



2G HTS Wire Produced in Pilot-scale Manufacturing at SuperPower and Application in Prototype Devices

Yi-Yuan Xie, Y. Chen, X. Xiong, X. Zhang, Y. Qiao, A. Rar, J. Reeves, K. Lenseth, R. Schmidt, M. Martchevskii, D. Hazelton J. Herrin, and V. Selvamanickam

*Partially funded through Title III Program & DOE (UT-Battelle), AFRL & AFOSR
Supported by CRADAs with Los Alamos, Oak Ridge, and Argonne National Laboratories*

ACASC, Xi'an, China • Dec. 2 – 4, 2007

Providing HTS Solutions for a New Dimension in Power – TODAY!

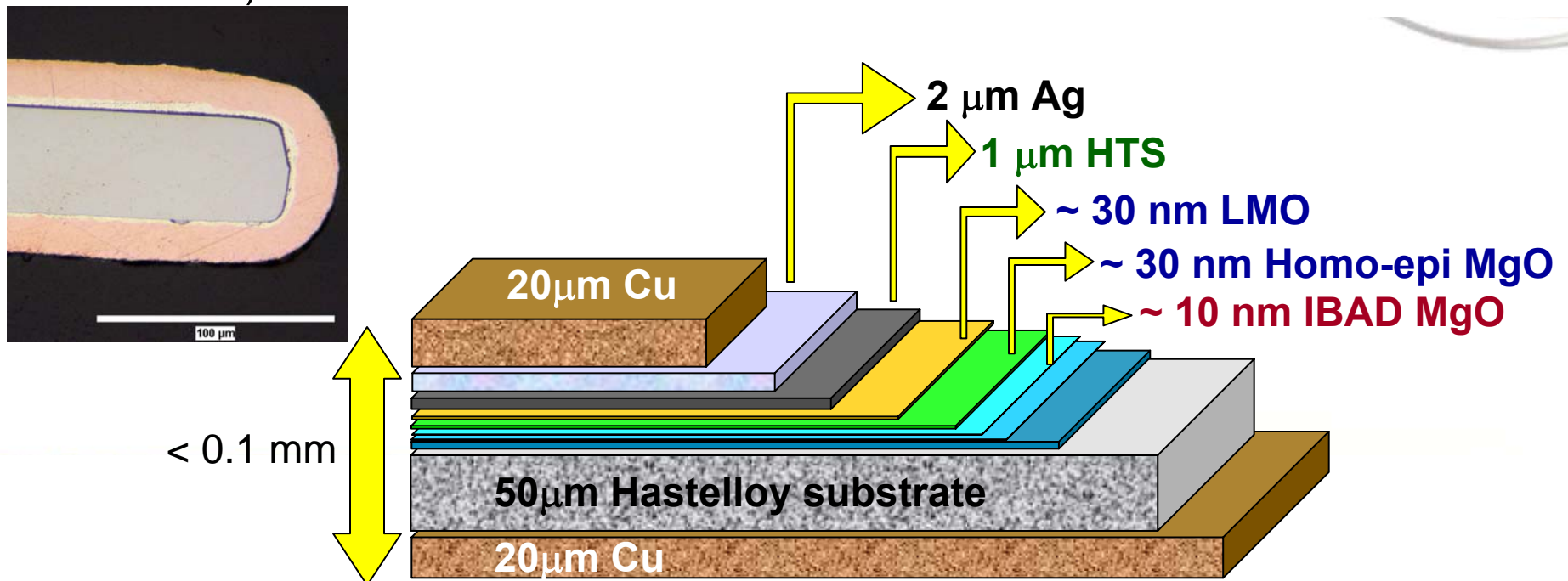
SuperPower's 2G wire is based on high throughput processes & superior substrate

High throughput is critical for low cost 2G wire and to minimize capital investment

SuperPower's 2G wire is based on high throughput IBAD MgO and MOCVD processes

Use of IBAD as buffer template allows us the choice of any substrate

- Advantages of IBAD are high strength, low ac loss (non-magnetic, highly resistive substrates) and high engineering current density (ultra thin substrates)



SuperPower's 2G Pilot Manufacturing facility has been operational since 2006

Majority of investment already made for 1000 km/year capability



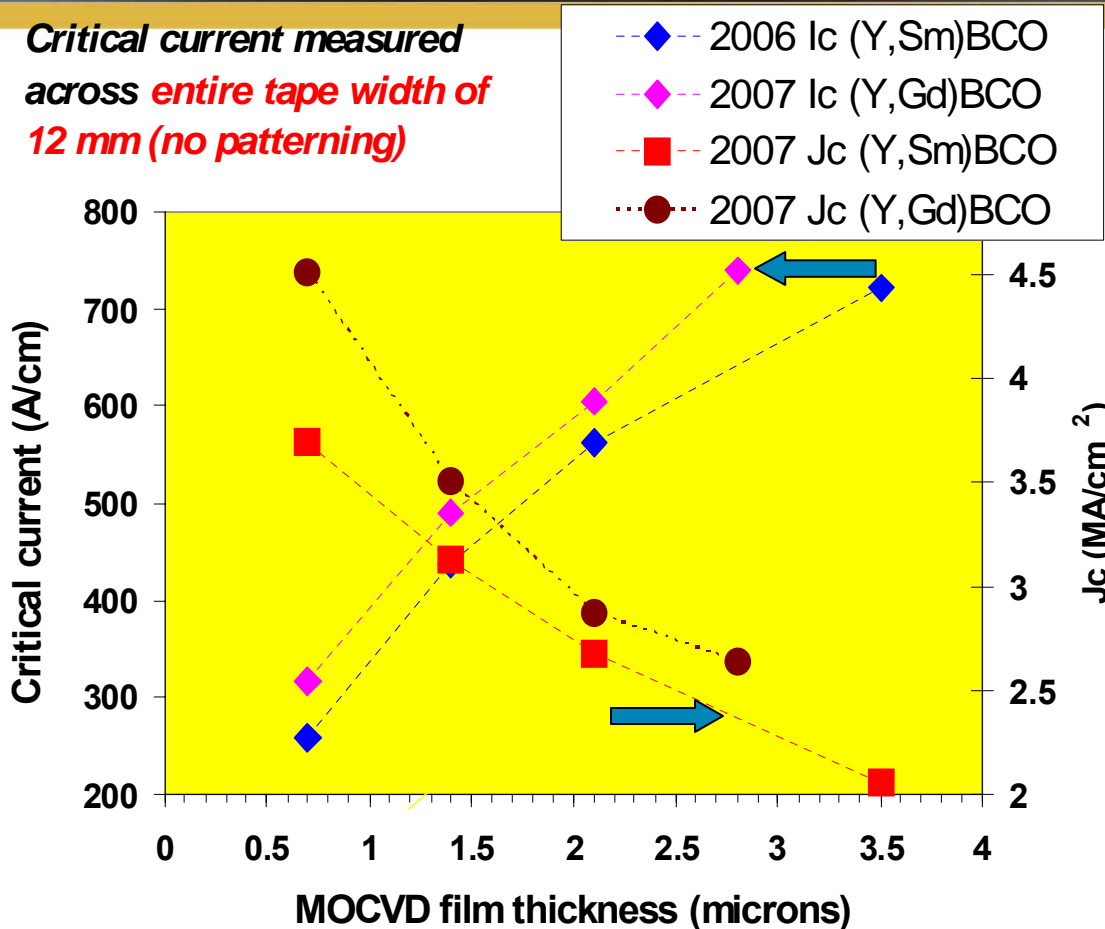
- *Producing marketable 2G HTS wire: high performance, large quantity and low cost*
- *Focus on three key metrics: high I_c , high throughput and long length*



