

# Progress towards Application Readiness of Coated Conductors at SuperPower

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# Introduction



- **SuperPower is scaling up YBCO coated conductors for use in electric power, military, and industrial applications. Over the last two years tremendous progress has been made in our scale-up program. Performance of 6,000-7,000 amp-meters in 50-100 m lengths has been achieved. *See O2-18 for some detail***
- **Good critical current ( $I_c$ ) retention in magnetic field, proper conductor geometry, electrical stabilization and reduced ac loss are important issues for coated conductors to be used in electric power, military, and industrial applications.**
- **SuperPower developed a rare-earth substituted composition that yields high  $I_c$  in high magnetic fields at LN<sub>2</sub> temperature.**
- **Also developed three key post YBCO processes: slitting, Cu-electroplating and photolithography for striation. Different combinations of these processes produce different products for various applications.**

# Funding Sources and Collaborations



- **The work at SuperPower was supported in part by contracts with the U.S. Department of Defense, U.S. Department of Energy, U.S. Air Force Research Laboratory, and the U.S. Air Force Office of Scientific Research.**
- **Part of the work was done under Cooperative Research & Development Agreements with Los Alamos National Laboratory (LANL) and Air Force Research Laboratory at Wright-Patterson Air Force Base.**

**H. Yamura** at Sumitomo Electrical Industries, LLC

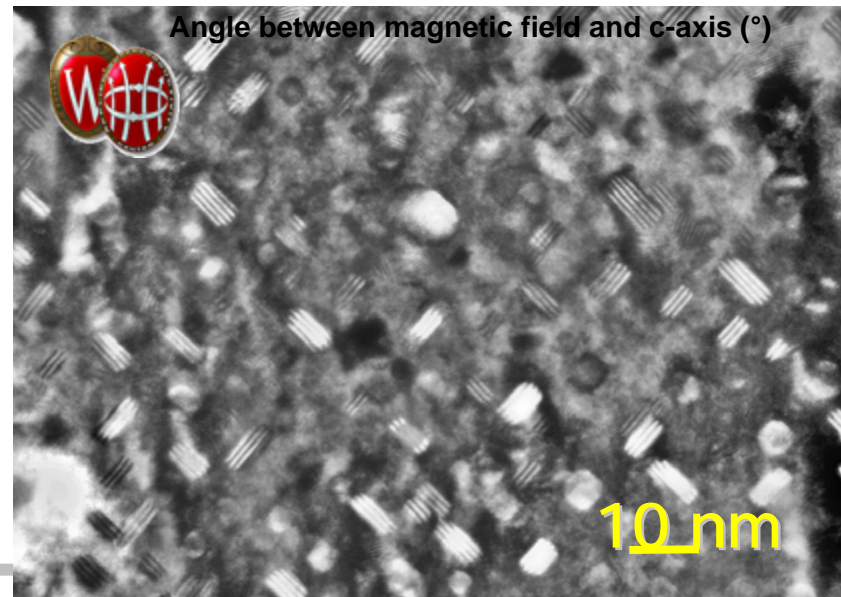
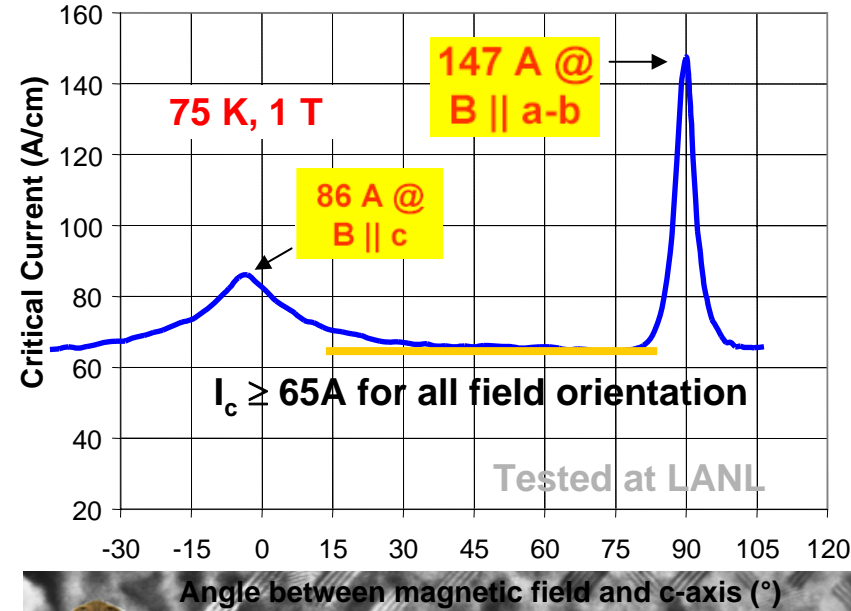
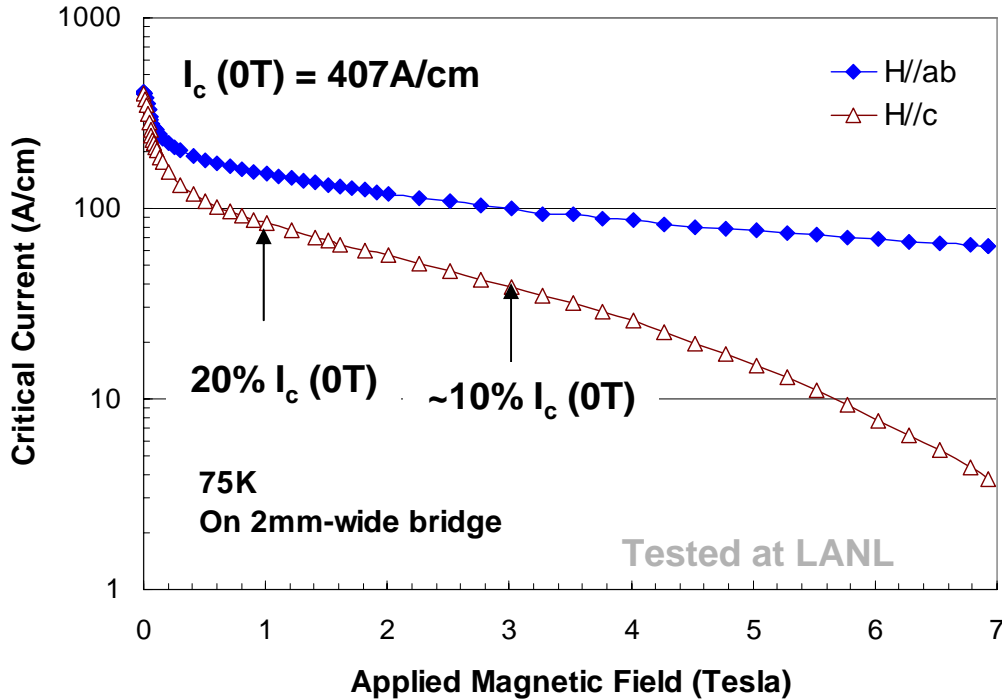
**L. Civale** and **B. Maiorov** at Los Alamos National Lab

