



# Design and Properties of SuperPower's Practical 2G HTS Conductor for Electric Power Applications

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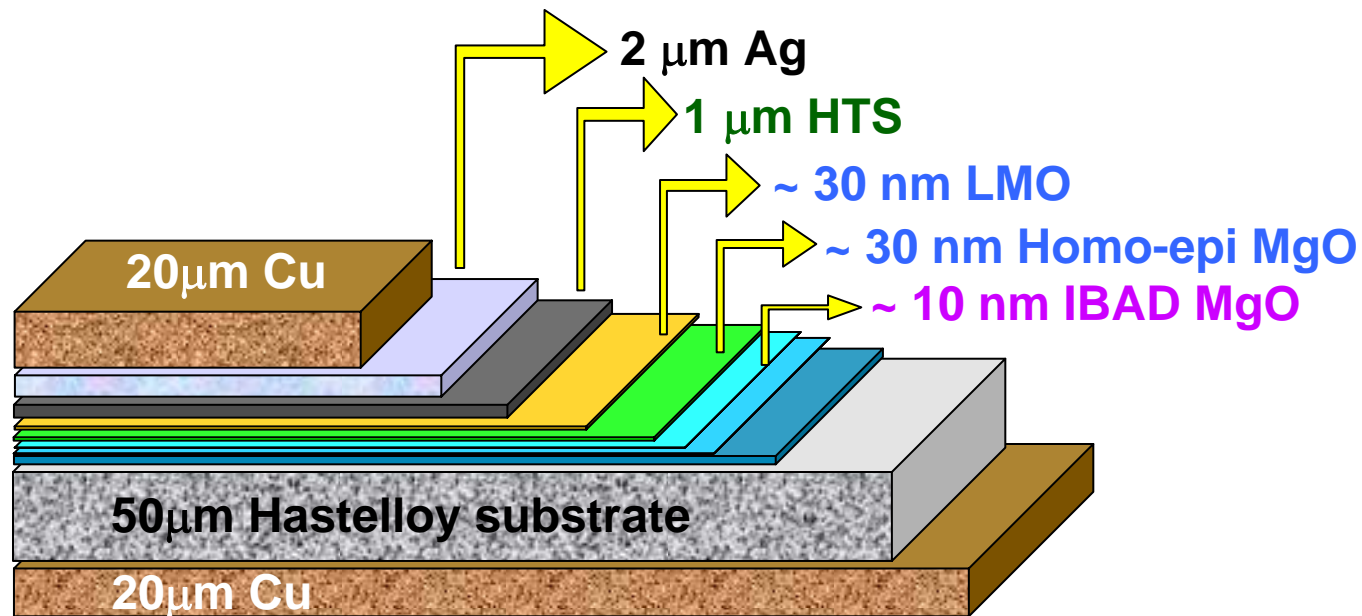
# SuperPower's 2G conductor is half as thick as 1G



