SuperPower Inc.
A Subsidiary of Intermagnetics General Corporation

Progress in Scale-up of 2G HTS Conductors at SuperPower

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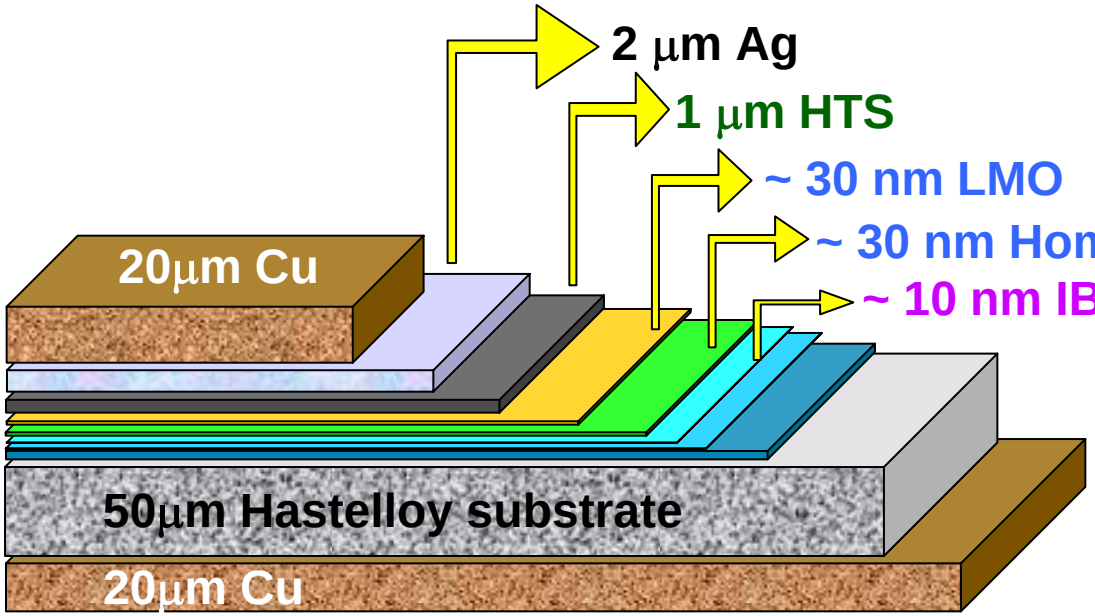
HTS Solutions for a New Dimension in Power

International Symposium on Superconductivity, Nagoya, October 30 – Nov. 1, 2006

2006 marked the first year of high-throughput Pilot Production of 2G conductor

	2005	Aug. 2006
IBAD	YSZ: 1 m/h	IBAD MgO: **65 m/h** of 12 mm wide tape
Buffer	n/a	Homo-epi MgO & LMO buffers: **40 m/h** of 12 mm tape
MOCVD	(Y,Sm)BCO: 5 m/h	(Y,Sm)BCO: **30 m/h** of 12 mm tape (single pass)



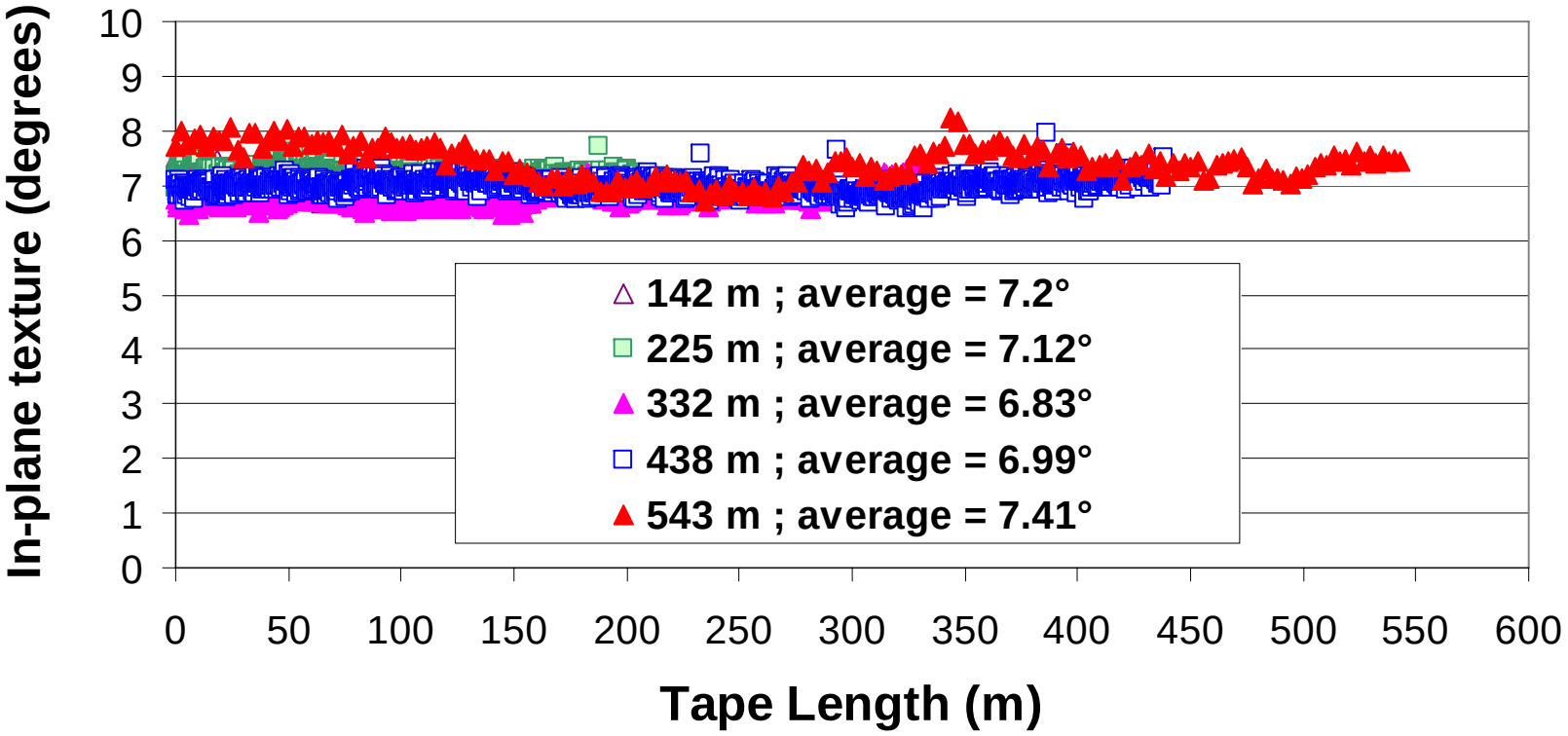
All layers produced at high throughput.

Minimum speed of 30 m/h corresponds to annual capacity of 350 km/year of 4 mm product.

550 m long tapes have been produced in Pilot IBAD & Pilot Buffer system at high linear speeds

Routine production of IBAD MgO in Pilot IBAD system at 65 m/h of 12 mm wide tape in piece lengths up to 570 m & process lengths up to 800 m (2 pieces)

Routine production of homo-epi MgO and LMO buffer layers in Pilot Buffer system at 40 m/h of 12 mm wide tape in piece lengths up to 550 m.



In-plane texture of LMO over 550 m produced at 40 m/h = 7.4°

High Ic with excellent uniformity over 300 m by MOCVD in a *single pass at 30 m/h on IBAD MgO*