**X. Song** at University of Wisconsin - Madison

**Y. Iwasa** at Massachusetts Institute of Technology

**N. Cheggour, C. Clickner, and J. Ekin** at National Institute of Standards and Technology

# High critical current in high magnetic fields by Sm-doping

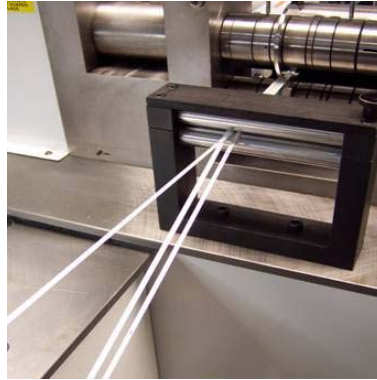


- High critical current in high magnetic field (H//ab and H//c)
- At 1 T, 75 K, minimal  $I_c$  above 65A for all field orientation
- Nano-precipitates observed in films. Further work underway to establish correlation

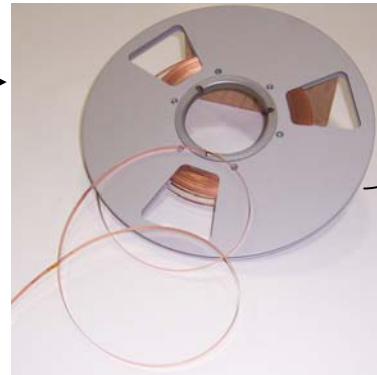
# Post-YBCO Processes



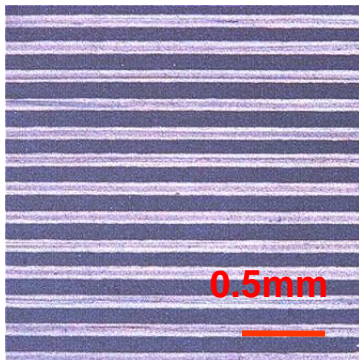
Slitting