Pathway to commercialization of 2G

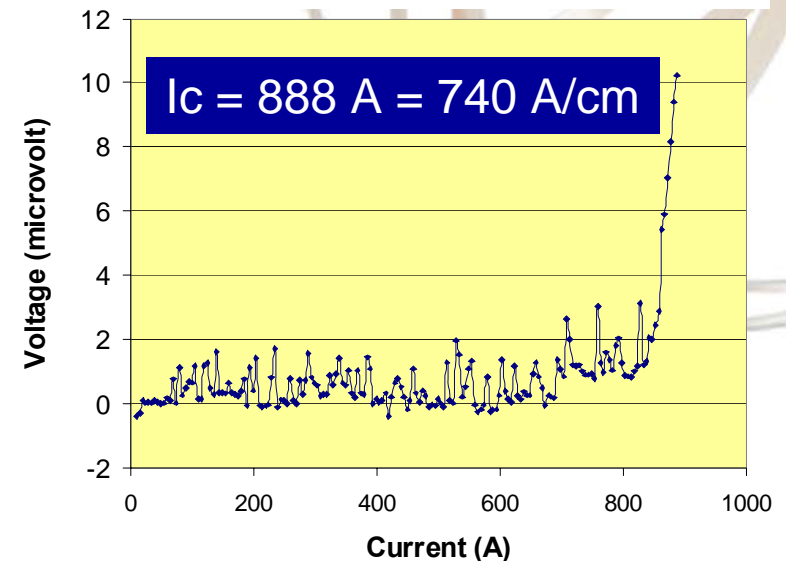
Metric 1 : Higher Currents

Critical current measured across **entire tape width of 12 mm (no patterning)**



Microstructural problems increase with increasing film thickness.

Can high currents be achieved in thinner films ?



In a 2.8 micron film made in 4 passes, achieved I_c of **740 A/cm ($J_c = 2.64 \text{ MA/cm}^2$)** over reel-to-reel processed 12 mm wide, 10 cm long tape.

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

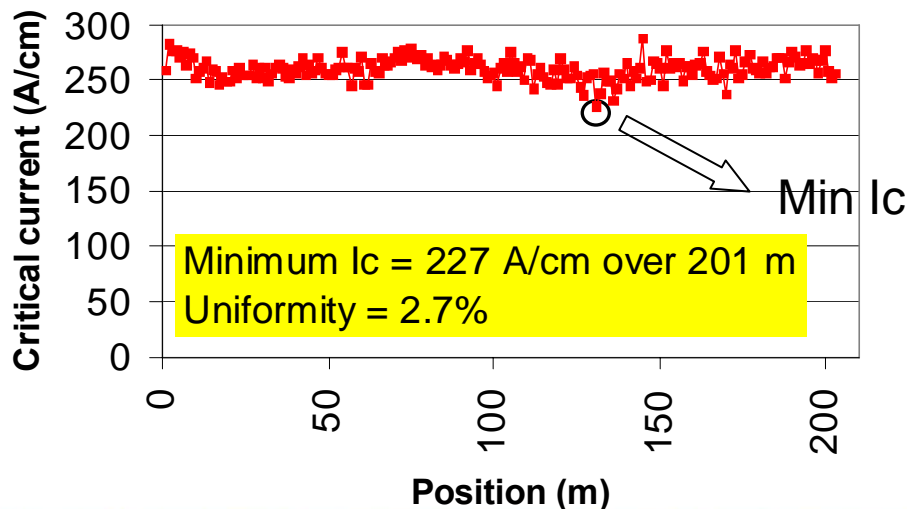
Thick film MOCVD technology continues to advance
Demonstrated 300 A conductor in 4 mm width, 50% better than today's best 1G.

Pathway to Commercialization of 2G

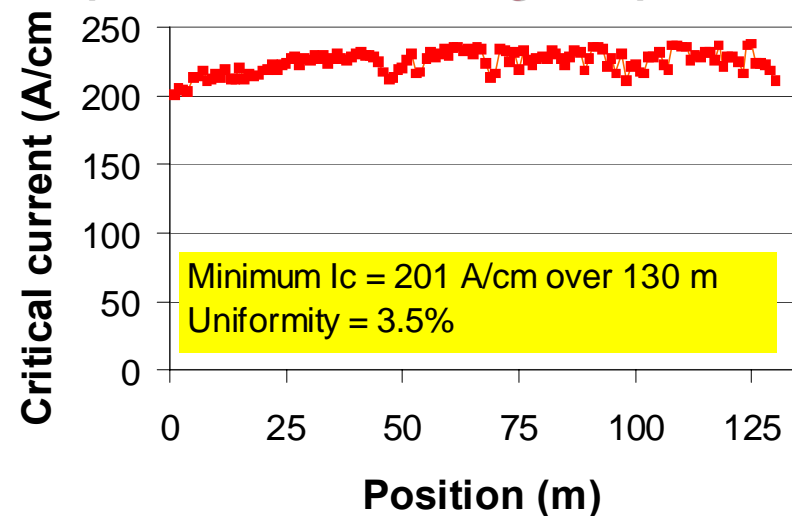
Metric 2: Higher Throughput

Process	Month	IBAD MgO	Homo-epi MgO	LMO	MOCVD YBCO
Speed of 4 mm wide tape (m/h)	Oct. 06	360	240	240	135
	June 07	360	345	345	180
Production Capacity (km/yr) (if 45% uptime)			1440	1380	1380

Oct. 06: High currents demonstrated over 200+m with **all processes at high speeds**

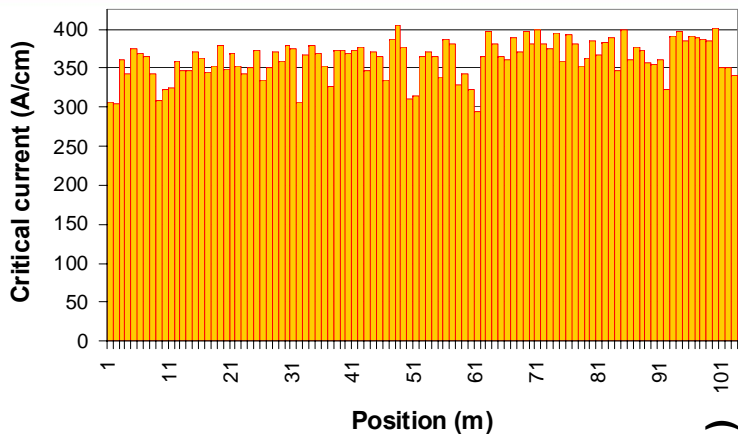


June 07: High currents over 130+m with **all processes at even higher speeds**

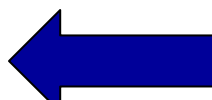


SuperPOWER Inc.

