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

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HTS Solutions for a New Dimension in Power

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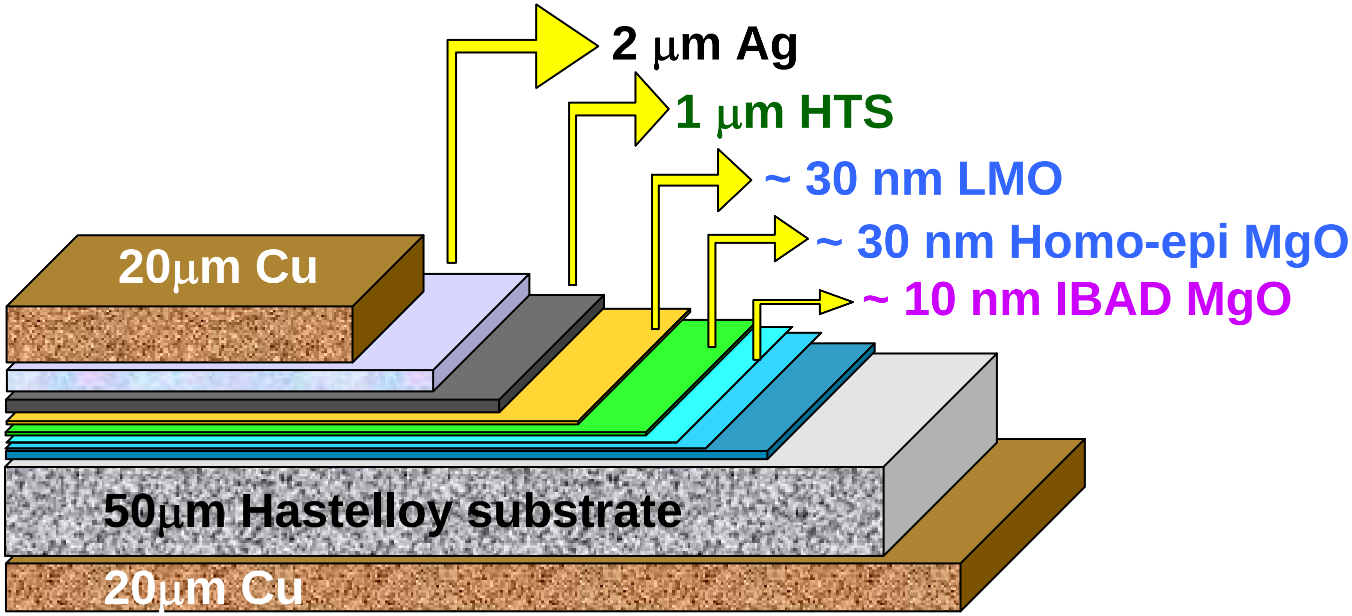
SuperPower's 2G conductor is half as thick as 1G

Substrate thickness = 50 microns

Surround copper stabilizer = 20 microns all around

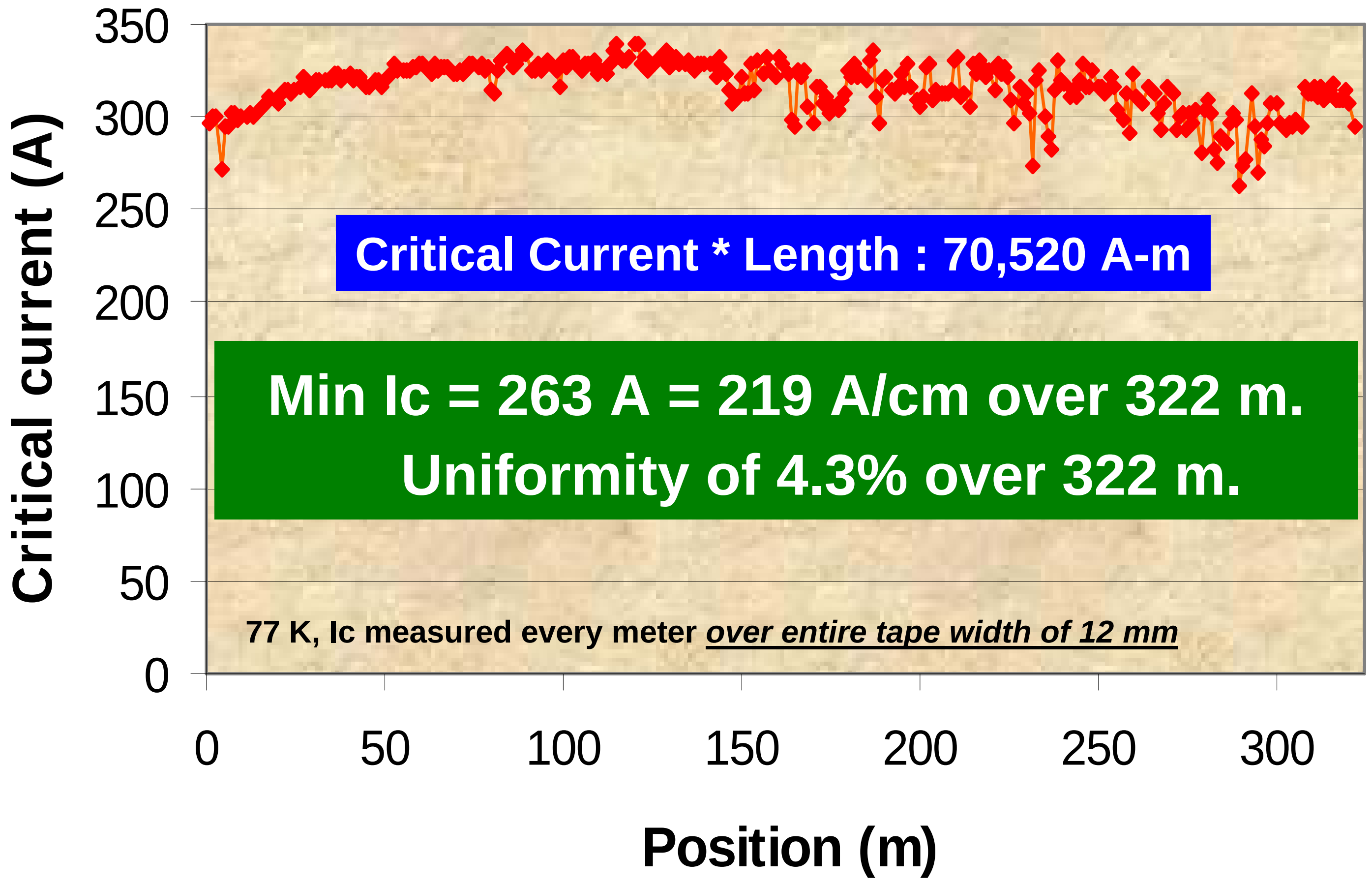
Total conductor thickness is only 0.095 mm