Cu E-P



Photolithographic  
striation



4mm wide



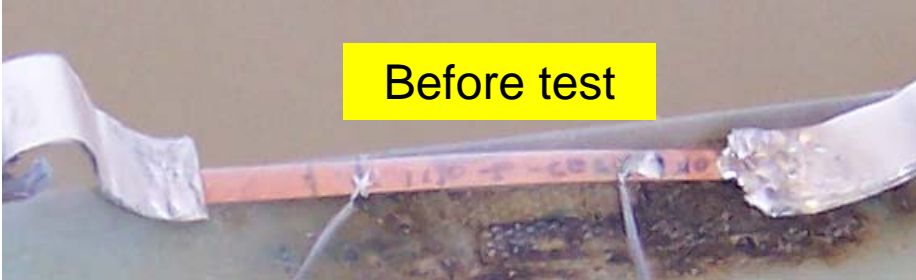
Electroplated with surround Cu.

**We have extensively evaluated this route and the product aiming at cable application**

**Yielded significant ac loss reduction [Selvamanickam *et al.* at ASC2004]**

**Long-length,  
1.2cm wide,  
w/ thin Ag layer**

# Overcurrent testing shows advantage of “Surround Stabilizer” conductor structure



Before test



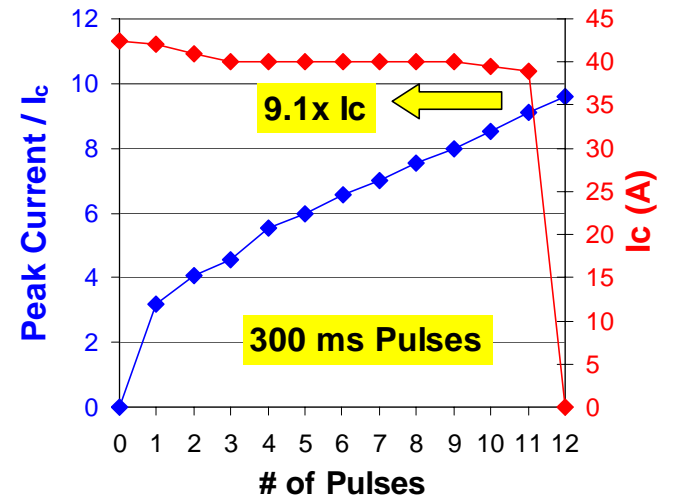
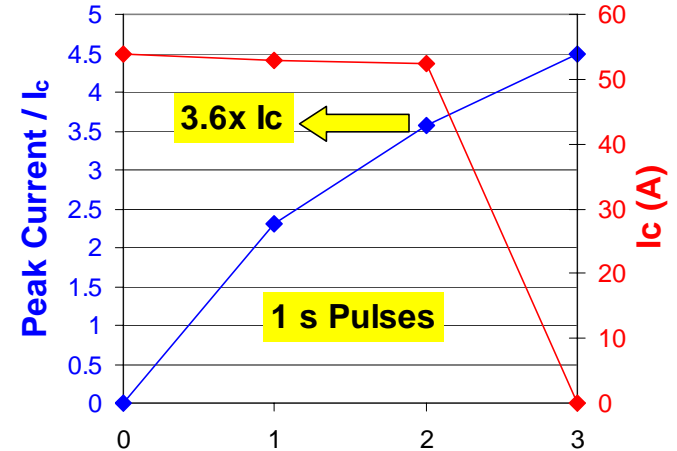
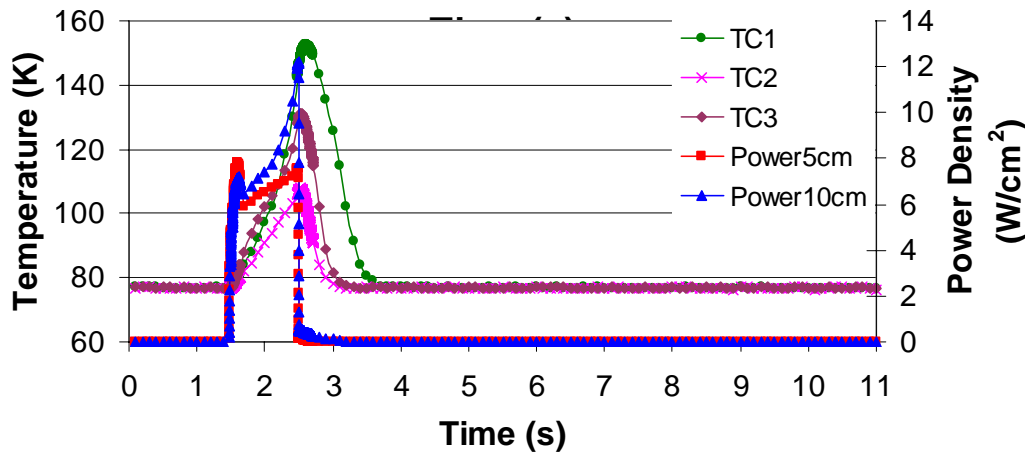
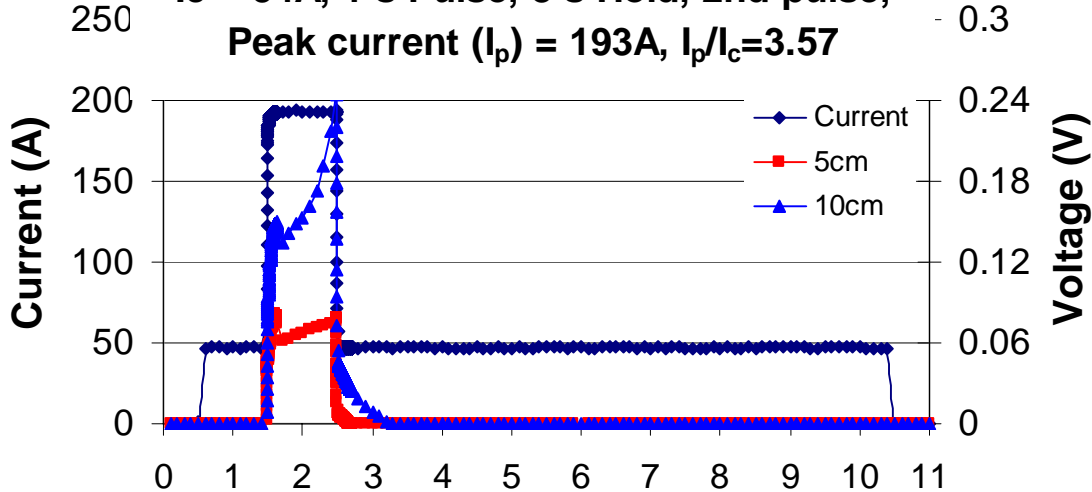
Burn-out after over current test