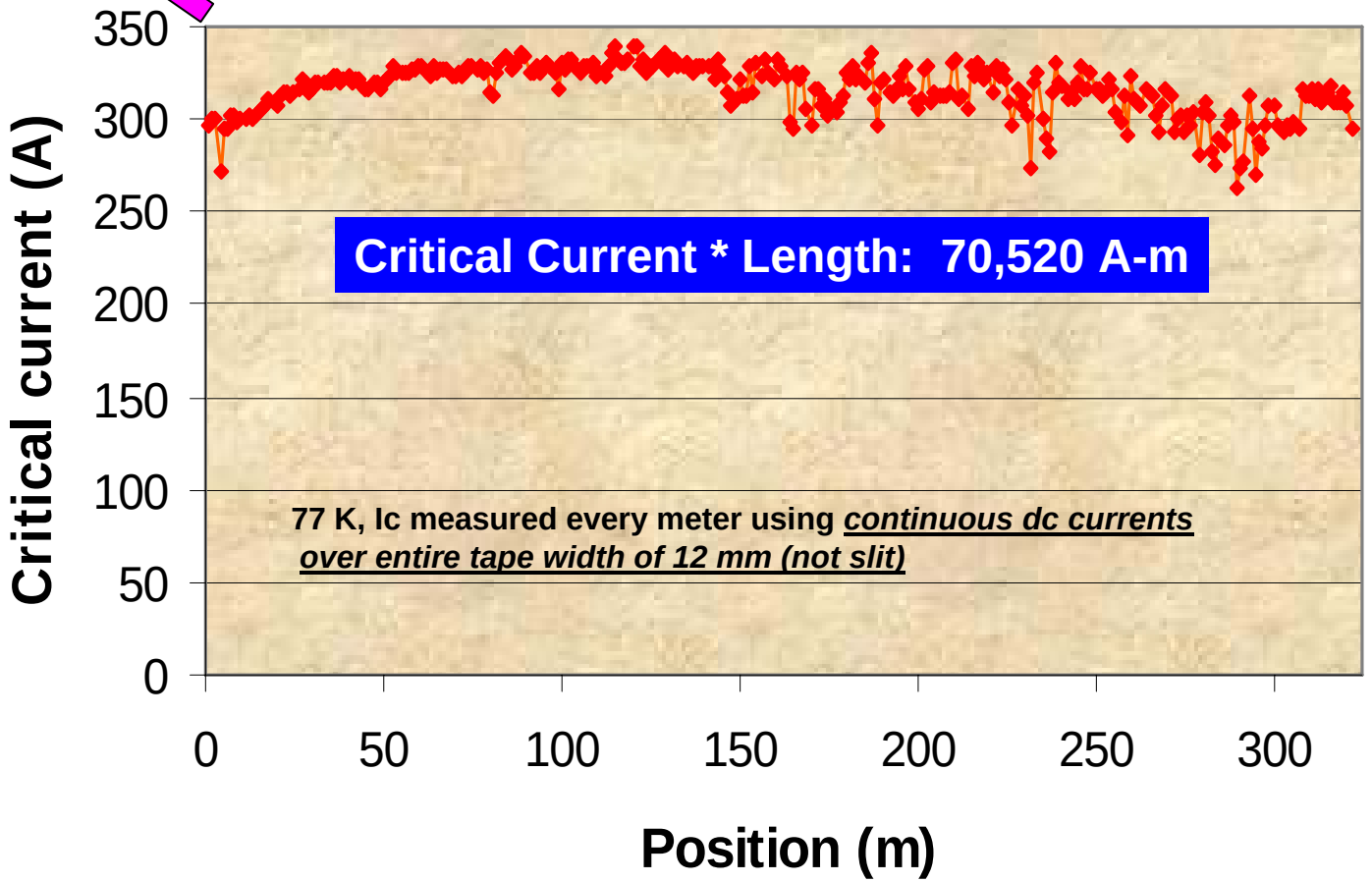
YBCO thickness

1.2 μm

Min Ic = 263 A = 219 A/cm over 322 m

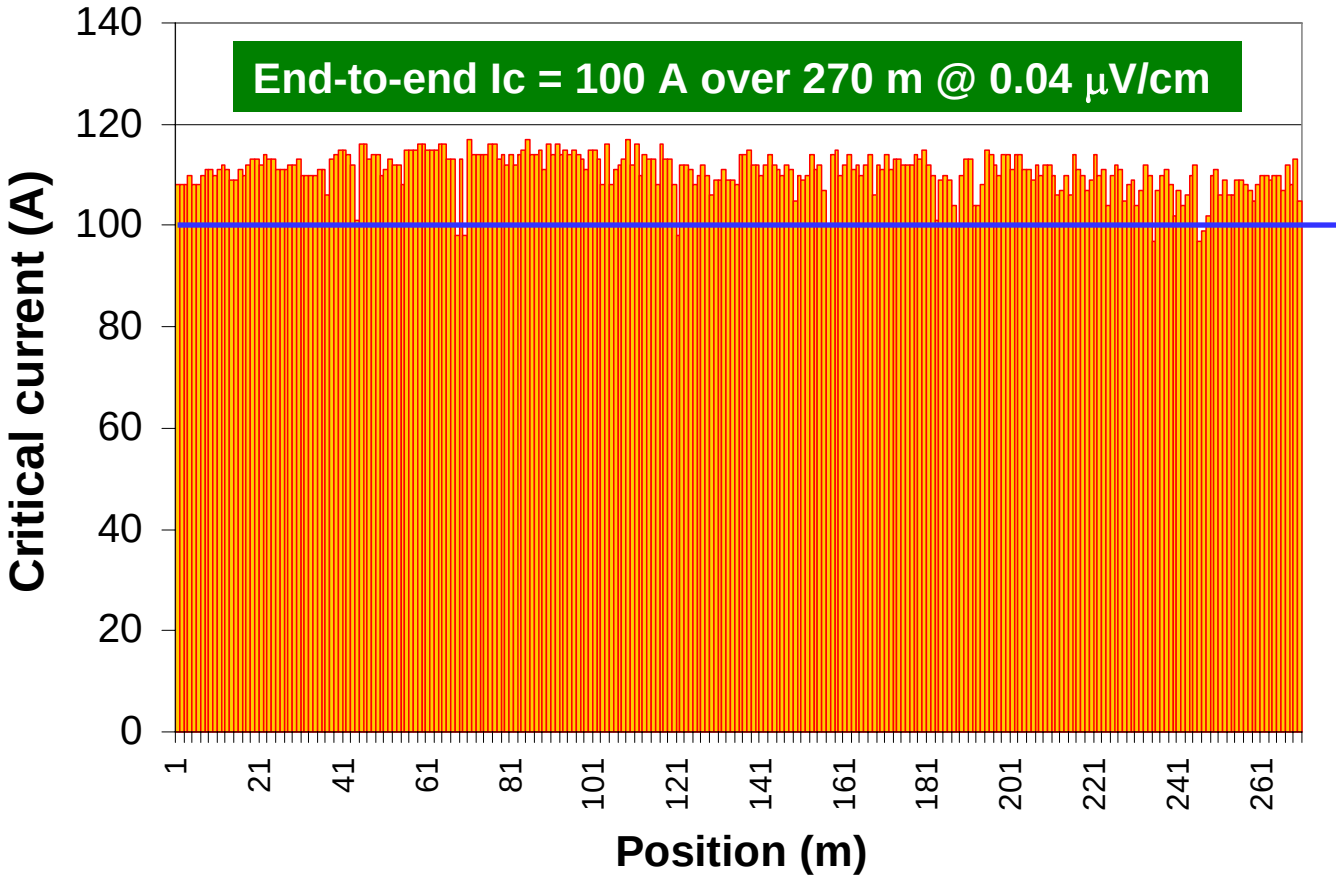
Uniformity of 4.3% over 322 m

1.2 μm



2G conductor now available in long lengths with Ic comparable to 1G & Je about 2x better than 1G

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



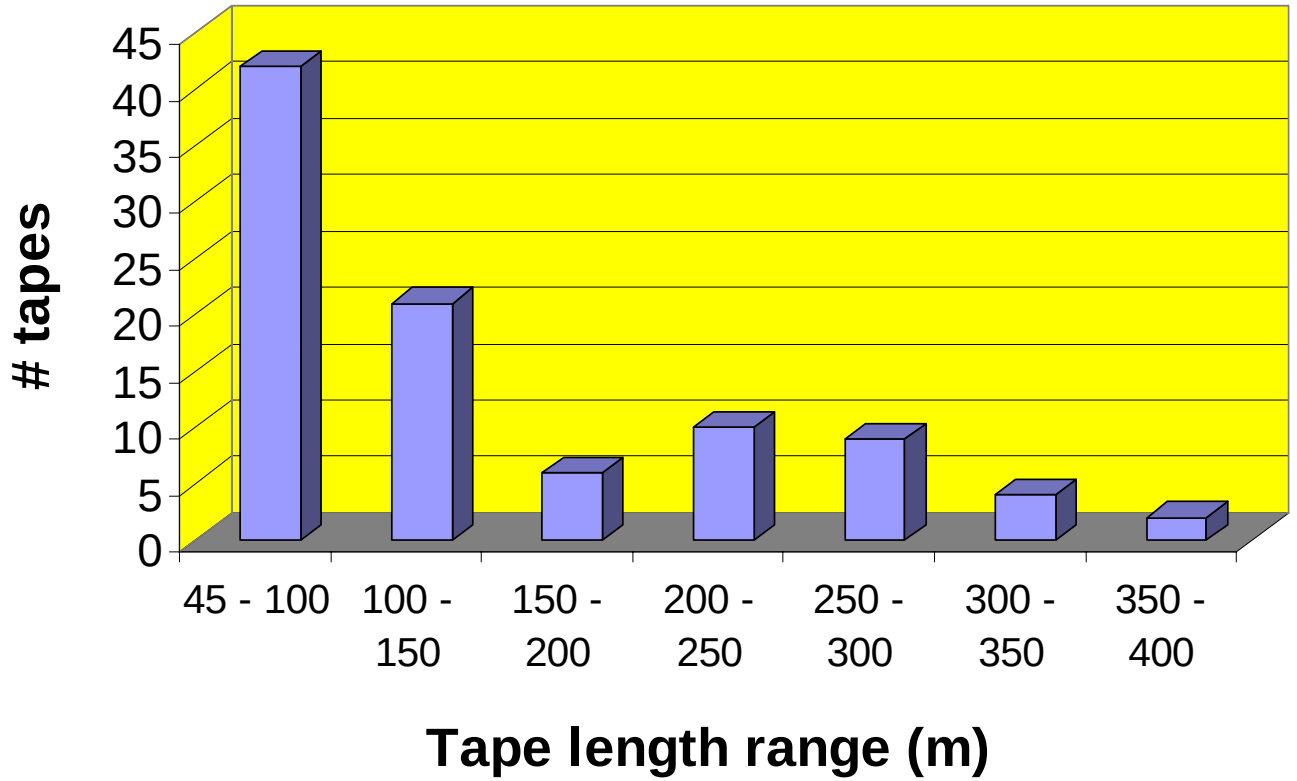
Ic = 100 A in a 4 mm wide 2G conductor over 270 m !