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

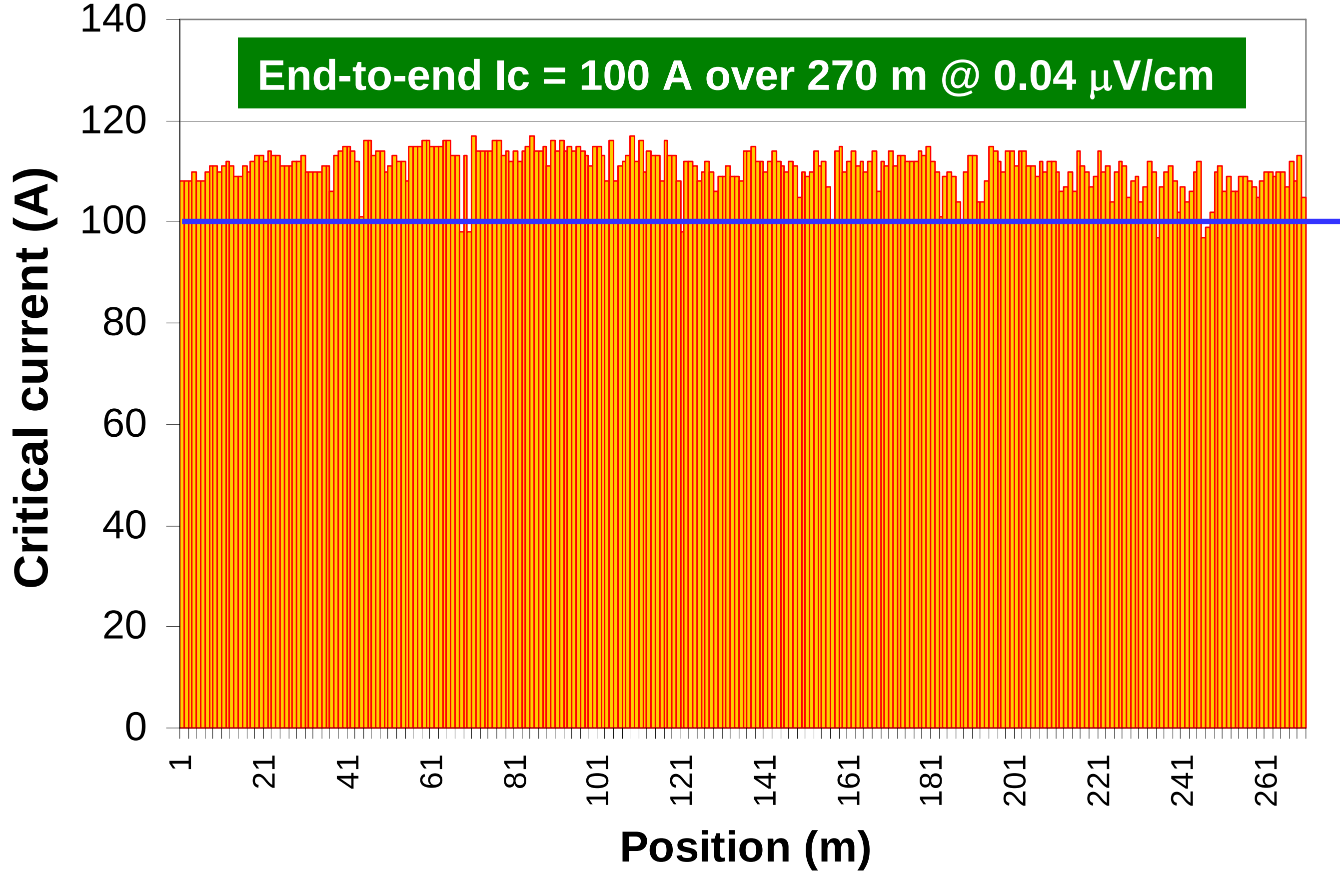
300+ m lengths of 2G conductor are routinely produced with high Ic and excellent uniformity at high throughput

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 Ic in the realm of 1G, & Je about 2x better than 1G