<b>Current &amp; Power applied to burnout conductor (Ic ~ 60A)</b>				
Conductor Type	Conductor 1	Conductor 2	Conductor 3	Conductor 4
<b>Single side Cu (40 microns)</b>	233A – 18.6W/cm <sup>2</sup>	205A - 18.1W/cm <sup>2</sup>		
<b>“Surround Stabilizer” Cu (20 microns all sides)</b>	279A – 33.3W/cm <sup>2</sup>	277A – 27W/cm <sup>2</sup>	158A (Etched out Cu from substrate side) – 15.3W/cm <sup>2</sup>	194A (Etched out Cu from substrate side) – 21.8W/cm <sup>2</sup>

**“Surround Stabilizer” conductor structure enables 50 - 100% increase in power handling capability**

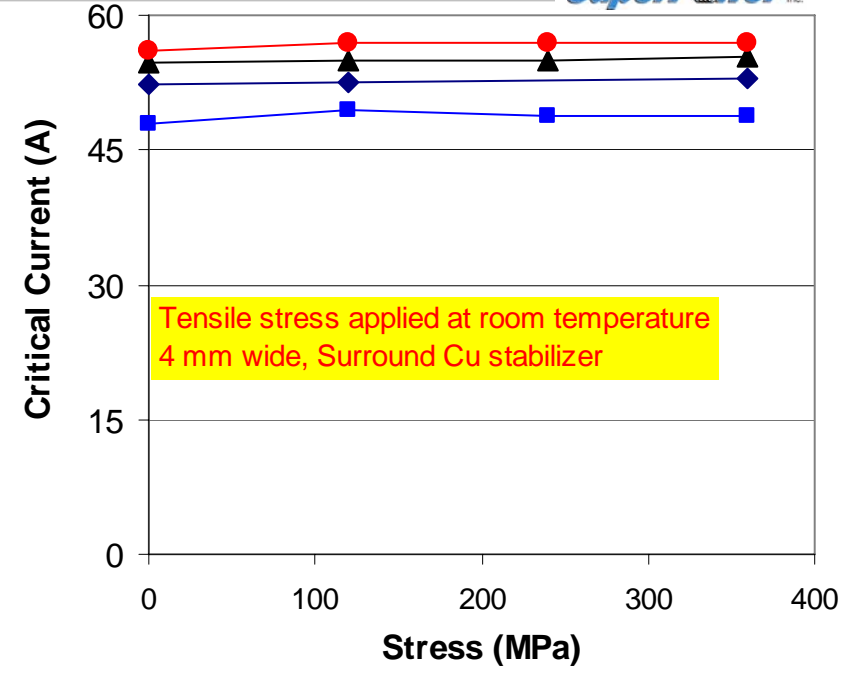
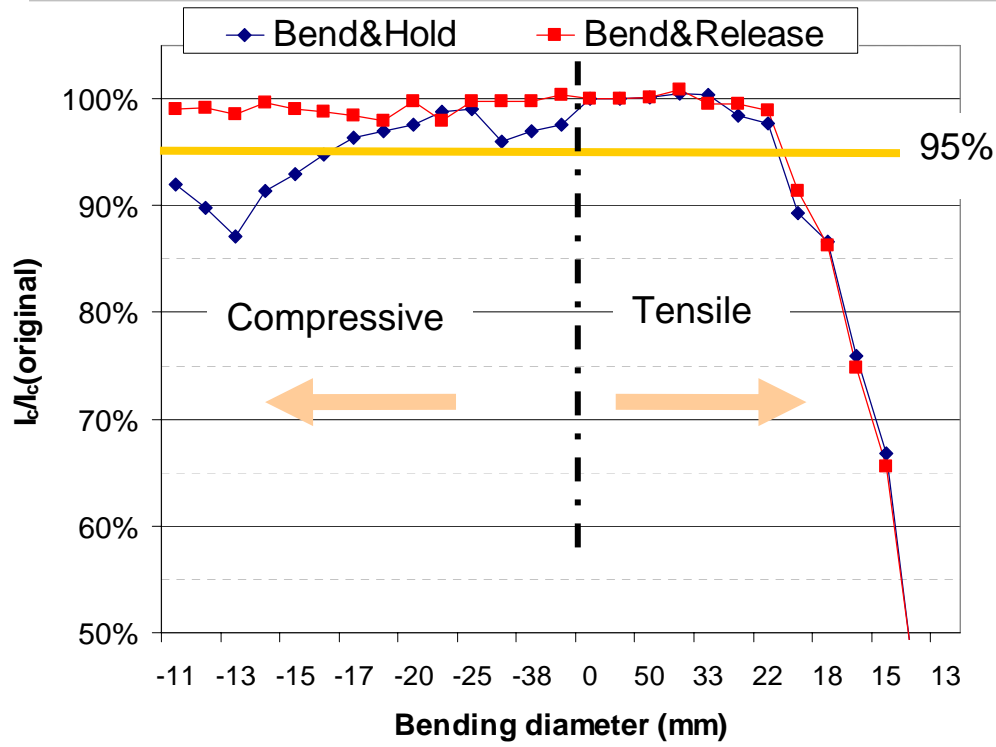
# Overcurrent handling capability of “Surround Stabilizer” structure verified with Pulsed Currents

$I_c = 54A$ , 1 s Pulse, 8 s Hold, 2nd pulse,  
Peak current ( $I_p$ ) = 193A,  $I_p/I_c=3.57$



Minimal  $I_c$  degradation and no tape burn out even at overcurrent levels of 9 times  $I_c$  with 300 ms pulses and 3.5 times  $I_c$  with 1 s pulses

