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Recent Progress in 2G HTS Wire Technology at SuperPower

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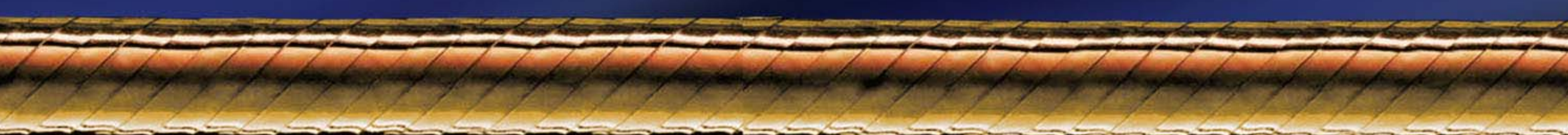
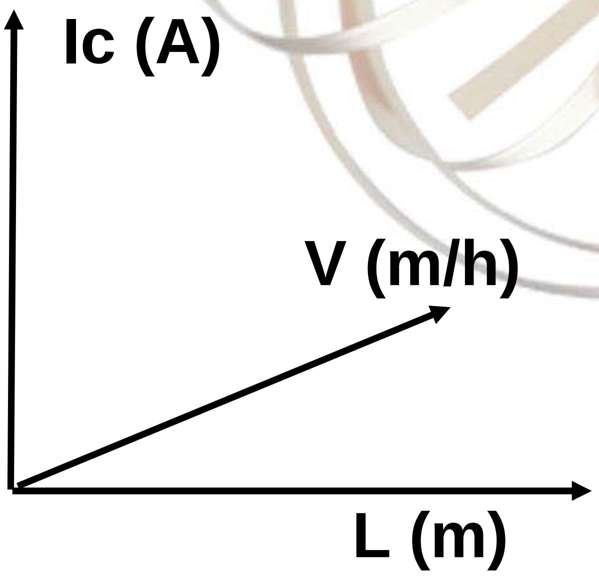


Materials Research Society Meeting, Spring 2008 – San Francisco, CA

Key metrics for 2G wire

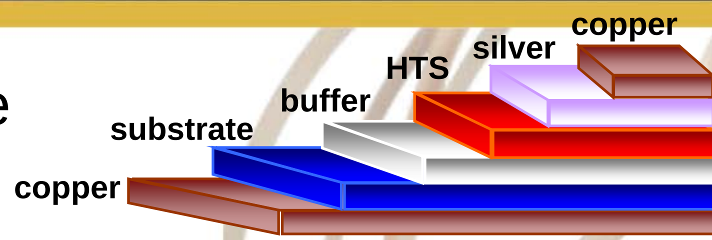
Key metrics determining the price-performance characteristics of 2G HTS wires and qualifying them for applications:

Ic	500 A/cm at 0T & 77K
Ic(B)	100 A/cm at 1.5T &77K
L	1 km
V	1000 km/year



SuperPower's 2G wire technology is based on high throughput processes

Typical architecture of SuperPower 2G wire



Architecture	Process method
20 μm Cu	Electroplating
2 μm Ag	Sputtering
1~ 5 μm ReBCO HTS	MOCVD
30 nm LMO	Sputtering
30 nm Homo-epi MgO	Sputtering
10 nm IBAD MgO	IBAD
7 nm Yttria	Sputtering
80 nm Alumina	Sputtering
50 μm metal alloy substrate	Electrochemical-polish
20 μm Cu	

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SuperPower's 2G wire technology is based on high throughput processes

Process	Throughput of 4mm wide tape (m/h)
MOCVD	180 (for ~ 1 μm HTS layer)
Homo-epi MgO + LMO	345
IBAD MgO	360
Alumina + Yttria	750

SuperPower's 2G pilot manufacturing facility has been operational since 2006

Majority of investment already made for 1000 km/year capability

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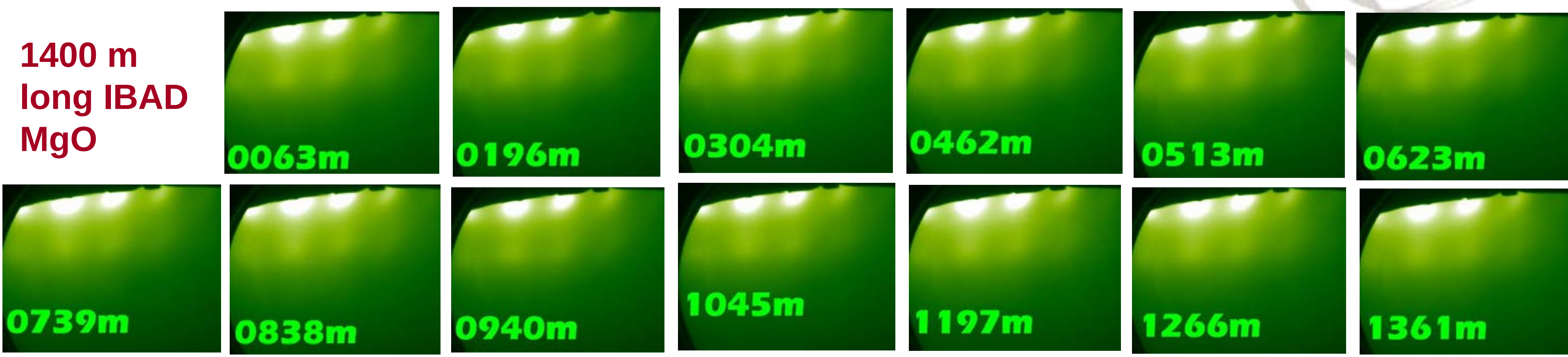
Several kilometer long tapes have been processed through IBAD MgO

High throughput established with IBAD enables 1000+m piece length processing within hours!

Ion beam sputtering and assist condition stability must remain constant to obtain uniformly good texture over 1000+m piece lengths.

