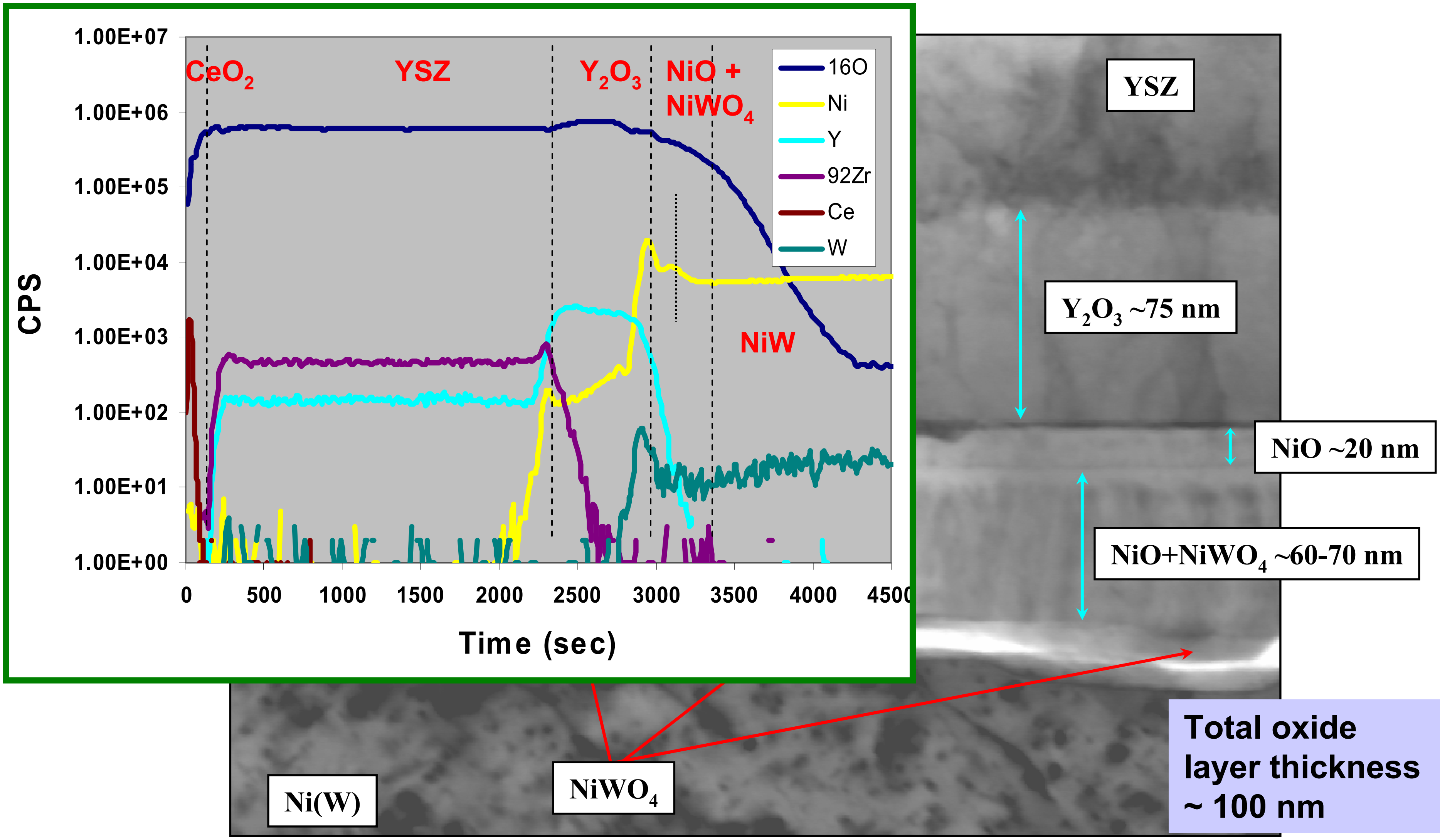


Ni diffusion is stopped by the YSZ layer
W diffusion is stopped in the Y_2O_3 layer

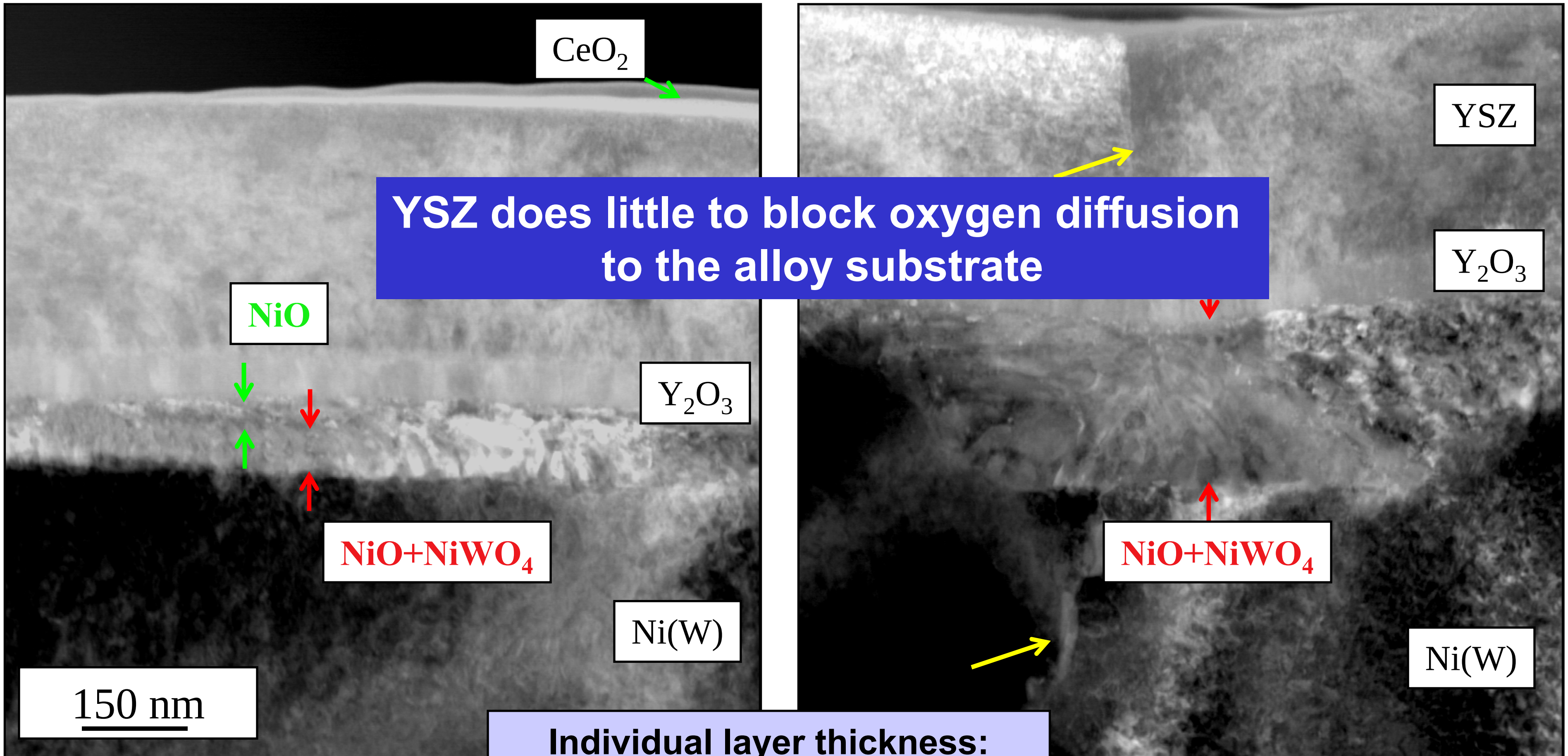
SIMS depth profiling shows that Y_2O_3 is a better barrier than YSZ for oxygen diffusion



Standard buffer annealed under simulated MOD YBCO processing conditions show formation of NiO and $NiWO_4$