Substrate thickness = 50 microns

Surround copper stabilizer = 20 microns all around

**Total conductor thickness is only 0.095 mm**

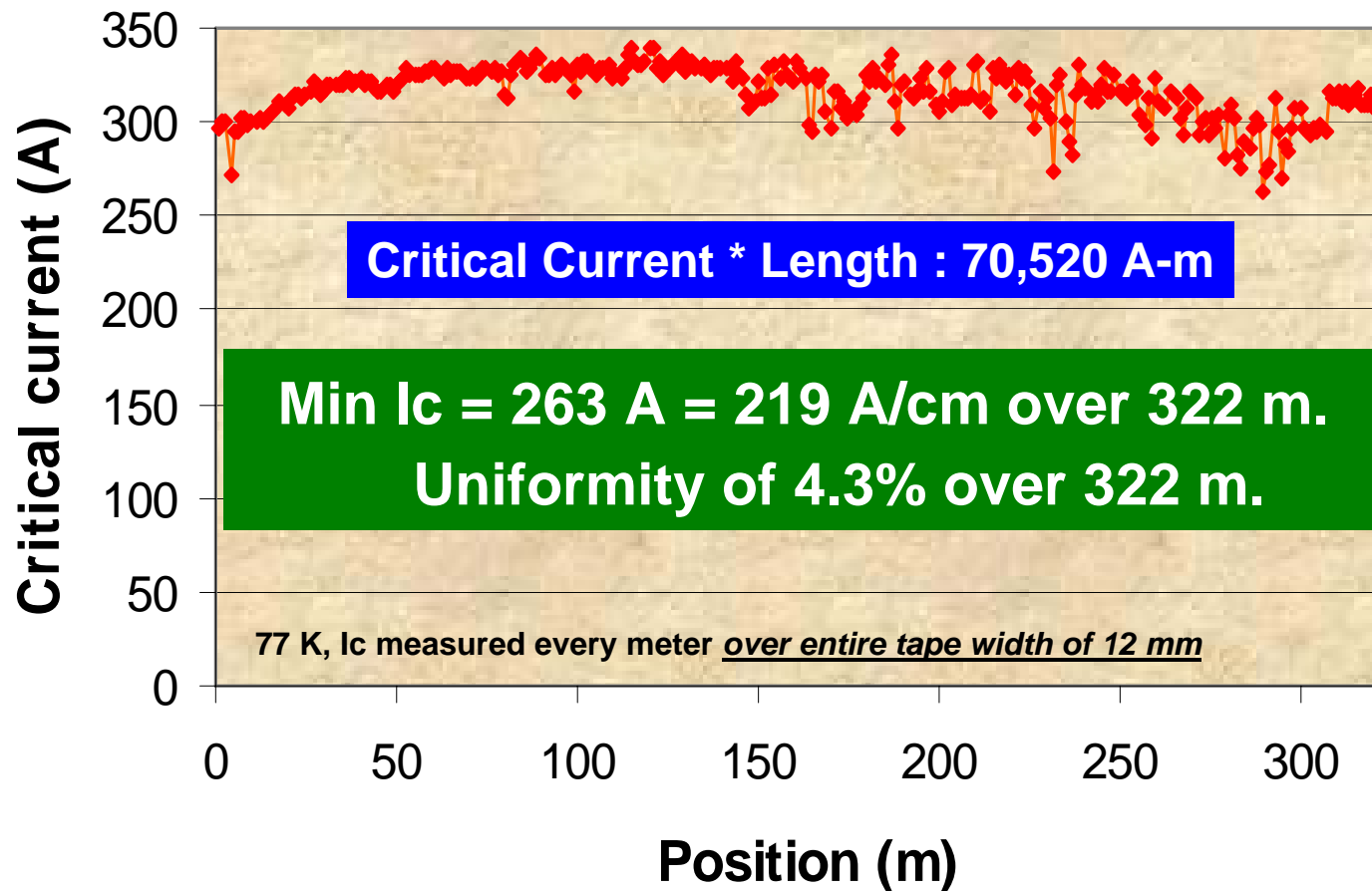


High-strength, non magnetic, highly resistive Hastelloy substrate is used

# 300+ m lengths of 2G conductor are routinely produced with high $I_c$ and excellent uniformity at high throughput



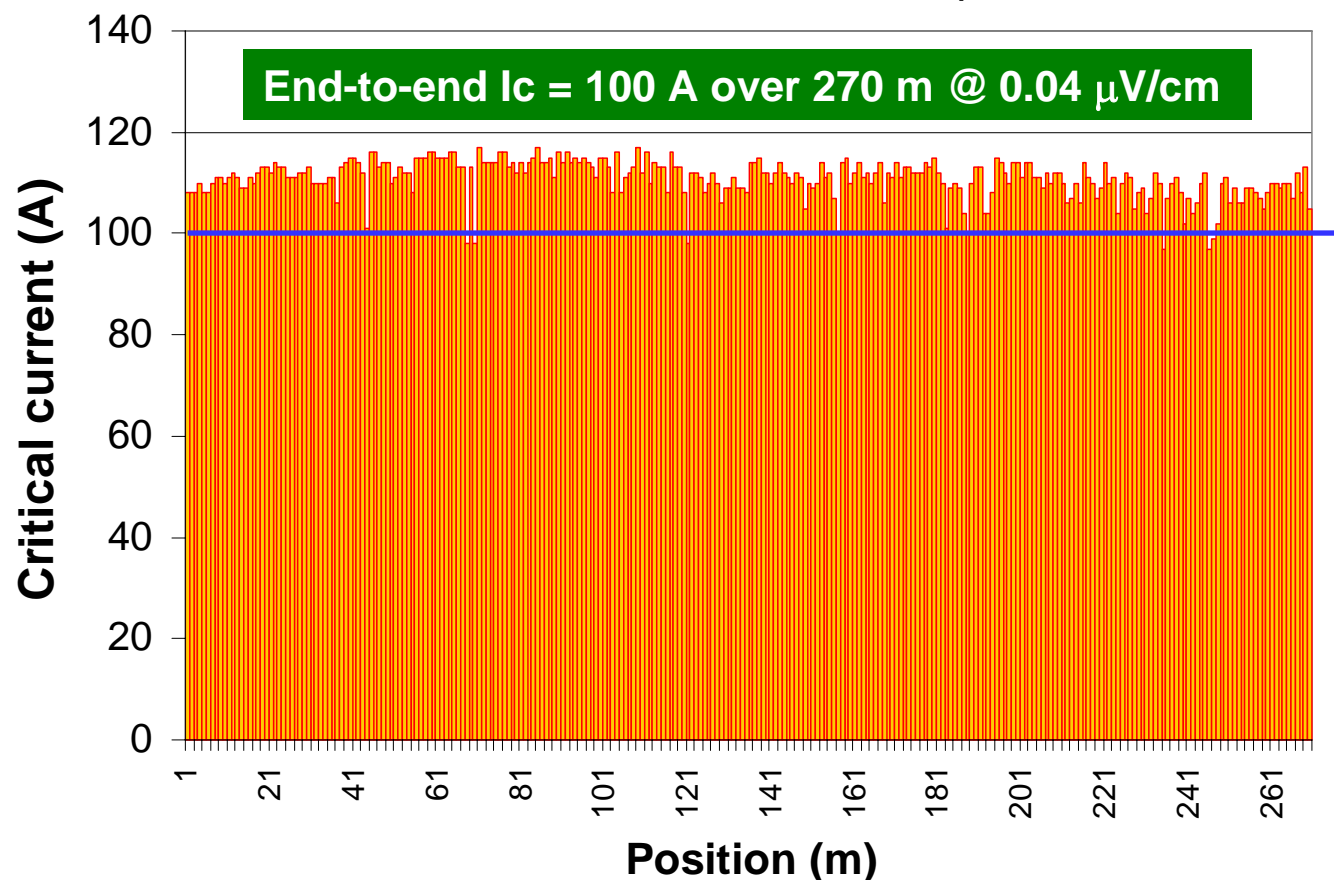
MOCVD: 30 m/h in a single pass on high-throughput IBAD MgO buffered Hastelloy substrate



