2G HTS Pilot-scale Manufacturing at SuperPower

Yi-Yuan Xie, Ph.D.

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

Funded by Title III, DOE through UT-Battelle, AFRL & AFOSR
Supported by CRADAs with Los Alamos, Oak Ridge, and Argonne National Laboratories

European Conference on Applied Superconductivity, Brussels, September 17 – 20, 2007

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

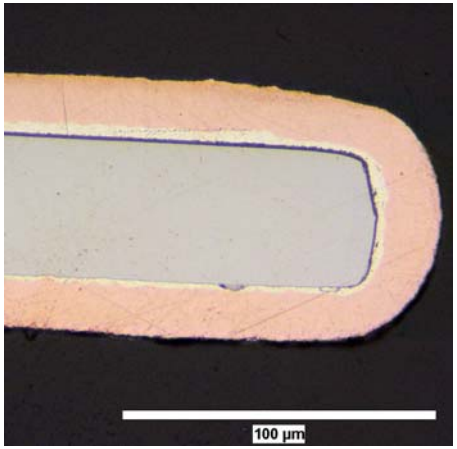
SuperPower's 2G wire is based on high throughput processes & superior substrate

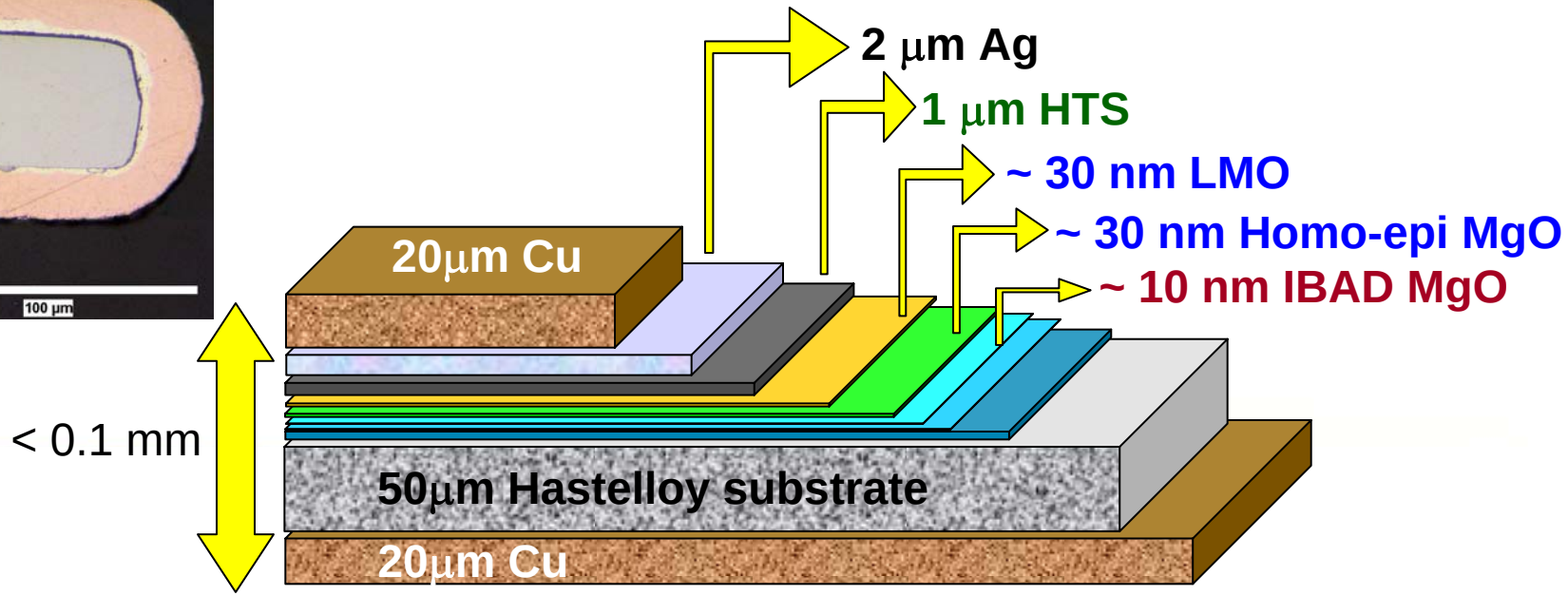
High throughput is critical for low cost 2G wire and to minimize capital investment.

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

Use of IBAD as buffer template provides us choice of any substrate.

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





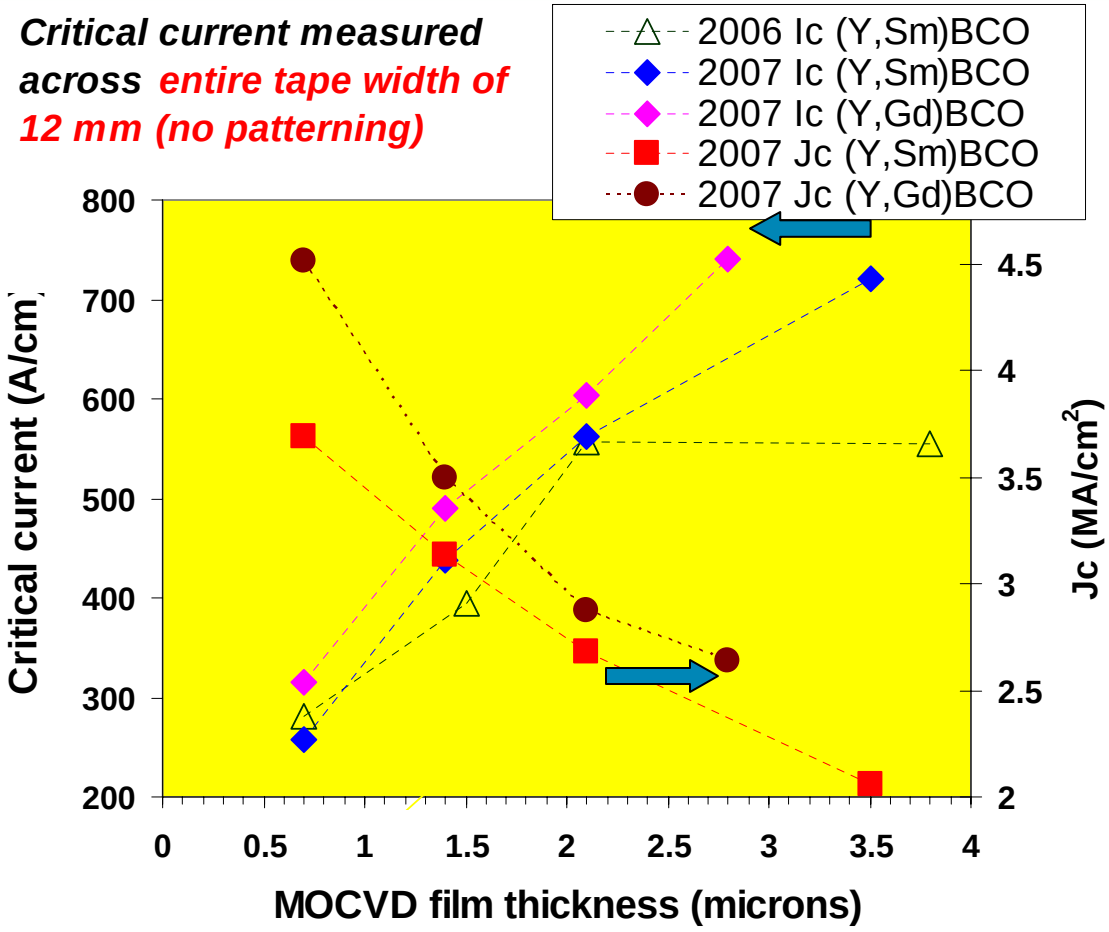
SuperPower's 2G pilot manufacturing facilities have been *operational* since 2006