On-line RHEED monitoring used to maintain texture uniformity over 1000+m lengths

1400 m long IBAD MgO



<u>Fifteen 1,200 – 1400 m</u> tapes have been successfully processed through IBAD MgO

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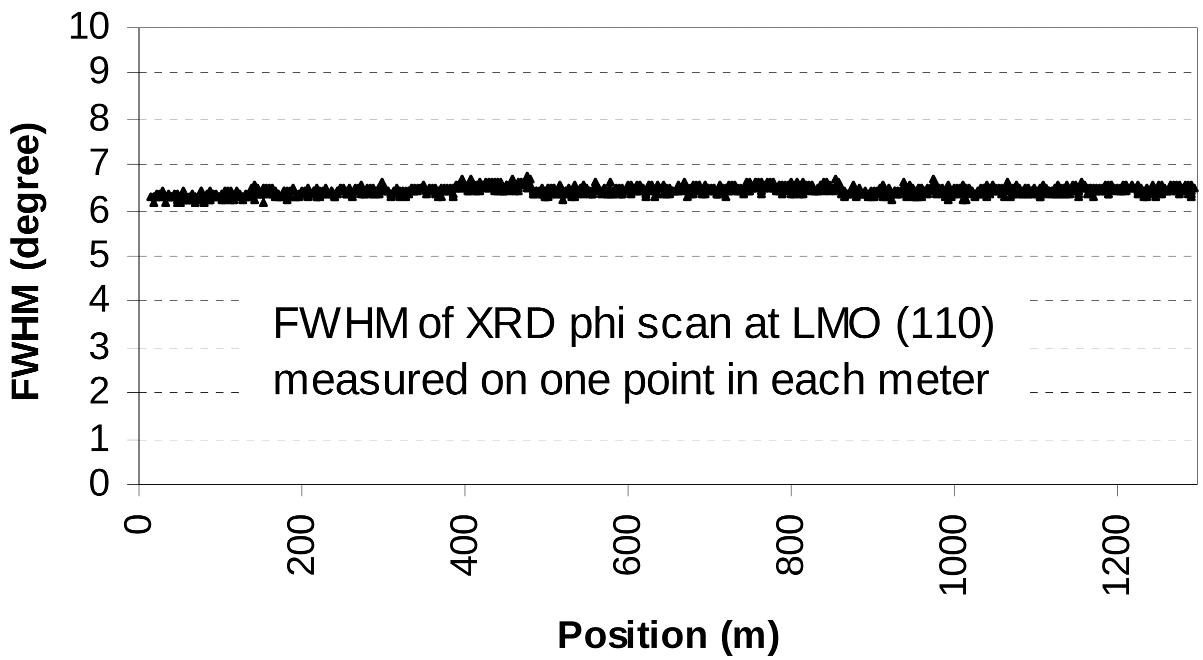
Excellent in-plane-alignment has been uniformly distributed on 1.3km+ lengths

The FWHM values of the phi-scan at (110) of LMO, the cap layer of the 5-layer buffer stack, typically range from 6 to 8 degrees for the km+ lengths.



30 nm LMO   **$\Delta\Phi$ = 6º-8º**
Homo-epi MgO
IBAD MgO
Y_2O_3
Al_2O_3

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Throughput increase in MOCVD

For growth of REBCO HTS layer

- **PLD had difficulty in extending deposition area**
- **CSD (or MOD) was limited in film thickness**
- **MOCVD was questioned for the stability of precursor delivery**

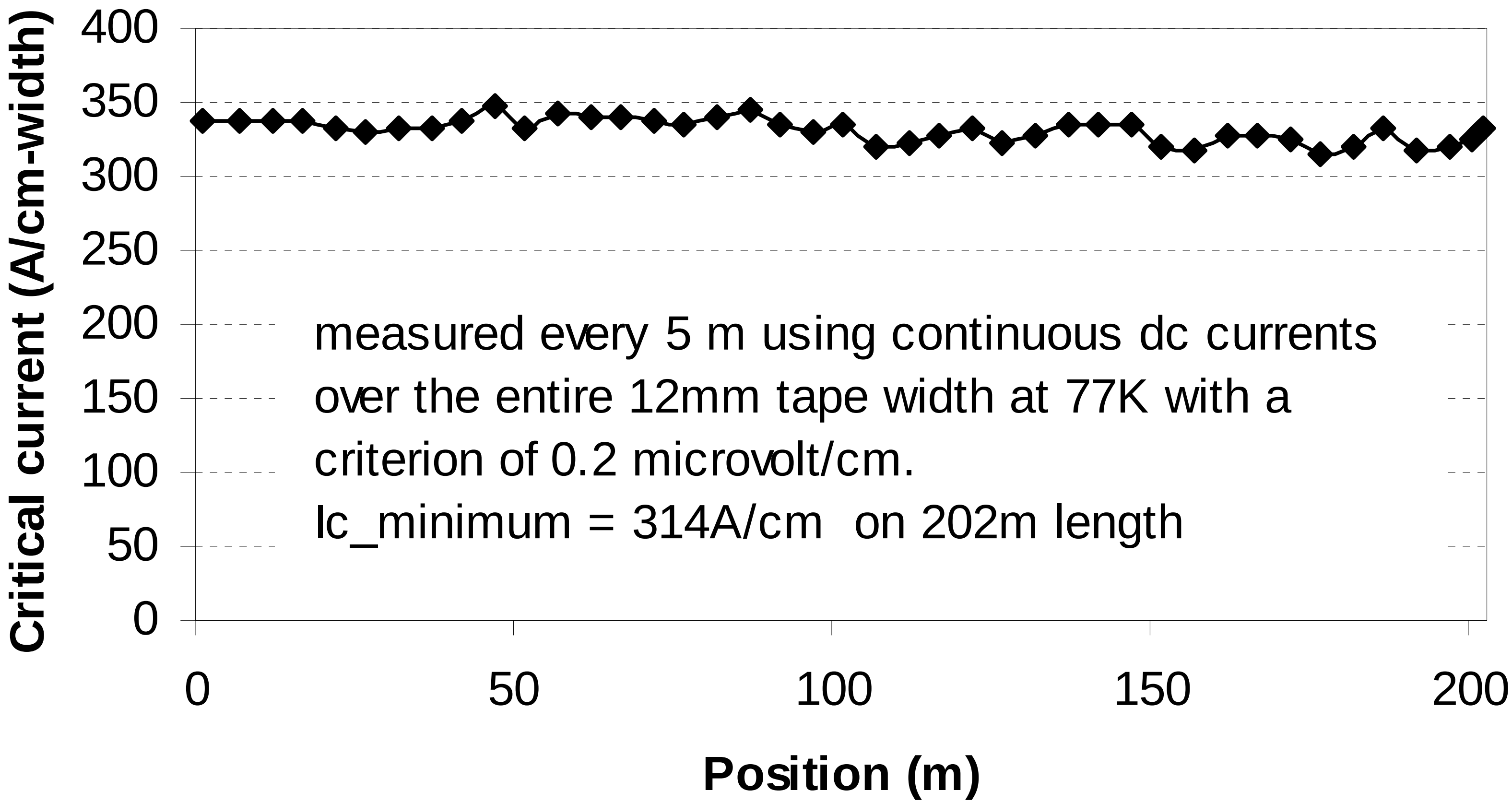
However, SuperPower has realized stable high rate precursor delivery with the use of Y. Chen injector since 2004.