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

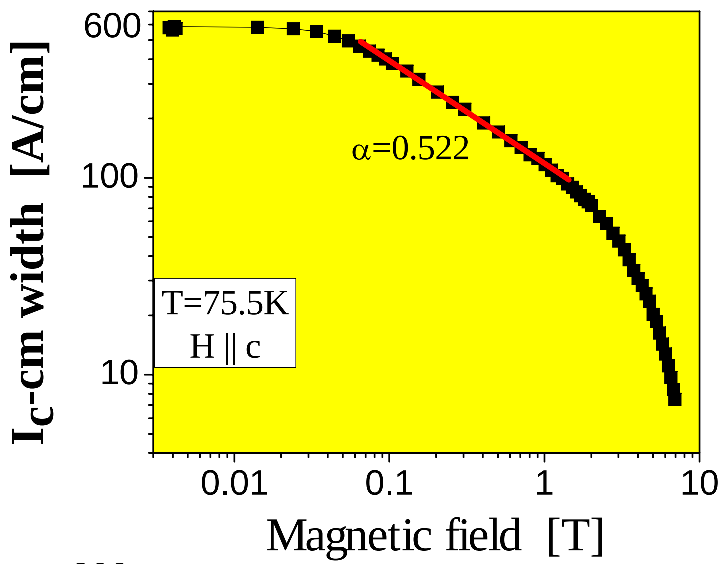


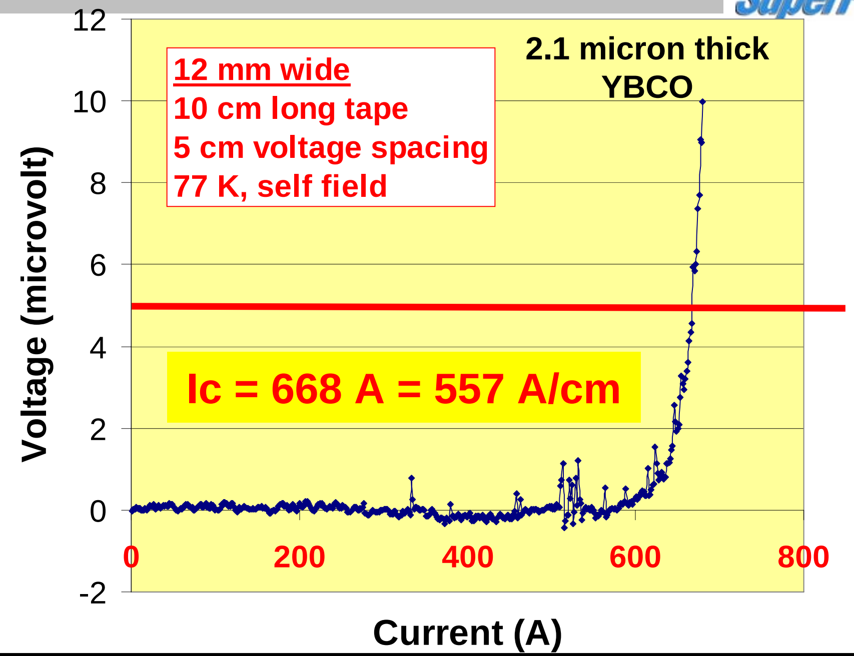
Ic = 100 A in a 4 mm wide 2G conductor over 270 m !

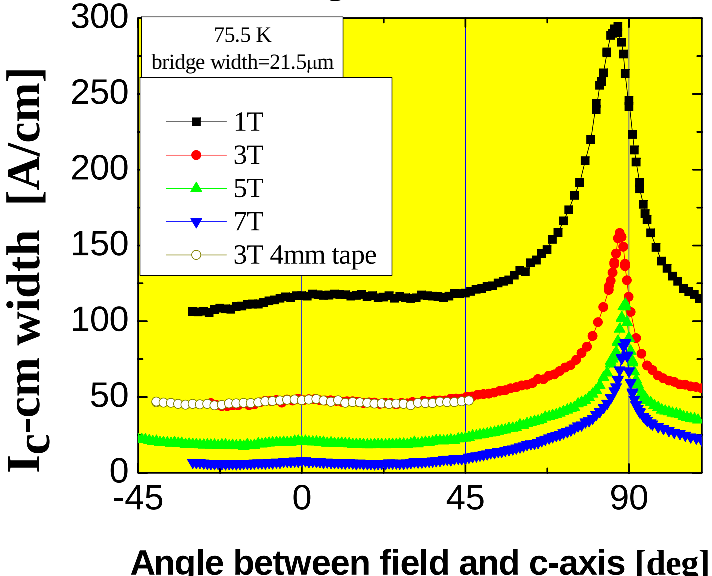
Je = 26.3 kA/cm² (for a 20 micron surround stabilizer i.e. 40 micron total)

compared to a **1G Je of 13 kA/cm² to 17 kA/cm²**

Even higher Ic & Je demonstrated in short lengths





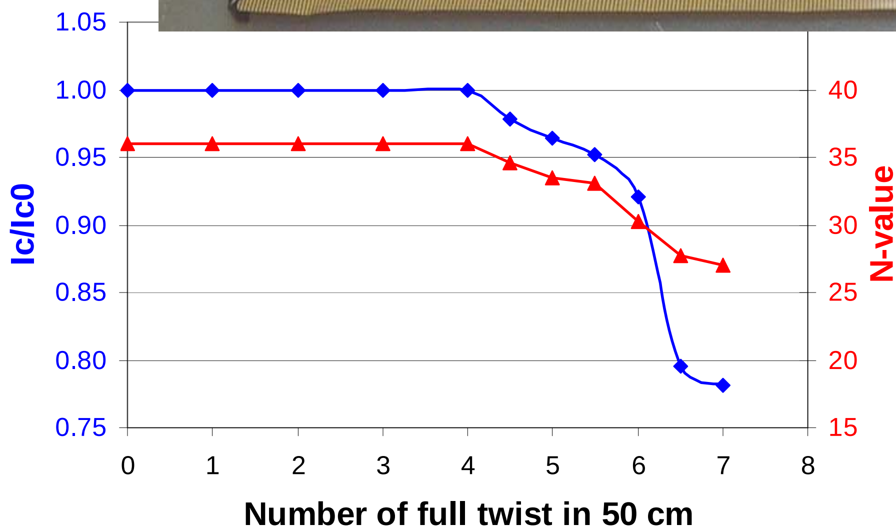


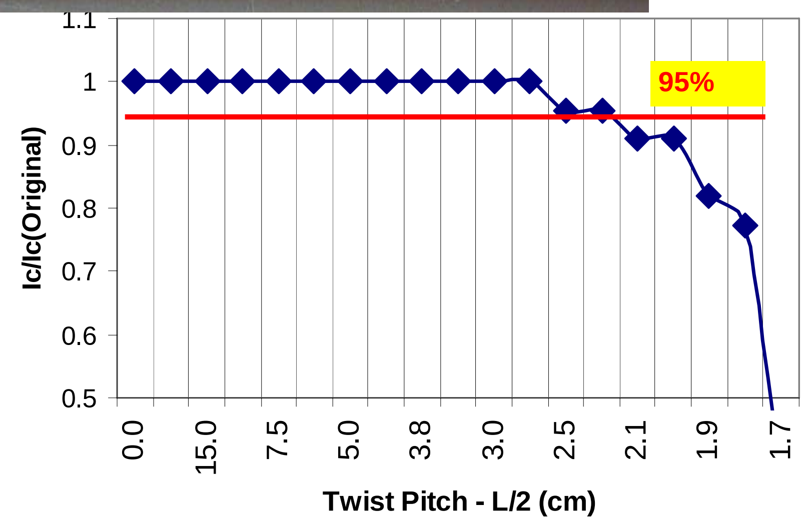
1 T, 75.5 K	Ic (A/cm)	Jc(MA/cm²)	Je (kA/cm²)
Self field, 77 K	557	2.65	100.1
B || c, 1 T, 75.5 K	116.7	0.56	21.1
B ~ || a-b, 1 T, 75.5 K	294.4	1.4	50.5