Majority of investment already made for 1000 km/year capability

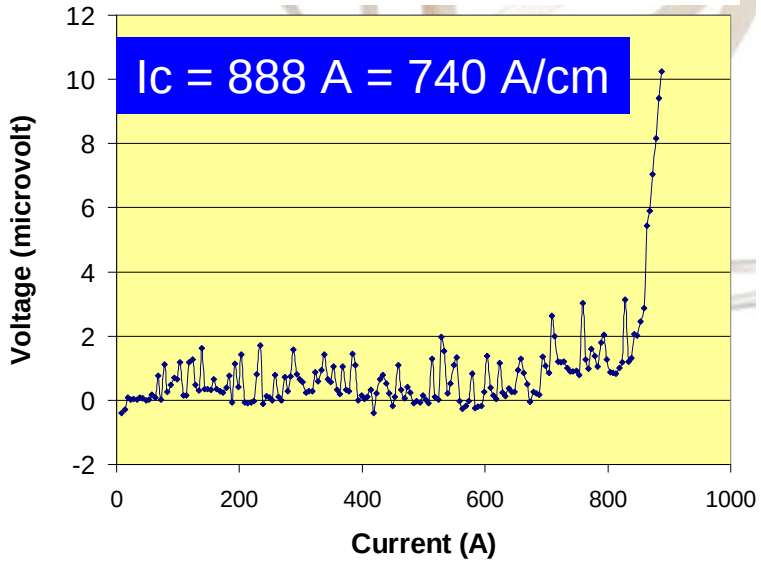
Inc.

Pathway to commercialization of 2G
Metric 1: Higher Currents

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



Achieved higher currents in thinner films using modified MOCVD precursor composition



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

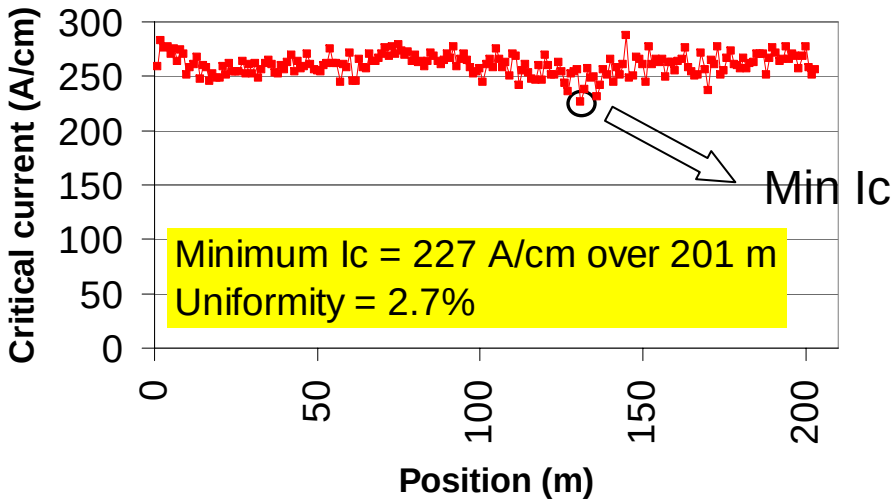
Ic measurement using continuous dc current (no pulsed current) across entire tape width of 12 mm No patterning

This demonstration of 300 A wire performance in 4 mm width is 50% better than the best 1G available today

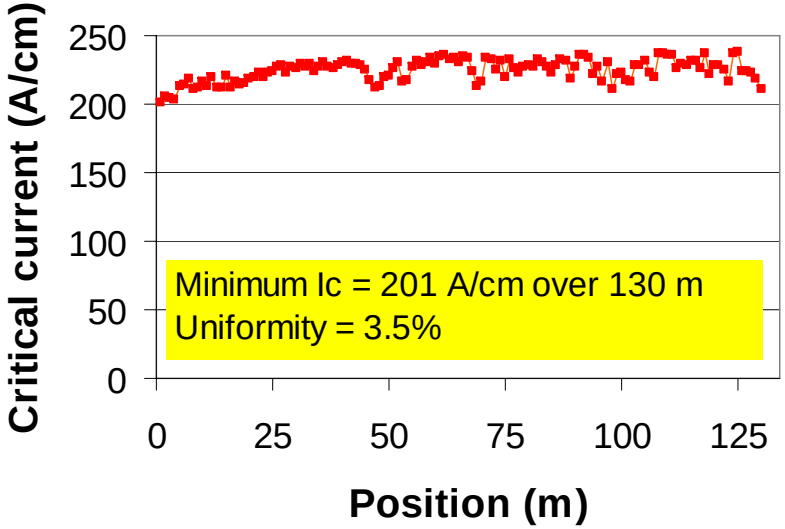
Inc.