Je = 26.3 kA/cm^2 (for a 20 micron surround stabilizer i.e. 40 micron total)

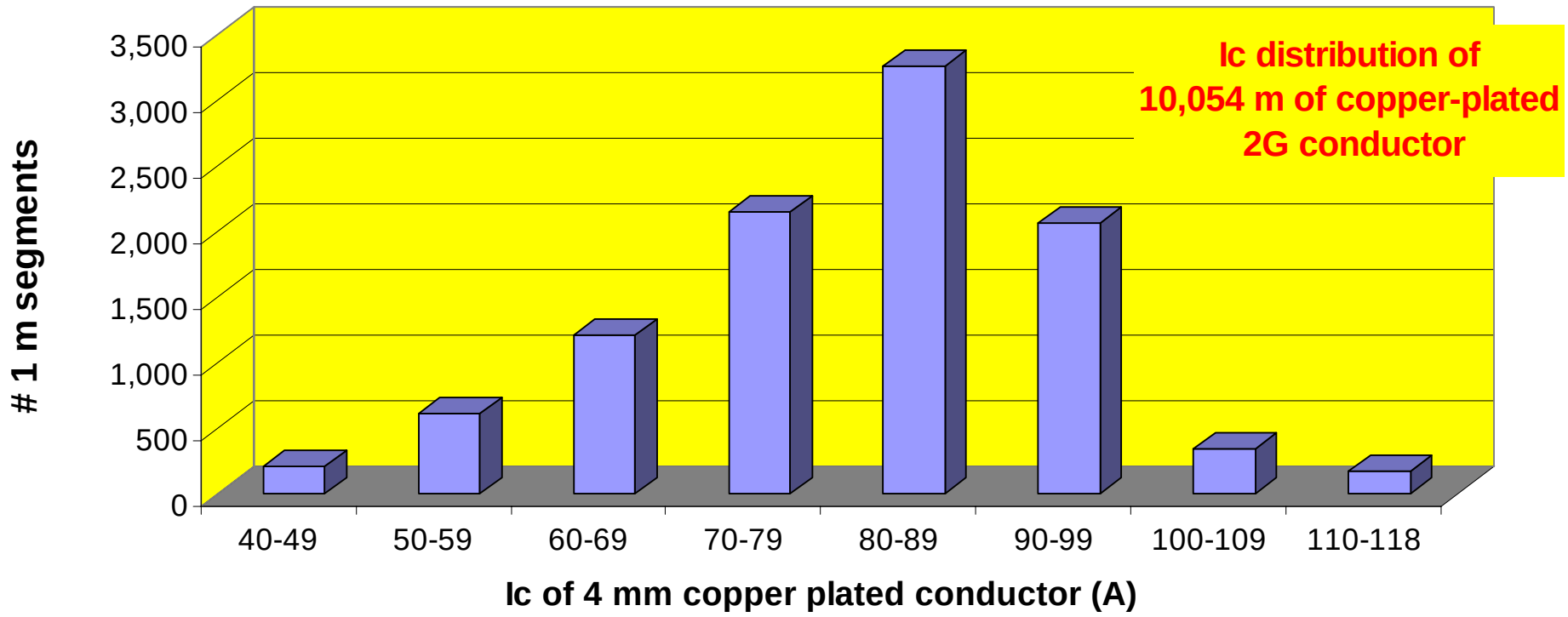
compared to a **1G Je of 13 kA/cm^2 to 17 kA/cm^2**

More than 12,000 m of qualified 4 mm slit tape produced by end of July for Albany Cable Project

- Piece length required = 42.4 m; Total length required = 9,700 m
- 55% of tapes in inventory > 100 m piece length
- 27% of tapes in inventory > 200 m piece length



Oct. 06: Completed electroplating of copper stabilizer on 12,000 m and subsequent Ic testing*



Average transport critical current of final product = 81 A

80 % of segments have Ic > 70 A, 58% have Ic > 80 A, 26% have Ic > 90 A

- Hermeticity tests on 10,000 m of final product are underway
- Tapes are being prepared for shipment of 225 individual spools each with ~ 43 m to Sumitomo Electric to construct a 35 m 2G cable

*meter-by-meter Ic & n-value testing

Next goal: Price competitiveness of 2G

2G conductors have been produced in long lengths with excellent performance and delivery of 10,000 m from the first volume Pilot Production is very imminent.

However, at ~ $ 600 to $1,200/kA-m, the price of 2G conductor is still at least 5 times higher than that of 1G

2G has to be cost competitive with 1G within the next 2 years in order to be used in the next round of various device prototype projects.

- Manufacturing improvements
  - Yield: Reliability of Equipment
  - Raw material cost
  - Effective labor use: 3 shift operation can yield 2 times output as 2-shift operation
- Technology improvements

Attribute	1G	2G (Aug 06)	2G goal (June 08)
Piece length (m)	1,500	300	1,000
Ic (A) in 4 mm over long lengths	200	100	200
Capacity (km/year)	< 1,000	350	1,000

Our focus since August 06 has been to further increase ***Ic, throughput, & piece lengths***

Goal 1: Higher Currents

Pathway to lower cost 2G

HTS Solutions for a New Dimension in Power

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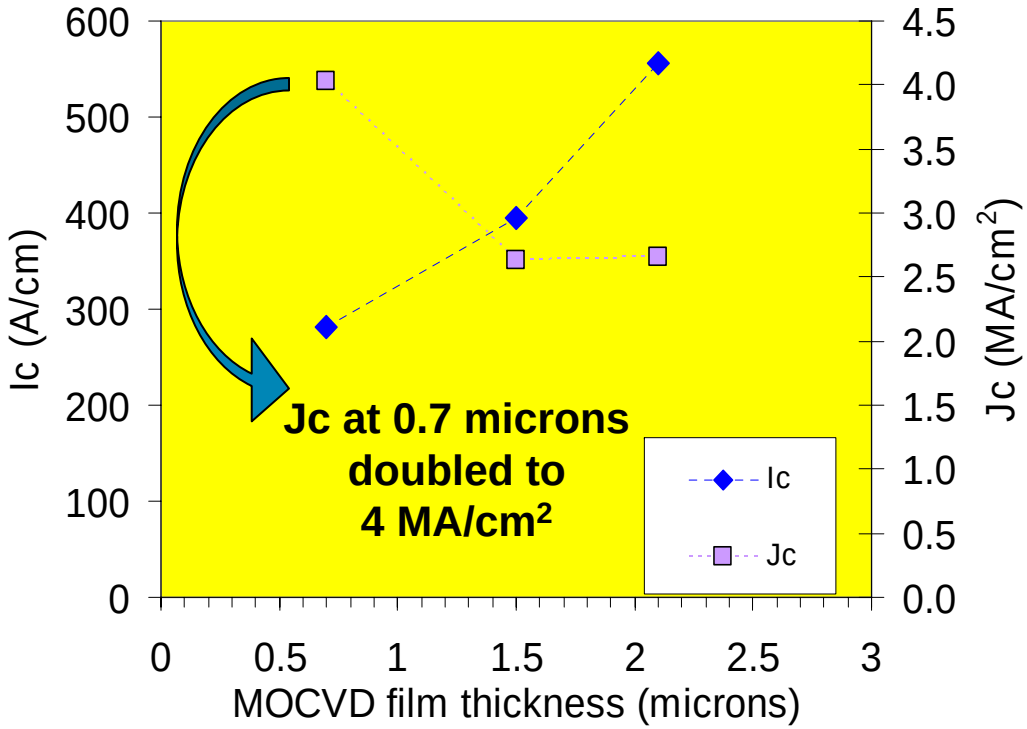
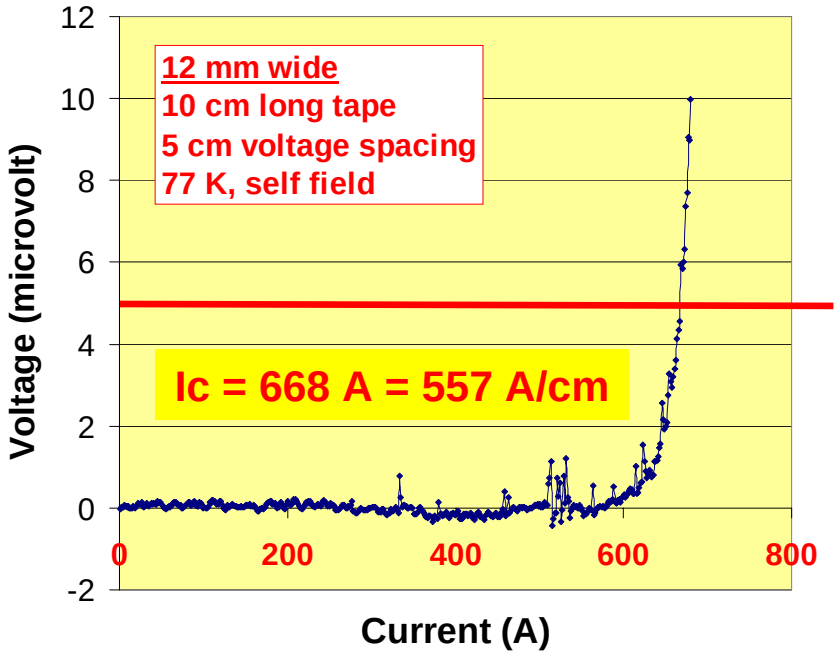
May 2006: 550+ A/cm demonstrated in *continuous, reel-to-reel processed* MOCVD conductor