In-field measurements by B. Maiorov, S. Baily, F. Hunte, and L. Civale

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

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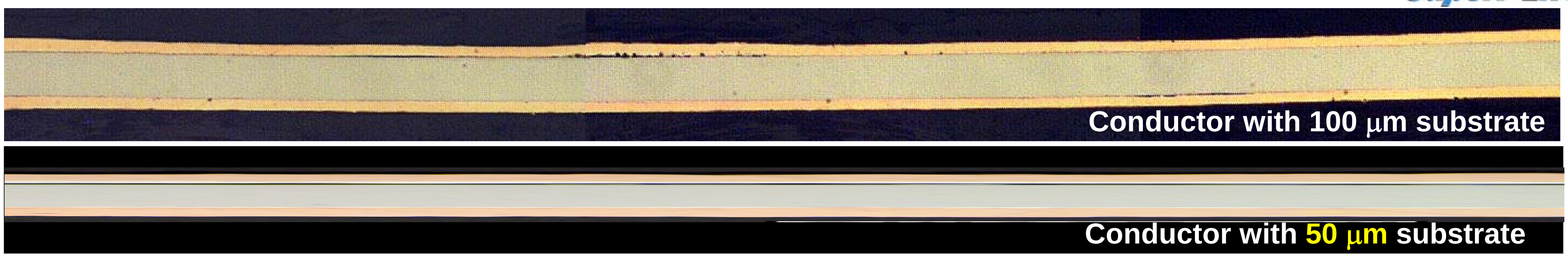

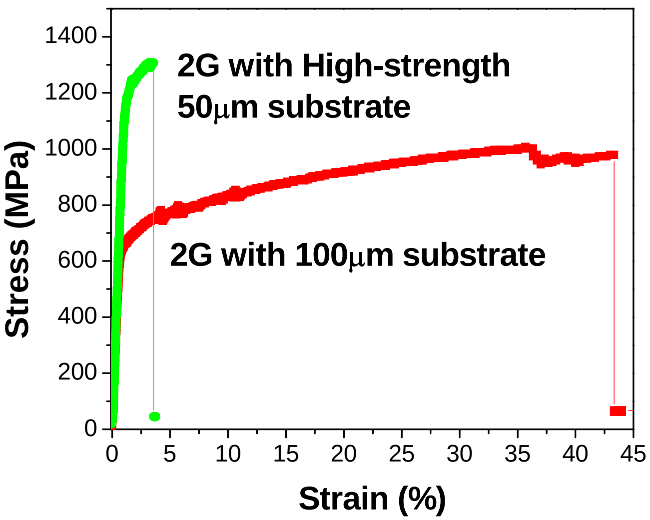

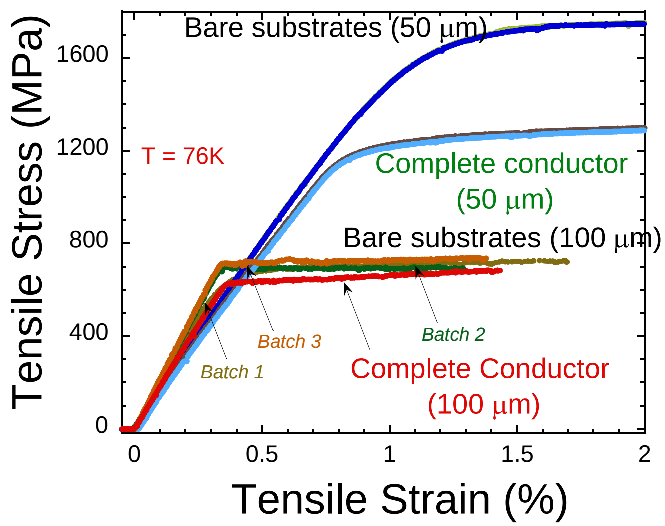

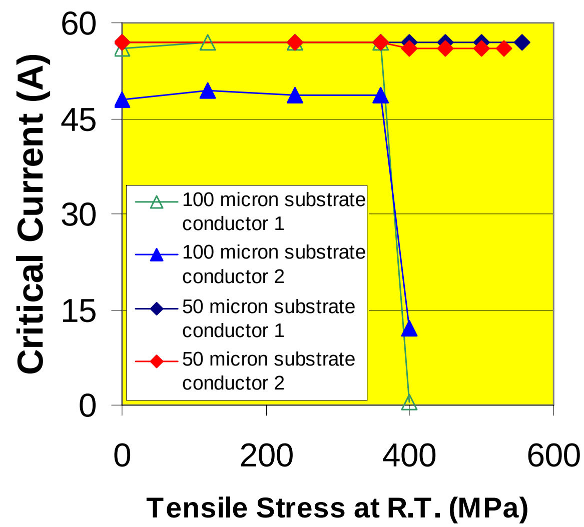

2G conductor made with	Yield strength at 77 K*
100 micron substrate	650 MPa
High-strength 50 micron substrate	1200 MPa