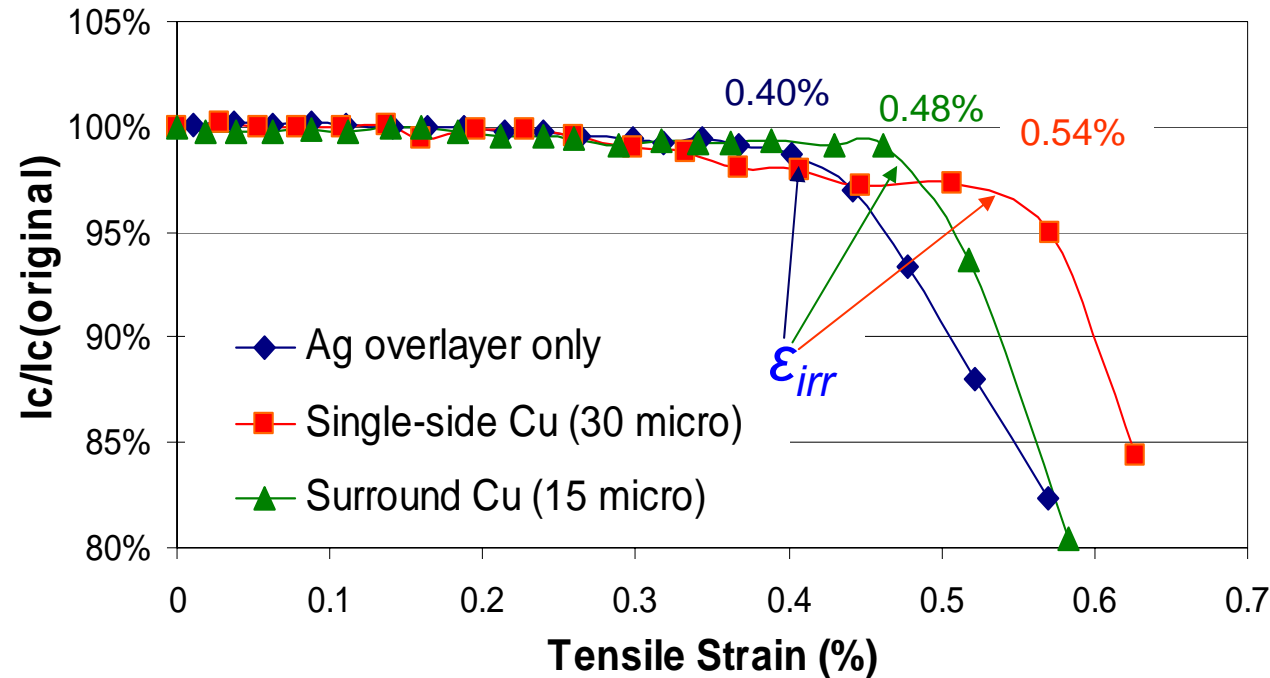
# 4 mm wide, Cu stabilized conductor shows superior bend & tensile properties



95 % Ic retention when bent:  
**Tension - 25 mm diameter** both Bend & Hold and Bend & Release  
**Compression - 16 mm diameter** in Bend & Hold and **< 11 mm diameter** in Bend and Release

Critical Tensile Stress of IBAD-based conductor > **360 MPa**  
 Critical Tensile Stress of RABiTS-based conductor = **150 MPa\***  
 Critical Tensile Stress of 1-G conductor = **150 MPa**