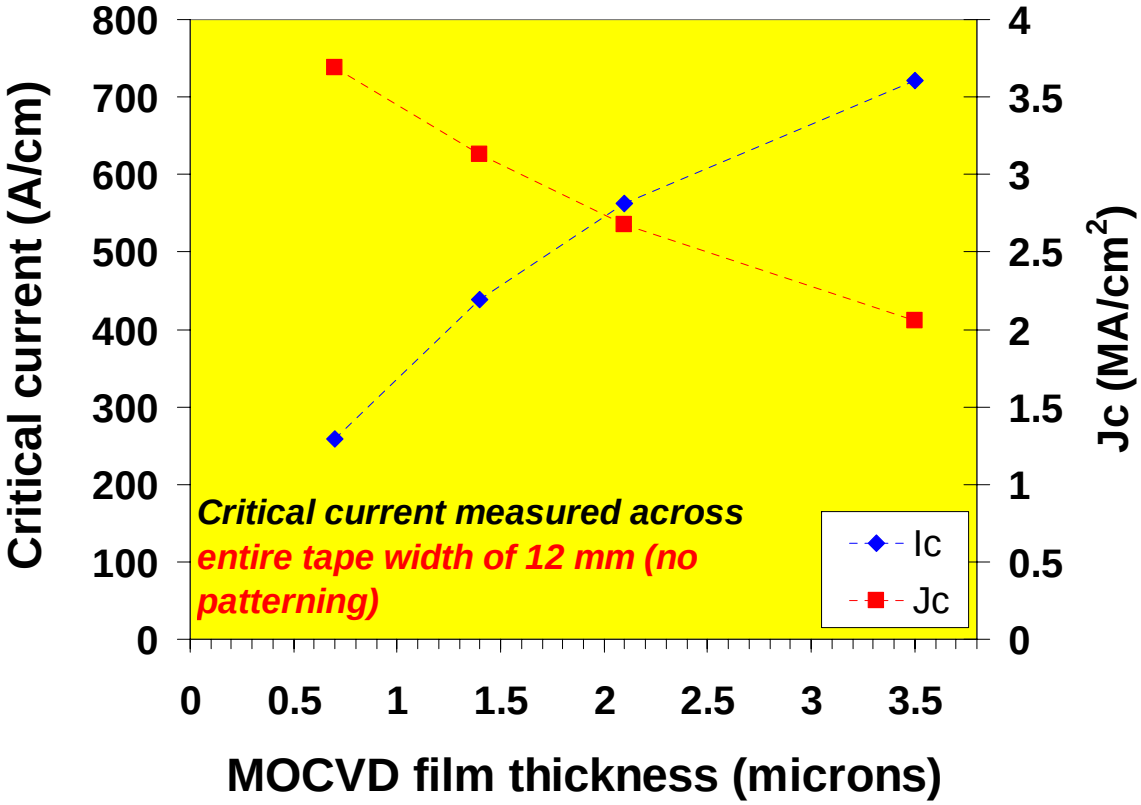
Thick films are fabricated in a multipass approach by MOCVD, i.e. layers of HTS films are deposited one over other in distinct runs

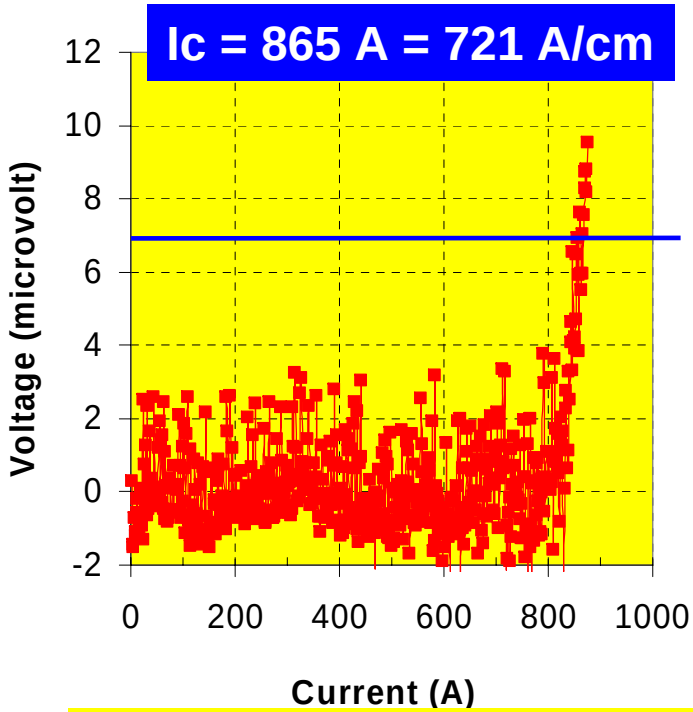




In a 2.1 micron film made in 3 passes, achieved Ic of **557 A/cm (Jc = 2.65 MA/cm²)** over 12 mm wide, 10 cm long tape.

Oct. 2006: Critical current of 721 A/cm achieved over 7 cm of *continuous, reel-to-reel processed* MOCVD conductor





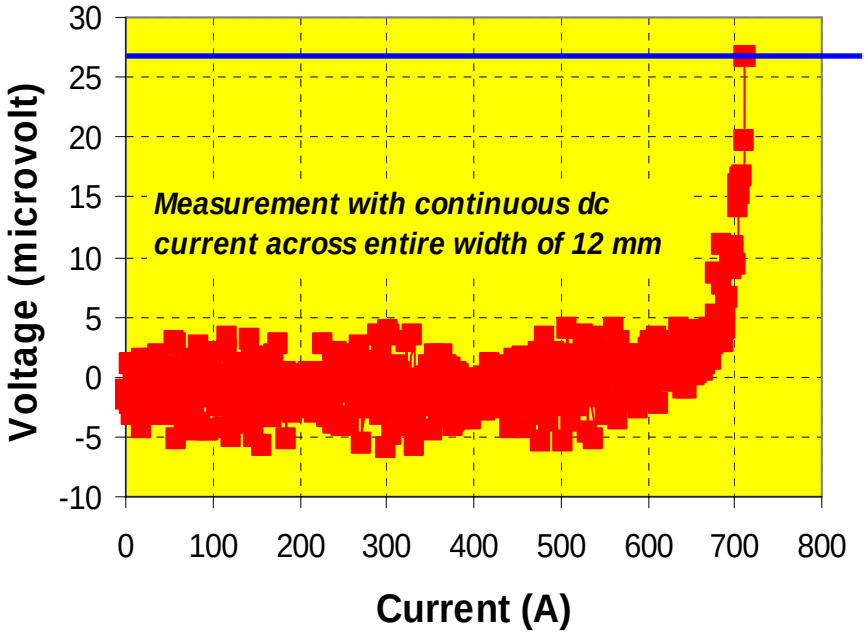
Ic measurement using continuous dc current (no pulsed current) across entire tape width of 12 mm No patterning

In a 3.5 micron film made in 5 passes, achieved Ic of **721 A/cm** **(Jc = 2.06 MA/cm²)** over 12 mm wide, 7 cm long tape.

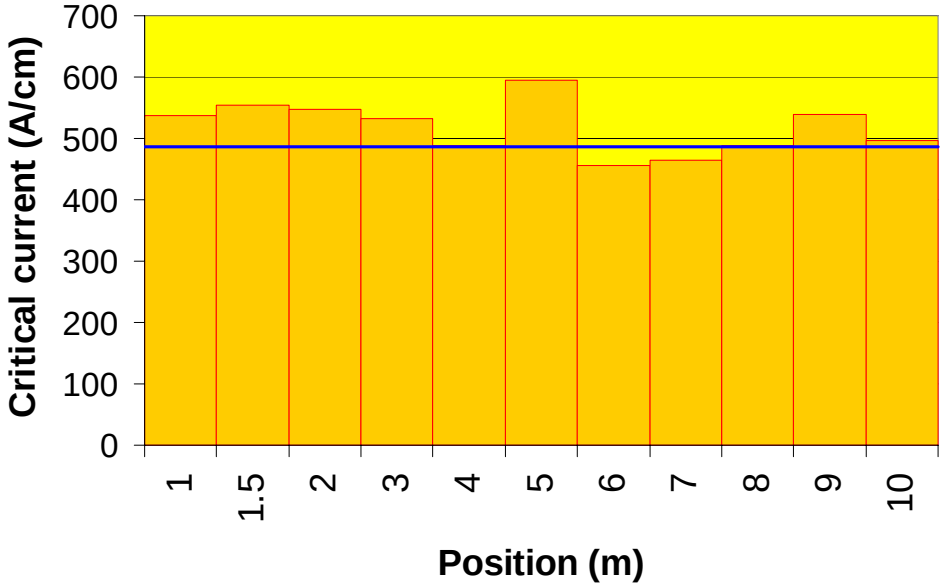
Oct. 2006: Scaled up thick film MOCVD process to longer lengths with high currents