# 2G conductor is now available in long lengths with $I_c$ in the realm of 1G, & $J_e$ about 2x better than 1G



End-to-end critical current of 4 mm wide 2G conductor slit from 12 mm wide tape

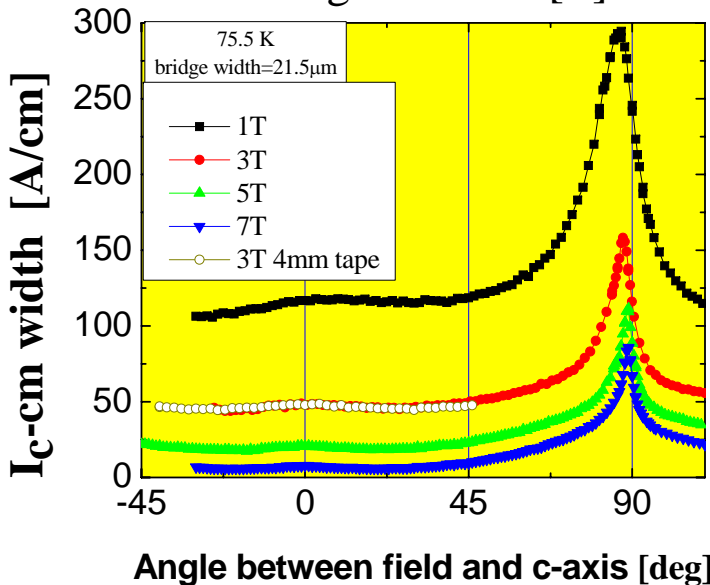
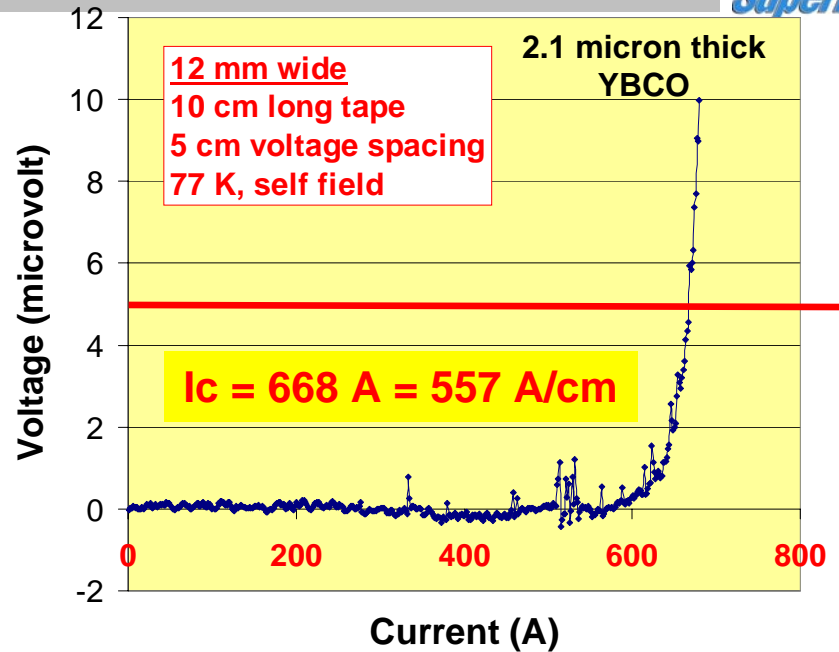
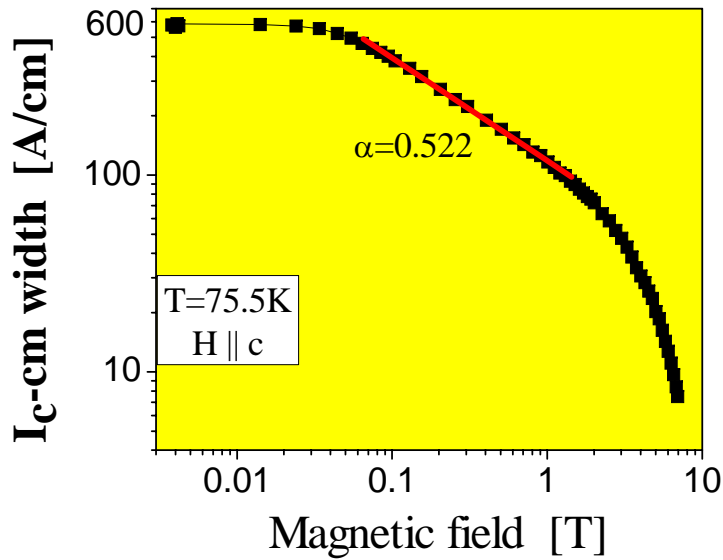


**$I_c = 100$  A in a 4 mm wide 2G conductor over 270 m !**

**$J_e = 26.3 \text{ kA}/\text{cm}^2$  (for a 20 micron surround stabilizer i.e. 40 micron total)**

**compared to a 1G  $J_e$  of  $13 \text{ kA}/\text{cm}^2$  to  $17 \text{ kA}/\text{cm}^2$**

# Even higher $I_c$ & $J_e$ demonstrated in short lengths

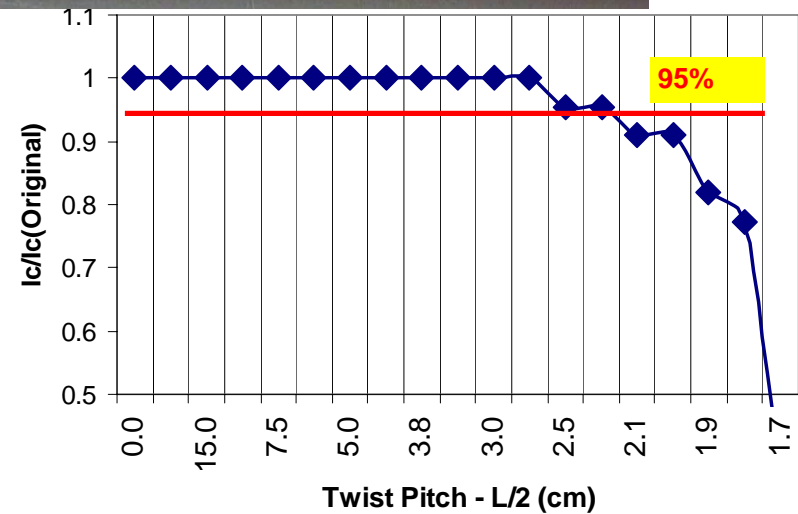
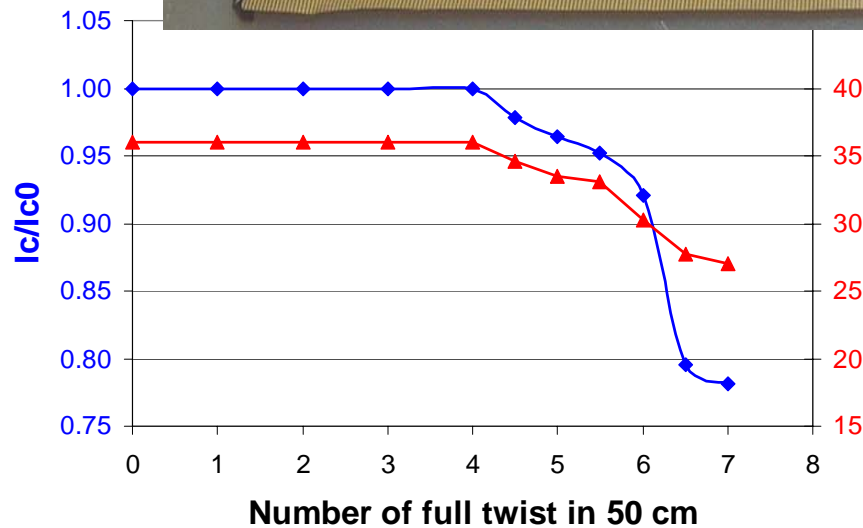
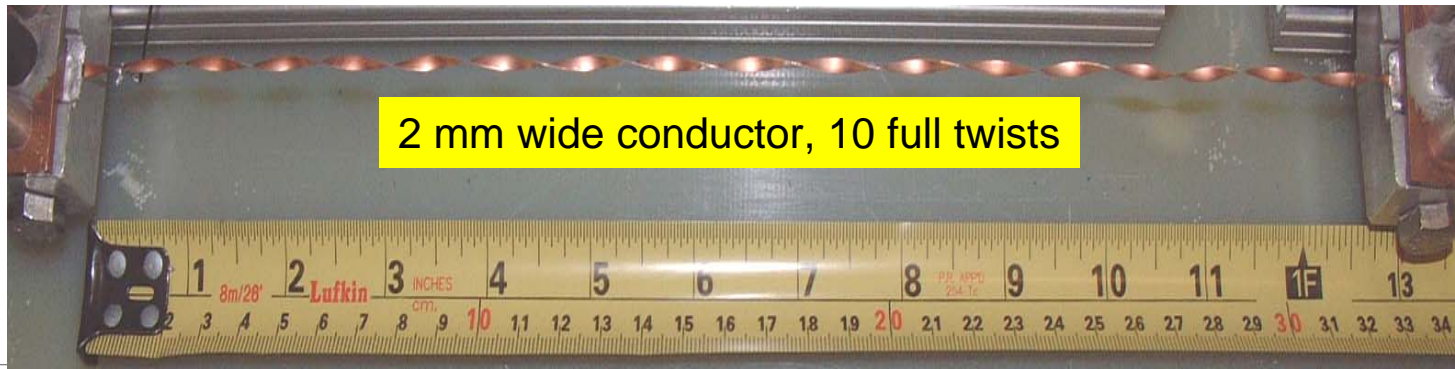