*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

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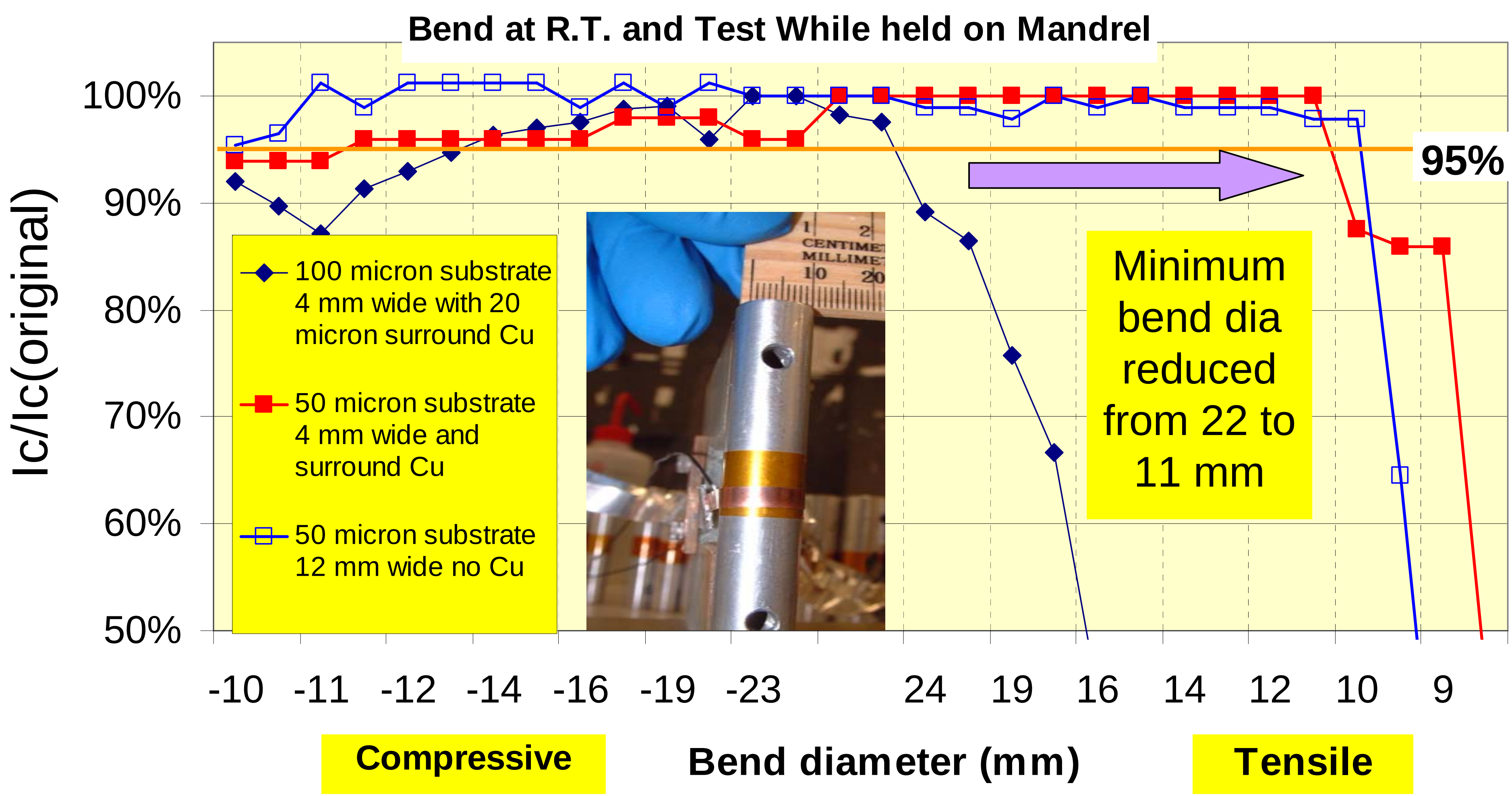
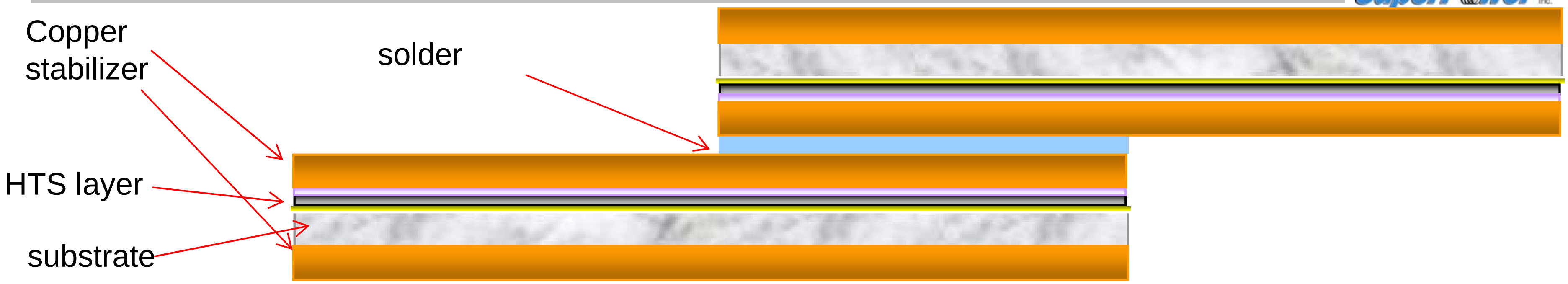