Doubling of the YSZ layer results in no reduction of NiO and $NiWO_4$ formation

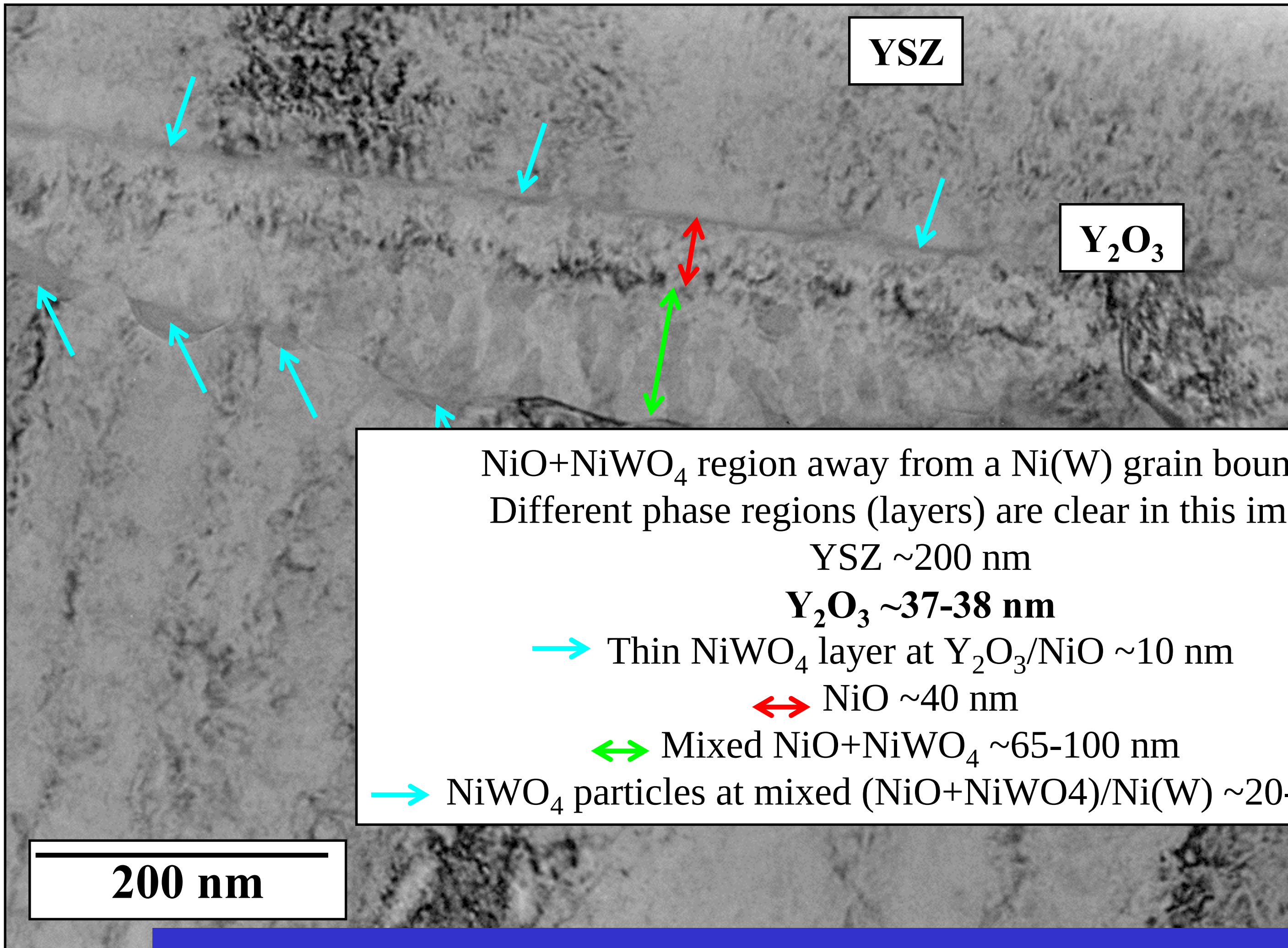


YSZ does little to block oxygen diffusion to the alloy substrate

Individual layer thickness:
Y_2O_3 ~75 nm; YSZ ~360-370 nm
CeO_2 ~27-30nm; NiO ~20-30 nm
$NiO+NiW0_4$ ~100 nm

SIMS depth profile near interface is unchanged

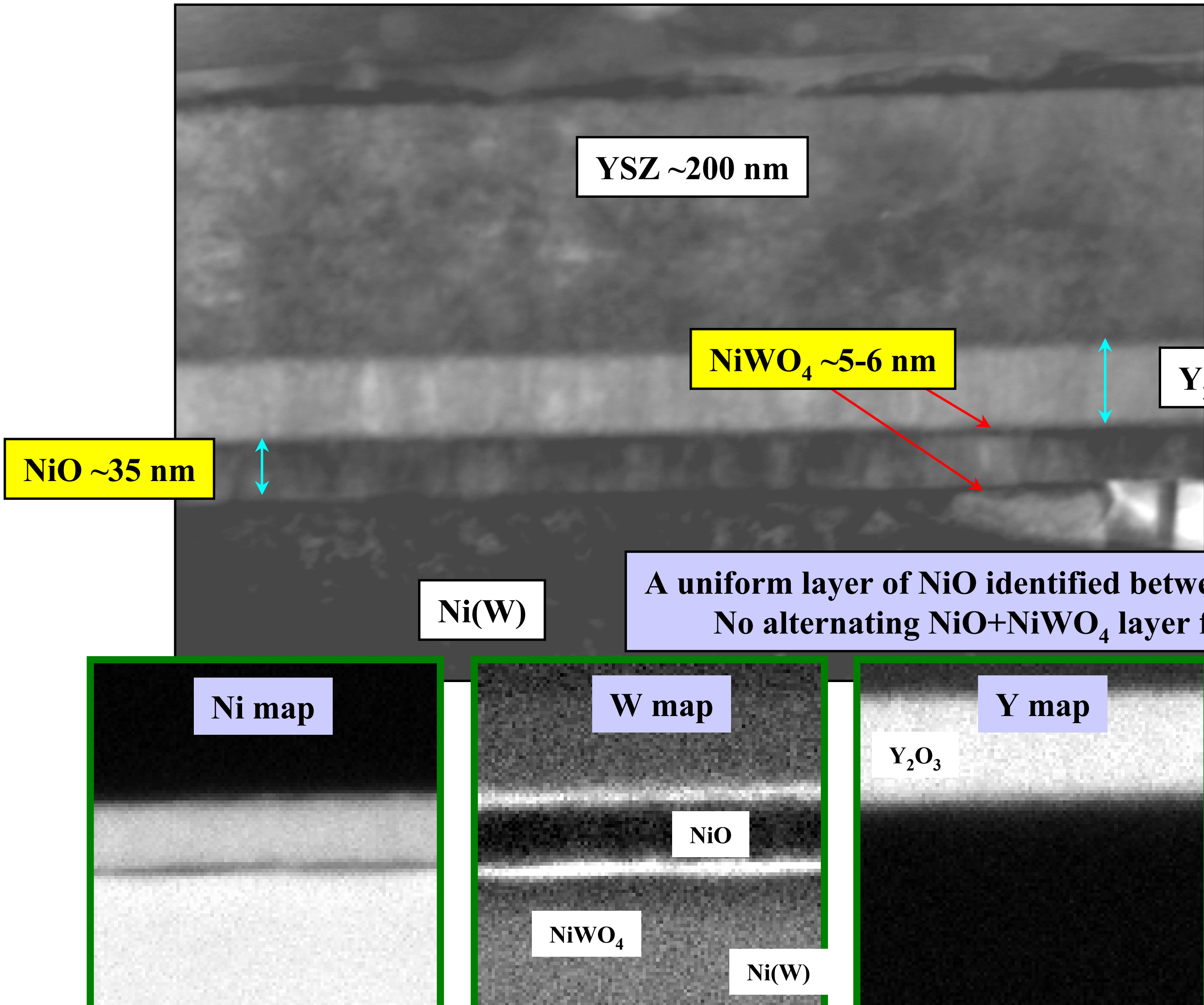
Increased NiO and $NiWO_4$ formation is observed away from the GB as well in sample with reduced Y_2O_3



NiO+$NiWO_4$ region away from a Ni(W) grain boundary
Different phase regions (layers) are clear in this image:
YSZ ~200 nm
Y_2O_3 ~37-38 nm
→ Thin $NiWO_4$ layer at Y_2O_3/NiO ~10 nm
↔ NiO ~40 nm
↔ Mixed NiO+$NiWO_4$ ~65-100 nm
→ $NiWO_4$ particles at mixed (NiO+NiWO4)/Ni(W) ~20-25 nm

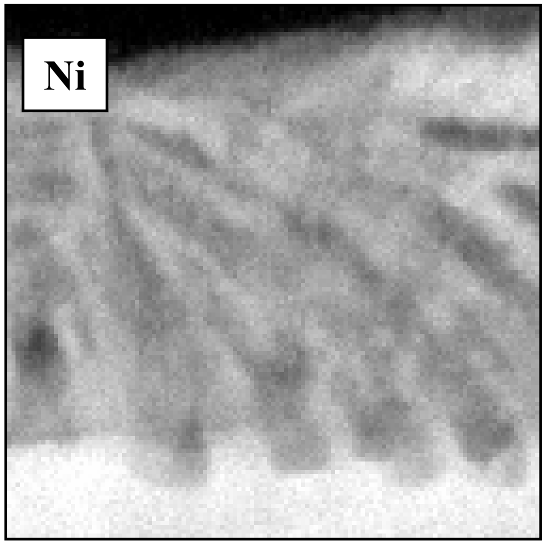
Y_2O_3 is a much better barrier than YSZ for O_2 diffusion

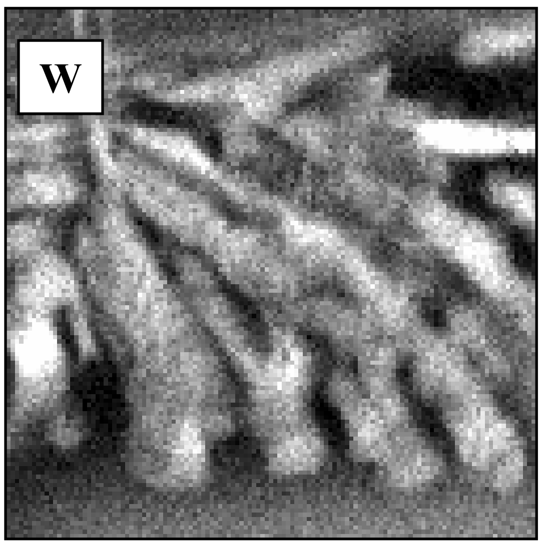
For a sample with YBCO by MOD, a continuous oxide layer is observed with a $NiWO_4$ layer sandwiching a NiO layer