Higher currents in 100+ m lengths at higher HTS processing speeds



In 2006, we demonstrated $I_c \sim 300$ A/cm over 100 m in MOCVD tape processed in Research MOCVD system.
Tape speed = 15 m/h*
Uniformity over 103 m = 6.8%

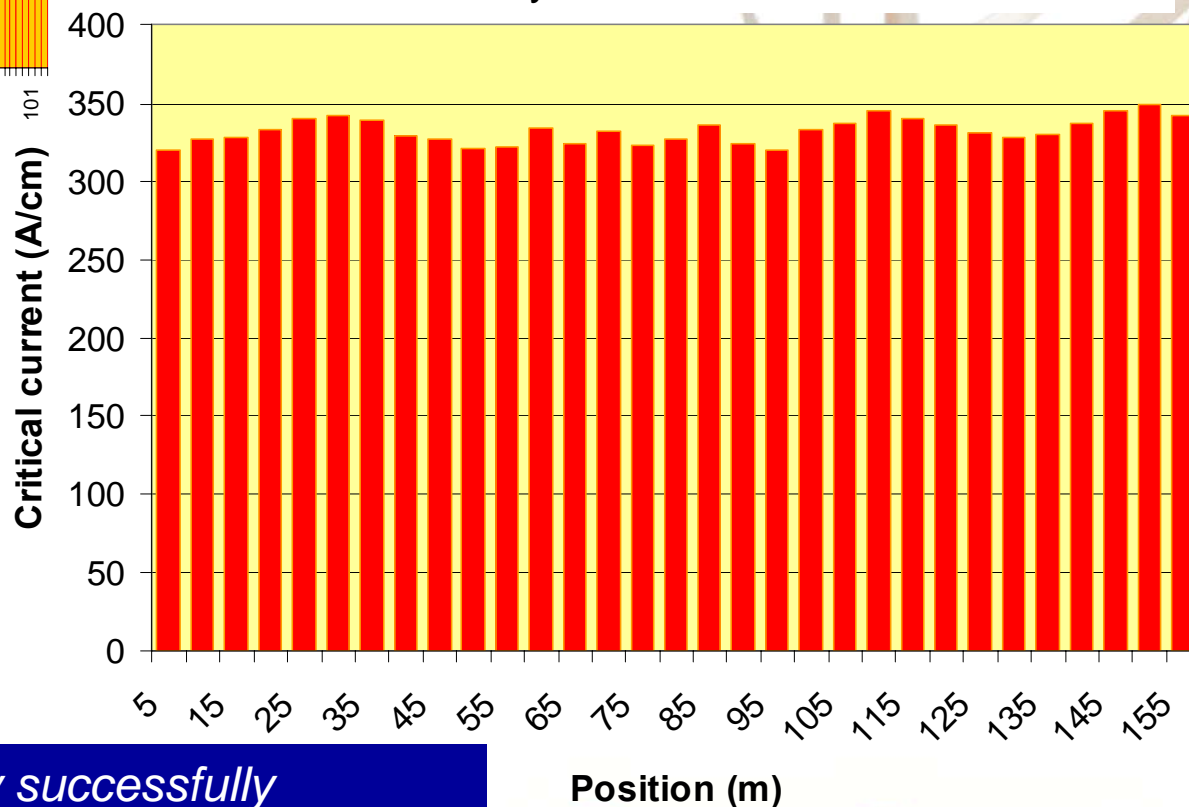


Oct 2007: produced 155m long wire in Pilot MOCVD system

Tape speed ~ 70 m/h*

Minimum I_c over 155 m = 320 A/cm

Uniformity over 155 m = 2.5%

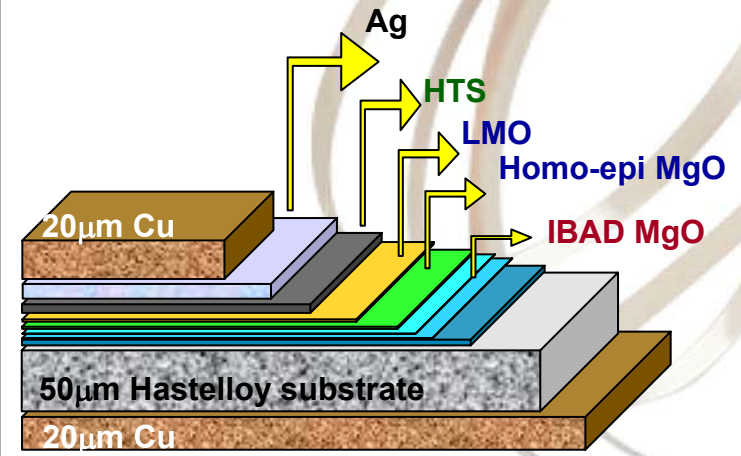
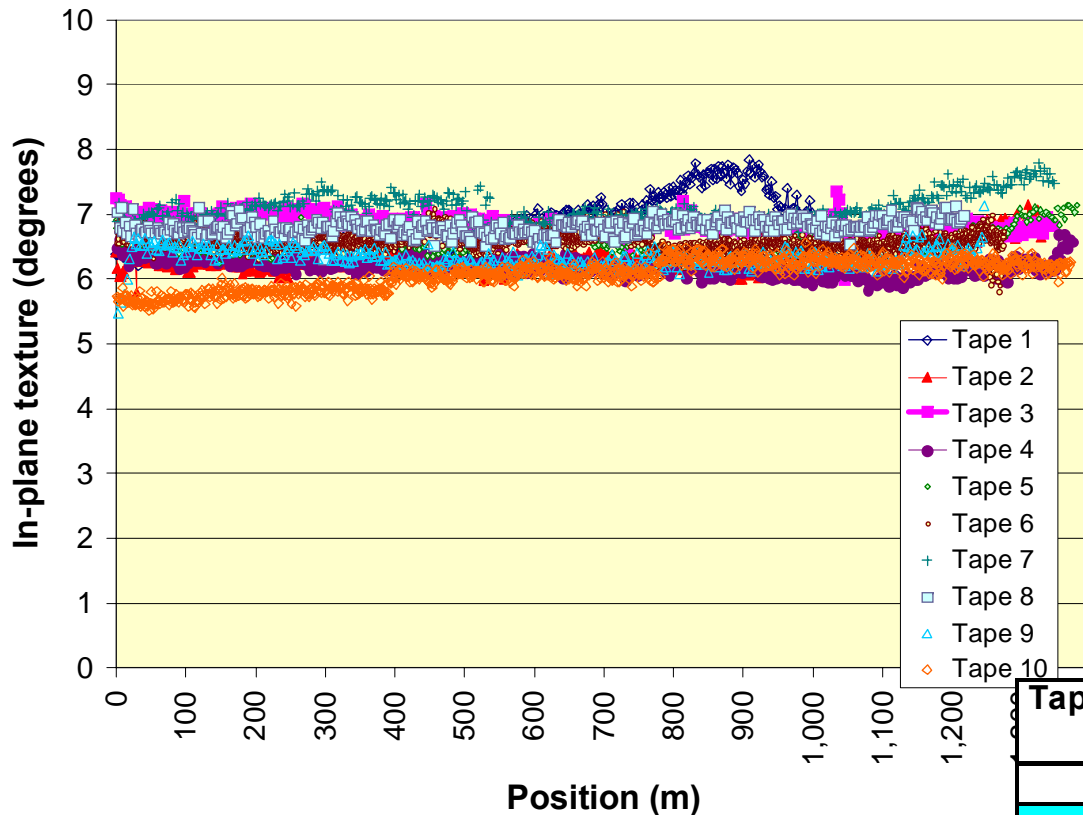