MOCVD is the only known REBCO deposition process that has advantages of both high deposition rate and large area deposition.

Throughput = Deposition Rate × Deposition zone length × Deposition zone width

We have extended the deposition area in our pilot MOCVD system to 80 cm in length and 8 cm in width with a single showerhead design

High critical currents in long lengths processed at high speeds



Minimum Ic = 314 A/cm over 202 m
processed with MOCVD throughput of 90m/h
Uniformity over 202 m = 2.4%

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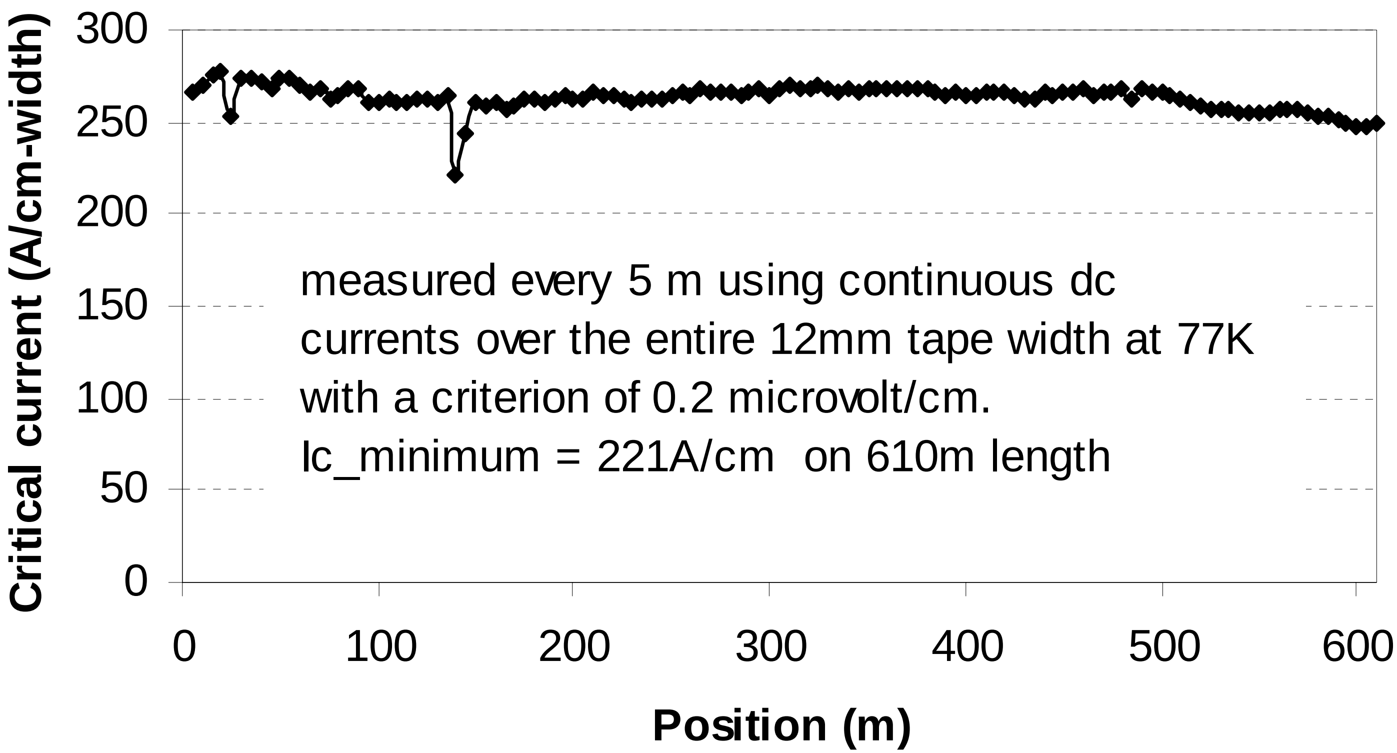
High critical currents in long lengths processed at high speeds



Minimum Ic = 221 A/cm over 610 m
Processed with MOCVD throughput of 90m/h
Uniformity over 610 m = 2.65%