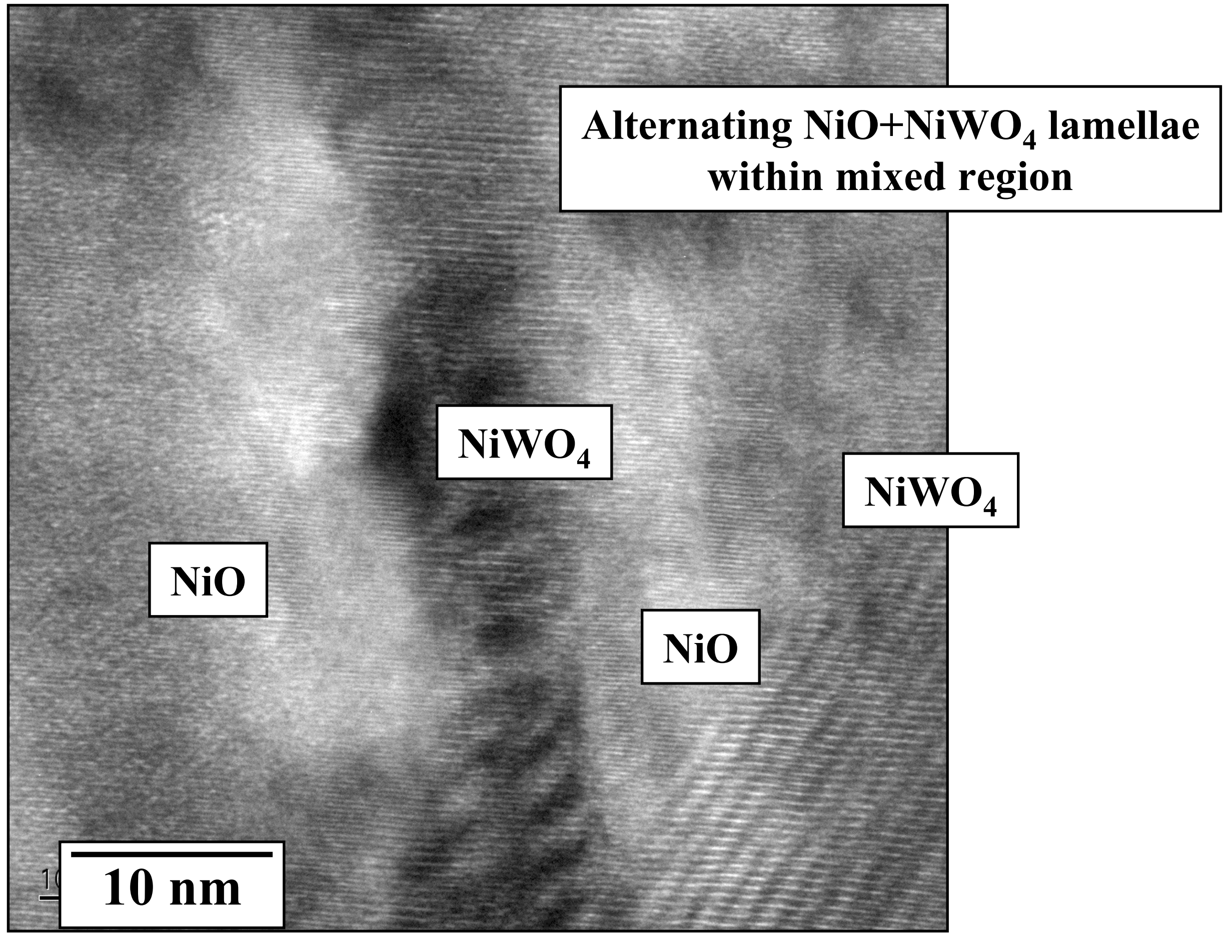


A uniform layer of NiO identified between thin $NiWO_4$ layers
No alternating NiO+$NiWO_4$ layer formed, only NiO

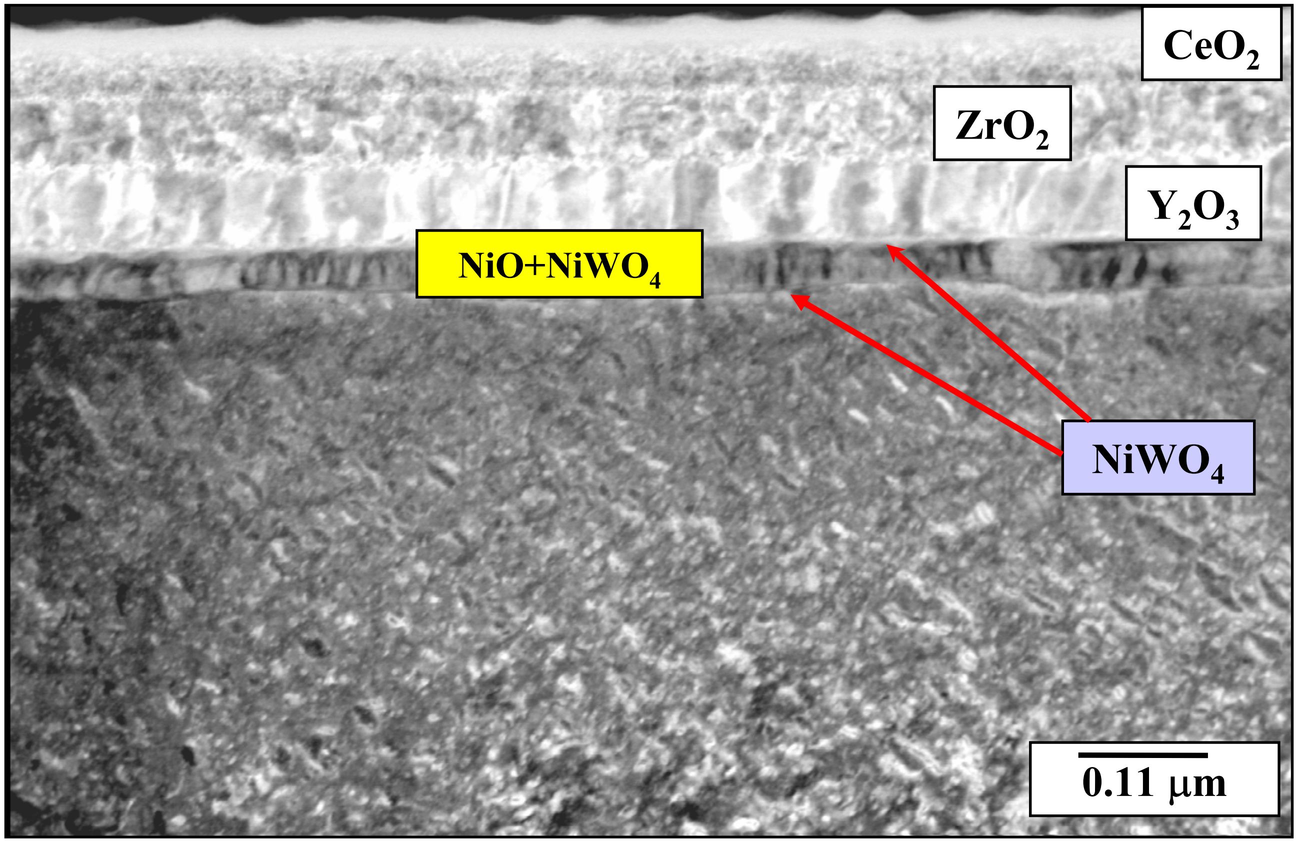
Characteristics of NiO and $NiWO_4$ lamellae in mixed region suggest rapid oxidation followed by phase separation





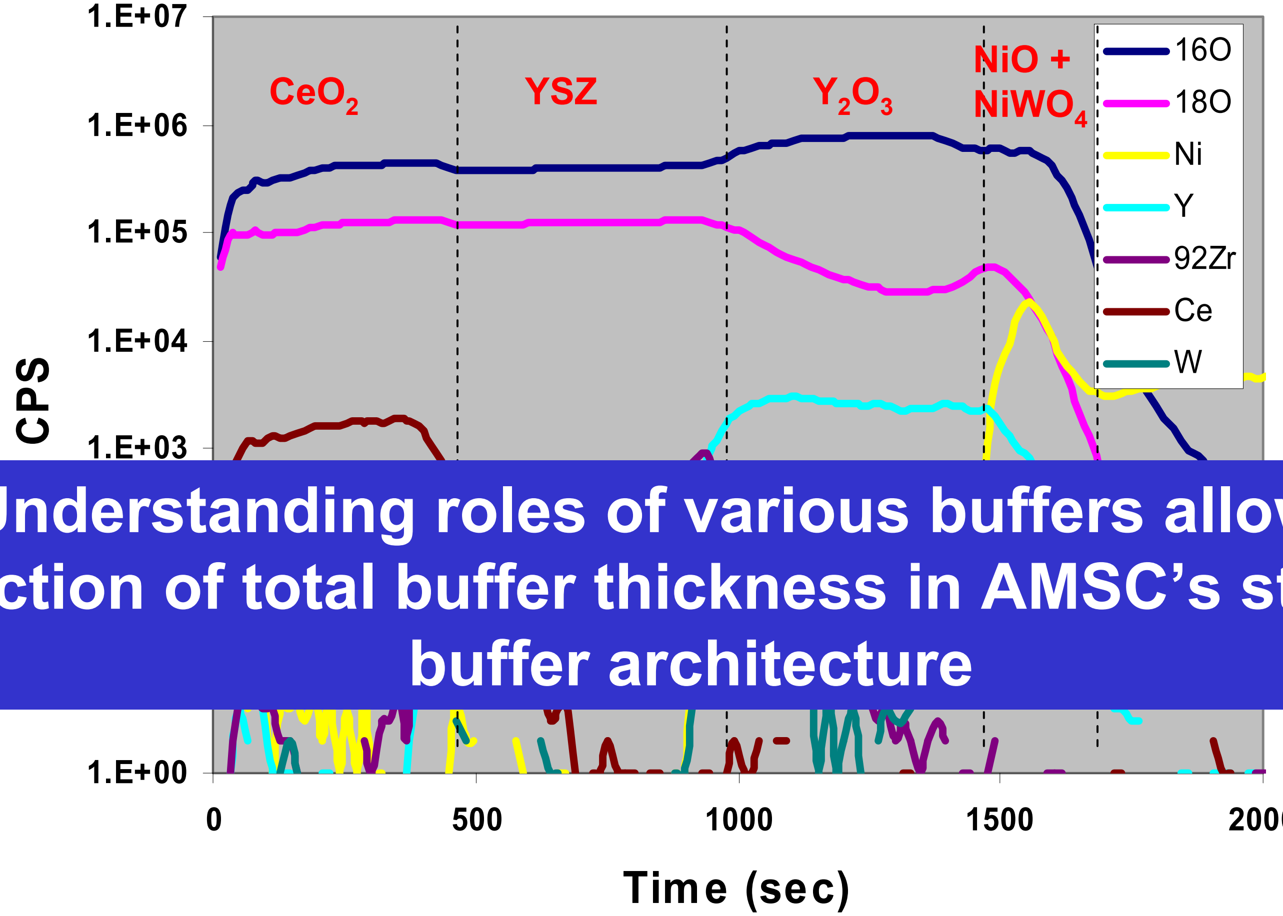


Buffer stack with reduced YSZ and increased CeO_2 with a configuration Y_2O_3 (75nm)/YSZ(75nm)/CeO_2(75nm)



Total reaction oxide layer thickness is same as before after annealing under simulated YBCO processing conditions

SIMS depth profile of Y_2O_3 (75nm)/YSZ(75nm)/CeO_2(75nm) buffer stack after annealing in O^{18}