Pathway to commercialization of 2G
Metric 2: High Throughput

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



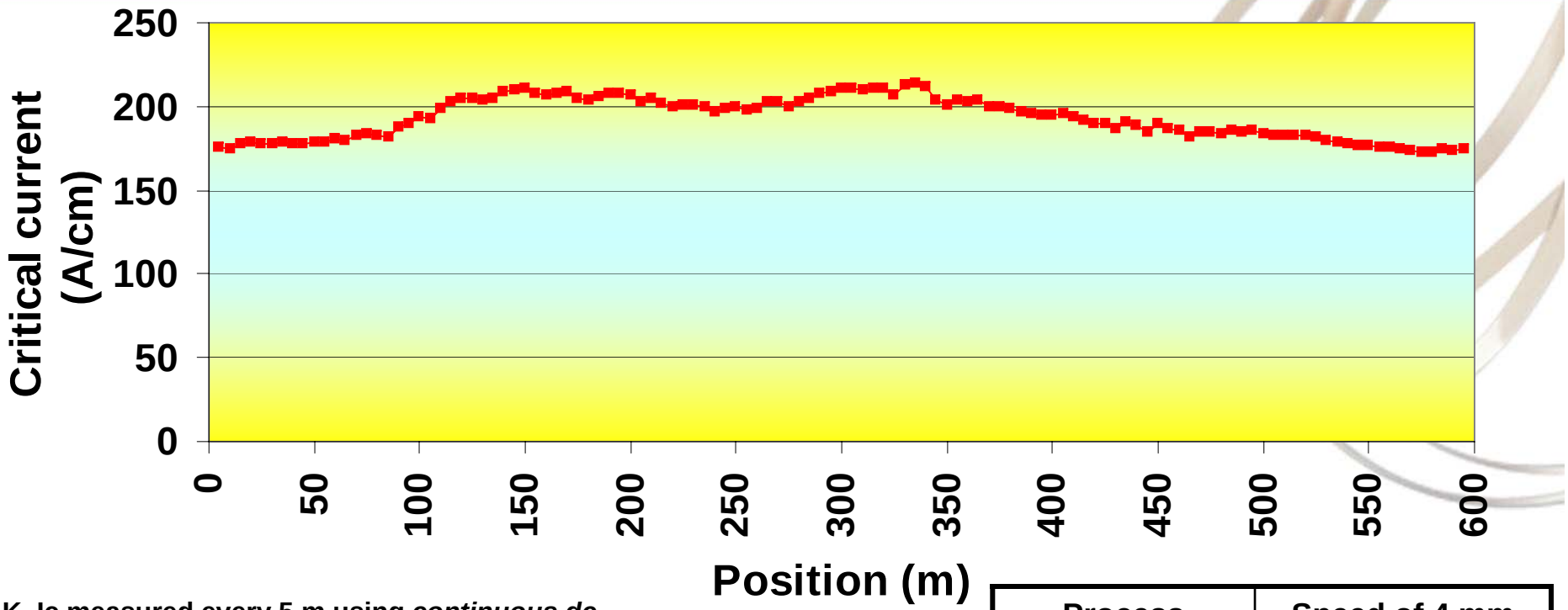
June 07: High currents over 130+m with all processes at even higher speeds



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% of time/year is available for deposition)	June 07	1,440	1,380	1,380	720

Production capacity goal of 1,000 km/year is already surpassed in IBAD MgO & Buffer processes and is close to being achieved with MOCVD