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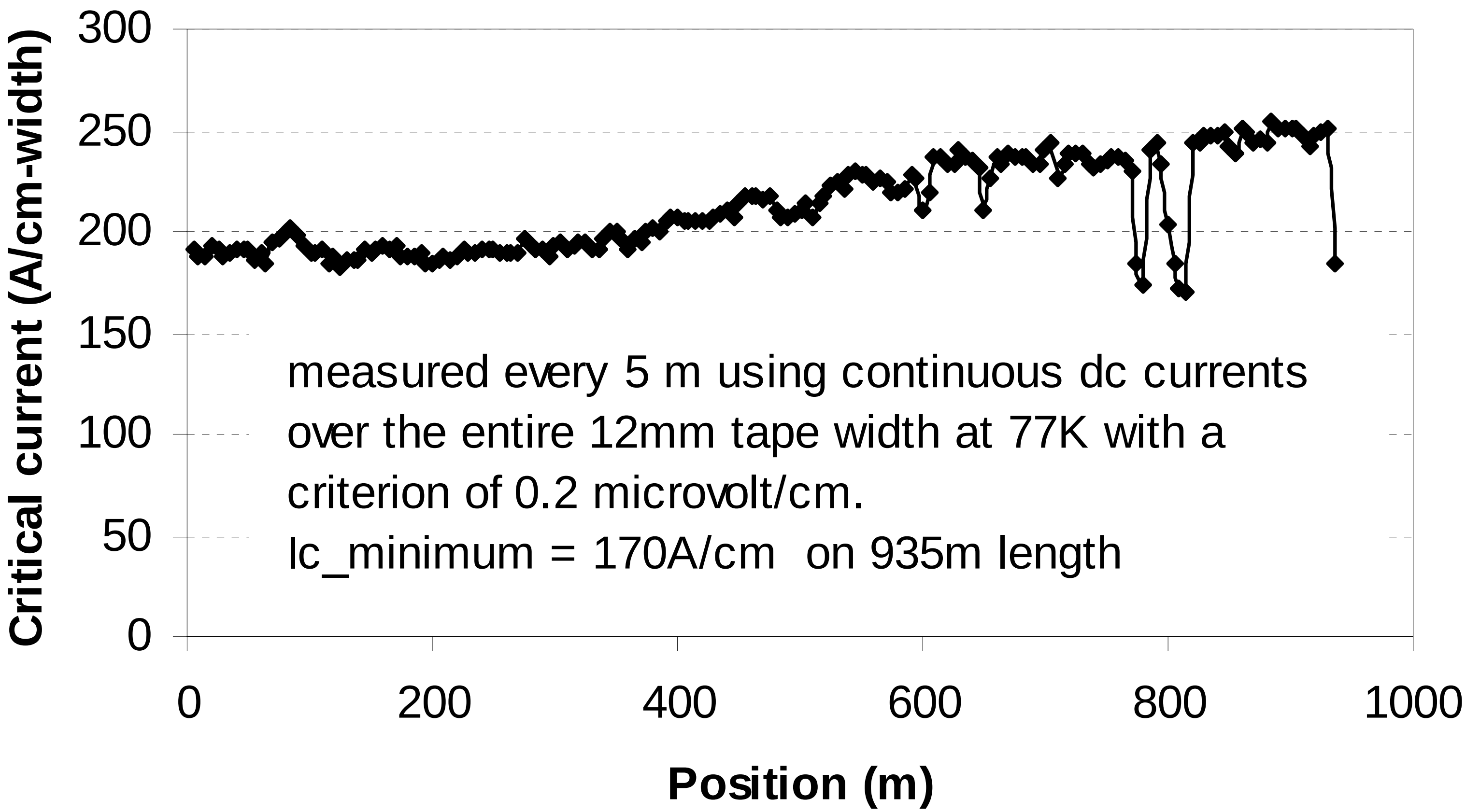
High critical currents in long lengths processed at high speeds



Minimum Ic = 170 A/cm over 935 m

Processed with MOCVD throughput of 135m/h

Ic × L = 158,950m

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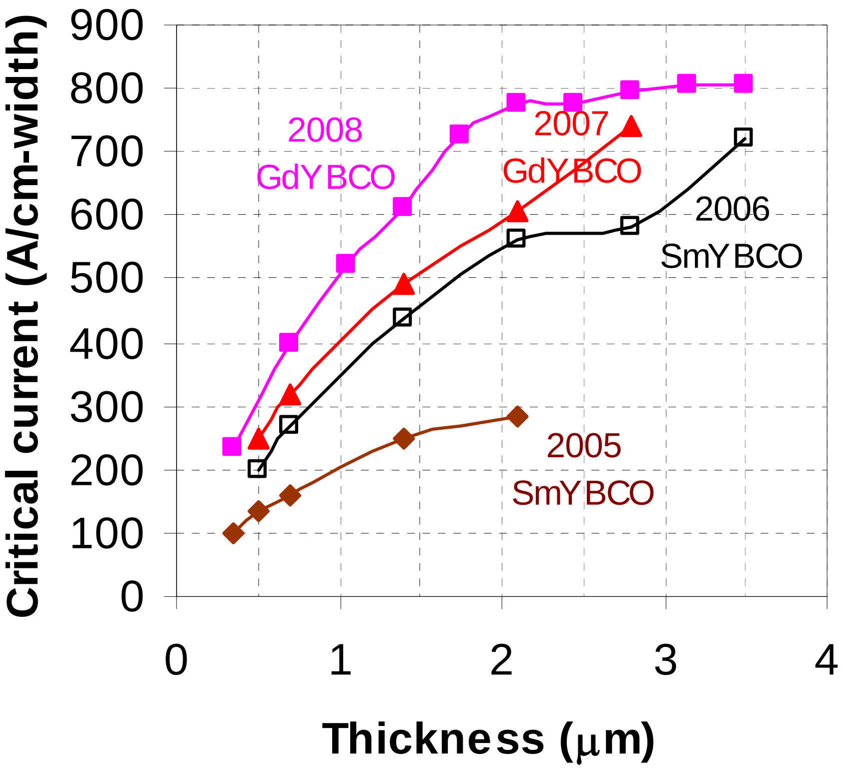
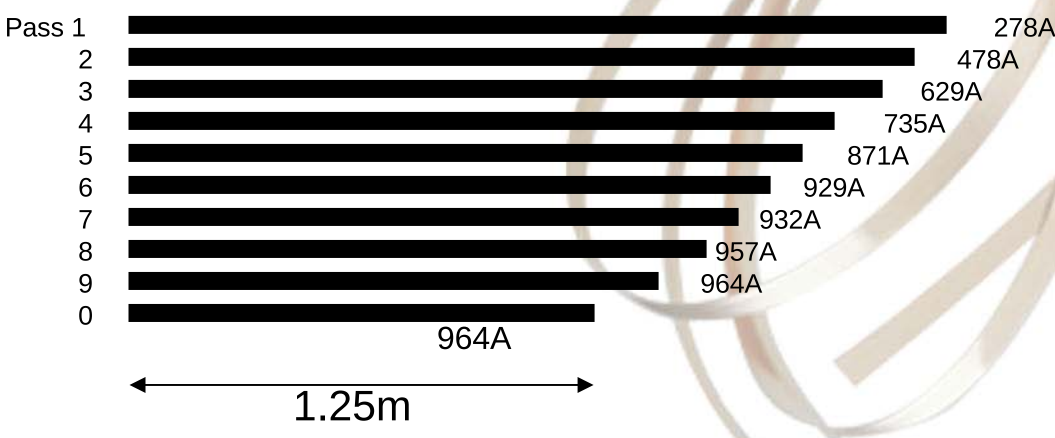
High critical currents in thick films -- advantage of MOCVD





Recently, we substituted Gd for Sm.

In previous experiments of multi-pass for thick films, we grew 0.7micron thick in each pass. In present experiments, we grew 0.35 micron thick in each pass.

Experiment began with a 2.5m long tape. After each pass of MOCVD growth of REYBCO film, we cut 10~20cm off for Ic testing; the remainder then went to the next pass. Finally, after 10 passes, a 1.25m length was left.