4-pass MOCVD process for a total HTS film thickness of 2.8 microns

Over 1 m length,
714 A at 0.27 μV/cm = 595 A/cm



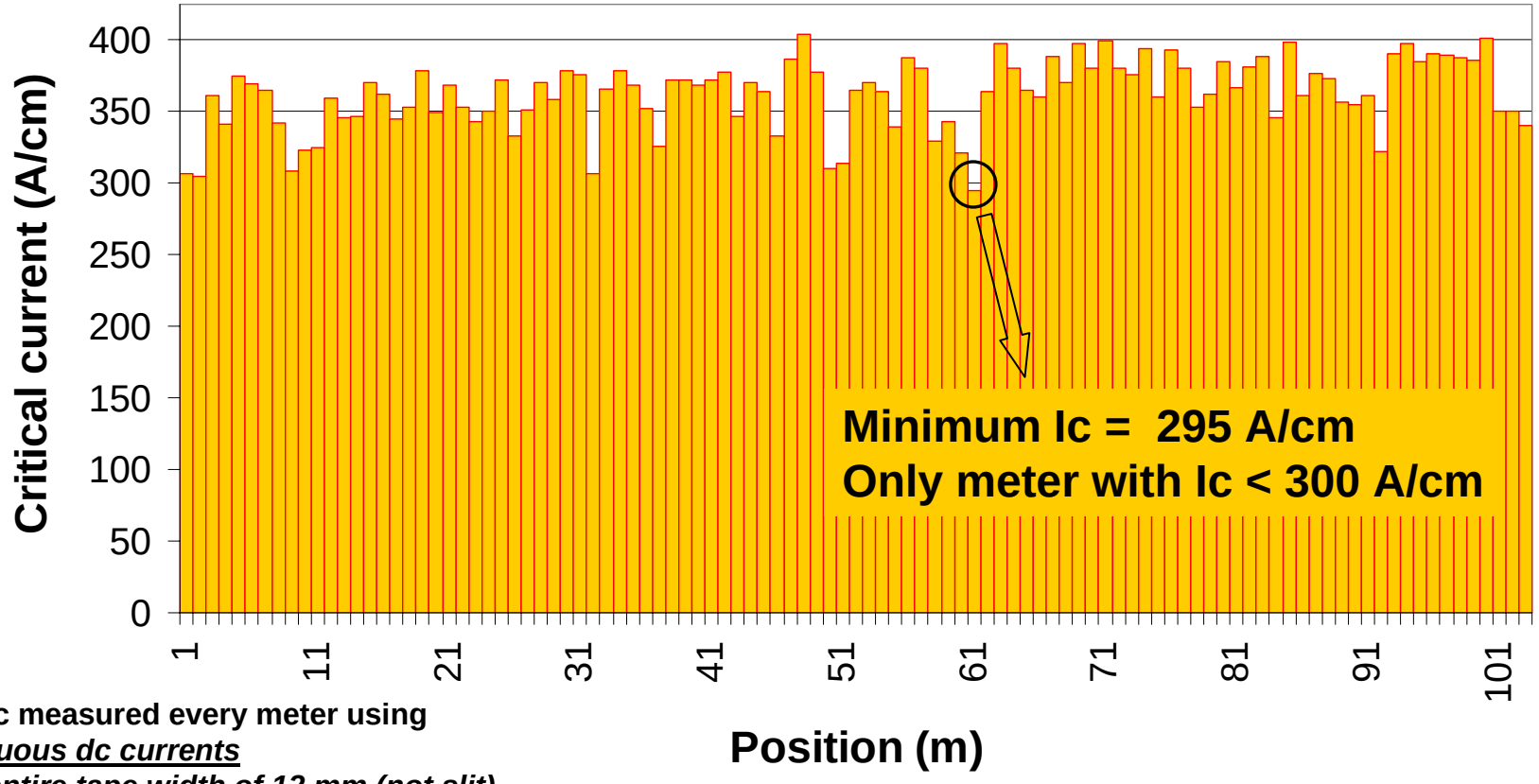
Over 11.1 m length,
End-to-end Ic of 583 A at 1 μV/cm = 486 A/cm



Demonstration of the feasibility of 200 A in a 4 mm wide tape in 10+ m lengths

Oct. 2006: 300 A/cm class conductor produced in 100+m lengths

1.4 micron thick HTS film produced in Research MOCVD system



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

Minimum Ic over 103 m = 295 A/cm

(End-to-end Ic over 103 m will be > 300 A/cm)