2x reduction in bend diameter using conductors with 50 micron substrates

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



4 mm wide conductors each with 20 μm surround copper stabilizer

Joint length = 3 cm

Original tape thickness = 0.145 mm

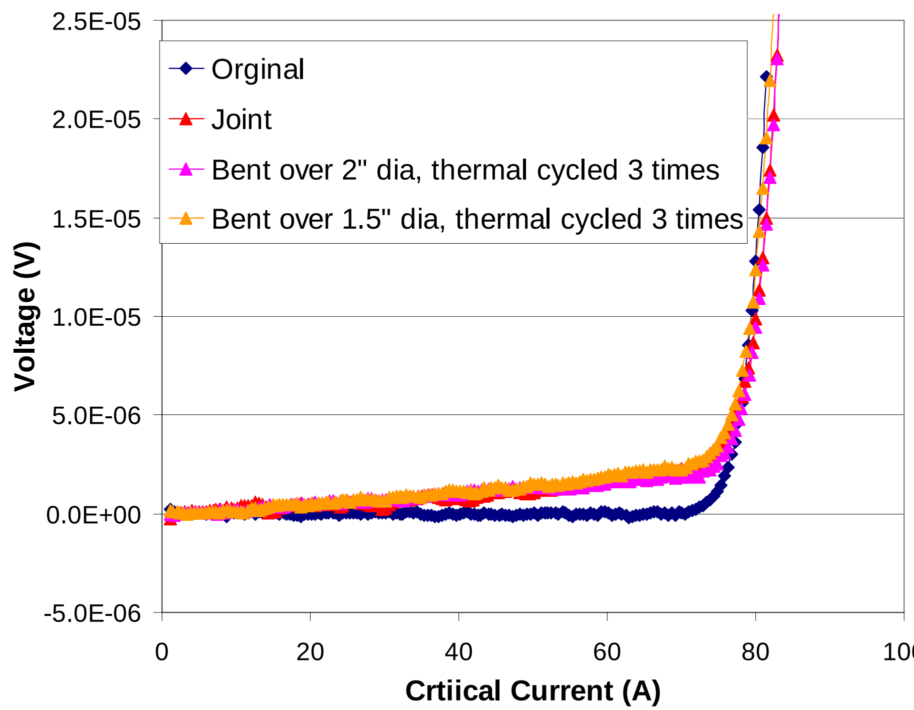
Thickness at joint = 0.32 mm

No degradation in Ic (1 μV/cm) over the joint

Resistivity over the joint is 38 nohm-cm^2

No degradation in Ic and resistivity when bent over down to <u>1.5”</u> diameter and thermal cycled three times. Ic 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

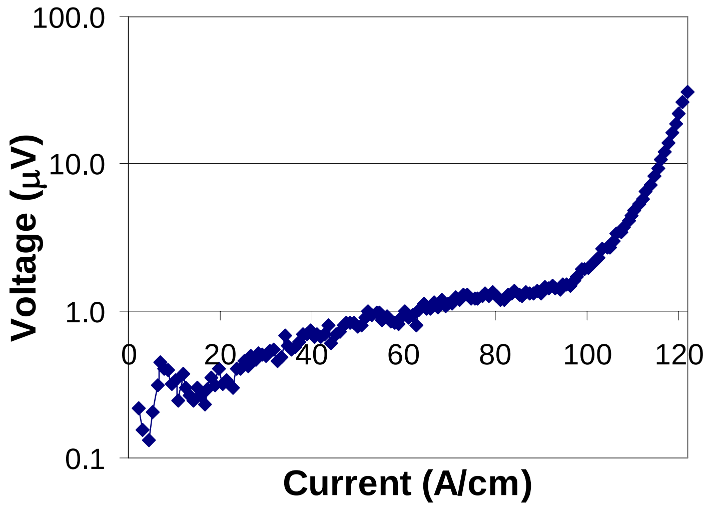
Thickness at joint can be reduced from 0.32 mm to 0.22 mm by using thin-profile conductors (w/ 50 micron substrates)

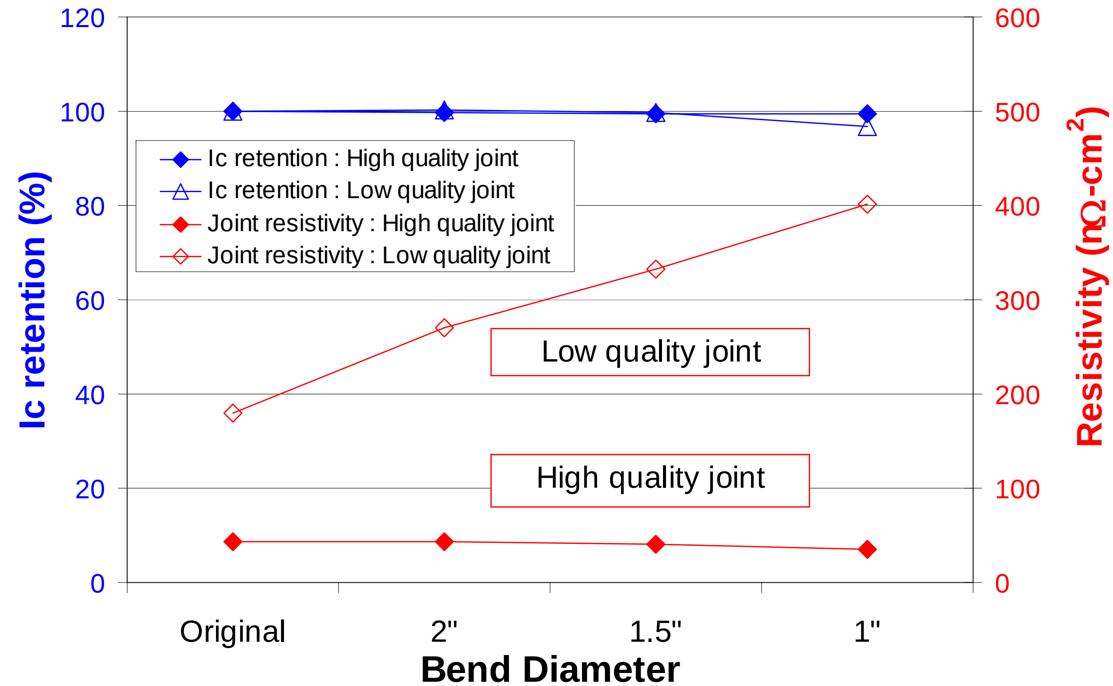
4 mm wide conductors each with 20 µm surround copper stabilizer