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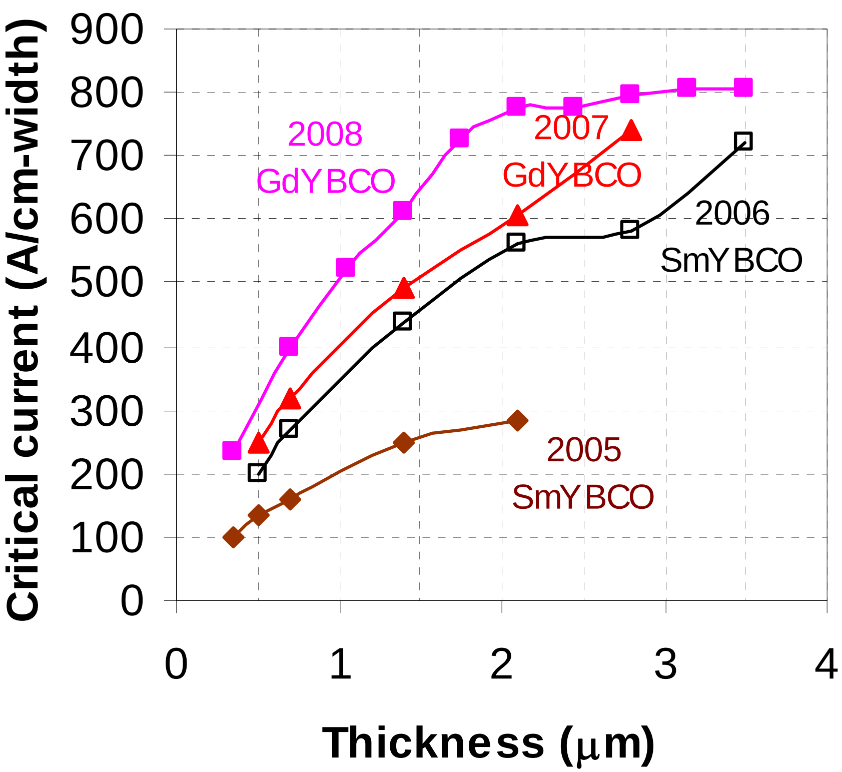
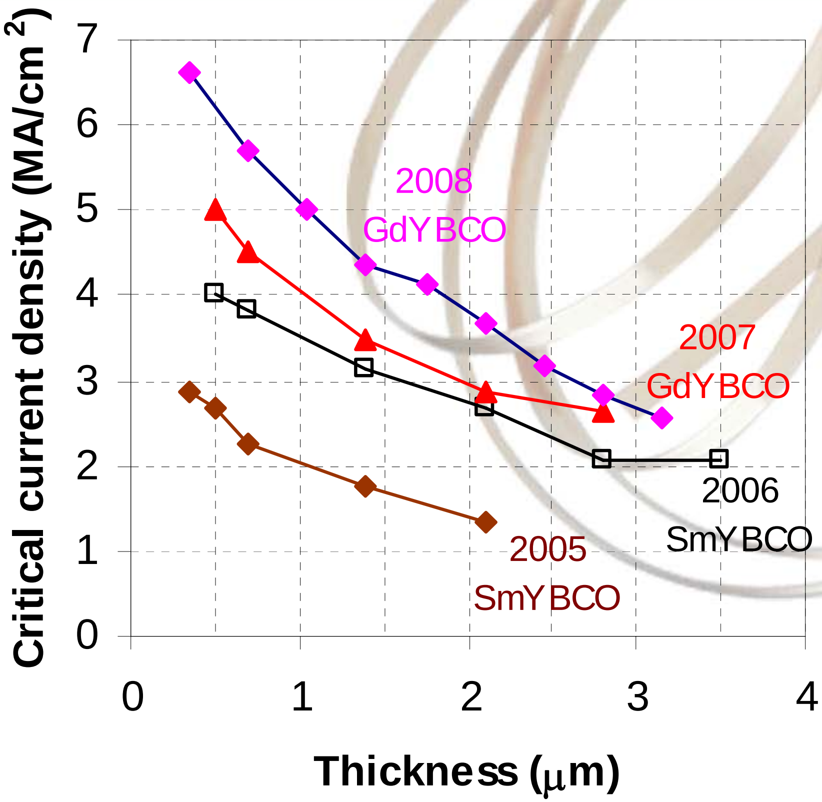
Capability of 320 A in 4 mm widths achieved !





Over 1.2 m length,
Ic = 964 A = 803 A/cm,

Ic measurement using continuous dc current (no pulsed current) across entire tape width of 12 mm No patterning