Pathway to commercialization of 2G
Metric 3: Long Lengths



77 K, Ic measured every 5 m using *continuous dc currents over entire tape width of 12 mm (not slit)*

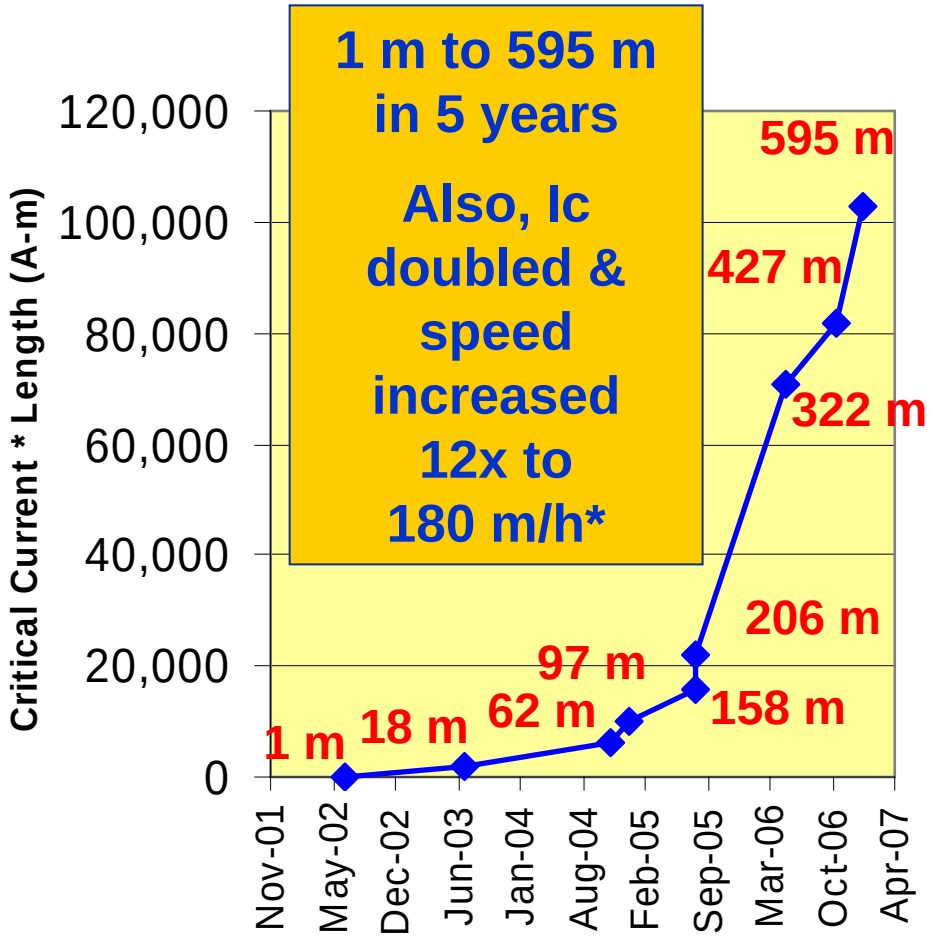
Minimum Ic = 173 A/cm over 595 m

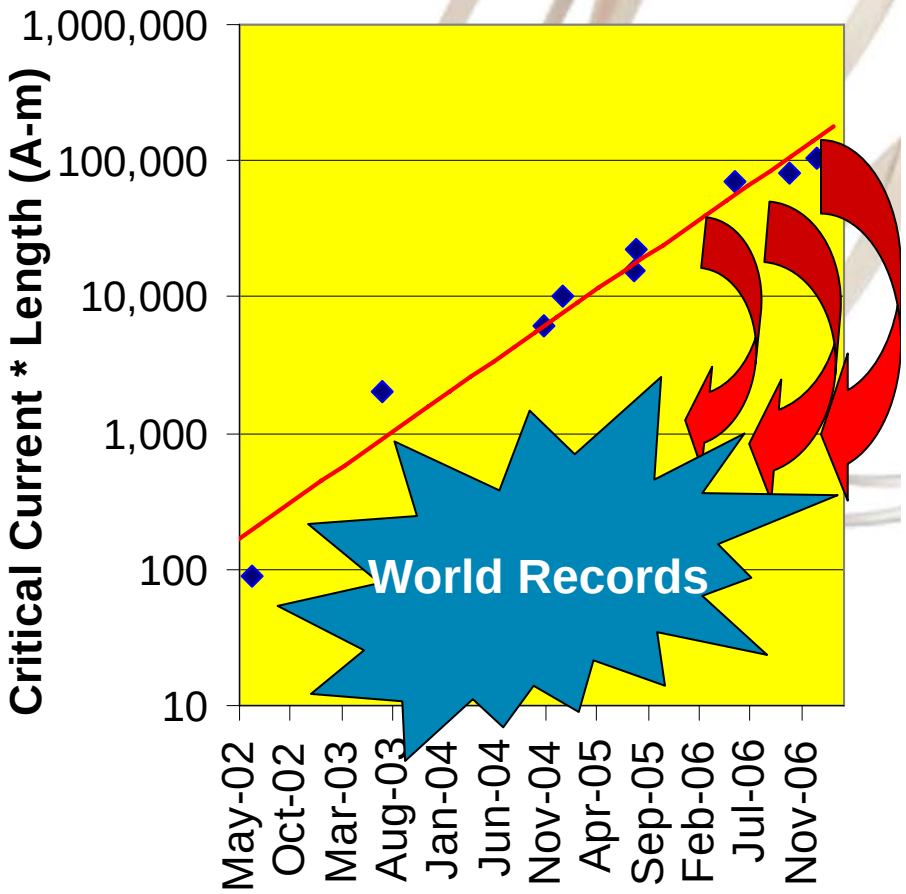
Ic × Length = 102,935 A-m

Uniformity over 595 m = 6.4%

Process (single pass)	Speed of 4 mm tape (m/h)
IBAD MgO	360
Homo-epi MgO	213
LMO	360
MOCVD	135

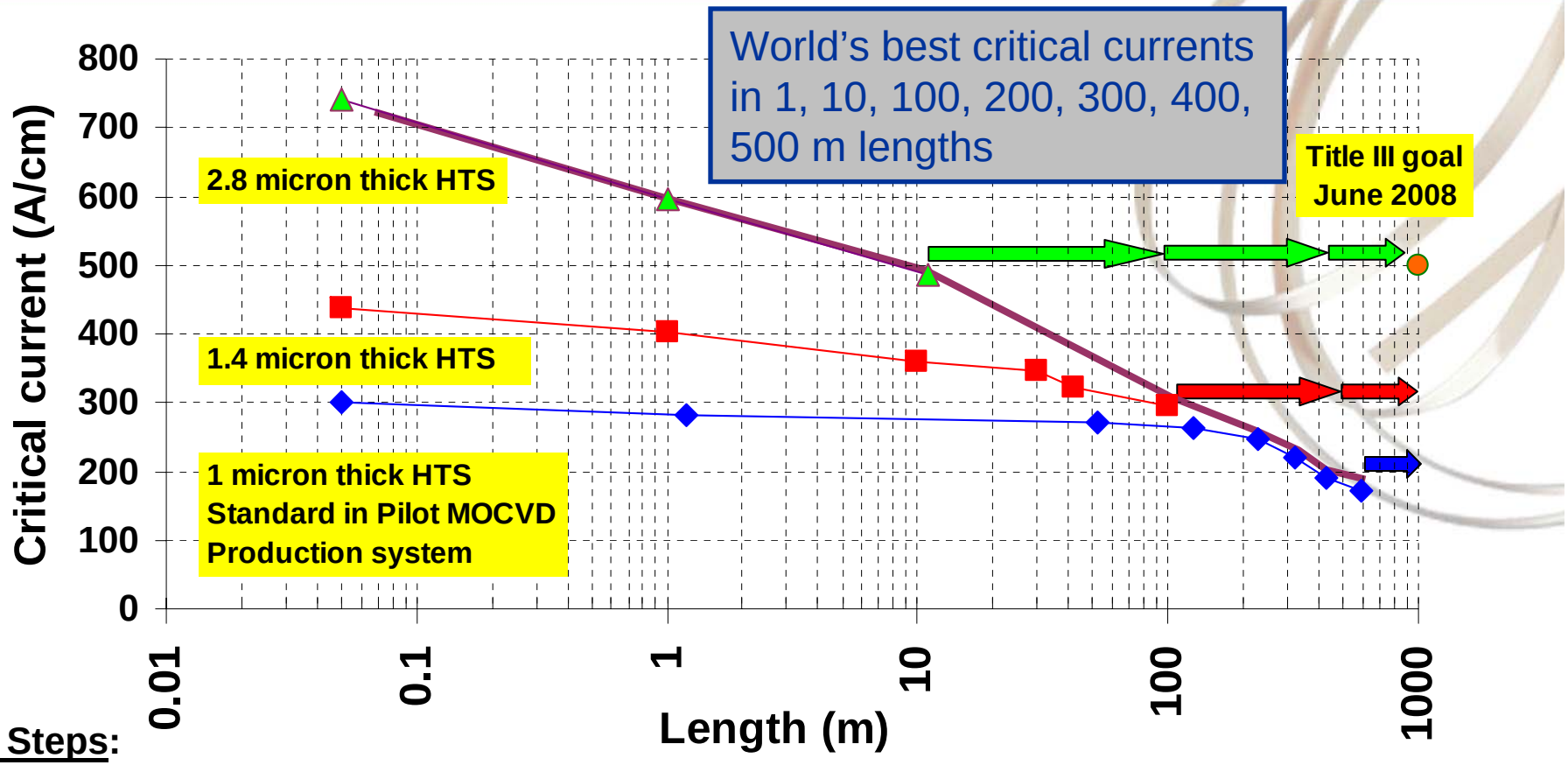
Remarkable progress in 2G wire scale-up over the last 5 years