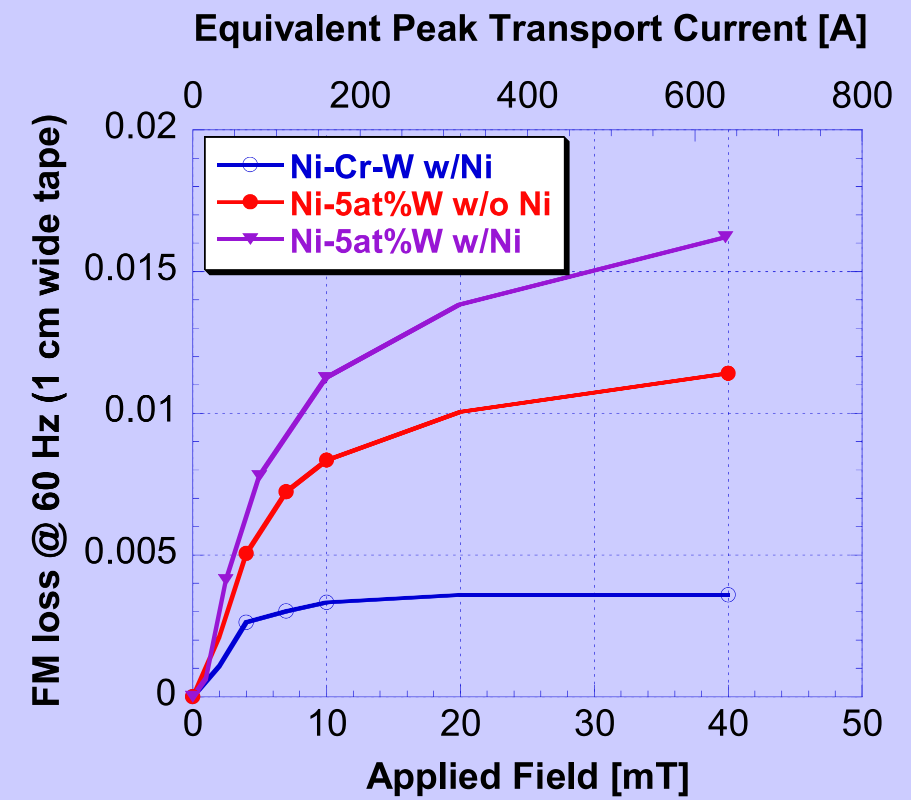


Understanding roles of various buffers allowed reduction of total buffer thickness in AMSC's standard buffer architecture

The reduced YSZ thickness has no significant effect on Ni, W or oxygen diffusion and hence is sufficient for a robust buffer

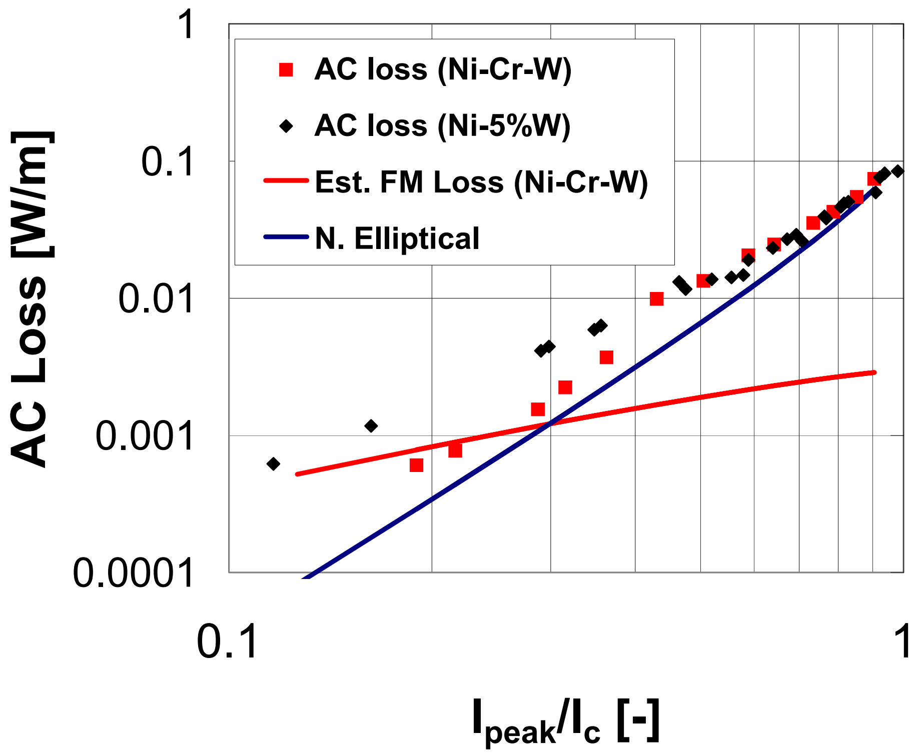
Transport AC loss of AMSC 2G wire measured at ORNL: Comparison of Ni-5at%W and Ni-Cr-W substrates

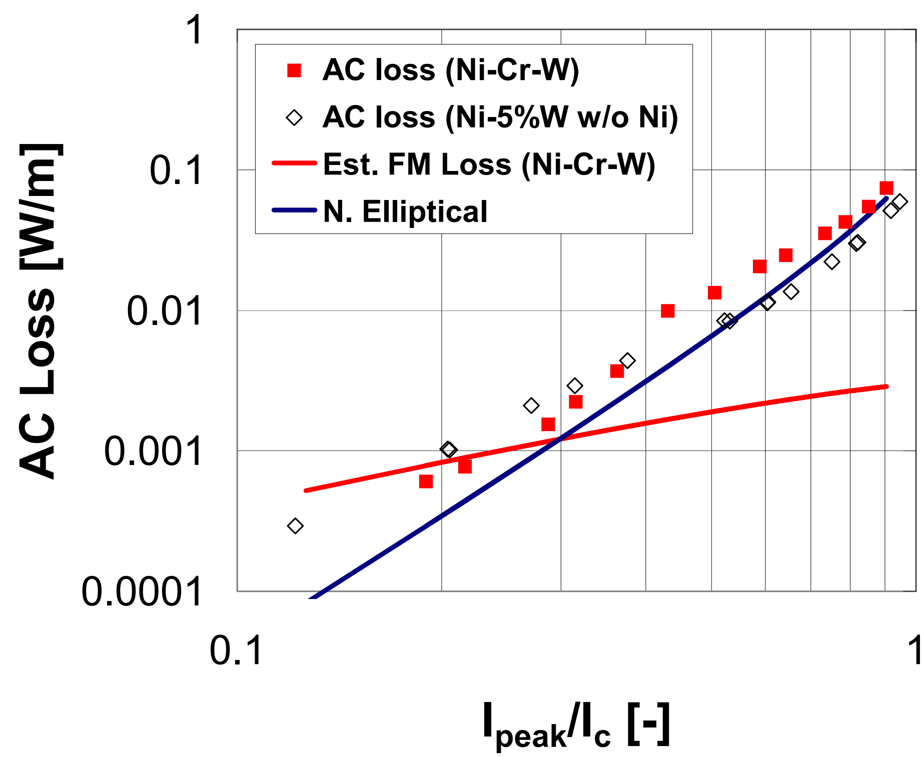
- **Motivation:**
  - Previous measurement of ac losses of YBCO on Ni-5at%W with 2 µm nickel overlayer showed additional ferromagnetic loss
- **Sample characteristics**
  - 75 µm thick Ni-10%Cr-2%W with 2.4 µm Ni overlayer
  - 4 mm and 1 cm sample widths
  - $I_c \approx 100$ A/cm-width



FM loss at $I_{peak} \approx I_c$ reduced by a factor of ~2 with Ni-Cr-W substrate

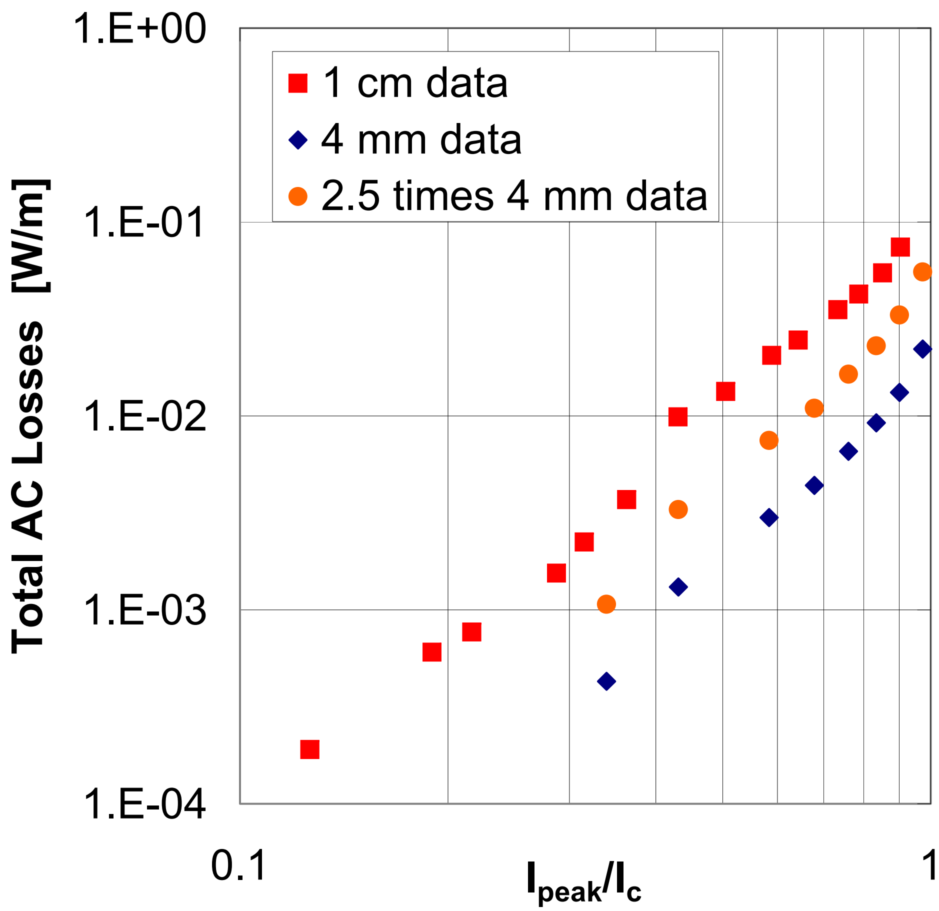
In 2G Wire the AC-Losses are Dominated by YBCO





For most applications (I_{peak}/I_c > 0.4) Ni-5at%W without Ni layer is a suitable substrate material.

How does AC loss scale with width?