3.5 μm film made in 10 passes: **Ic = 964 A** = **803 A/cm (Jc = 2.06 MA/cm²)**

2.1 μm film made in 6 passes: **Ic = 929 A** = **774 A/cm (Jc =3.68 MA/cm²)**

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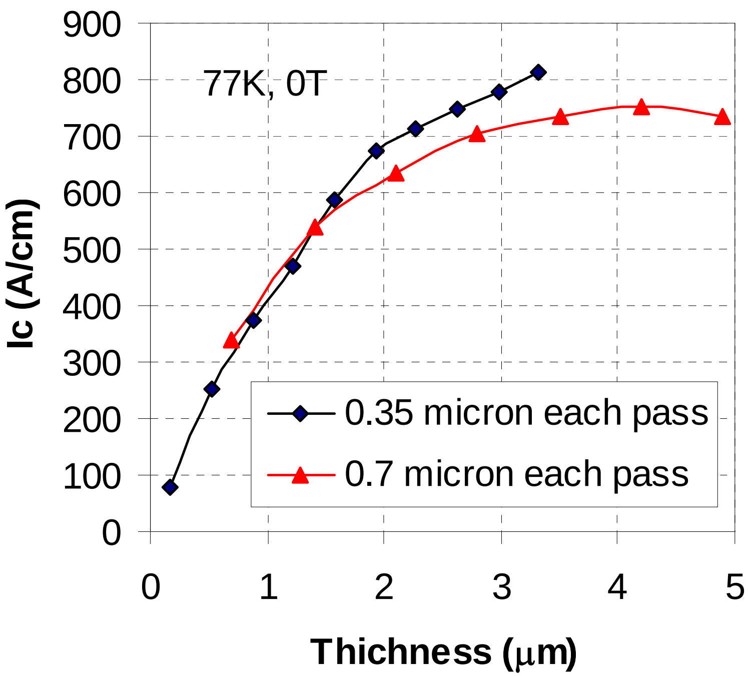
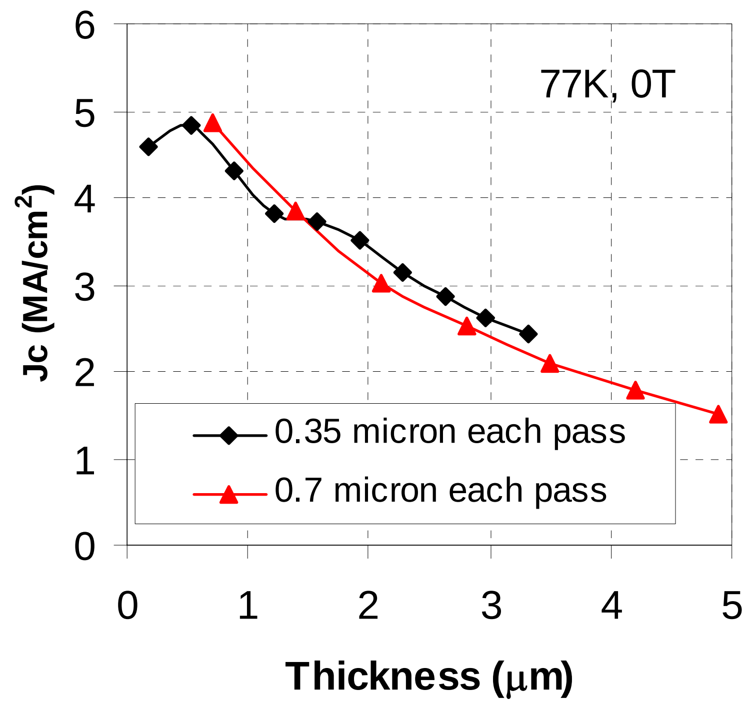
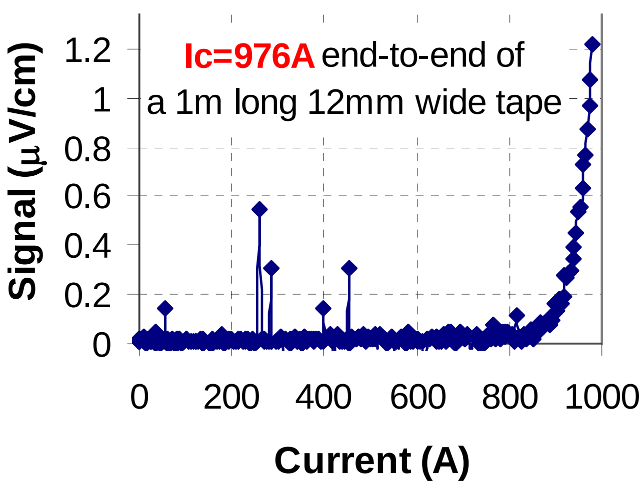
Repeat to confirm the process approach



The first 6 passes of this experiment were not as good as the first 6 passes in a previous experiment, but last 4 passes were better than previous experiment





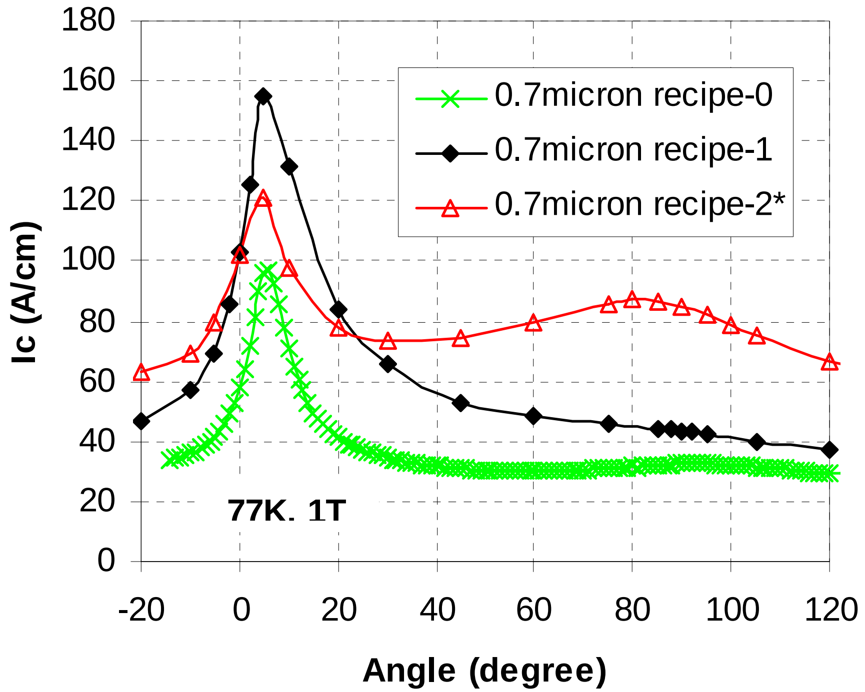
Over 1 m length,

Ic = 976 A = 813 A/cm,

3.33 μm, Jc = 2.44 MA/cm²

Ic measurement using continuous dc current (no pulsed current) across entire tape width of 12 mm No patterning

Improved magnetic-field-angle dependence of Ic



For 0.7micron recipe-2*

Recipe-1: strong pinning for B//ab

Recipe-2*: strong pinning for B//c

Data from: Y. Zhang, Y. Zuev, S. Cook, M. Paranthaman, A. Goyal, ORNL

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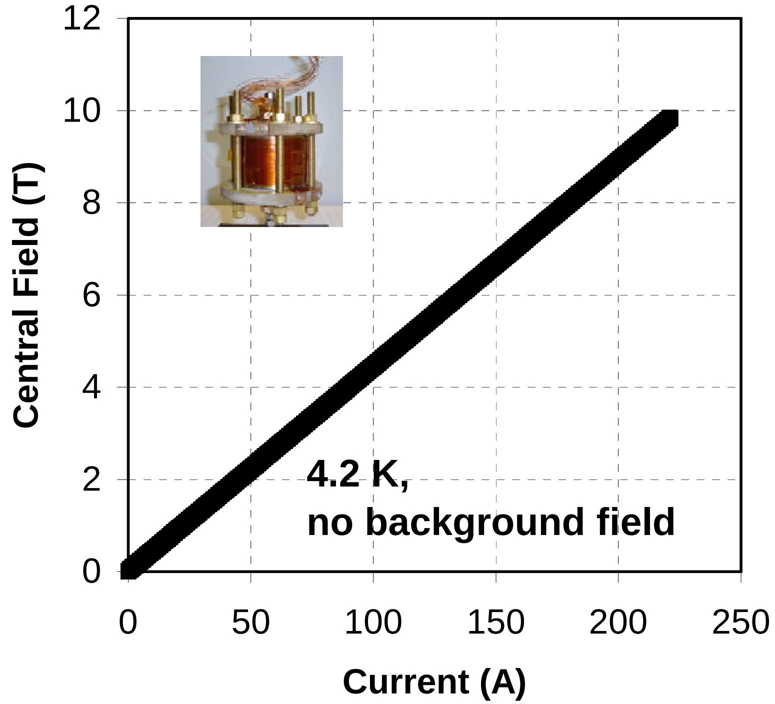
Prototype applications - coil