1 T, 75.5 K	$I_c$ (A/cm)	$J_c$ (MA/cm <sup>2</sup> )	$J_e$ (kA/cm <sup>2</sup> )
Self field, 77 K	557	2.65	100.1
$B \parallel c$ , 1 T, 75.5 K	116.7	0.56	21.1
$B \sim \parallel a\text{-}b$ , 1 T, 75.5 K	294.4	1.4	50.5

# 2G conductors are very mechanically robust: Can be slit to narrow widths & twisted to small twist pitches



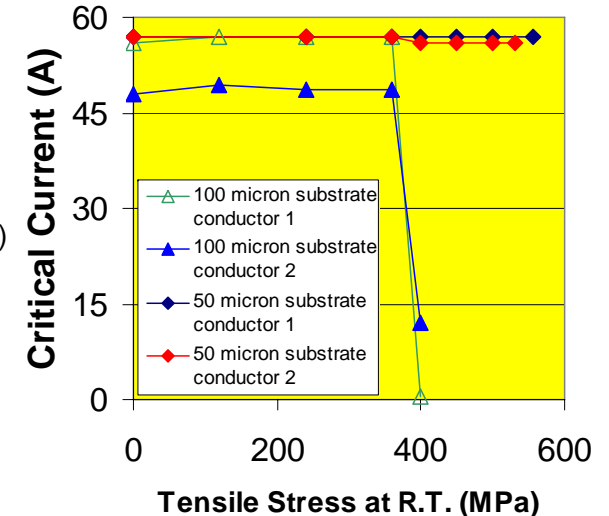
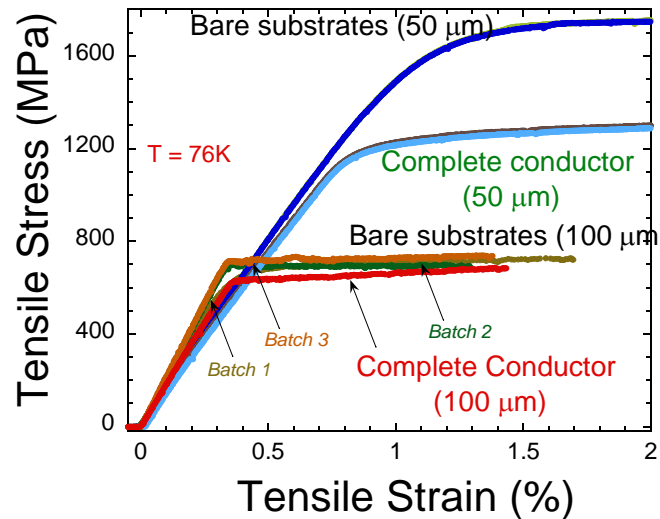
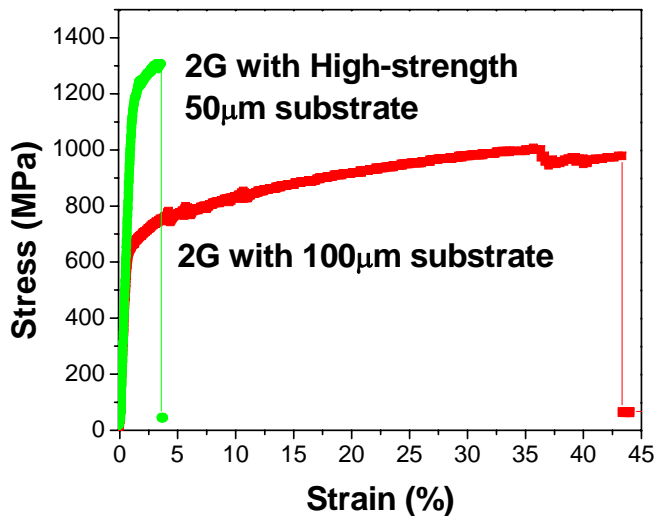
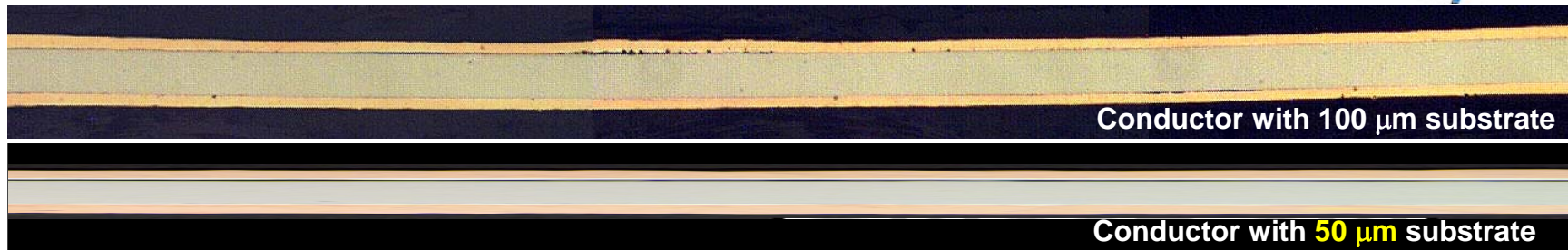
- Twisting needs to be demonstrated in order for striated geometry to be fully effective in long lengths



95% original Ic retained at 5.5 full twists (Twist pitch = 9.4 cm)

95% original Ic retained even at 10 full twists (Twist pitch = 4.6 cm)

# Use of high-strength 50 micron substrates yielded thin-profile 2G conductors with much higher tensile strain & critical tensile stress