# 4 mm wide, Cu stabilized conductor shows excellent irreversible axial strain and yield strength



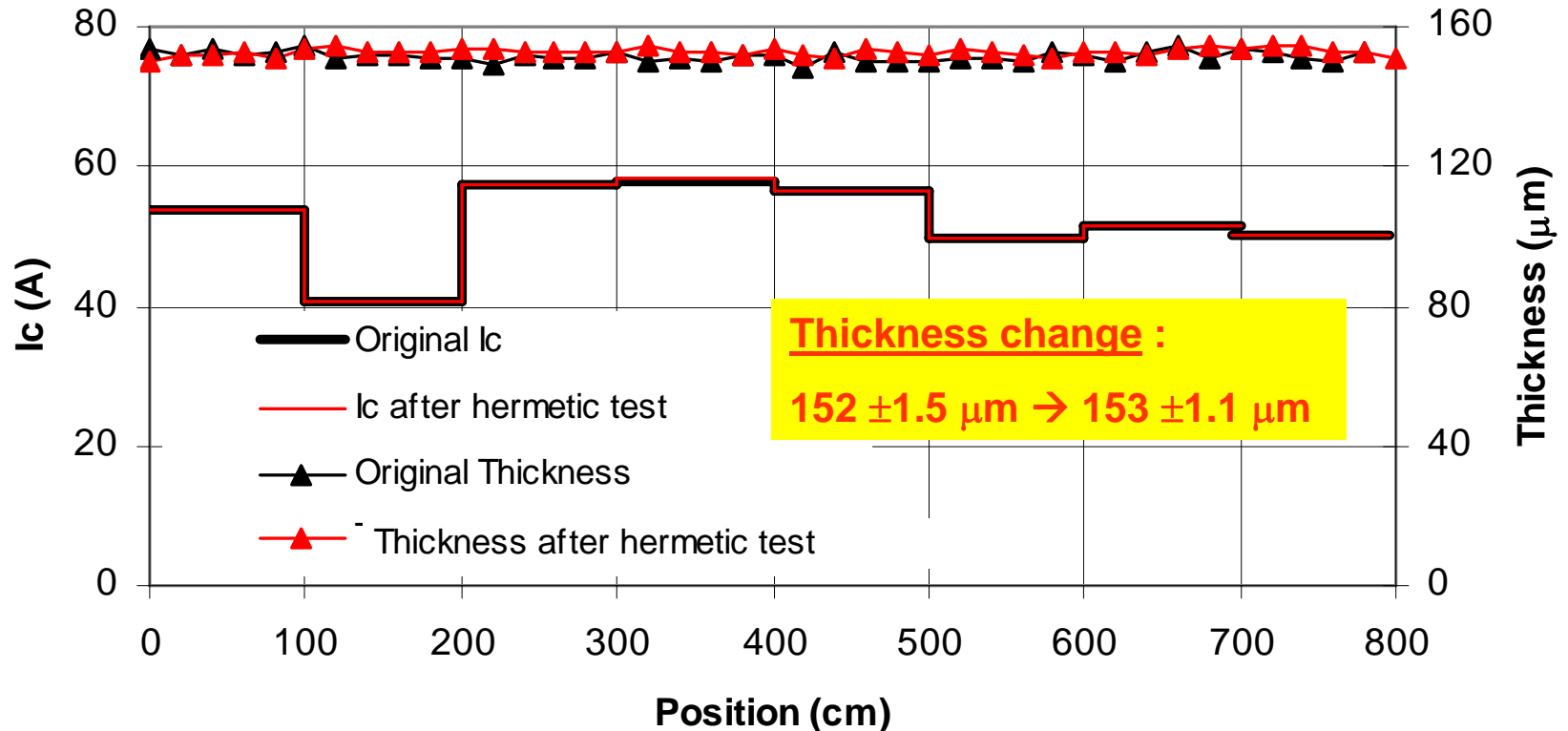
	$\sigma_y$ (MPa) at 0.2%
Bare Metal Sub.	455 (295K) 690 (76K)
Ag overlayer Only	693 (76K)
S.R. Cu (15 $\mu\text{m}$ )	454 (295K) 640 (76K)

➤ Axial-strain performance of the prototype practical conductor “comfortably meet the most severe benchmarks for applications”

➤ IBAD-based conductors are twice more robust than others, both 2G and 1G

# No noticeable change in $I_c$ & thickness after hermetic test of 4 mm wide, Cu stabilized conductor

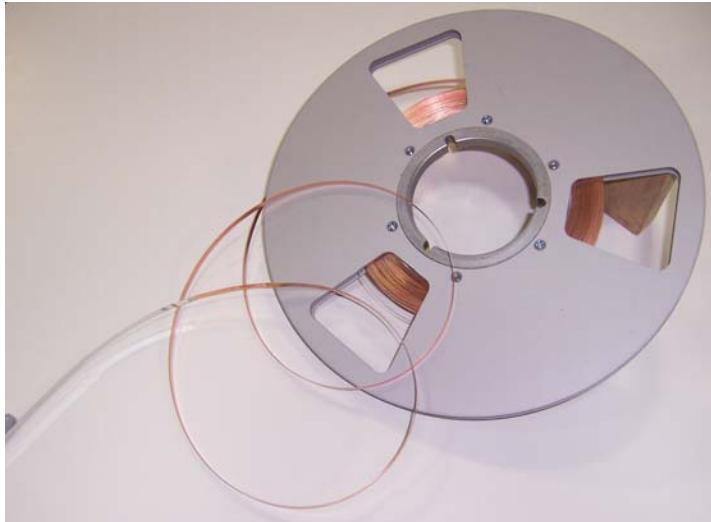
*Hermetic test (10atm, 24h in LN<sub>2</sub>): inherited test requirement from 1G*



**“Surround Stabilizer” conductor structure completely encapsulates HTS & protects it from environment**

# 1 m 2G cable fabricated: Shows robustness of 4 mm 2G conductor

- ✦ 61 m of fully processed conductor i.e. slit to 4 mm width and plated with copper “Surround Stabilizer” shipped to SEI. Av. Ic of all tapes = 122 A/cm.