Coil ID	9.5 mm (clear)
Winding ID	19.1 mm
Winding OD	~ 87 mm
Coil Height	~ 51.6 mm
# of Pancakes	12 (6 x double)
2G tape used	~ 462 m
Average Ic of tapes in coil	78 A in 4 mm width (77 K,0T)
# of turns	~ 2772
Coil Je	~1.569 A/mm2 per A
Coil constant	~ 44.46 mT/A

4.2 K Coil Ic - self field	221 A
4.2 K Amp Turns @ Ic - self field	612,612
4.2 K Central field – self field	9.81 T

World record field for HTS coil: 9.81T

Coil tested by H. Weijers, D. Markewicz, & D. Larbalestier, NHMFL, FSU

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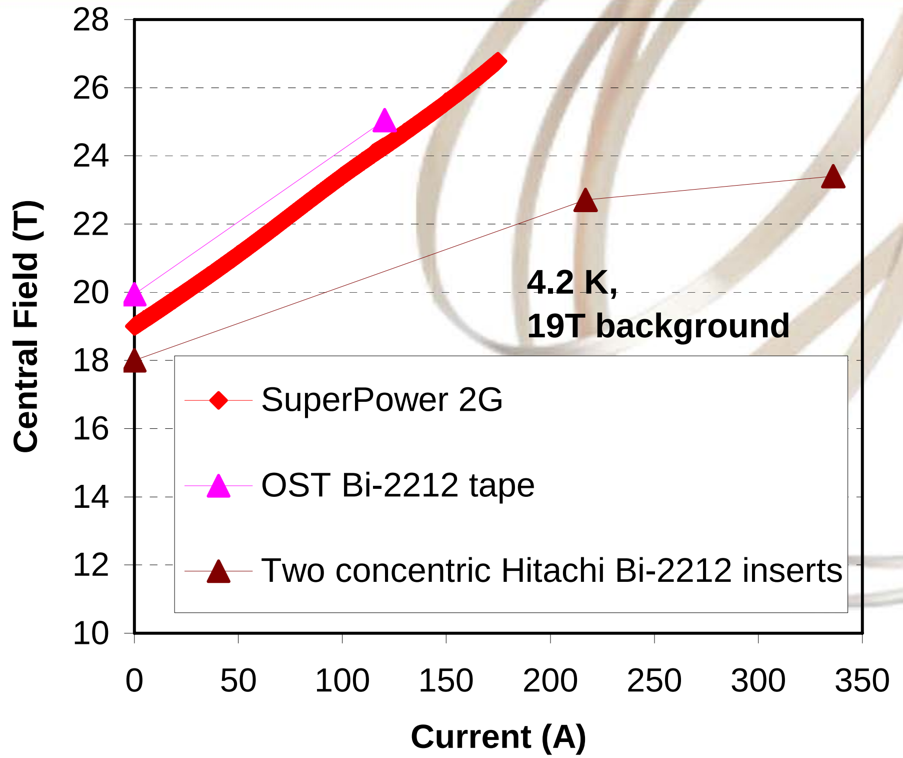
High field insert coil demonstrated

4.2 K Coil Ic – 19 T background (axial)	175 A
4.2 K Amp Turns @ Ic – 19 T background (axial)	485,100
4.2K Central Field – 19 T background (axial)	26.8 T

	2007 SP	**2003 OST**	**1999 Hitachi 2- insert**
Conductor length (km)	0.46	2.1	1.0
Winding Je (A/mm^2)	275	86	125/112
Additional field generated (T)	7.8	5.1	5.4
Total field achieved (T)	26.8	25.1	23.4



Coil tested by H. Weijers, D. Markewicz, & D. Larbalestier, NHMFL, FSU

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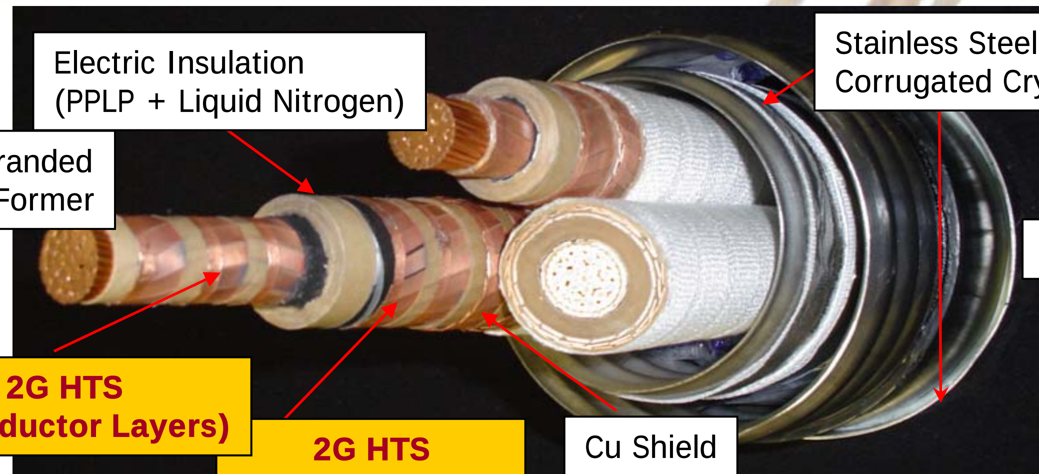
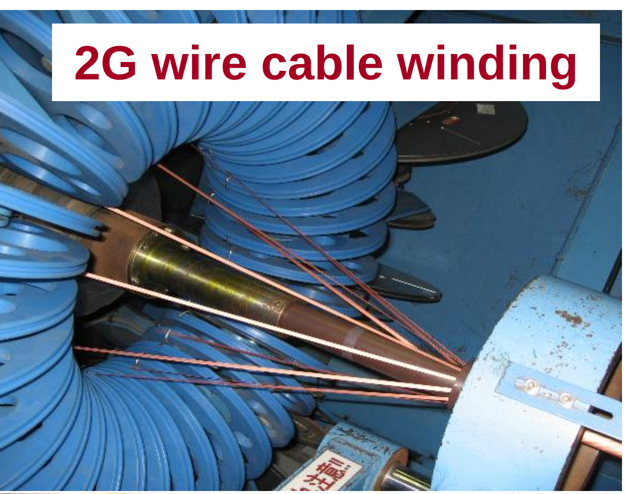
2G cable for in-grid demonstration