Reduction of tape width may lower losses if coupling is negligible

For certain AC applications, a fully non-magnetic substrate may be required

We are investigating two non-magnetic substrate options as part of the CRADA:

- **Ni-9.3at%W substrate:**
  - **difficult to roll and yet to demonstrate 100% cube texture**
  - **standard buffer layer architecture possible**

- **Ni-Cr-W ternary alloy substrates:**
  - **100% cube texture demonstrated**
  - **difficult to deposit epitaxial buffer layers**

Development of ~100% cube-textured, PM based Ni-9.3at%W substrates is a developmental CRADA task

Ni-9at%W coating on Ni-5at%W as a demonstration for standard buffer stack compatibility

Buffer stack configuration

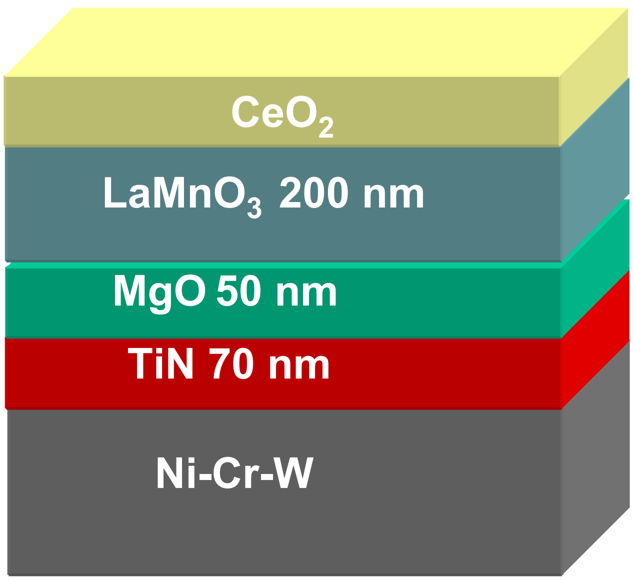
YBCO (0.8 μm)
CeO_2 (75 nm)
YSZ (75 nm)
Y_2O_3 (75 nm)
Ni-9at%W (1 μm)
Ni-5at%W (75 μm)

Texture through the stack

J_c = 2.4 MA/cm^2 YBCO = 0.8 μm
YBCO: $\Delta\phi_{102}$ = 4.1° $\Delta\omega$ = 4.6°; 5.4°
CeO_2: $\Delta\phi$ = 3.6° $\Delta\omega$ = 5.7°; 8.9°
Ni: $\Delta\phi$ = 5.8° $\Delta\omega$ = 5.3°; 8.7°

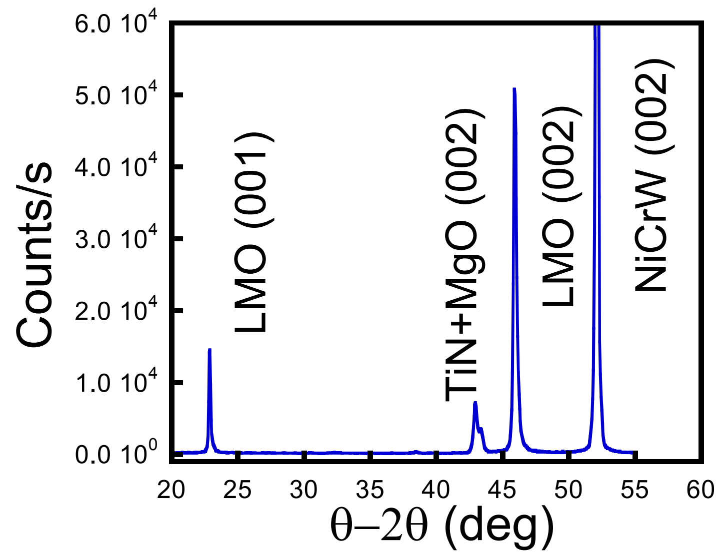
Standard buffer stack is compatible with Ni-9at%W substrate and that a Ni-9at%W could be used as a overlayer instead of Ni for Ni-Cr-W substrates

Alternate Buffer layer option for Ni-Cr-W substrates
TiN/MgO/LMO/CeO_2



Buffers grown by PLD

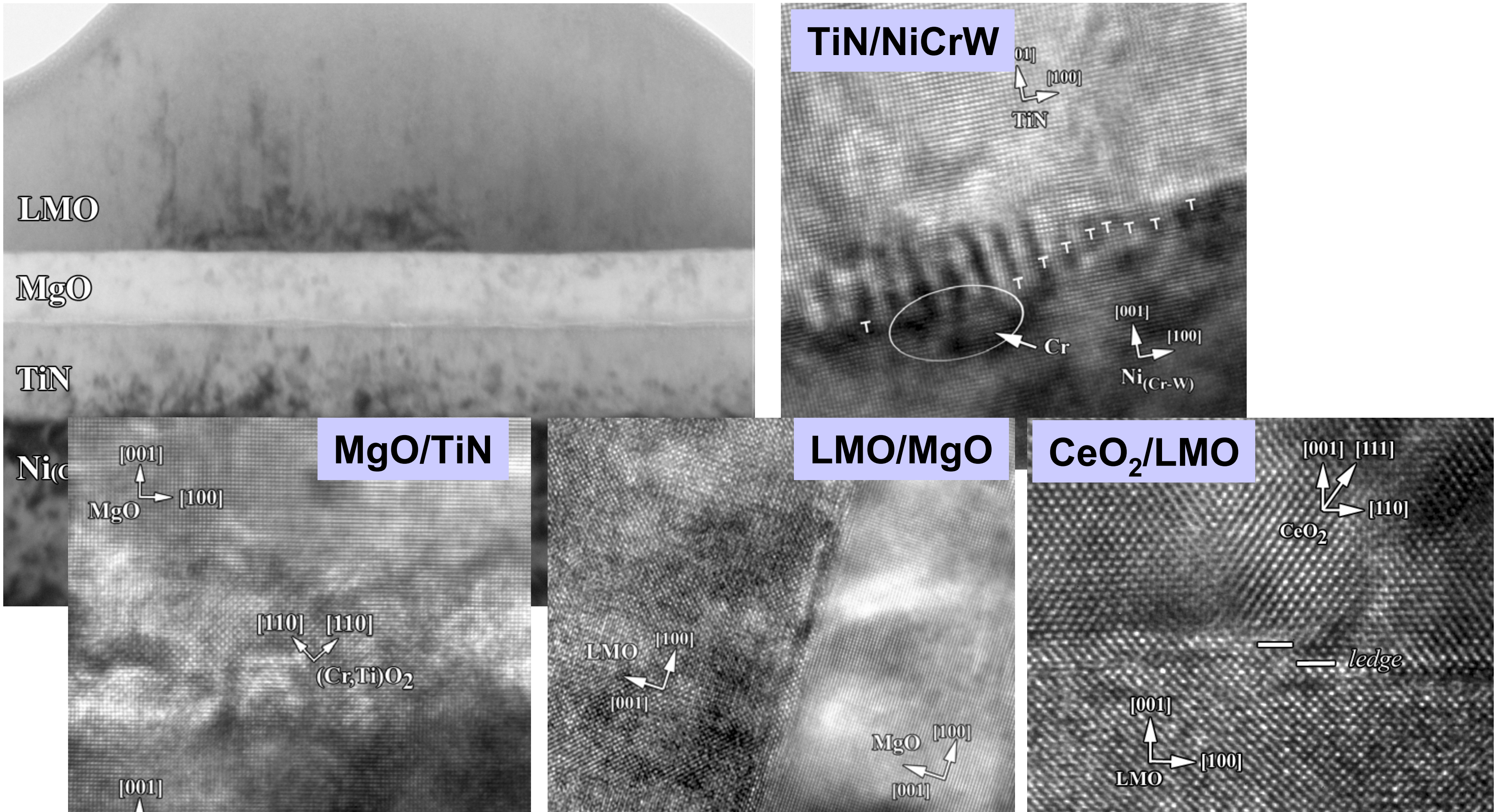
MOD YBCO 1μm-thick
J_c = 1.8 MA/cm²



6.5° Δω improvement

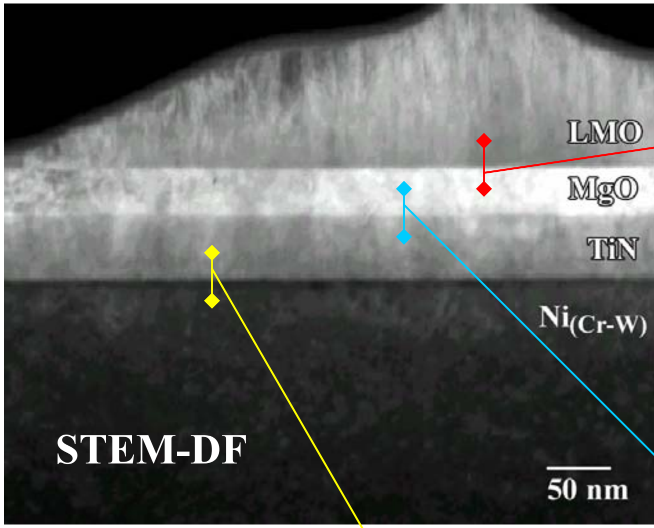
	Δω,t	Δω,r	Δφ (m)	Δφ (t)
NiCrW	8.97	5.69	7.6	5.49
TiN+MgO	2.47	2.64	6.16	5.89
LMO	3.07	3.25	7.14	6.79

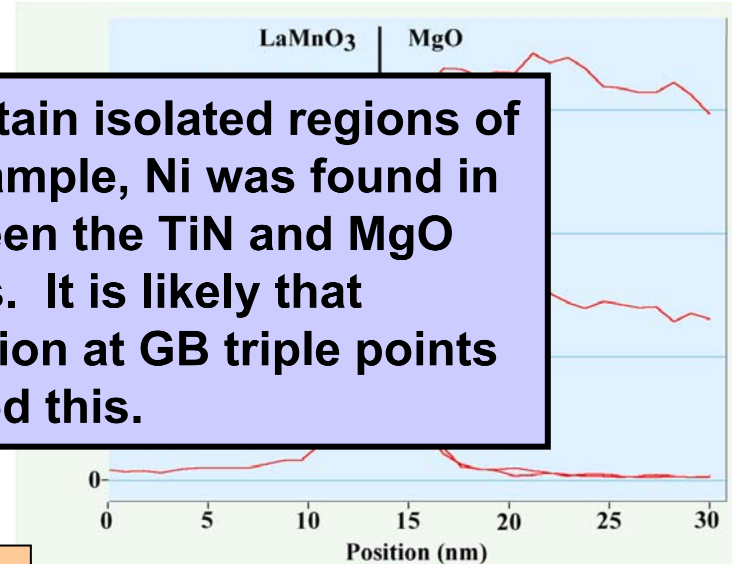
TEM shows that the interfaces are sharp for the substrate NiCrW/TiN/MgO/LMO/CeO_2