*4 mm speed equivalent

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



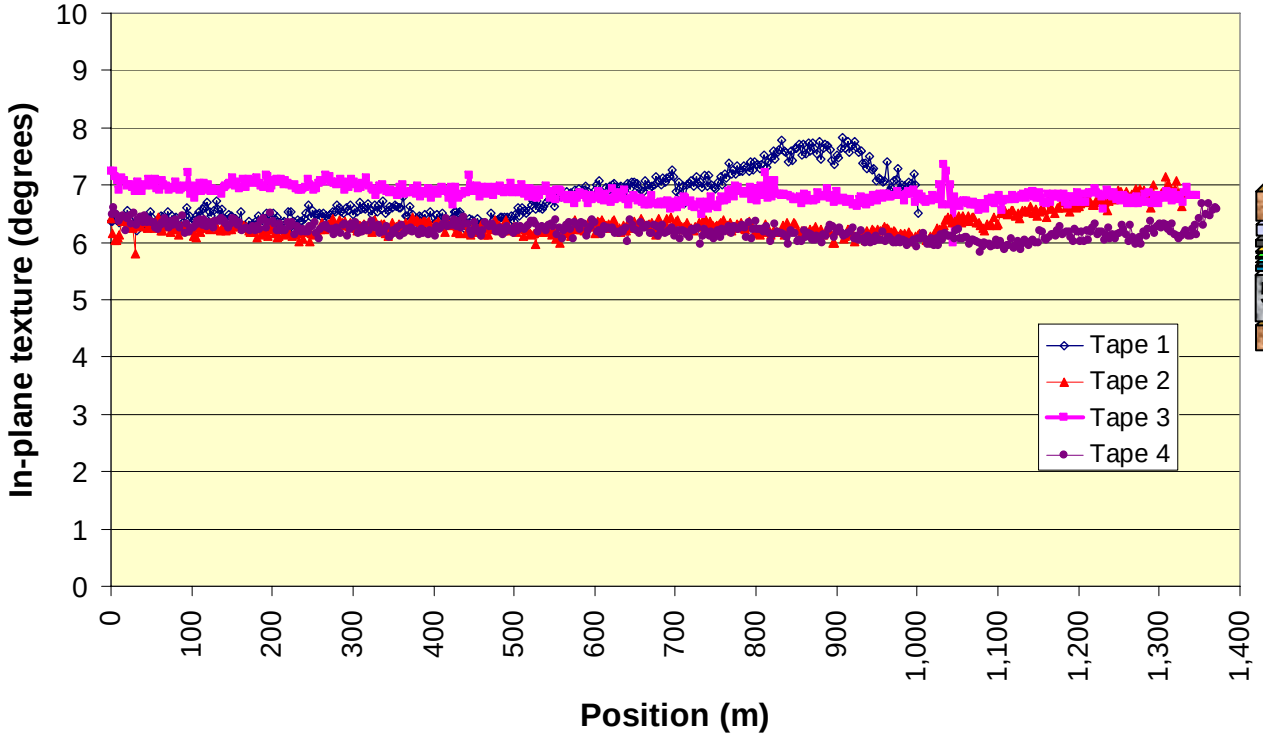
Next Steps:

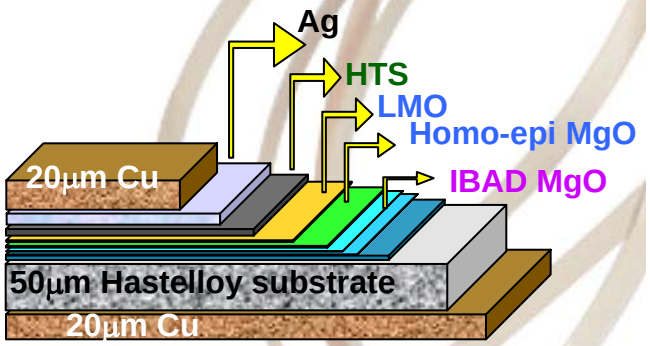
Manufacturing scale-up to reach 1000 m with Ic > 200 A/cm

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

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

Kilometer lengths of fully buffered tape produced with 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%

Several wires with complete 5-layer buffer stack produced in lengths of 1,350 m with in-plane texture of 6 – 7 degrees and excellent uniformity of ~ 2%.

This achievement brings us one step closer to producing kilometer long 2G wires!

SuperPower Inc.

Substantial improvements made *in the last year* in all key metrics: Ic, speed, and piece lengths of 2G wire

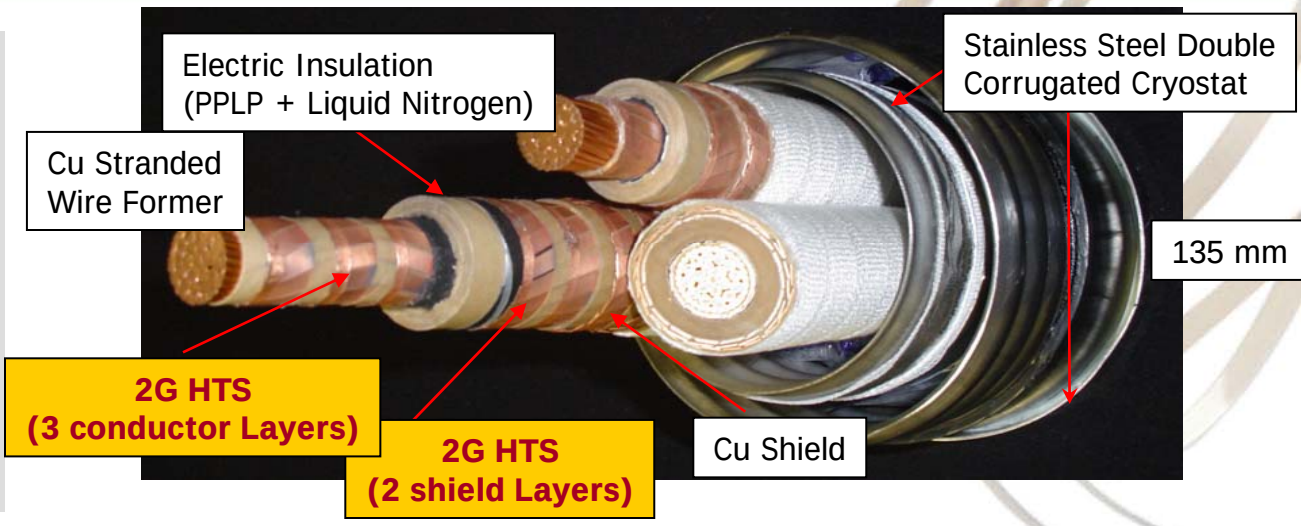
Metric	2005	2006	2007	Improvement in 2007
Ic (A/cm) – short, reel-to-reel processed	407	557	**740**	30%
Ic (A/cm) over 1 m	236	470	**595**	27%
Ic (A/cm) over 10 m	215	276	**484**	75%
IBAD speed* (m/h)	3	195	**360**	85%
Buffer speed* (m/h)	n/a	120	**345 to 360**	185 to 200%
MOCVD speed* (m/h)	15	90	**180**	100%
Ic over 200 m at stated speed	106	246	**227**	**Same Ic level with much higher speeds in all processes**
Buffered tape piece length (m)	210	550	**1,375**	150%
Completed 2G wire Piece Length (m)	207	322	**595**	85%
Ic × L (A-m)	22,000	70,520	**102,935**	46%