2G conductor made with	Yield strength at 77 K*
100 micron substrate	650 MPa
High-strength 50 micron substrate	1200 MPa

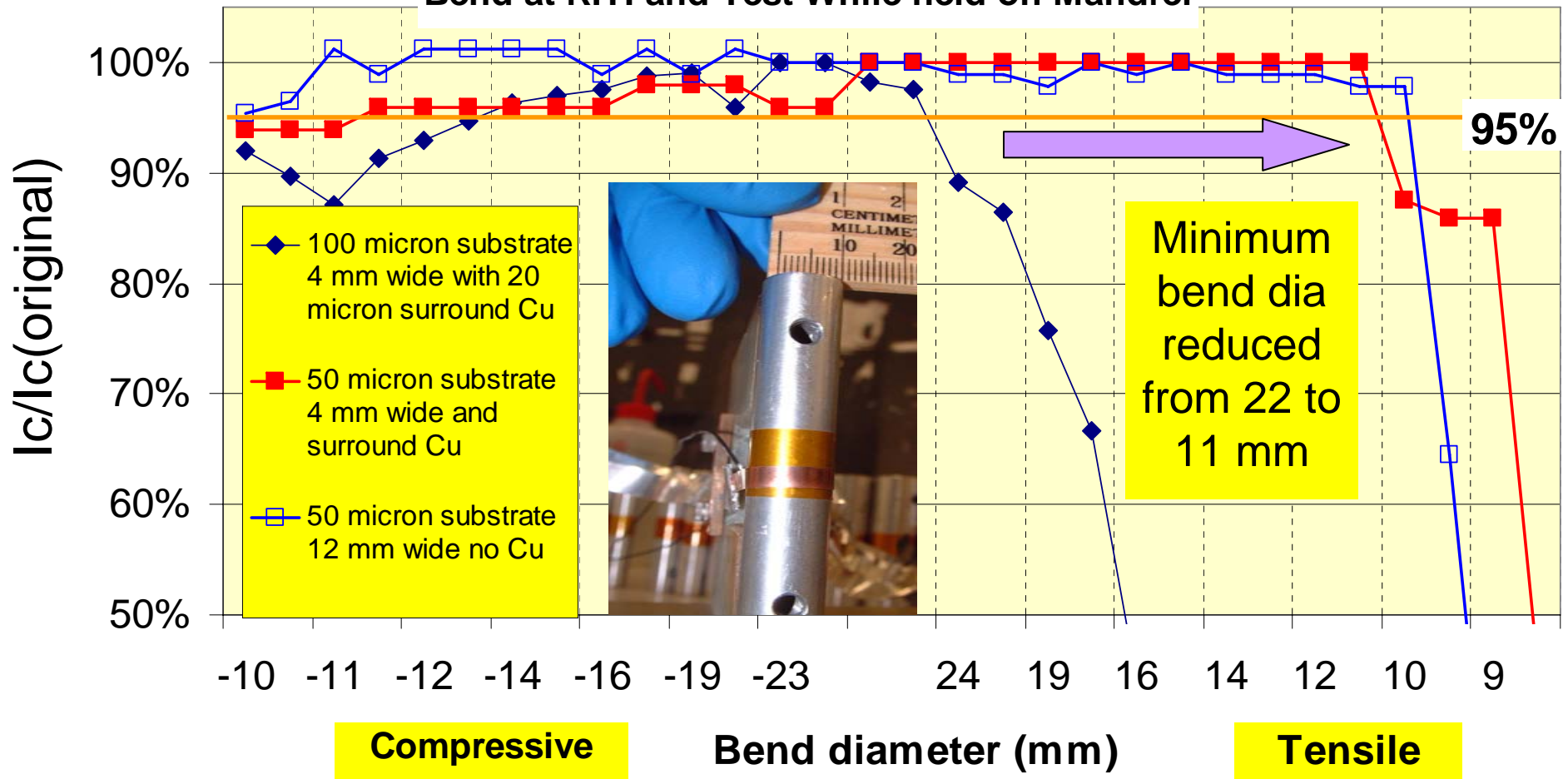


\*Measurements Y. Zhou and K. Salama (U.Houston) N. Cheggour, D. Van der Laan, J. Ekin (NIST)



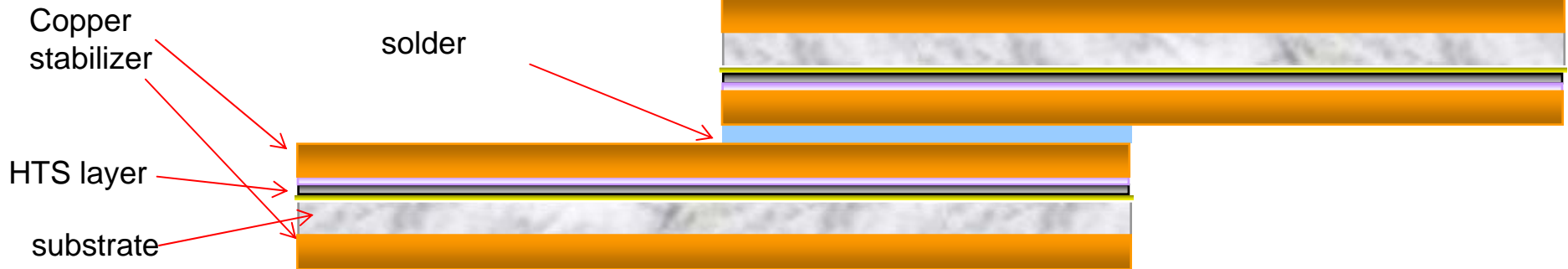
# Bend performance significantly improved using thin-profile 2G conductors