Ni $_{(Cr\text{-}W)}$ [010] // TiN [010] // MgO [010] // LMO [010] // CeO_2 [110]

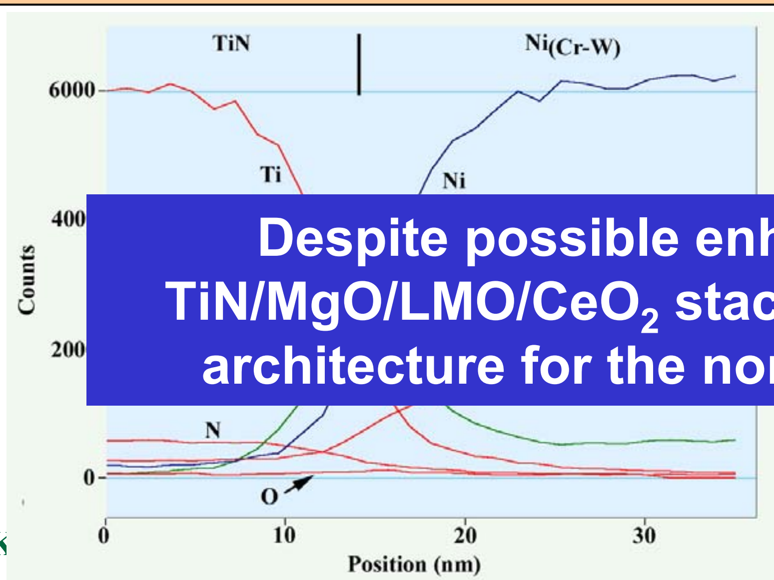
TEM shows that the interfaces are sharp for the substrate NiCrW/TiN/MgO/LMO/CeO_2

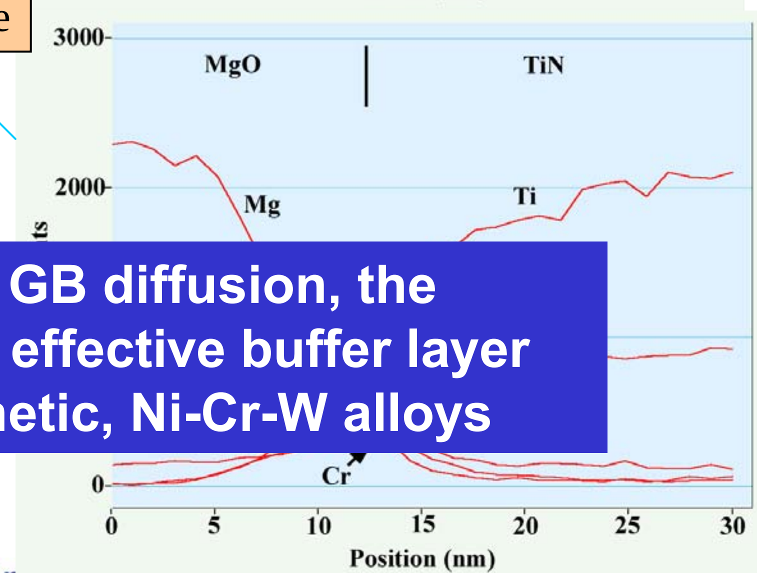




In certain isolated regions of the sample, Ni was found in between the TiN and MgO layers. It is likely that diffusion at GB triple points caused this.

Cr detected between TiN / MgO and at Substrate Interface

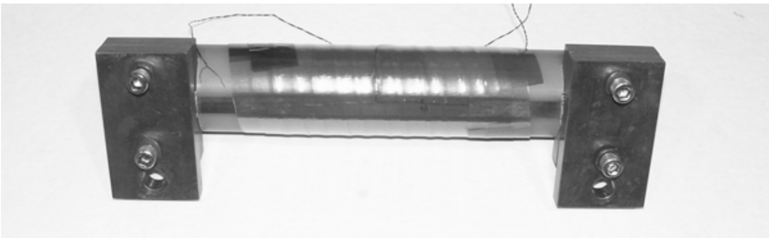




Despite possible enhanced GB diffusion, the TiN/MgO/LMO/CeO_2 stack is an effective buffer layer architecture for the non-magnetic, Ni-Cr-W alloys

Short-Circuit Over-current Limitation of AMSC 2G Copper Stabilized Conductor

- **Determine the operational limit and mechanism of degradation (electromechanical or thermal)**
- **Current pulses up to 2.1 kA for 0.1 to 0.3 s on single tapes**
- **Sample characteristic**
  - YBCO 1 cm wide tape on Ni-alloy substrate ($I_c \approx 160$ A)
  - Stabilization
    - 50 µm copper laminate onto silver cap layer
    - 50 µm copper laminate with additional 250 µm copper strip attached at current lead ends
- **Sample setup**
  - Tape insulated with dielectric tape and placed in LN_2 bath



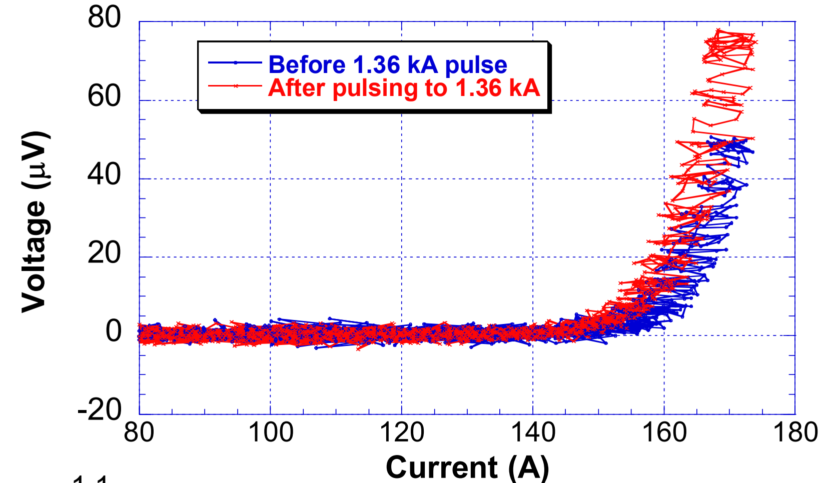
Electromechanical and Thermal Characterization of AMSC 2G Copper Laminated Conductor

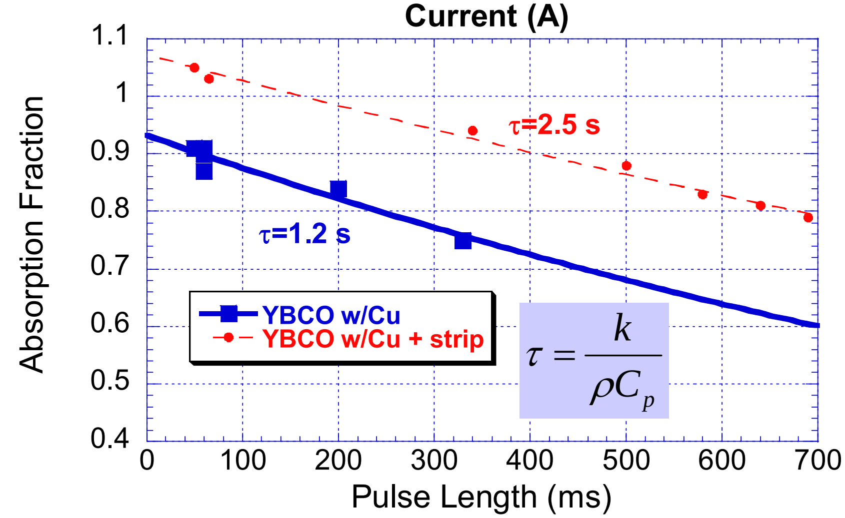
- ## Electromechanical
  - No change for 1.23 kA pulse
  - As the pulse magnitude increased from 1.23 kA to 1.36 for 35 ms, I_c degraded from 161 A to 157 A. T_{tape} at center of tape 370 K.

- ## Thermal
  - **An increase in pulse length from 0.2 s (T_{tape}=370 K) to 0.33 s (T_{tape}=670 K) for a 665 A pulse results in I_c degradation from 160 A to 90 A**

- **Ratio of heat absorbed by sample to measured V-I product shows that the majority of the energy is absorbed by the conductor**

- **Addition of a 250 µm copper strip causes a significant increase in both limits due to copper shunting**





tau ≈ thermal diffusion time constant

AMSC-ORNL CRADA Presentation

- **FY 2004 Results**

  2G Development (YBCO/RABiTS) at AMSC (Urs)
  2G wire manufacturing at AMSC
  2G wire characteristics

  Rolling and annealing of alloys (Amit)
  Correlation of texture to J_c
  Buffer layers: Methodology development and characterization
  AC Losses and stabilization

  Development of low-cost, solution buffer layers (Parans)

- **FY 2004 Performance and FY 2005 Plans (Parans)**
- **Research Integration**

Development of Low-cost, Solution Buffer Layers

<u>Goal</u>:

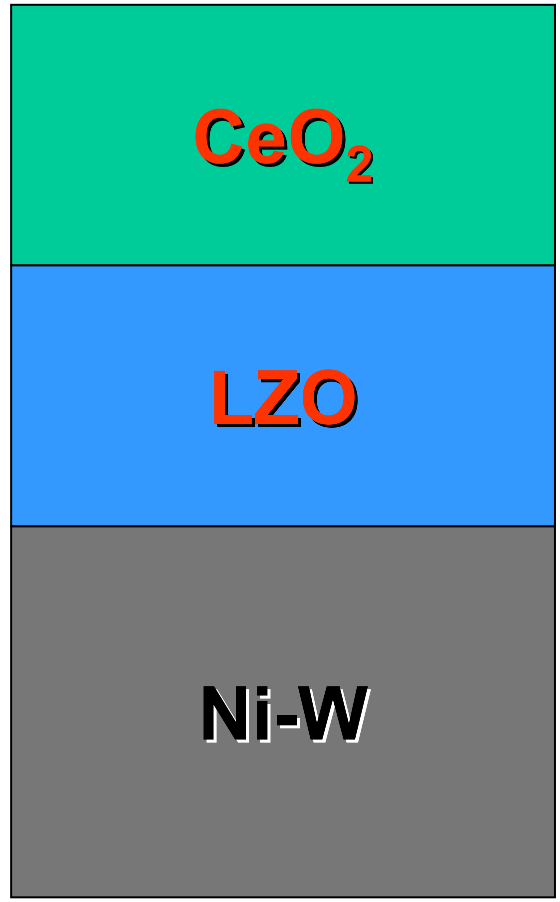
MOD Buffer Development

<u>Objective</u>:

Demonstrate via diffusion studies that solution buffers are comparable to vapor deposited buffers

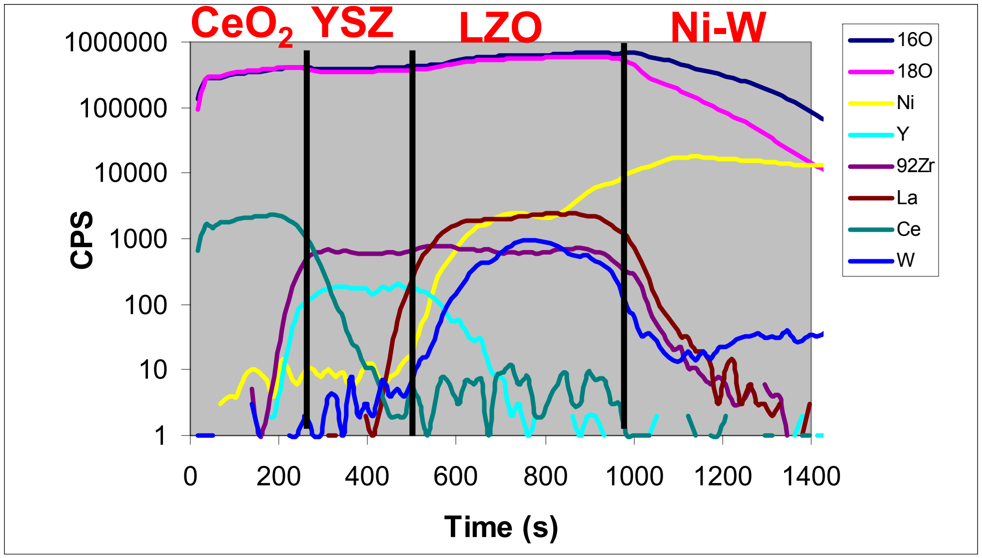
<u>Candidate Materials</u>:

$La_2Zr_2O_7$ (LZO) as a seed+barrier layer
CeO_2 as a cap layer



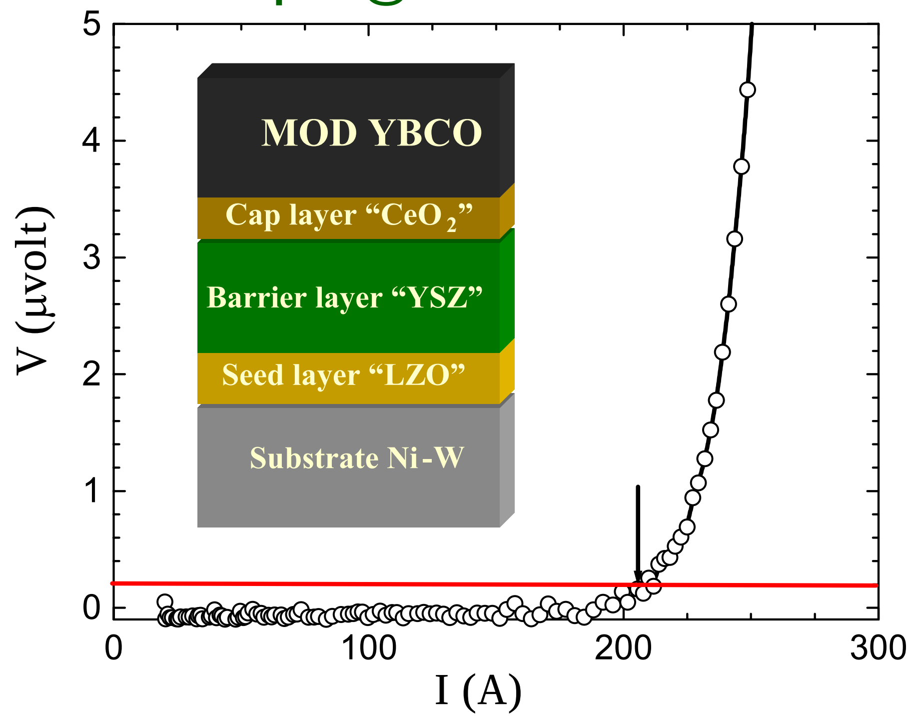
210 A/cm-width Performance with MOD YBCO Film on MOD LZO Seed (short sample)

SIMS on ^{18}O annealed CeO_2/YSZ/LZO/Ni-W



Total buffer thickness: 150 nm

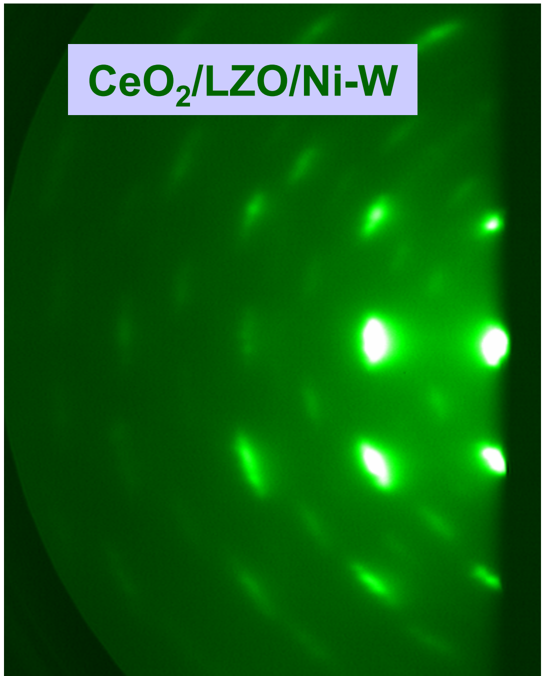
I-V plot @ 77 K and sf



J_c (77K, sf) = 2.7 MA/cm^2, I_c = 213A/cm-w, YBCO thickness: 0.8 μm; T_c=90.1K, ΔT_c=1.2K

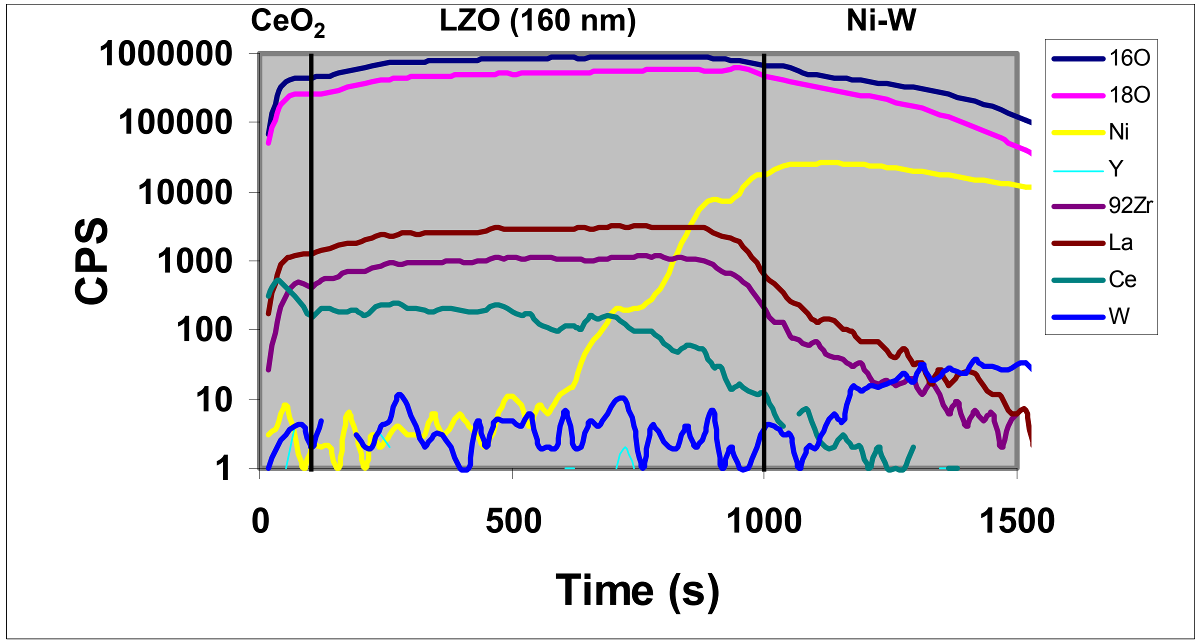
SIMS data indicate that 80 nm LZO behaves similar to Y_2O_3

All Solution CeO_2/LZO/Ni-W

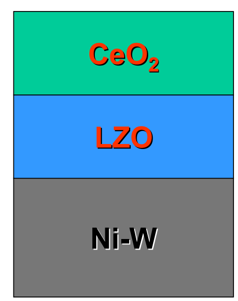


RHEED indicates that there is no polycrystalline film present at the CeO_2 surface