Thicker film MOCVD technology successfully transitioned to Pilot system to produce long high current tapes at $\sim 5x$ higher speeds



Pathway to commercialization of 2G

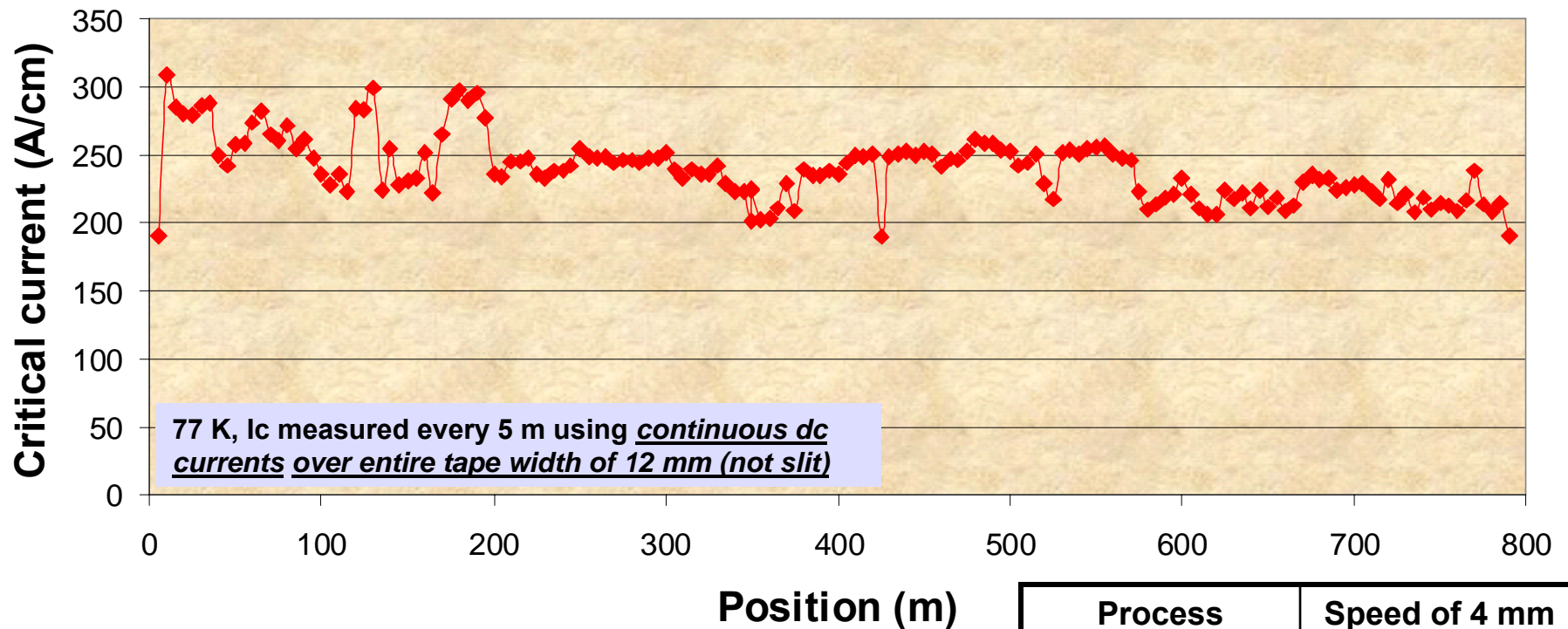
Metric 3: Long Lengths



Buffered tapes: produced kilometer lengths with complete 5-layer buffer stack and excellent & uniform in-plane texture

Tape	Length (m)	In-plane texture (°)			Uniformity
		Average	Min	Max	
1	1,001	6.79	6.20	7.84	6.2%
2	1,343	6.33	5.80	7.16	3.3%
3	1,346	6.85	6.00	7.35	2.1%
4	1,372	6.20	5.83	6.68	2.2%
5	1,375	6.58	6.23	7.14	2.5%
6	1,277	6.59	5.80	7.09	2.1%
7	1,346	7.09	6.66	7.79	2.9%
8	1,265	6.81	6.30	7.12	1.7%
9	1,246	6.33	5.47	7.13	2.4%
10	1,369	6.18	5.95	6.26	1.2%

Sept. 2007: New long length record !