Standard deviation = 6.8%

Average Ic = 362 A/cm

Maximum Ic = 404 A/cm

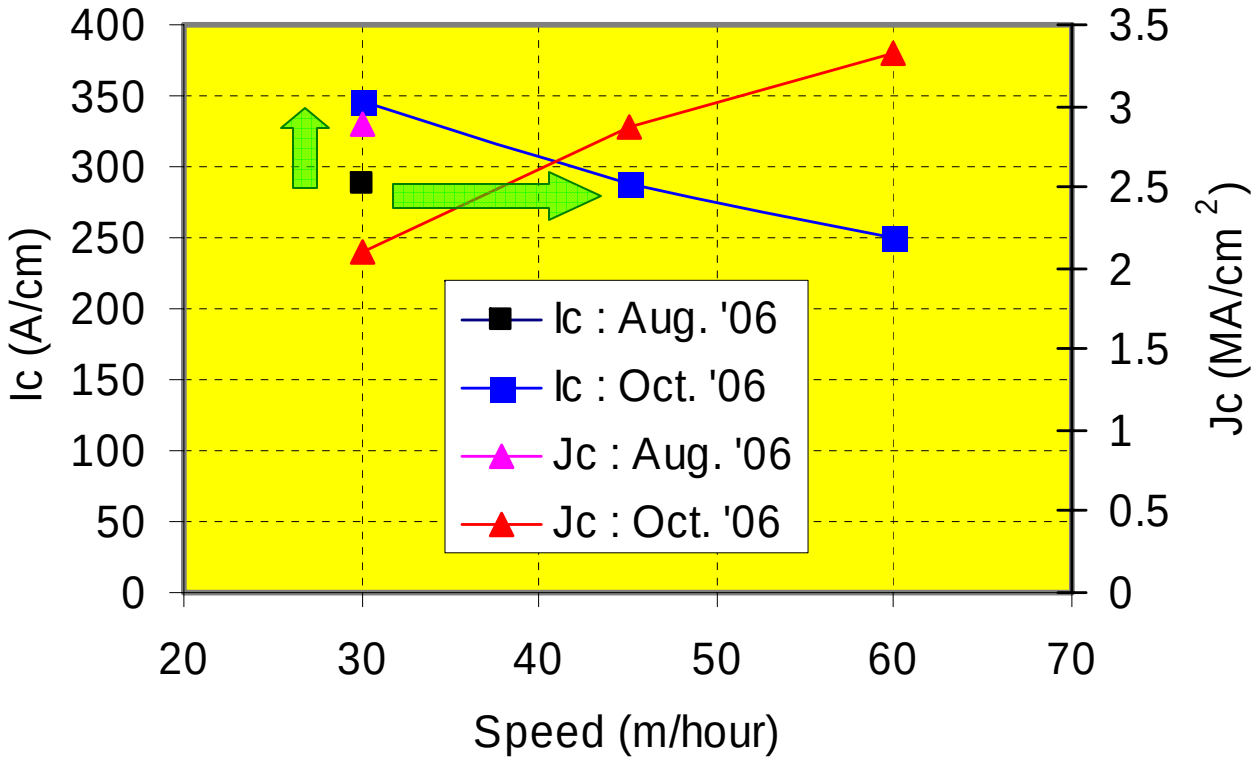
Goal 2: Higher Speeds

Pathway to lower cost 2G

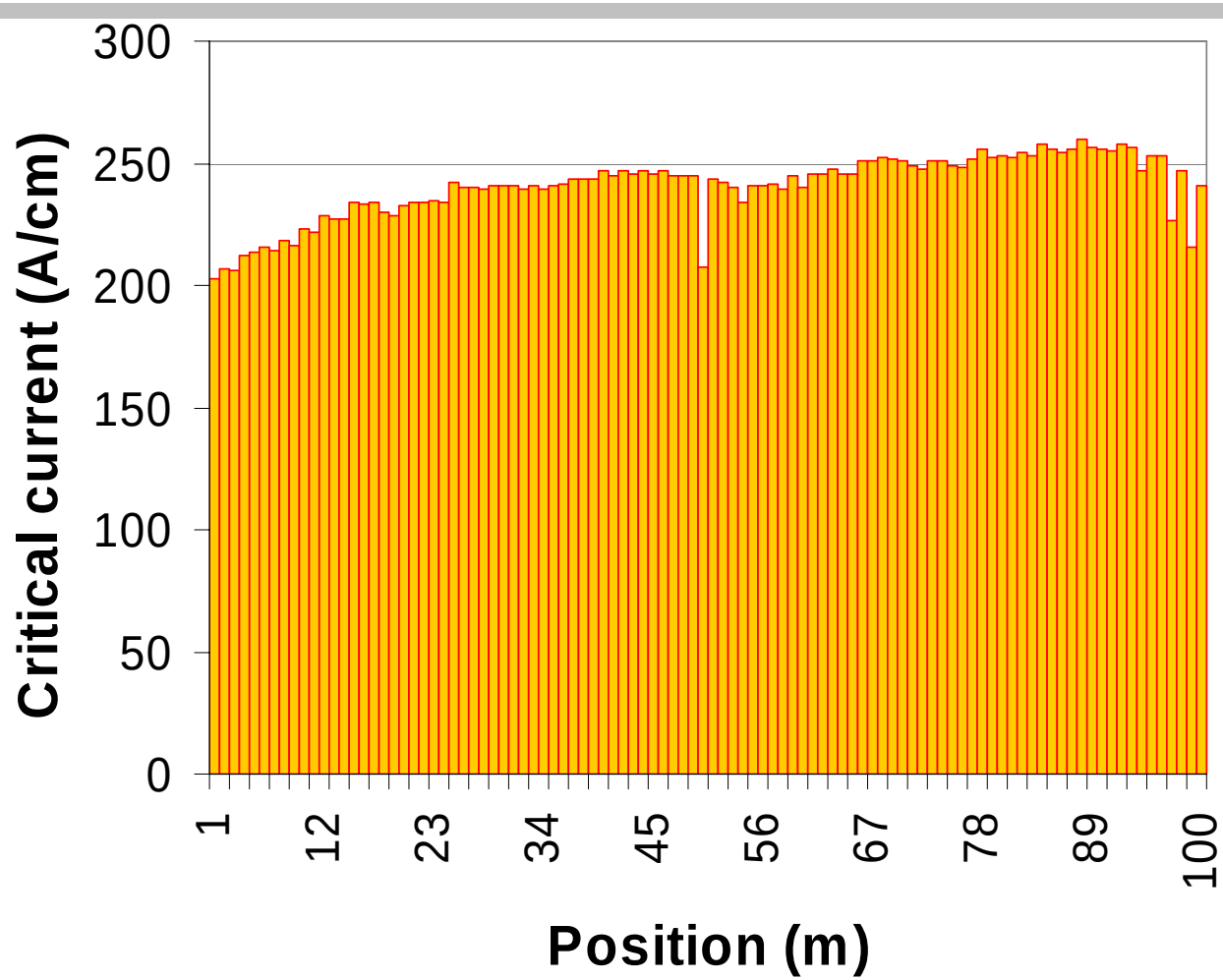
Oct. 06: MOCVD tape speed increased by 50% to 45 m/h of 12 mm wide tape (single pass)

MOCVD precursor flow increased by **33%** to achieve 1 micron thick YBCO films at 45 m/h compared to at 30 m/h in Aug 06. *Same Ic of ~ 285 A/cm achieved at 45 m/h compared to 30 m/h in Aug 06.*

With higher precursor flow, 1.65 micron thick films produced at 30 m/h to achieve a higher Ic of 340 A/cm.



Oct. 06: 100 m lengths demonstrated with good Ic at 50% higher MOCVD tape speed



Process	Speed of 12 mm tape (m/h)
IBAD MgO	65
Homo-epi MgO	34
LMO	40
MOCVD	45

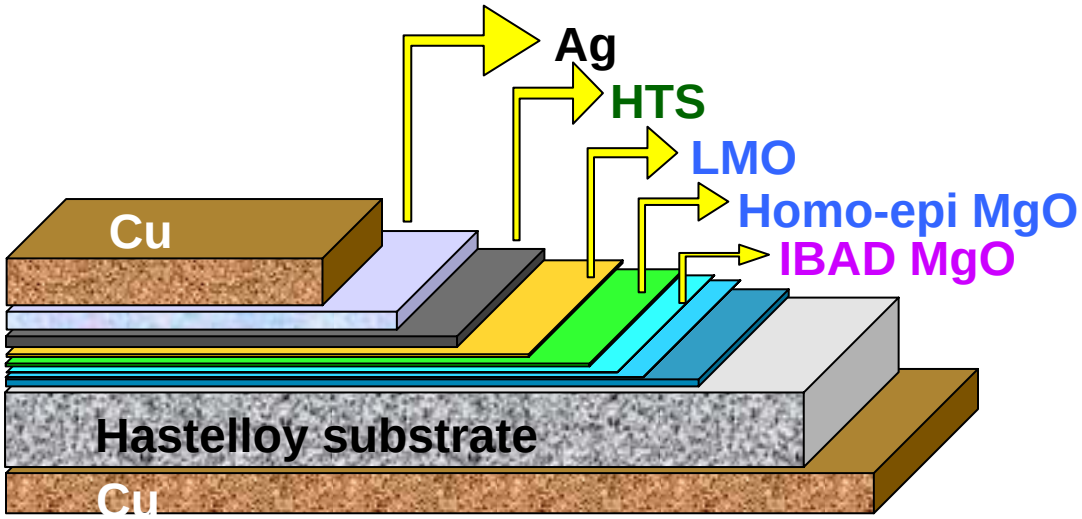
Minimum Ic of 202 A/cm over 100 m in MOCVD tape processed at 45 m/h in a single pass (film thickness of 1 micron)

IBAD MgO & Buffer processing speeds were doubled in the last two months

Using reactive sputtering of metal Mg target instead of an oxide target, deposition rate in IBAD MgO process was increased by 55%. Assist-ion beam profile was re-optimized to match the higher deposition rate profile.

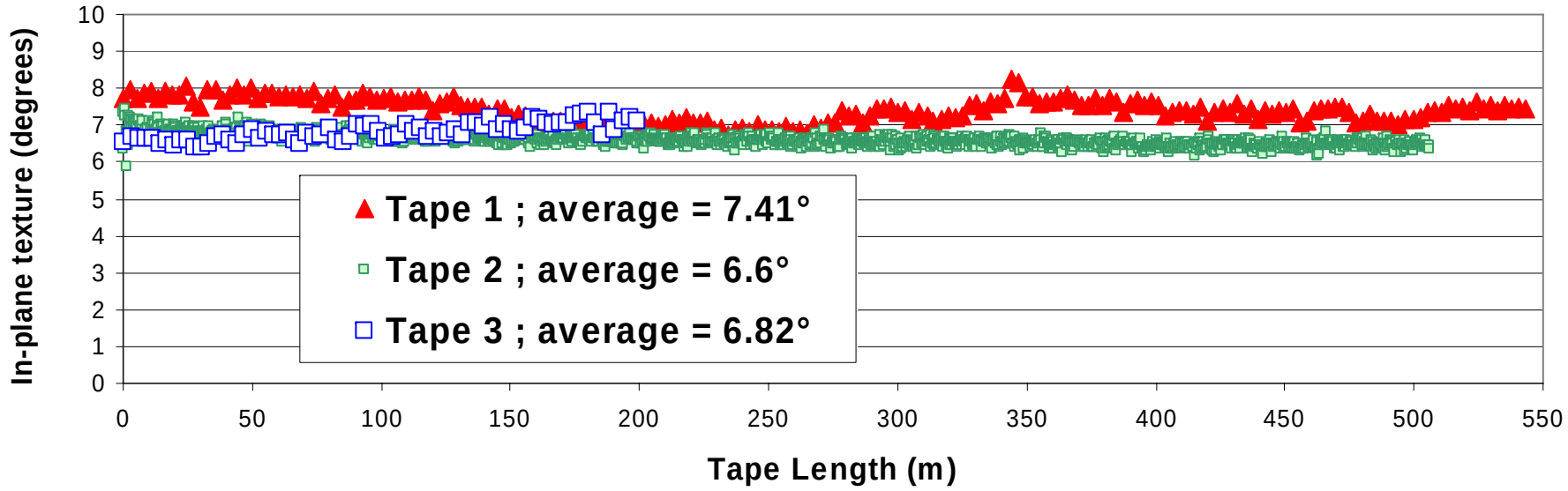
Speed of IBAD MgO process was increased from 65 m/h to 120 m/h for 12 mm wide tape.