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

*4 mm wide tape equivalent, single pass

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

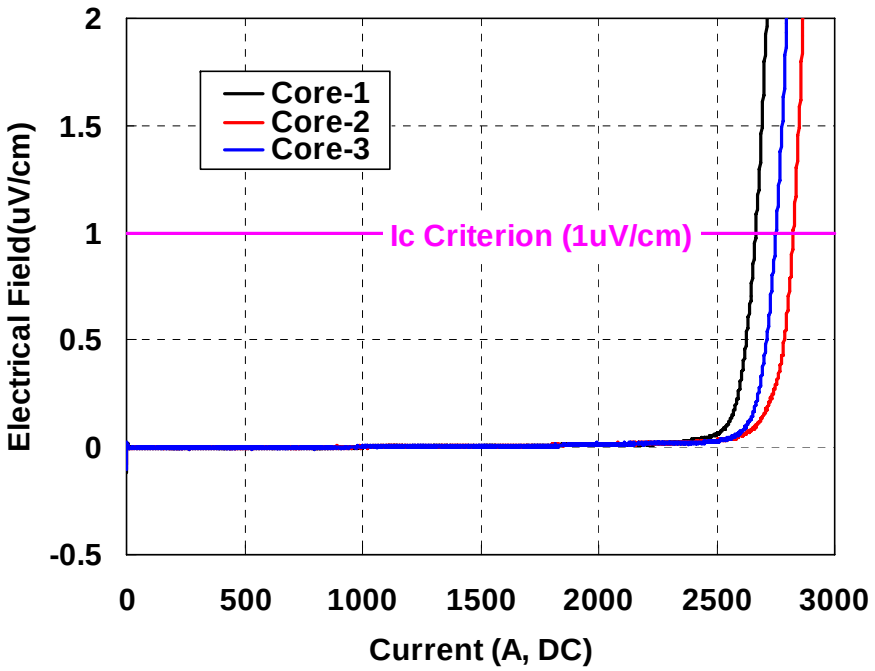
Nearly 10,000 m of 2G wire in 43 m piece lengths and minimum Ic over 70 A was delivered by SuperPower in Dec. 2006, marking the single largest delivery of 2G wire