Joint length = 3 cm

Original tape thickness = 0.095 mm

Thickness at joint = 0.22 mm



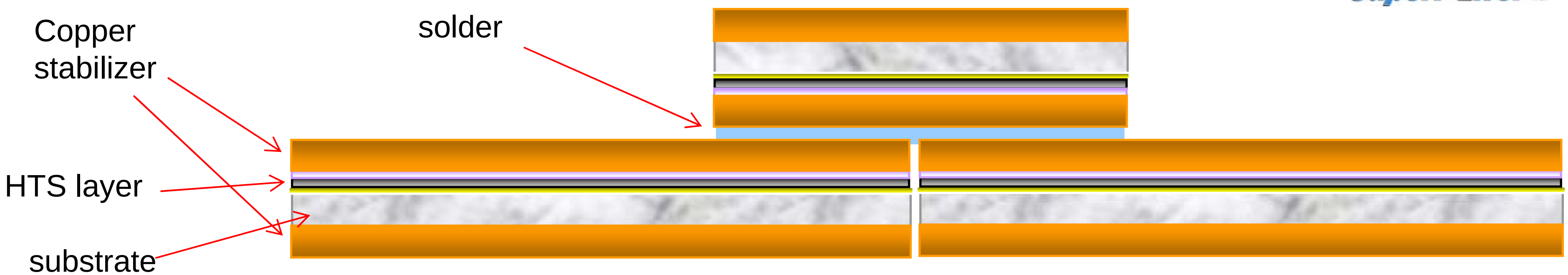


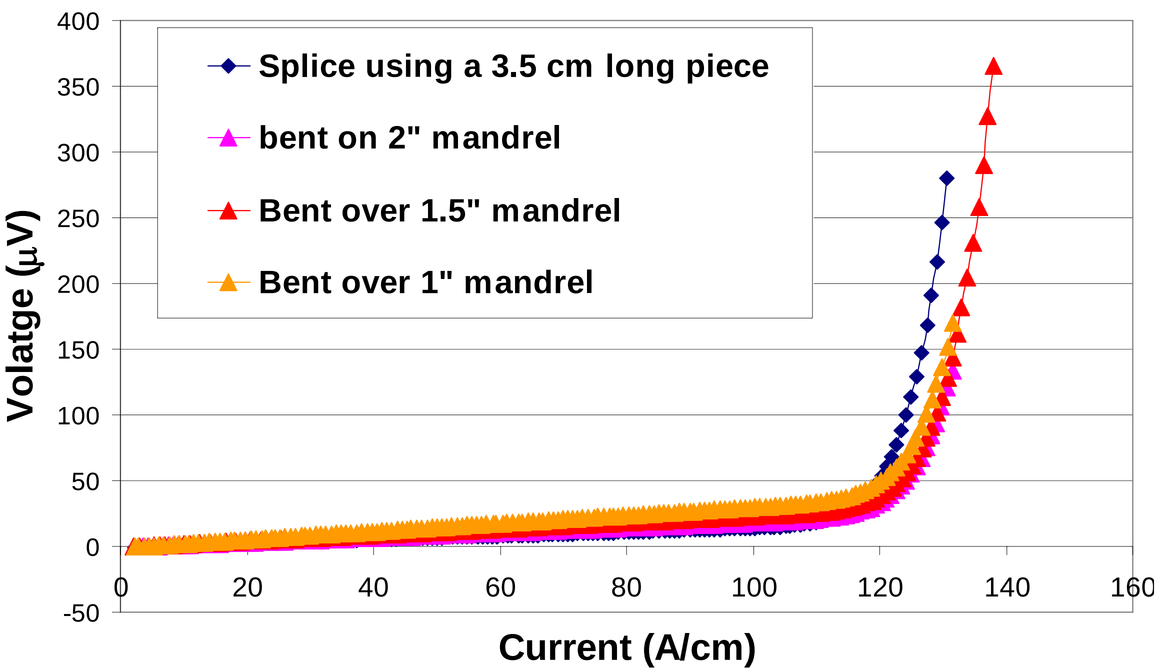
Joint resistivity = 40 nΩcm²

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





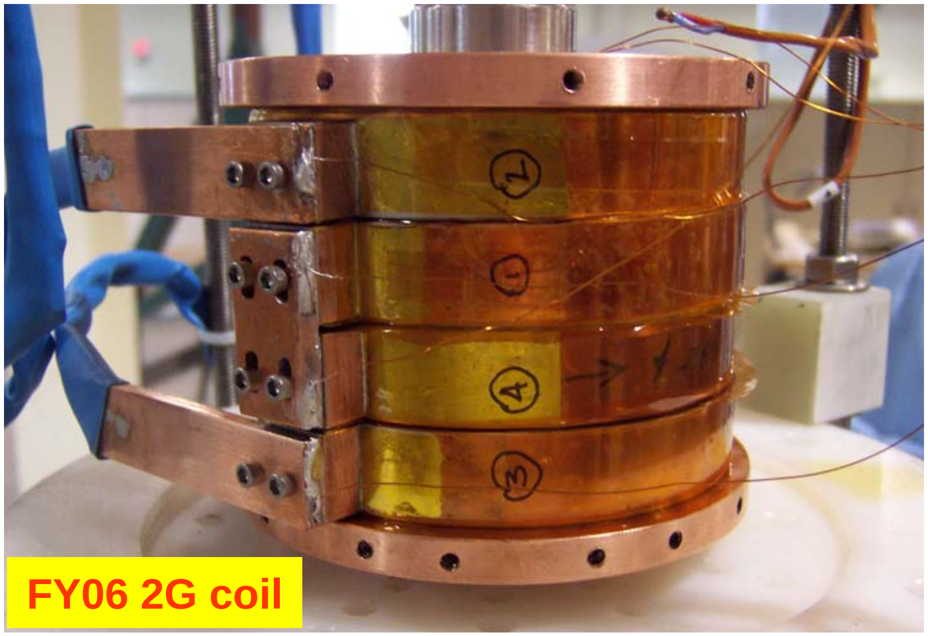
Two 4 mm wide, 0.095 mm thick (50 micron substrate, 20 micron surround copper stabilizer spliced with a similar piece 3.5 cm long.

Splice Resistivity = 50 nΩcm^2

No Ic degradation when splice was bent down to 1" diameter.

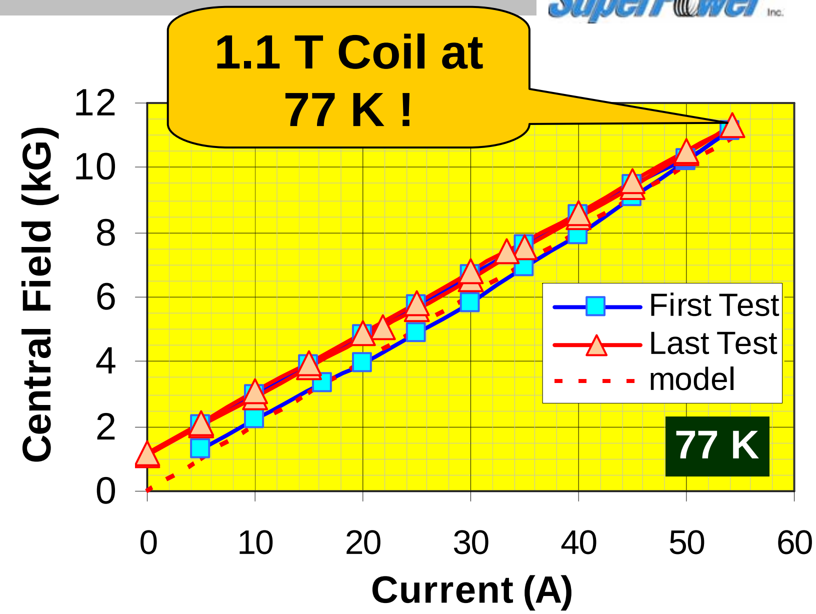
Use of thin-profile 2G conductor enabled fabrication of high-field HTS coil