Bend at R.T. and Test While held on Mandrel



2x reduction in bend diameter using conductors with 50 micron substrates

# Joints between 2G conductors show good electrical & thermo-mechanical properties



4 mm wide conductors each with 20  $\mu\text{m}$  surround copper stabilizer

Joint length = 3 cm

Original tape thickness = 0.145 mm

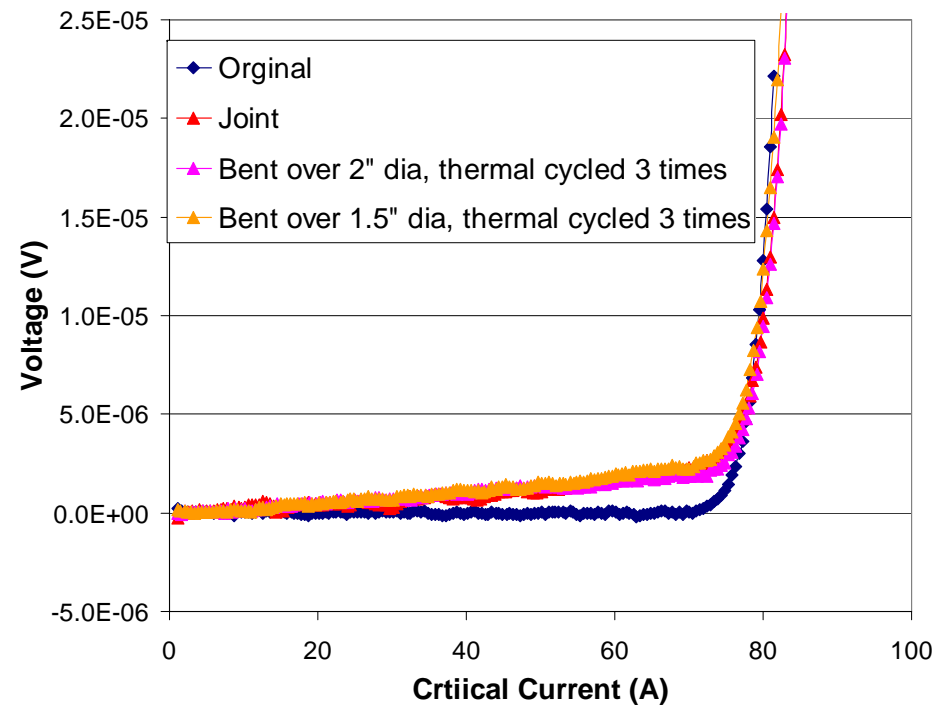
Thickness at joint = 0.32 mm

No degradation in  $I_c$  ( $1 \mu\text{V}/\text{cm}$ ) over the joint

Resistivity over the joint is **38 nohm-cm<sup>2</sup>**

**No degradation in  $I_c$  and resistivity when bent over down to 1.5" diameter and thermal cycled three times.  $I_c$  was tested at every thermal cycle**

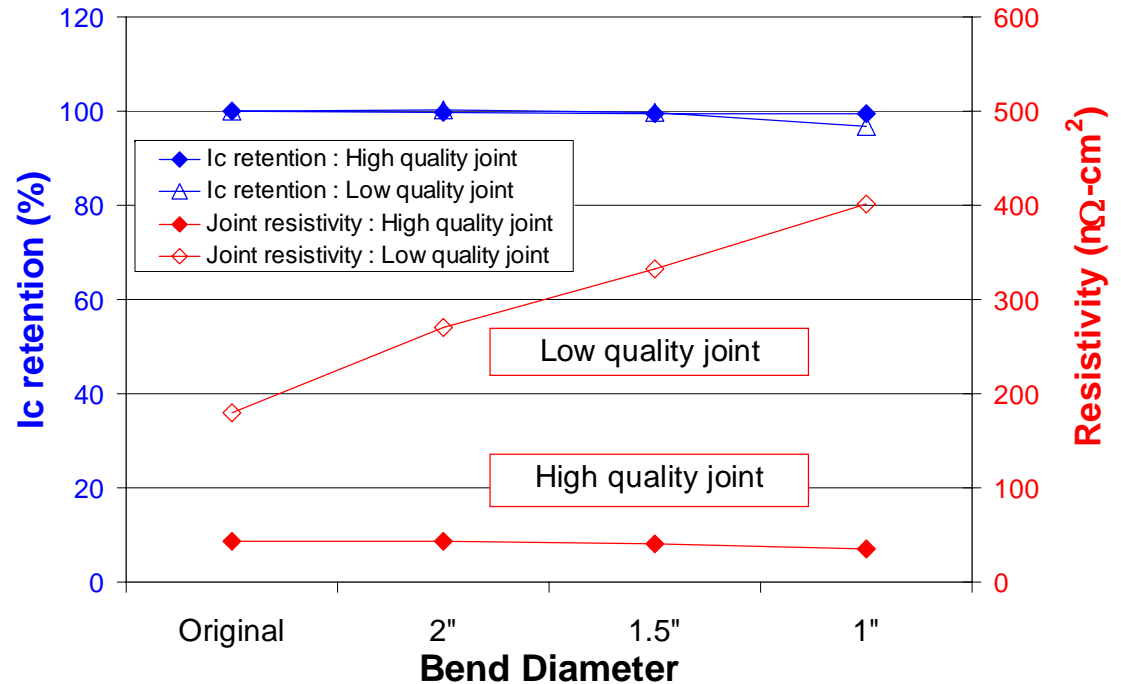
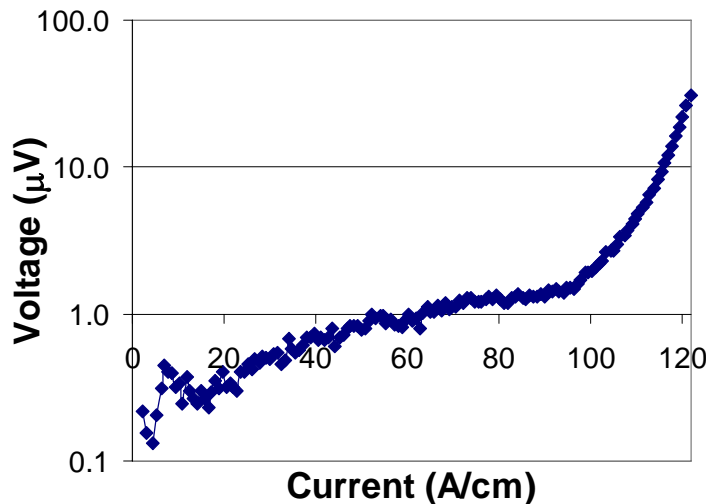
**When further bent over 1" mandrel, solder material failed.**



# Joints between thin-profile conductors show excellent mechanical & electrical performance

**Thickness at joint can be reduced from 0.32 mm to 0.22 mm by using thin-profile conductors (w/ 50 micron substrates)**

4 mm wide conductors each with 20  $\mu\text{m}$  surround copper stabilizer  
 Joint length = 3 cm  
 Original tape thickness = **0.095 mm**  
 Thickness at joint = **0.22 mm**