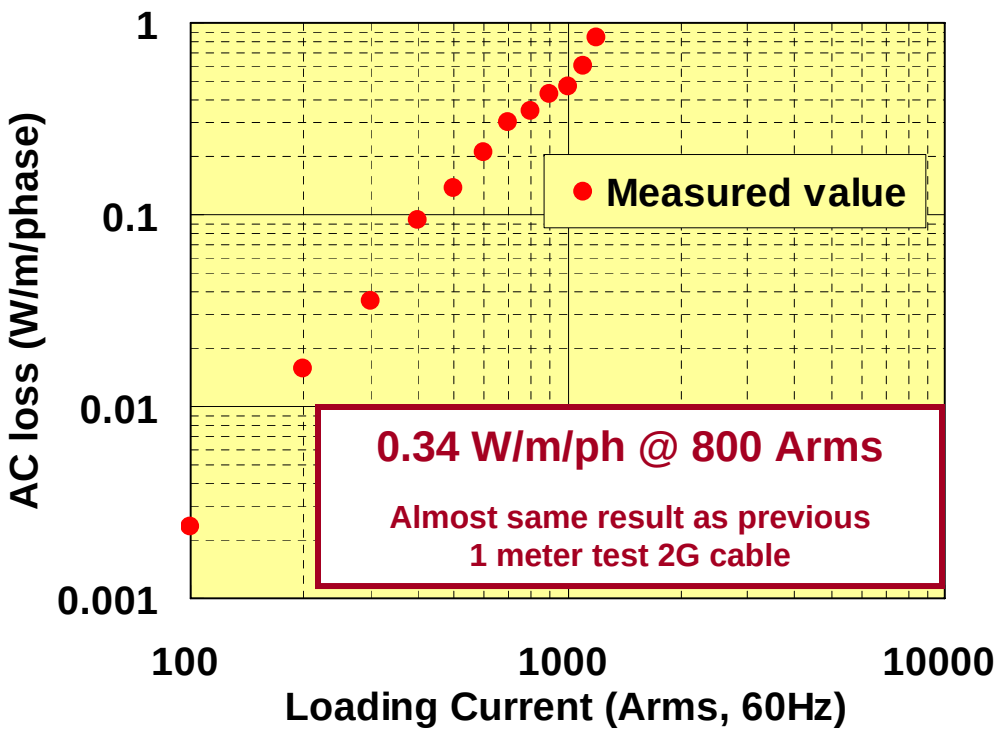


SUMITOMO ELECTRIC

Ingenious Dynamics

Excellent overall performance obtained in 2G cable





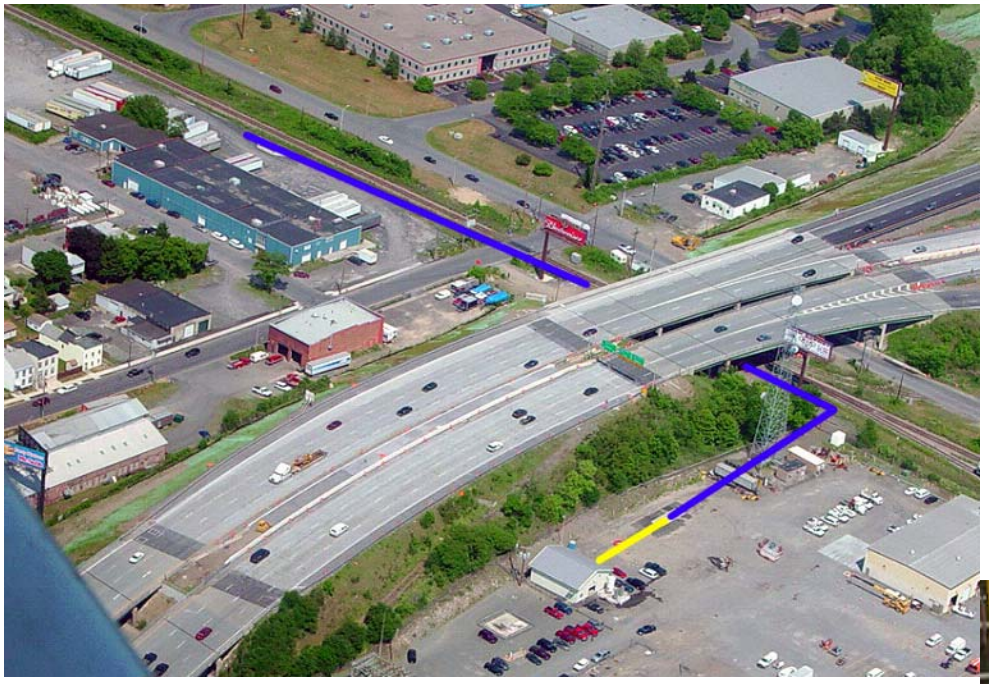
Ic of conductor layers ~ 2660 – 2820A
(DC, 77K, 1μV/cm)

Ic of shield layers ~ 2400 – 2500A
(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

2G cable has been installed in the National Grid system at the Albany Cable site



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

2G cable will be energized in the grid by November 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
- 30m segment of 1G cable replaced by 2G cable: the world's first 2G device

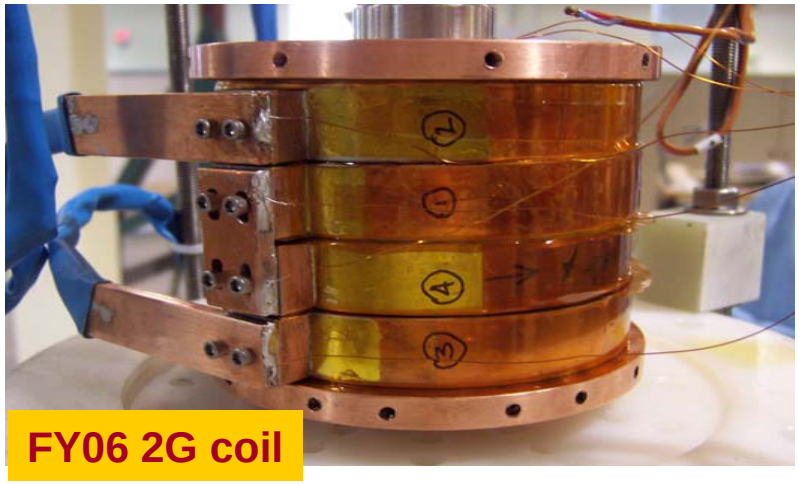
SUMITOMO ELECTRIC Ingenious Dynamics

wer Inc.

New high field coil constructed with 2G wire

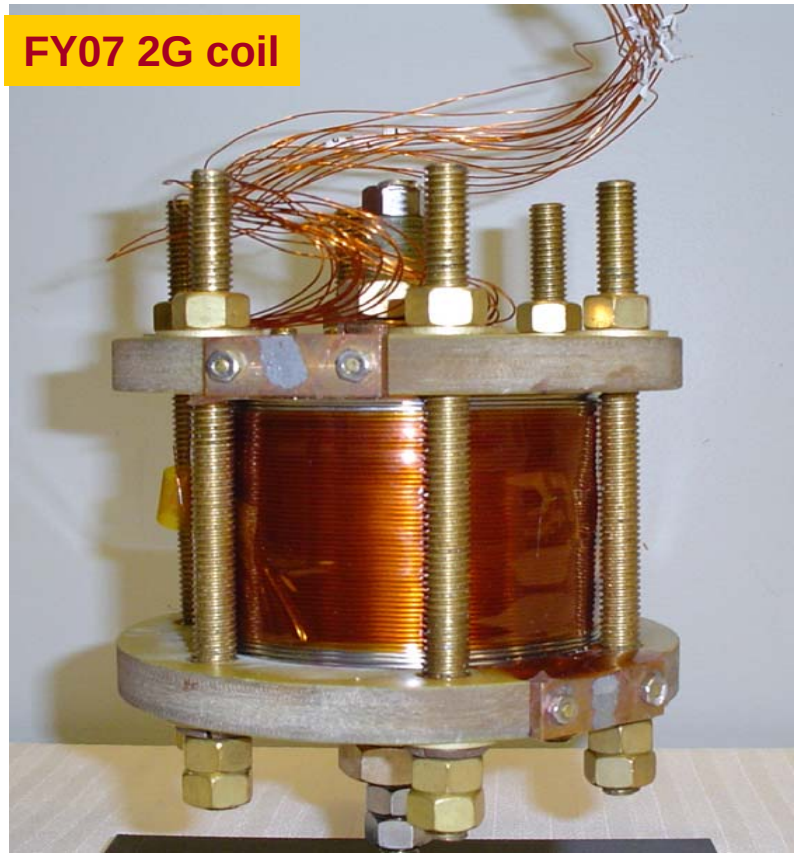
Total thickness of our 2G wire including copper stabilizer is only 0.095 mm which is half the thickness of 1G and other 2G wires. This is very useful for coil applications where higher number of amp-turns can be obtained.