Minimum $I_c = 190$ A/cm

$I_c \times \text{Length (790 m)} = 150,100$ A-m

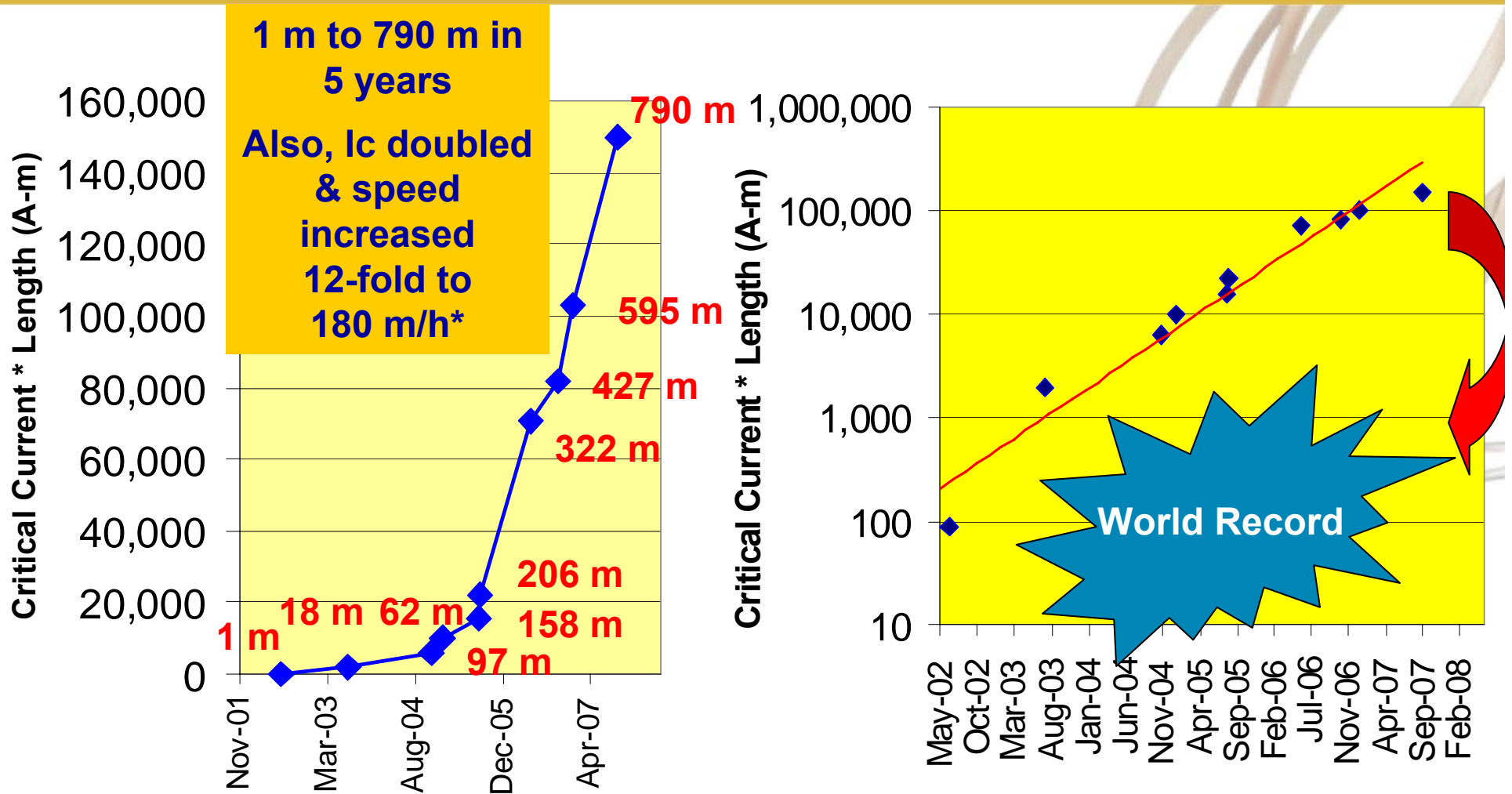
Uniformity over 790 m = 9.7%

Process (single pass)	Speed of 4 mm tape (m/h)
IBAD MgO	360
Homo-epi MgO	345
LMO	345
MOCVD	~ 100

We are getting very close to kilometer long 2G wire!

SuperPower Inc.

Remarkable progress in 2G wire scale-up over the last 5 years



*4 mm speed equivalent

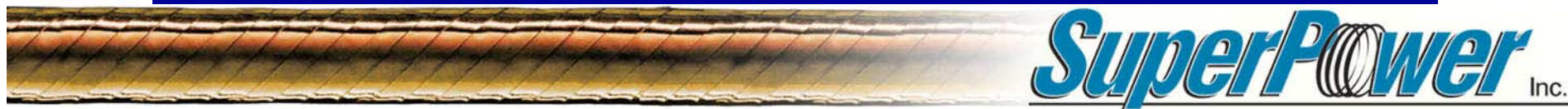


Substantial improvements made in 2007 in all key metrics - I_c & speed, & piece lengths of 2G wire

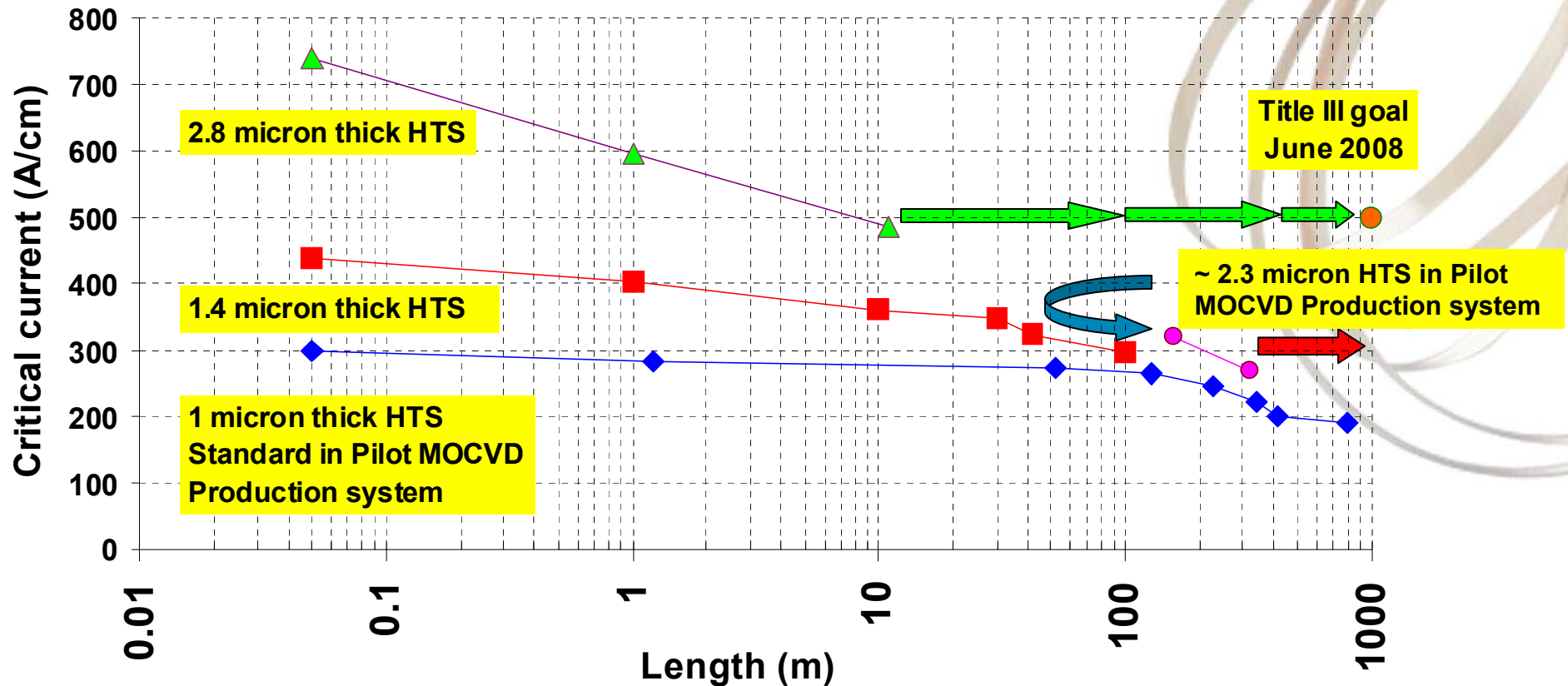
Metric	2006	2007	Improvement in 2007
I_c (A/cm) – short, reel-to-reel processed	721 in 3.5 micron film	740 in 2.8 micron film	30% higher J_c
Buffer speed* (m/h)	240	345 to 360	40 to 50%
MOCVD speed* (m/h)	135	180	33%
I_c over 100 m at stated speeds of Buffer & MOCVD	227	201	Same I_c level with much higher speeds in all processes
Buffered tape piece length (m)	550	1,375	150%
Completed 2G wire Piece Length (m)	427	790	85%
$I_c \times L$ (A-m)	81,550	150,100	84%