SIMS on ^{18}O annealed all MOD CeO_2/LZO/Ni-W

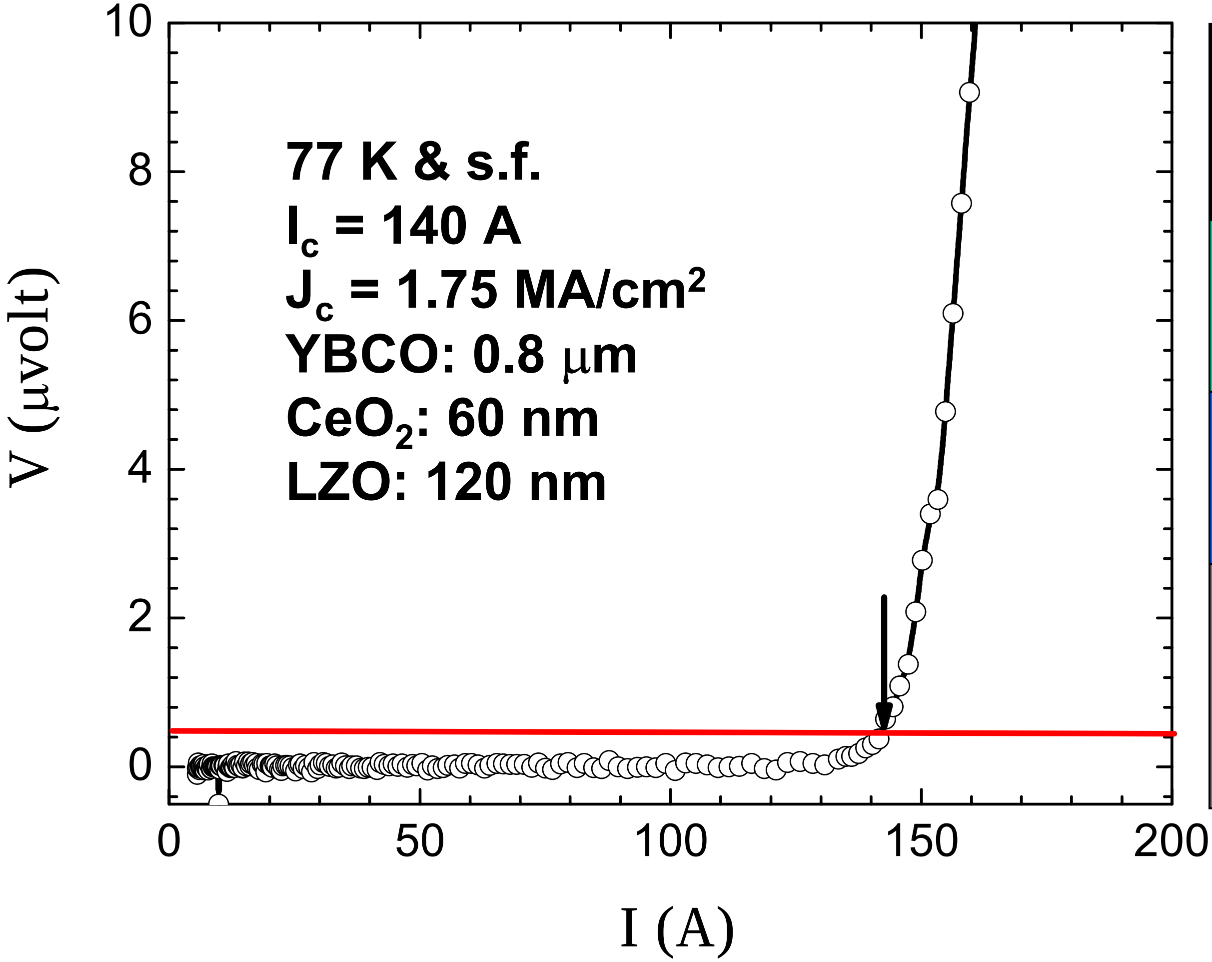


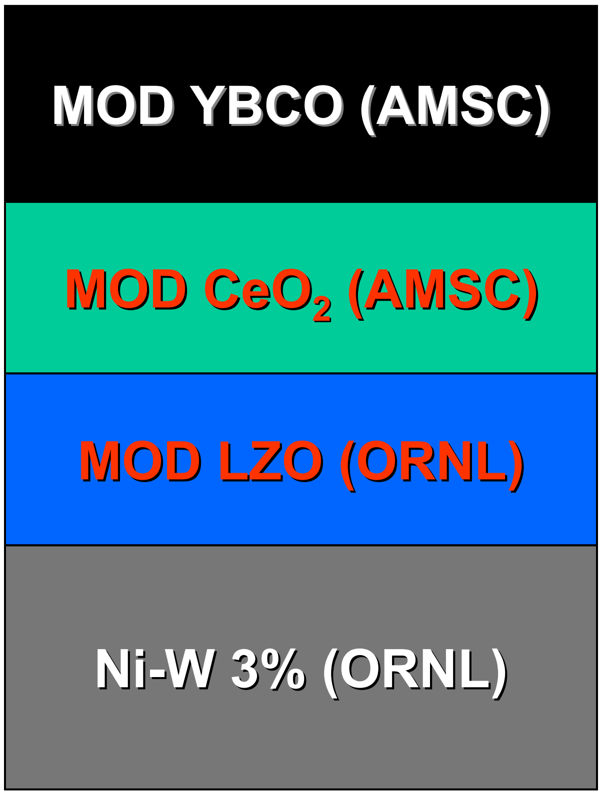
SIMS indicate that Ni diffusion is contained within 160 nm thick MOD LZO layers



All MOD CeO_2/LZO buffers have been identified as good metal diffusion barriers

FY2004 Result: Two-layer All-MOD Buffer for a Low-cost RABiTS Process; 140 A/cm-width (77K,sf) Performance Demonstrated





A route towards fabrication of lower-cost YBCO coated conductors

FY 2004 Plans and Performance

FY2004 Plans

- **Produce pilot line quality alloy substrates using the ORNL rolling mill facility**

FY2004 Performance

✓ **Textured RABiTS substrates in 10 cm x 80 m were fabricated**

✓ **Modifications to the rolling mill and experimentation with lubricant viscosity enabled production of Ni-alloy tapes with R_a 8-10 nm at high rolling speeds**

✓ **ORNL's rolling facility was the primary facility used by AMSC for scale-up research towards wide substrates**

FY 2004 Plans and Performance

FY2004 Plans (cont'd)

- **Development of non-magnetic substrates for limited ac applications**

FY2004 Performance

✓ **FM loss at $I_{peak} \approx I_c$ reduced by a factor of 2-3 with Ni-Cr-W substrate. AC loss contribution from Ni-Cr-W substrates is significantly lower than YBCO hysteretic loss**

✓ **J_c of 1.8 MA/cm^2 for 0.8 μm thick YBCO demonstrated on buffer stack CeO_2/LMO/MgO/TiN/Ni-Cr-W**

✓ **Use of standard buffer stack for Ni-9.3at%W substrate demonstrated. Also showed that a Ni-9.3at% coating can be used on Cr containing non-magnetic Ni-alloys to allow use of standard buffers**

FY 2004 Plans and Performance

FY2004 Plans (cont'd)

- Demonstration of scalable continuous processing of the MOD-YBCO on RABiTS through implementation of 4 cm wide process

FY2004 Performance

✓ Scalability demonstrated for substrate production, PVD deposition and lamination

✓ Highly quality buffers were deposited on 4 cm wide Ni-W tapes in a continuous process

✓ AMSC's internal goal's were altered during the year to defer MOD processing on 4cm wide webs to next fiscal year

FY 2004 Plans and Performance

FY2004 Plans (cont'd)

- Produce 20 meter lengths of 2G wire with an I_c of 250 A/cm from the 4cm wide manufacturing process

FY2004 Performance

✓ Multiple 10 m lengths with I_c = 250-270 A/cm-w produced

✓ ORNL's involvement in understanding the RABiTS template has assisted AMSC to increase the length of 2G wire

FY 2004 Plans and Performance

FY2004 Plans (cont'd)

- **Optimize buffer layer stack for manufacturing of YBCO coated conductors**

FY2004 Performance

✓ **Buffer layers were optimized for improved manufacturing methods. Standard buffer layer thicknesses were reduced based on this study to Y_2O_3(75 nm)/YSZ(75nm)/ CeO_2(75 nm)**

✓ **^{18}O SIMS diffusion studies indicated that Y_2O_3 seed is a good oxygen diffusion barrier**

✓ **YSZ layer was identified as the primary Ni diffusion barrier**

FY 2004 Plans and Performance

FY2004 Plans (cont'd)

- Correlate "texture" to J_c. Analyze the importance of out-of-plane alignment with respect to J_c.

FY2004 Performance

✓ Correlated J_c with in-plane texture and showed that a true phi of ~ 5° supports 70-80% of single crystal J_c YBCO in RABiTS

✓ Total grain boundary mis-orientation for CeO_2 cap layer was separated into both in-plane and out-of-plane contributions

✓ GB maps show that in-plane misorientation correlates best with J_c.

FY 2004 Plans and Performance

FY2004 Plans (cont'd)

- **Demonstrate MOD buffers with properties comparable to AMSC PVD buffers**

FY2004 Performance

- ✓ **Focus was shifted to develop a better understanding of buffer layer requirements**
- ✓ **O^{18} SIMS studies indicate that 80-100 nm thick LZO layer is enough to prevent Ni diffusion**
- ✓ **213 A/cm or a J_c of 2.7 MA/cm^2 was demonstrated on LZO seeds**
- ✓ **140 A/cm or a J_c of 1.75 MA/cm^2 was demonstrated on an ALL-SOLUTION process**

FY 2005 Plans

- Pilot line production of high quality (4 cm wide by 100 m long) alloy substrates using the ORNL rolling mill facility with clean room
- Improvement of RABiTS template manufacturing process reliability through fundamental characterization of the buffer layer properties
- Reduction of the substrate/buffer manufacturing cost through improved understanding of the interactions of buffer deposition rates and intrinsic properties
- Detailed analysis of the role of RABiTS template texture and manufacturing defects as current limiting mechanisms in long length, 4 mm wide YBCO wires
- Analysis of the uniformity and reproducibility of long length, 4 cm wide RABiTS templates produced in a high-rate reel-to-reel manufacturing process
- Development of new, low-cost template architectures that are applicable to Ni-5at%W as well as non-magnetic Ni-9at%W and NiCrW substrates

Research Integration

- Regular weekly conference calls
- Frequent sample exchanges
- CRADA meetings
- Personnel exchange – use of ORNL rolling mill facilities by AMSC staffs (once a month)
- Joint development, joint materials evaluation and testing
- Interacted with LANL and SNL through AMSC on buffer evaluation studies
- Participates in YBCO wire development group
- Several joint publications and joint presentations
- Joint invention disclosures

ORNL is the primary RABiTS Template R & D lab. for American Superconductor Corporation