Higher power levels was used in reactive sputtering of **homo-epi MgO to increase speed from 34 - 40 m/h to 80 m/h of 12 mm wide tape.**



Tape tracks used in helix tape handling system was increased and film thickness was decreased by 25% to **increase speed of LMO process from 40 m/h to 80 m/h.**

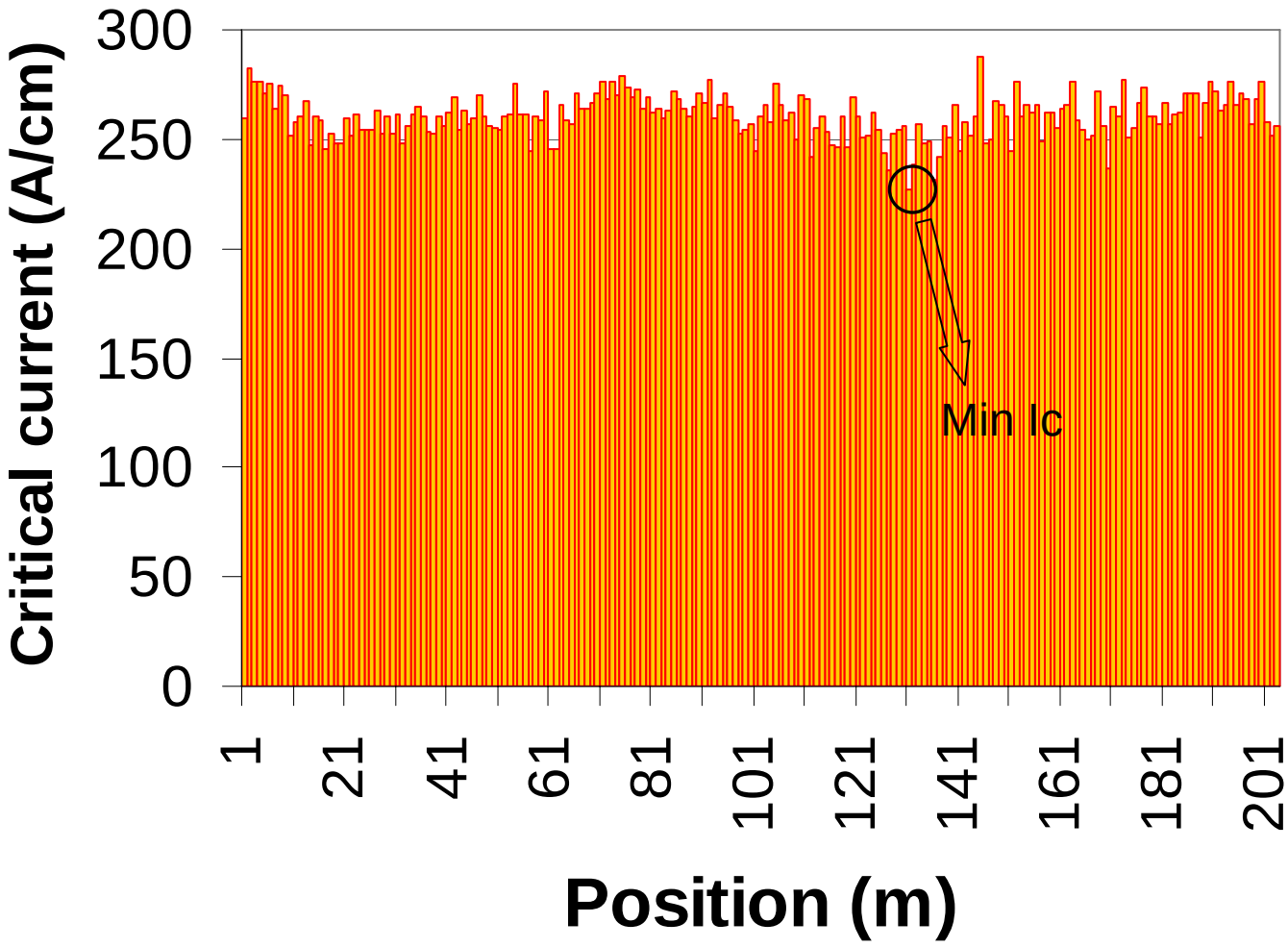
Excellent texture achieved in IBAD MgO & Buffer tapes produced at 2x processing speeds



Tape	Length (m)	Production date	Linear Tape Speed (m/h)		
			IBAD MgO	Homo-epi MgO	LMO
1	543	Jun. 06	65	34	40
2	506	Sept. 06	65	60	60
3	200	Oct. 06	120	80	80

Albany Cable Project Production

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



Process	Speed of 12 mm tape (m/h)
IBAD MgO	120
Homo-epi MgO	82
LMO	82
MOCVD	45

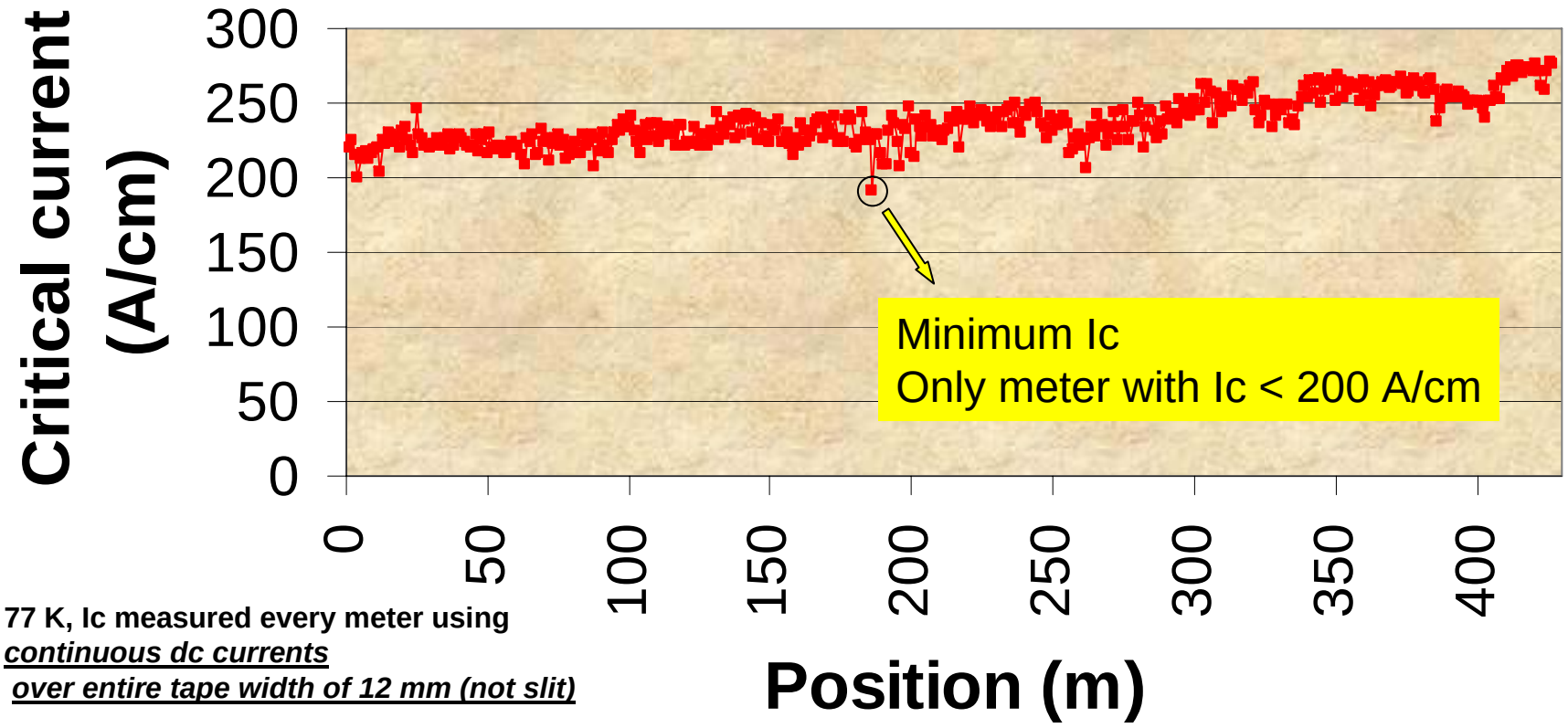
Minimum Ic = 227 A/cm over 203 m

Uniformity over 203 m = 3.7%

Goal 3: Longer Lengths

Pathway to lower cost 2G

Longer lengths (Oct. 06): 427 m produced by MOCVD at the higher speed of 45 m/h in 1 pass



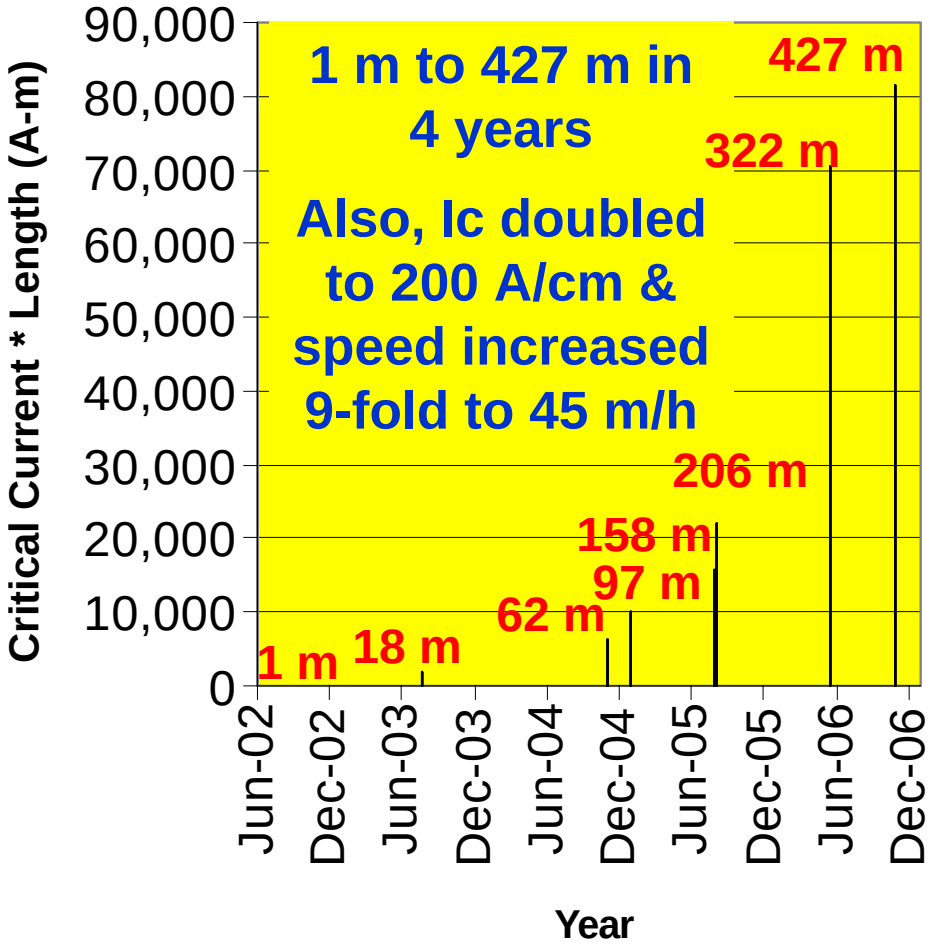
77 K, Ic measured every meter using *continuous dc currents over entire tape width of 12 mm (not slit)*