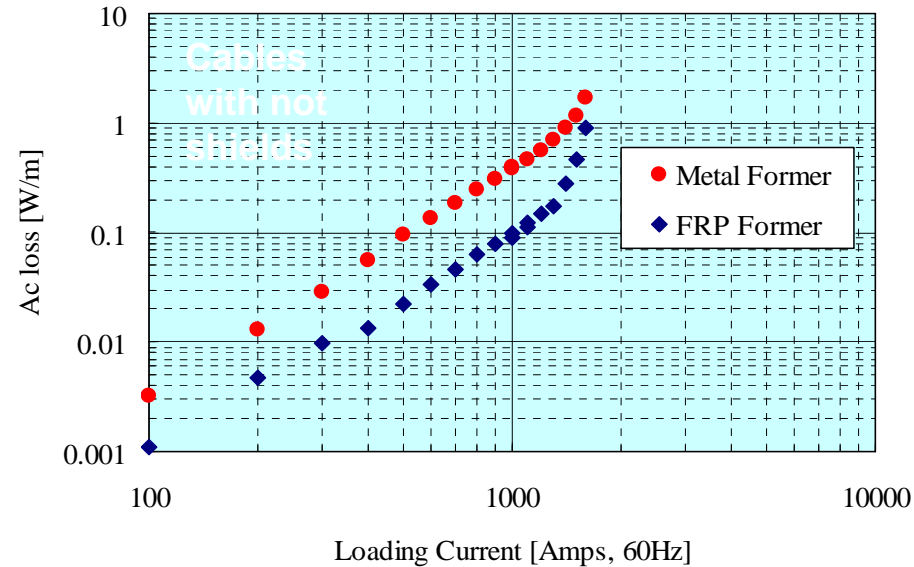
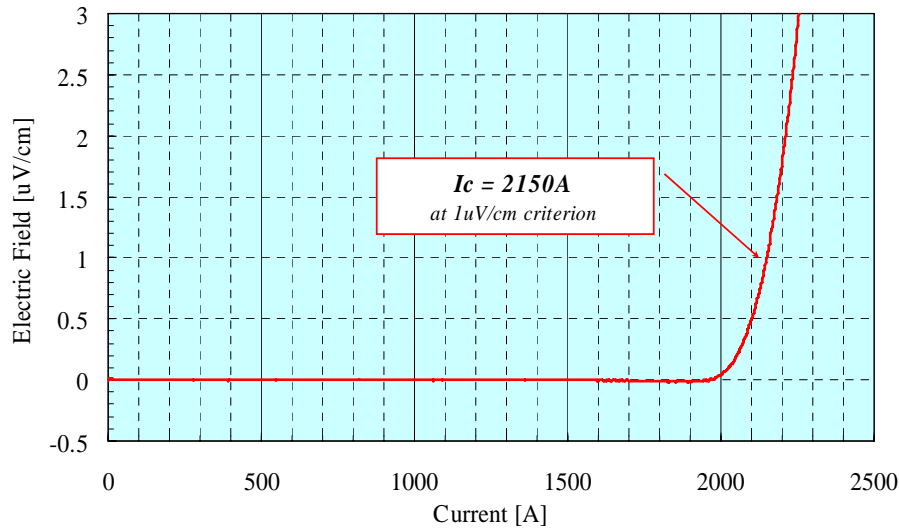


Total # tapes ea. 1.2 m	48
Average Ic of tapes	50.4 A
Average Ic × # tapes	2421 A
Estimated Ic of cable (accounting for field)	2140 A
<b>Measured Ic of cable</b>	<b>2150 A</b>



No degradation in Ic of cable even though the HTS layers were spiral wound in tension with a small diameter former (16 mm)

# First demonstration of a 2G cable with acceptable ac losses for practical HTS applications



	Albany Cable SuperPower/SEI	AMSC-Southwire Cable* AMSC/Southwire/ORNL
AC loss @ $I_{\text{peak}}/I_c = 0.67$	<p><b>0.1 W/m – FRP former</b></p> <p><b>0.4 W/m – Metal former</b></p>	<p>2 W/m</p> <p>(*AMSC presentation DOE Peer review 2003)</p>

**AC losses of new 2G cable is 5 - 20 times less than that of 2G cable previously demonstrated**

# Summary

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- ▶ Sm-substituted coated conductors show high critical current in high magnetic fields
- ▶ Post-YBCO processes developed at SuperPower yielded high-quality practical conductors
- ▶ Excellent environmental stability, electrical stability and electrical mechanical properties indicate that SuperPower's 4mm wide conductors with surround Cu stabilizer are applications-ready