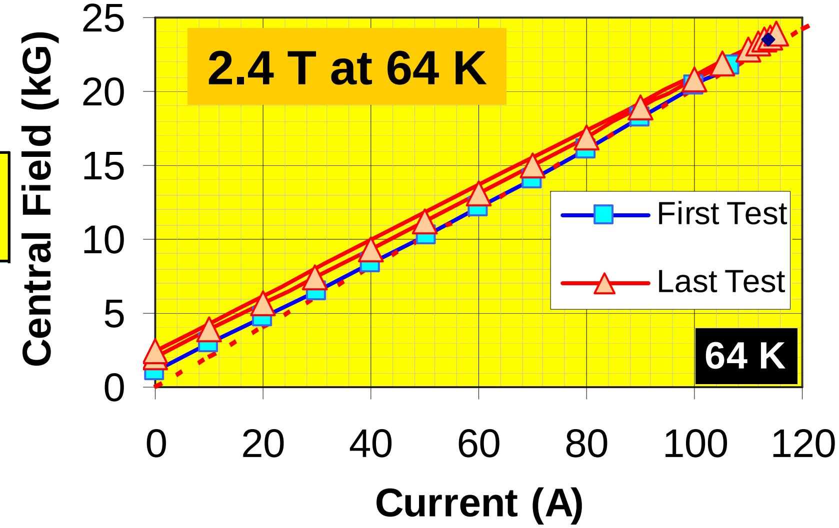
In FY06, we demonstrated a 2G coil that generated 0.4 T at 77 K and 0.87 T at 64 K



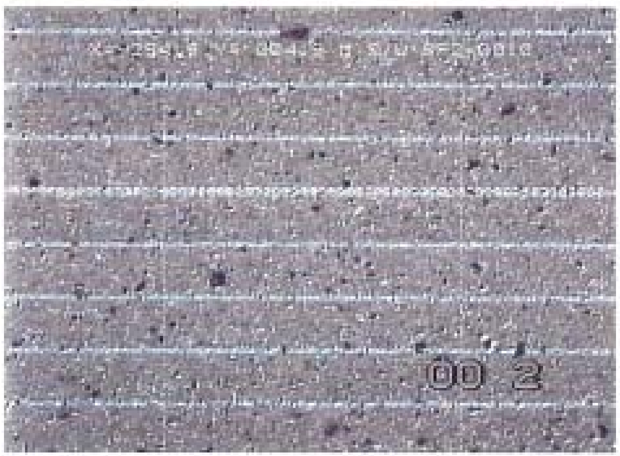
Coil ID (mm)	10.92
Winding ID (mm)	12.70
Winding OD (mm)	75.2
Height (mm)	57.2
2G Tape Used (m)	159.6
# Turns	1156

Avg Ic of Tape in Coil (A)	246



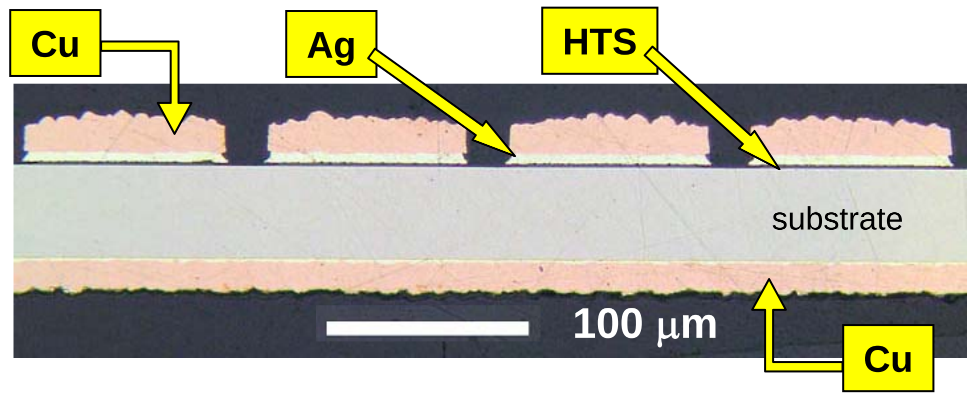


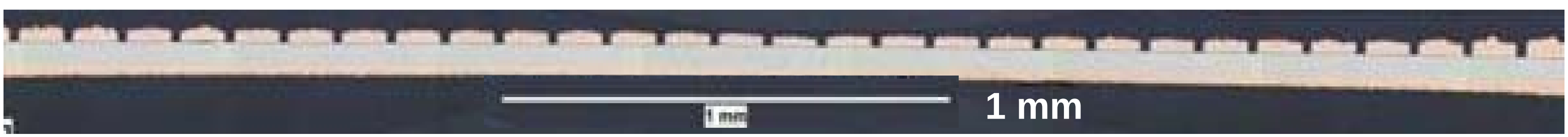
New conductor geometries developed for ac loss reduction



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 Je & better mechanical properties

- **High Je**
  - 26.3 kA/cm^2 in 322 m lengths (2x 1G)
  - In self-field at 77 K, Je of 100,000 A/cm^2 in short tapes (with no Cu), 58.4 A/cm^2 for a 40 micron total copper stabilizer
  - At 1 T at 75.5 K, 21.1 kA/cm^2 in short tapes (with no Cu), 12.2 kA/cm^2 for a 40 micron total copper stabilizer
- **Better mechanical properties**
  - Bend diameter of 11 mm even with YBCO in tension with 95% Ic retention
  - Low contact resistance & no Ic 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