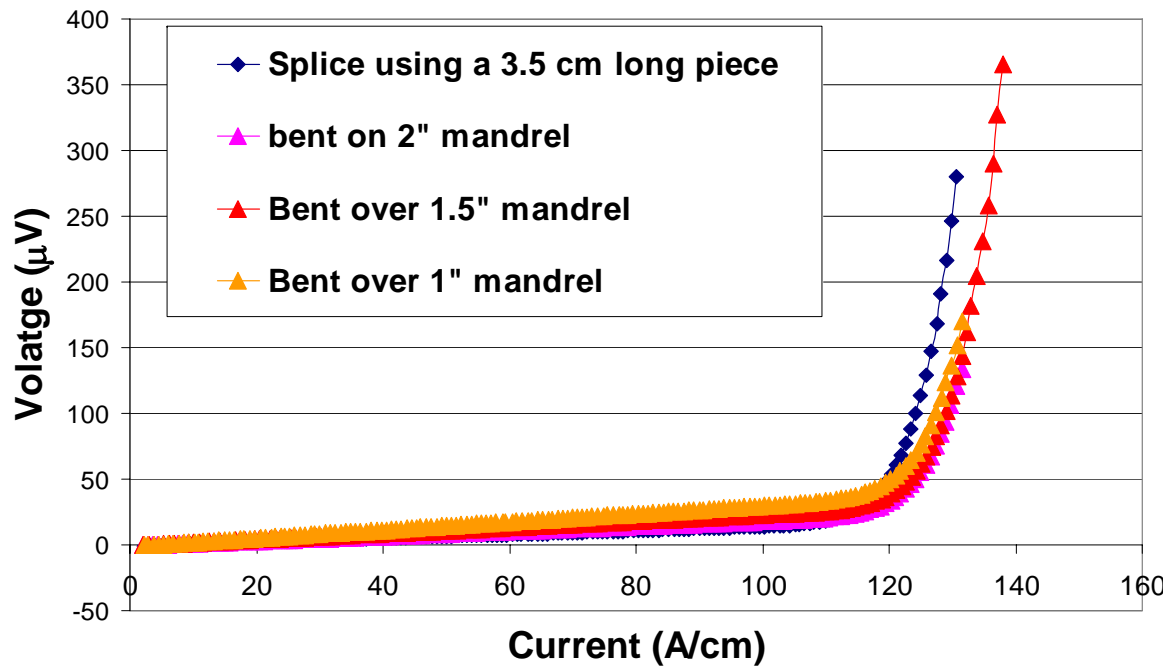
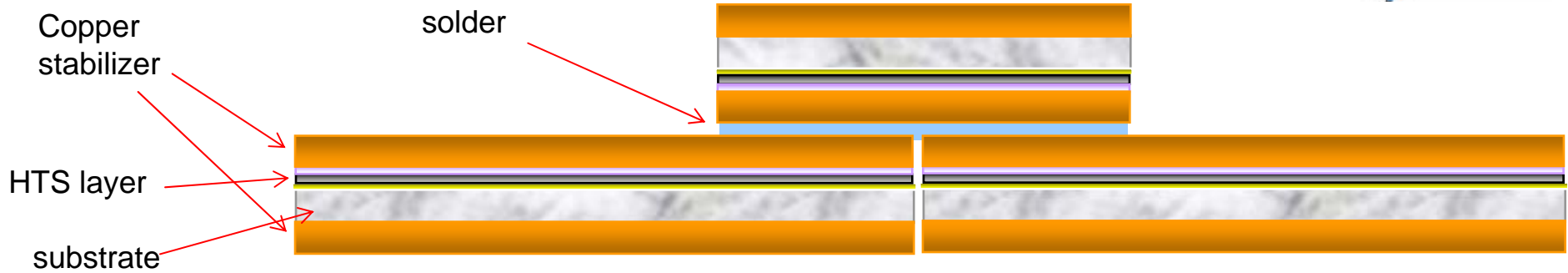


**Joint resistivity = 40  $\text{n}\Omega\text{cm}^2$**

**Ic across joint & resistivity of joint are not affected down to a bend diameter of 1"**

**Quality of joint primarily determines electrical & mechanical performance**

# Splices of thin-profile conductors show excellent mechanical & electrical properties



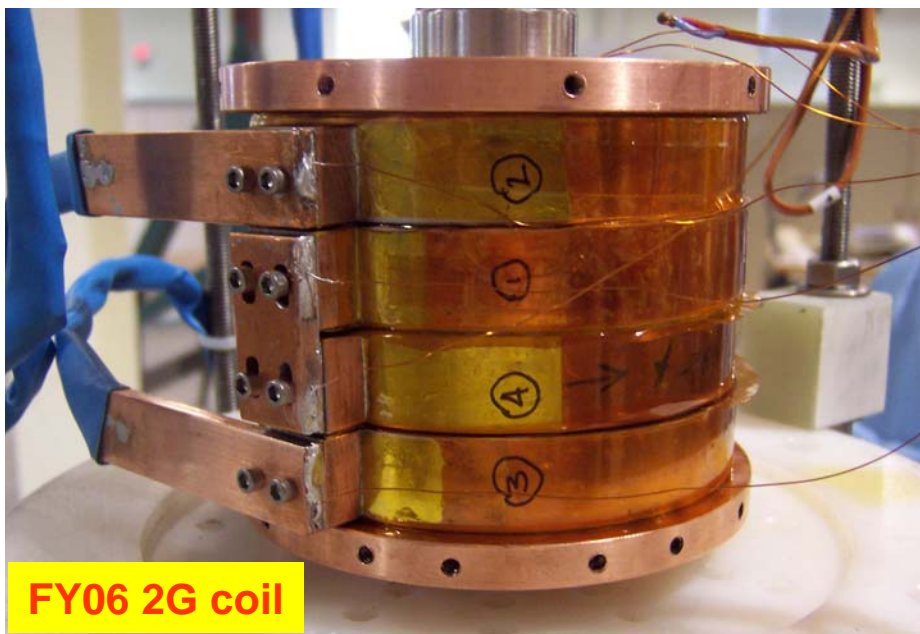
Two 4 mm wide, **0.095 mm** thick (50 micron substrate, 20 micron surround copper stabilizer) spliced with a similar piece 3.5 cm long.

Splice Resistivity = **50 nΩcm<sup>2</sup>**

No  $I_c$  degradation when splice was bent down to **1"** diameter.