*4 mm wide tape equivalent, single pass

Rapid progress with higher currents, higher speeds, and longer lengths are all leading the way to a lower-cost 2G wire



Progress being made both in Pilot Manufacturing of long lengths & technology development with shorter lengths



Next Steps:

Manufacturing scale-up to reach 1000 m with $I_c > 200$ A/cm (almost there !)

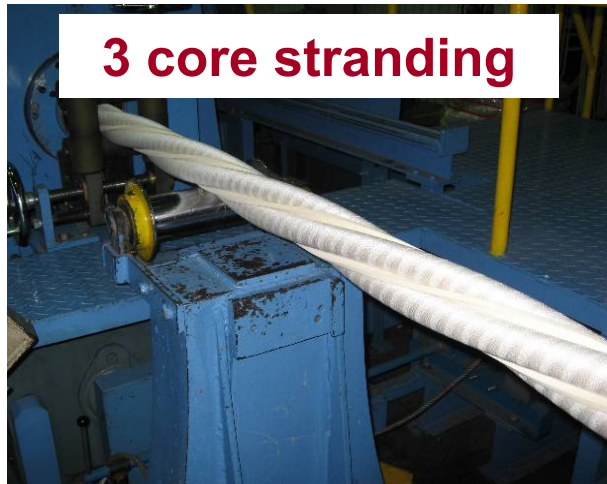
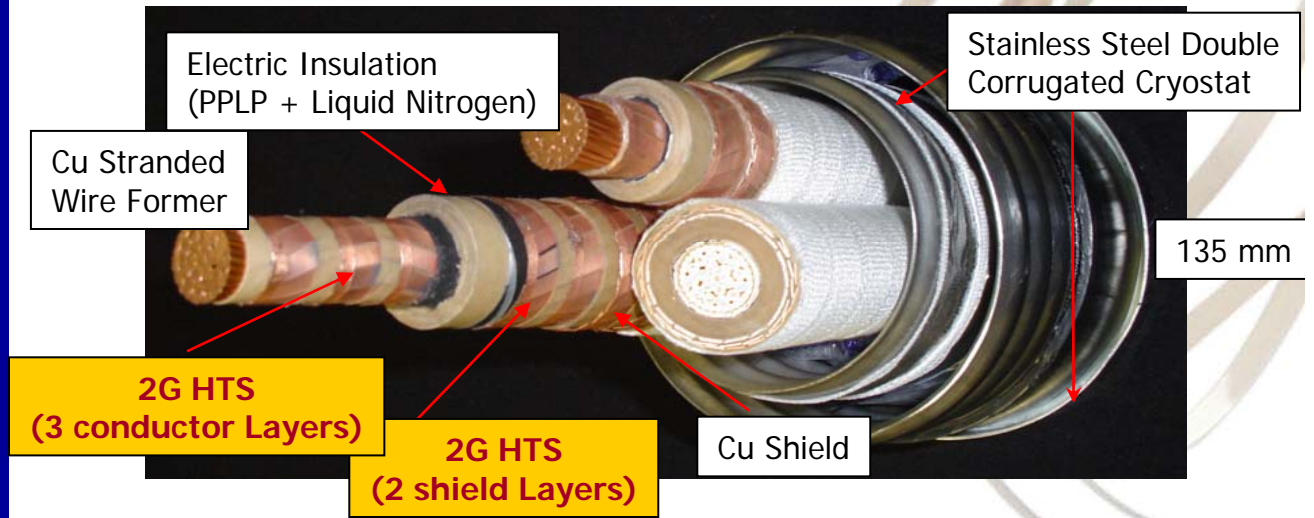
Manufacturing improvements to raise I_c level of 500+m Production lengths to that of short lengths of same film thickness i.e. 500 m and then 1000 m with $I_c > 300$ A/cm

Technology transition of higher- I_c conductors to Pilot manufacturing, i.e., 100 m, then 500 m and then 1000 m with I_c of 500 A/cm