In FY06, we demonstrated a 2G coil that generated 1.1 T at 77 K and 2.4 T at 64 K



FY06 2G coil

FY07 2G coil

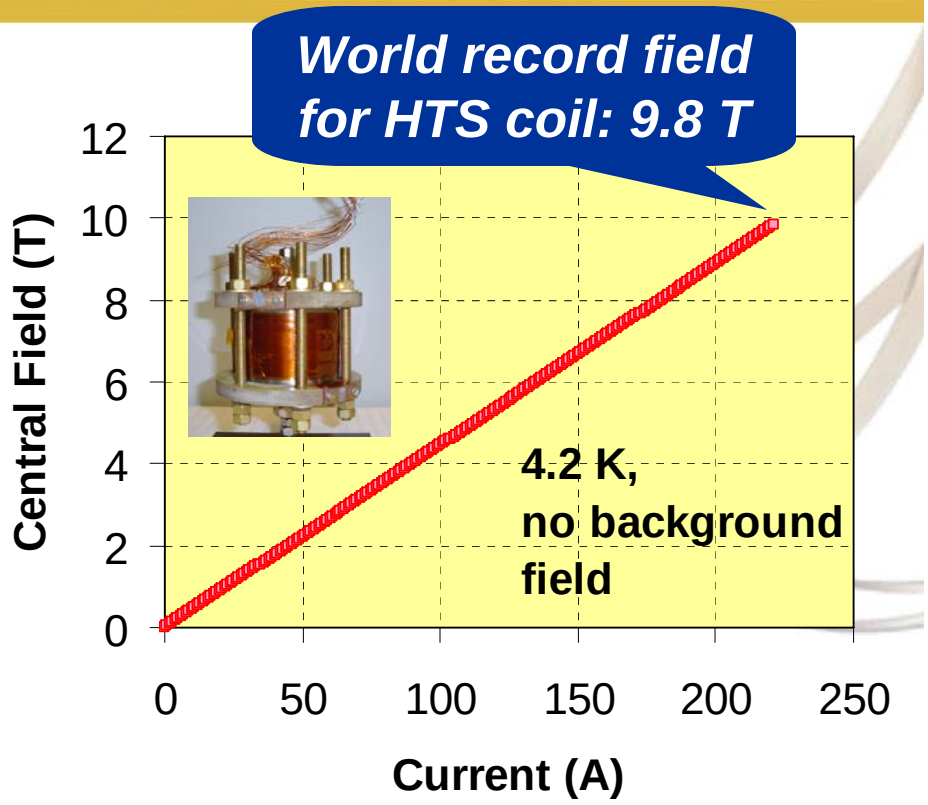


- In FY07, we constructed a coil with 6 double pancakes using 462 m of 2G wire.
- The coil was tested in the National High Magnetic Field Lab at FSU

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 Ic of tapes in coil	78 A in 4 mm width (77 K, self field)
# of turns	~ 2772
Coil Je	~1.569 A/mm^2 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

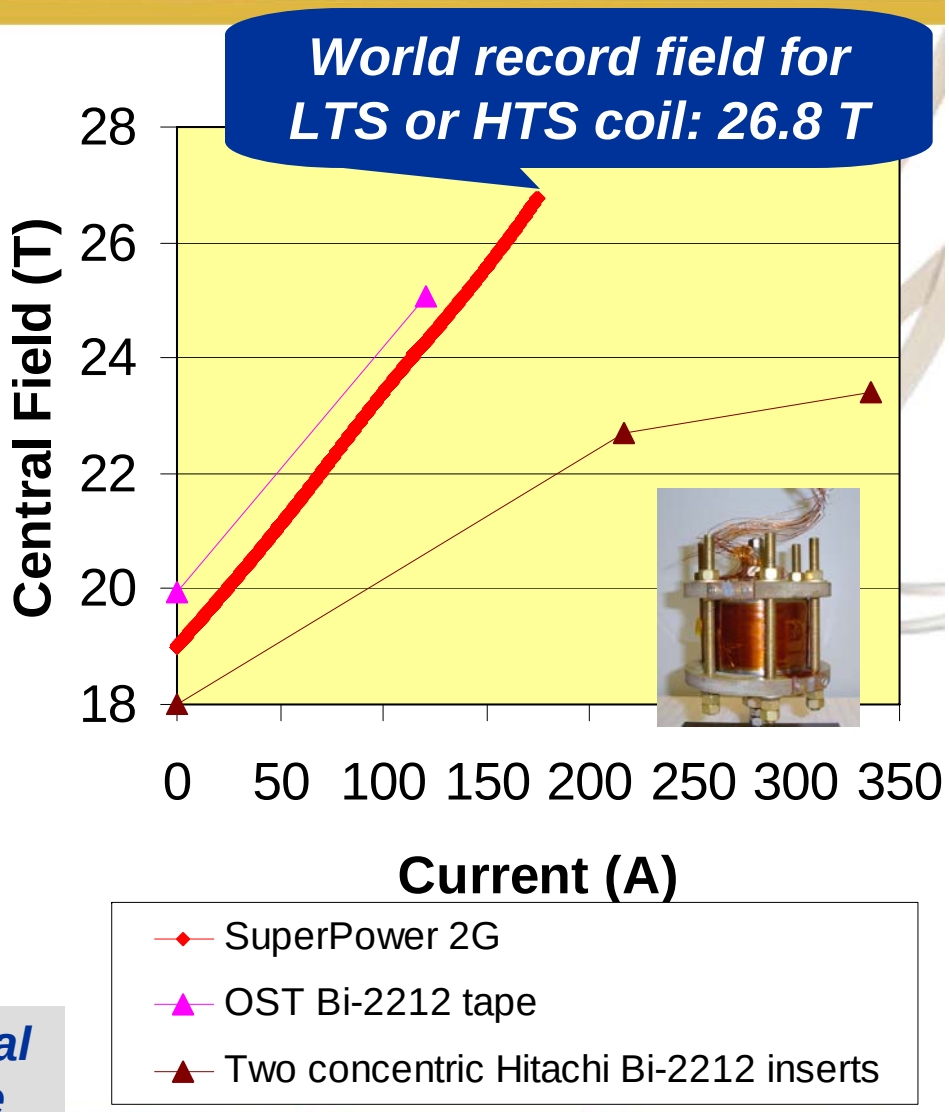
Coil tested by H. Weijers, D. Markewicz, & D. Larbalestier, NHMFL, FSU

World record performance achieved with 2G coil

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/mm²)	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



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