# Use of thin-profile 2G conductor enabled fabrication of high-field HTS coil

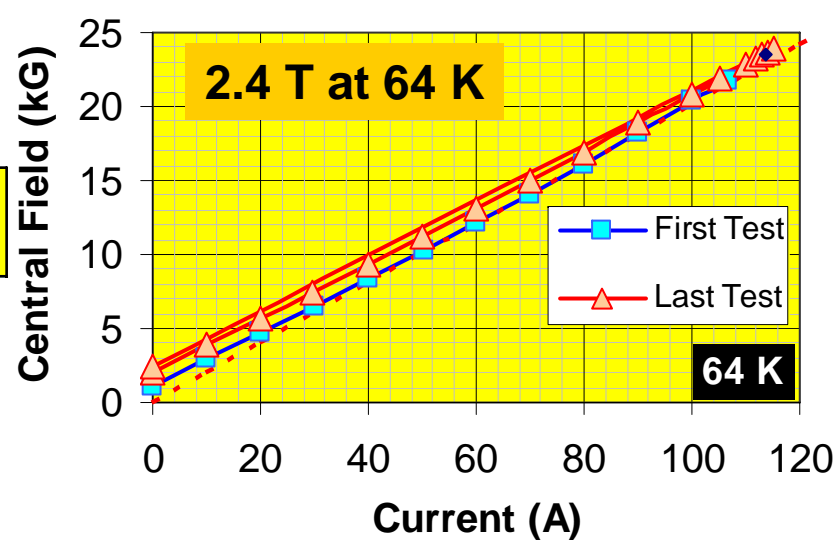
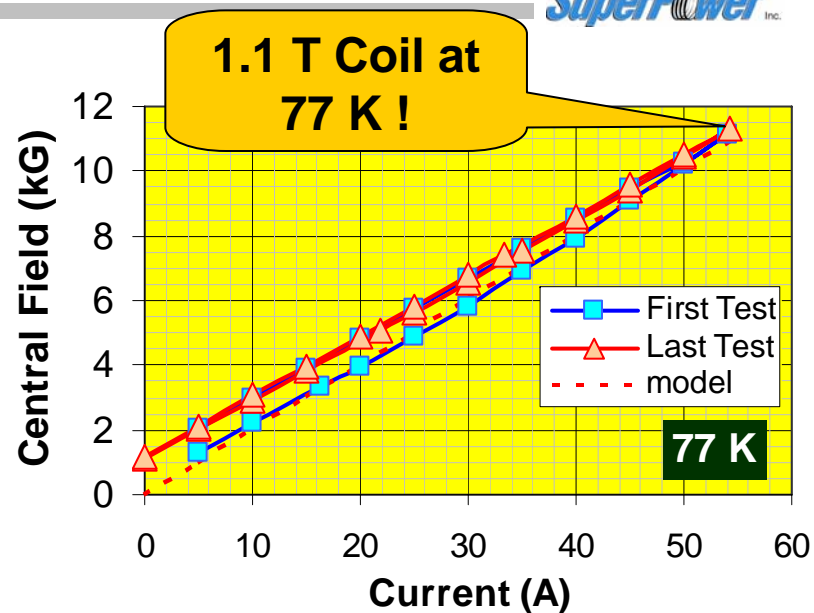
In FY06, we demonstrated a 2G coil that generated 0.4 T at 77 K and 0.87 T at 64 K



**FY06 2G coil**

Coil ID (mm)	10.92
Winding ID (mm)	12.70
Winding OD (mm)	75.2
Height (mm)	57.2
<b>2G Tape Used (m)</b>	<b>159.6</b>
# Turns	1156

Avg $I_c$ of Tape in Coil (A)	246
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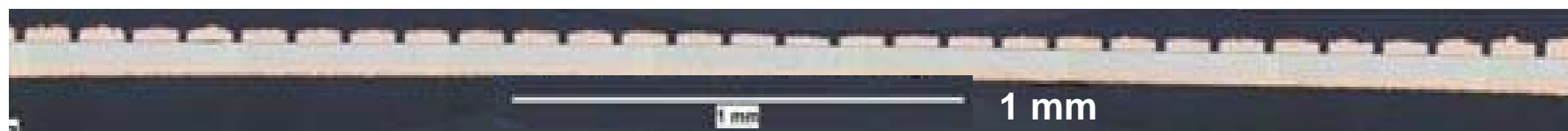
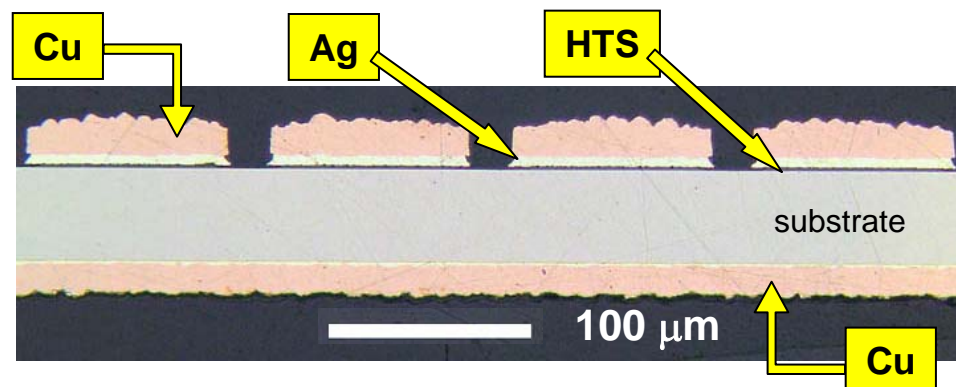


# New conductor geometries developed for ac loss reduction



Tapes with striated YBCO & silver overlayer have been produced by several groups

In order to benefit from patterning of YBCO, thick copper stabilizer also need to be striated






**Very first demonstration of striation of a thick copper stabilizer**

Mechanical properties of fully-striated conductor need to be investigated





# Thin profile 2G conductors enable higher $J_e$ & better mechanical properties





## High $J_e$

-  26.3 kA/cm<sup>2</sup> in 322 m lengths (2x 1G)
-  In self-field at 77 K,  $J_e$  of 100,000 A/cm<sup>2</sup> in short tapes (with no Cu), 58.4 A/cm<sup>2</sup> for a 40 micron total copper stabilizer
-  At 1 T at 75.5 K, 21.1 kA/cm<sup>2</sup> in short tapes (with no Cu), 12.2 kA/cm<sup>2</sup> for a 40 micron total copper stabilizer

## Better mechanical properties

-  Bend diameter of 11 mm even with YBCO in tension with 95%  $I_c$  retention
-  Low contact resistance & no  $I_c$  degradation of joints & splices when bent over 25 mm and thermal cycled 3 times from 77 K to RT
-  Yield stress of conductor = 1200 MPa (6 - 8 times 1G).  
Critical tensile stress > 550 MPa
-  Twist pitch of 9.4 cm with 4 mm wide & 4.6 cm with 2 mm wide conductors

## High-performance devices

-  Can pack more wire in a coil and wind it around small diameter.
-  Coil generating 1.1 T at 77 K and 2.4 T at 64 K demonstrated