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

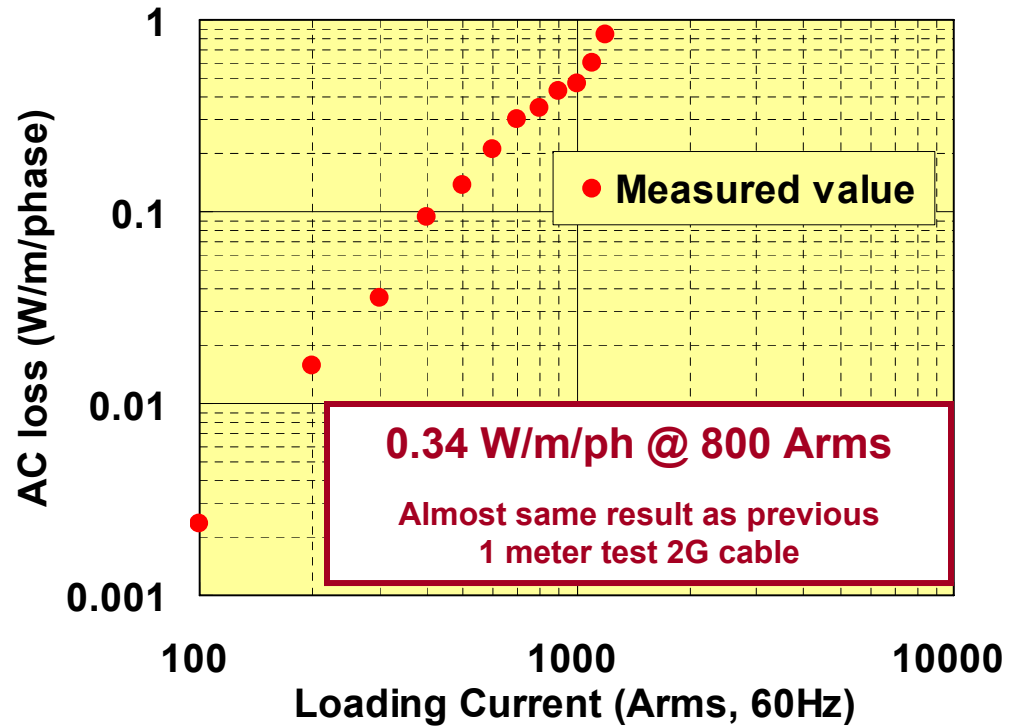
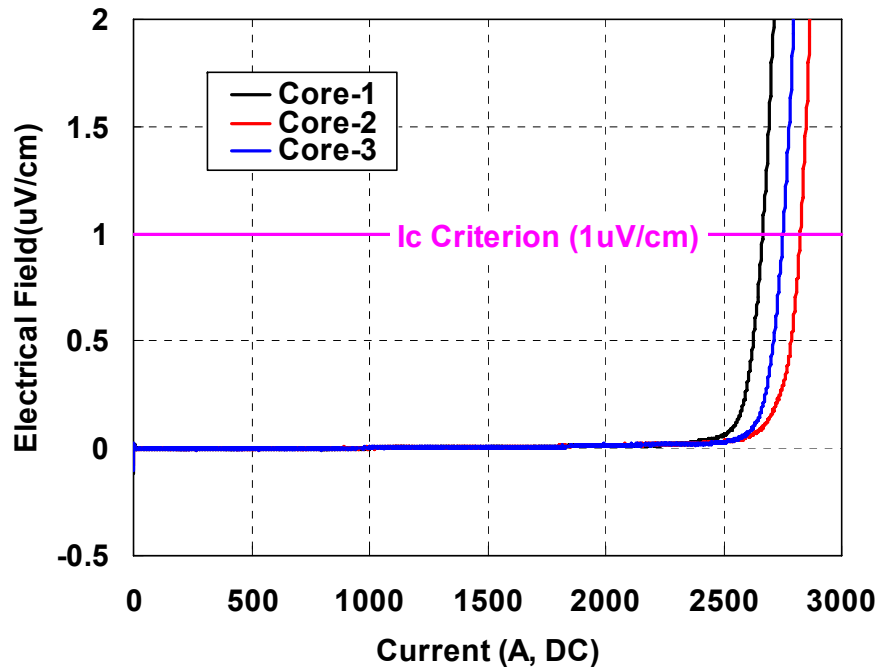
Nearly 10,000 m of 2G wire in 43 m piece lengths and minimum I_c over 70 A was delivered by SuperPower in Dec. 2006, marking the single largest delivery of 2G wire



 SUMITOMO ELECTRIC

Ingenious Dynamics

Excellent overall performance obtained in 2G cable



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

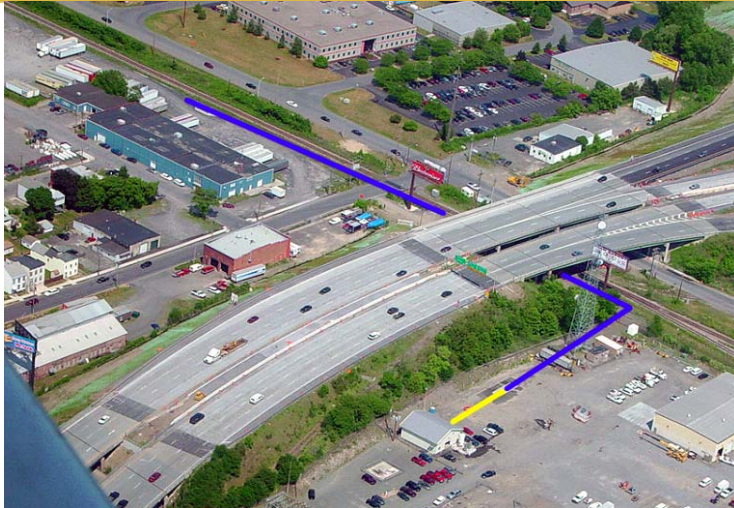
Ic of shield layers ~ 2400 – 2500A
(DC, 77K, 1 μ V/cm)

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 \pm 200kV, 10 times



2G Cable has been installed in grid at Albany Cable site



Installation at Albany Cable site
(Aug. 5, 2007)



- World's first in-grid cable, first underground HTS cable, first cable-to-cable joint, 350 m long
- On-grid operations began July 20, 2006
- 30 m segment of 1G cable replaced by 2G cable which is world's first 2G device

- ***Assembly of joint between 2G & 1G cables completed***
- ***Terminated assembly completed***
- ***2G cable cool-down began late Nov. 2007 and will be energized soon thereafter***

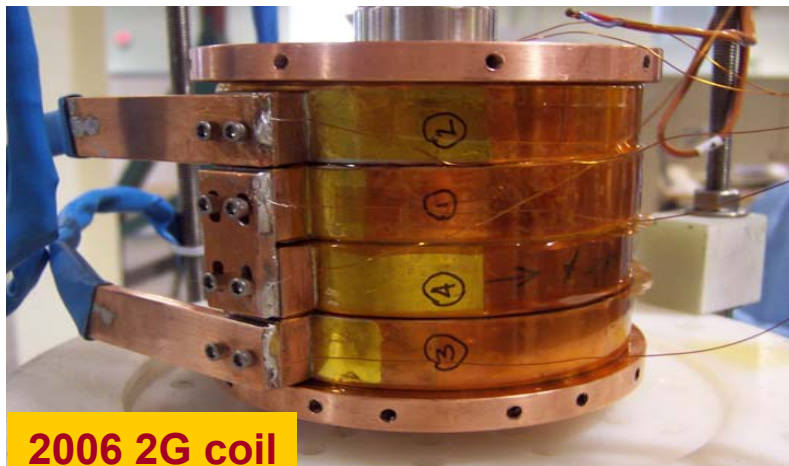


SuperPower Inc.