30 m 2G-Cable has been manufactured & tested by Sumitomo with ~ 10,000 m of our 2G wire

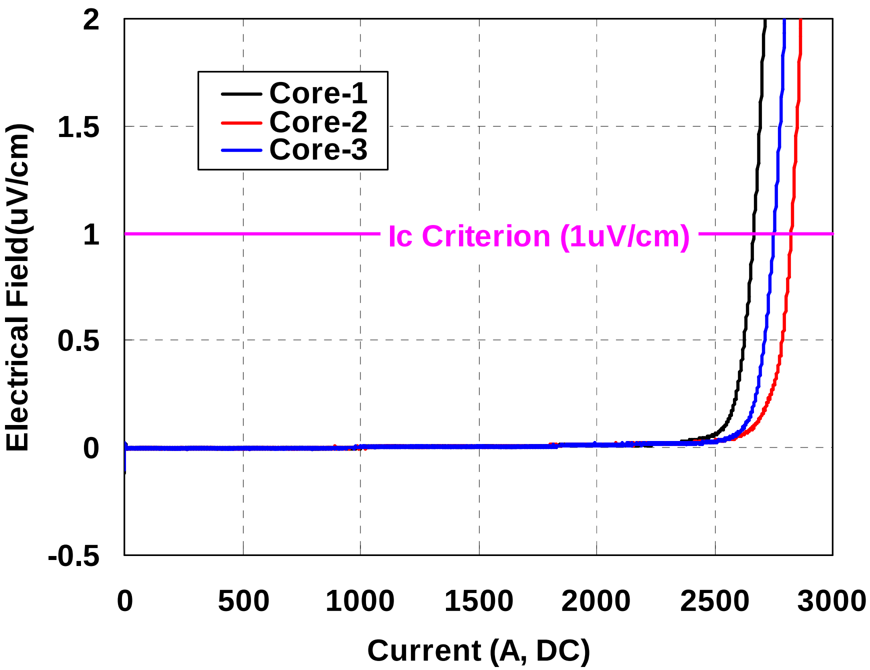




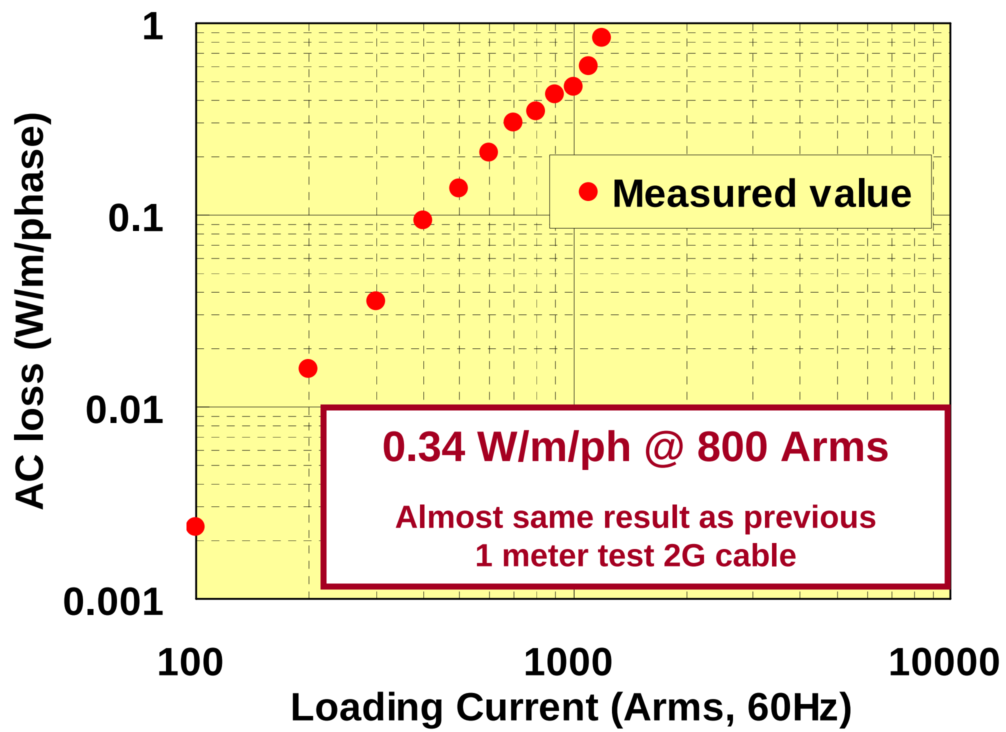
SUMITOMO ELECTRIC

Ingenious Dynamics

Excellent overall performance obtained in 2G cable



Ic of conductor layers ~ 2660 – 2820A (DC, 77K, 1μV/cm)



No Ic degradation and No defect was found at dismantling inspection when bend to a diameter of 2.4 m

Cable withstood AC 69kV for 10 minutes and Impulse ±200kV, 10 times

World's first 2G device in a live power grid, in Albany, NY

Summary

High throughput:

- 750m/h for sputtering Al_2O_3+Y_2O_3 base layer
- 360m/h for IBAD MgO template
- 345m/h for sputtering Homo-epi MgO+LMO buffer
- 180m/h for MOCVD REBCO

High Ic:

- 813A/cm-width at 77K and self-field over 1 meter length

Summary

Long lengths:

- 314A/cm-width over 202m
- 221A/cm-width over 610m
- 170A/cm-width over 935m

Prototype Applications

- A coil made with our 2G wire generated a 26.8T magnetic field in the magnet
- A 30m-long cable made with nearly 10,000 meters of SuperPower 2G HTS wire showed excellent overall performance and has been installed and energized in the power grid