New high field coil constructed with 2G wire

Total thickness of our 2G wire including copper stabilizer is only 0.095 mm which is ½ the thickness of 1G and other 2G wires. This is very useful for coil applications where higher number of amp-turns can be obtained.

In FY'06, we demonstrated a 2G coil that generated **1.1 T at 77 K and 2.4 T at 64 K**



- In FY07, we constructed a coil with 6 double pancakes using 462 m of 2G wire.
- The coil was tested in the National High Magnetic Field Lab at FSU

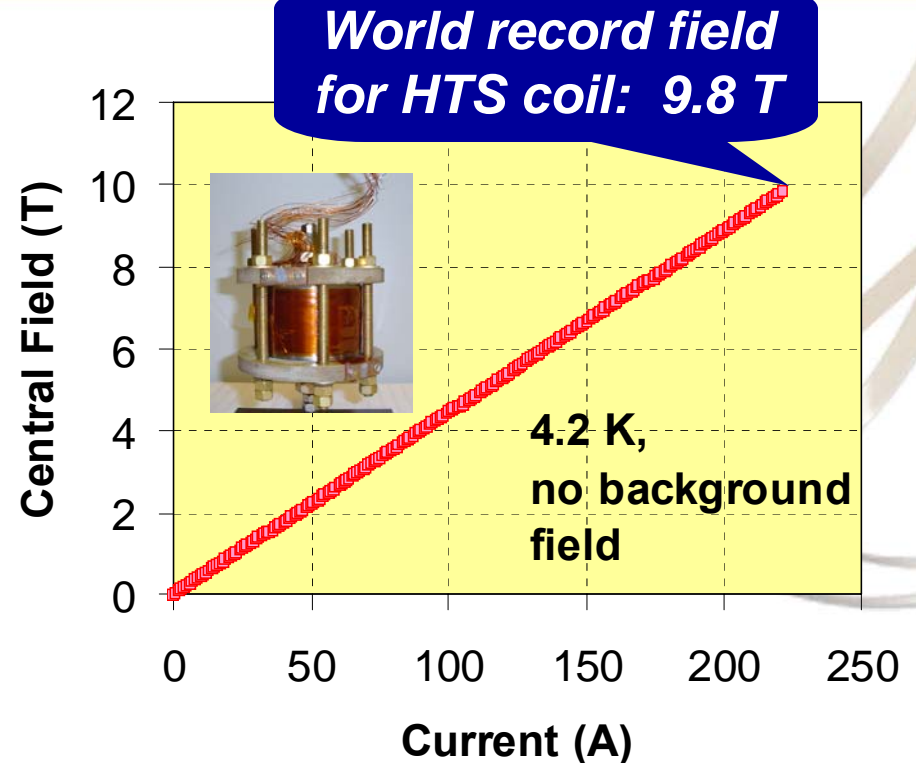


SuperPower Inc.

World record performance achieved with 2G 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 I_c of tapes in coil	78 A in 4 mm width (77 K, self field)
# of turns	~ 2772
Coil J_e	~1.569 A/mm ² per A
Coil constant	~ 44.46 mT/A

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



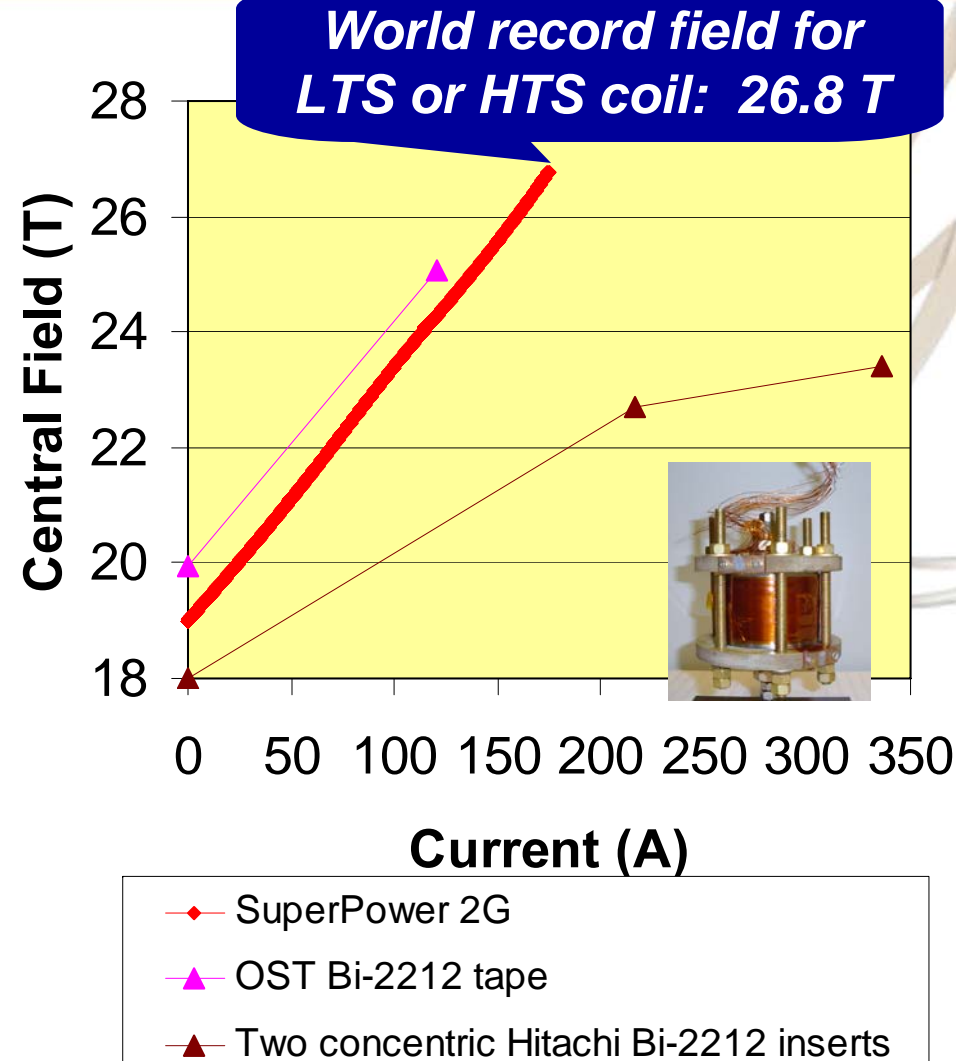
4.2 K Coil I_c - self field	221 A
4.2 K Amp Turns @ I_c - self field	612,612
4.2 K Central field – self field	9.81 T



World record performance achieved with 2G coil

4.2 K Coil I_c – 19 T background (axial)	175 A
4.2 K Amp Turns @ I_c – 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 J_e (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



This demonstration extends the potential of 2G over a wider application range