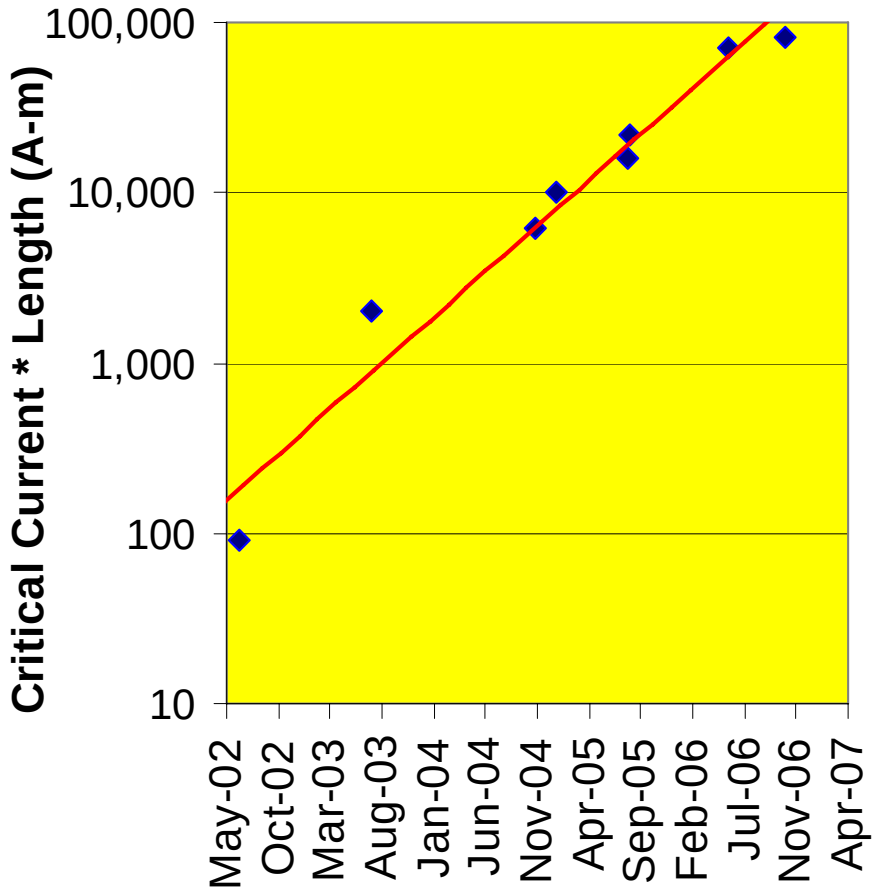
Minimum Ic = 191 A/cm over 427 m

Ic × Length = 81,550 A-m

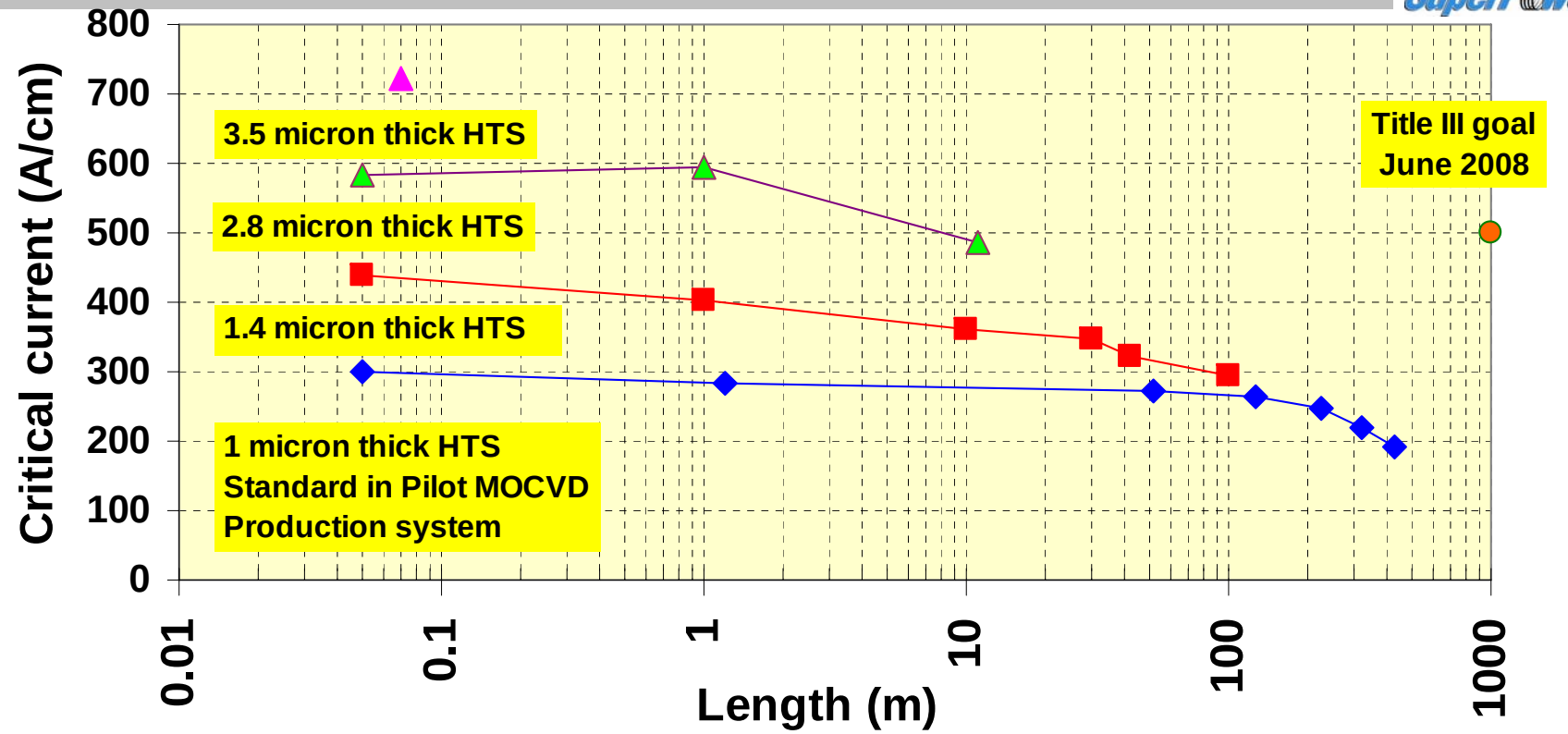
Higher Ic × Length achieved at 50% higher MOCVD speed

Significant progress in MOCVD scale-up in the last 4 years





Ic vs. Length summary shows progress being made both in Pilot Manufacturing of long lengths & technology development with shorter lengths



Next Steps:

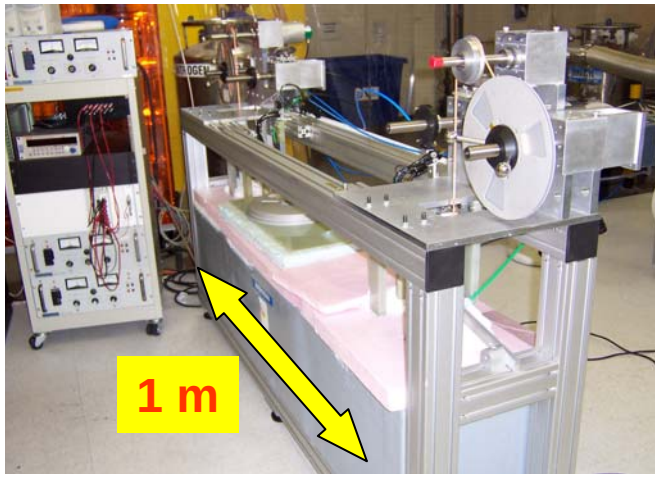
Manufacturing scale up to reach 500 m threshold & then 1000 m with Ic > 200 A/cm

Manufacturing improvements to raise Ic level of 400+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

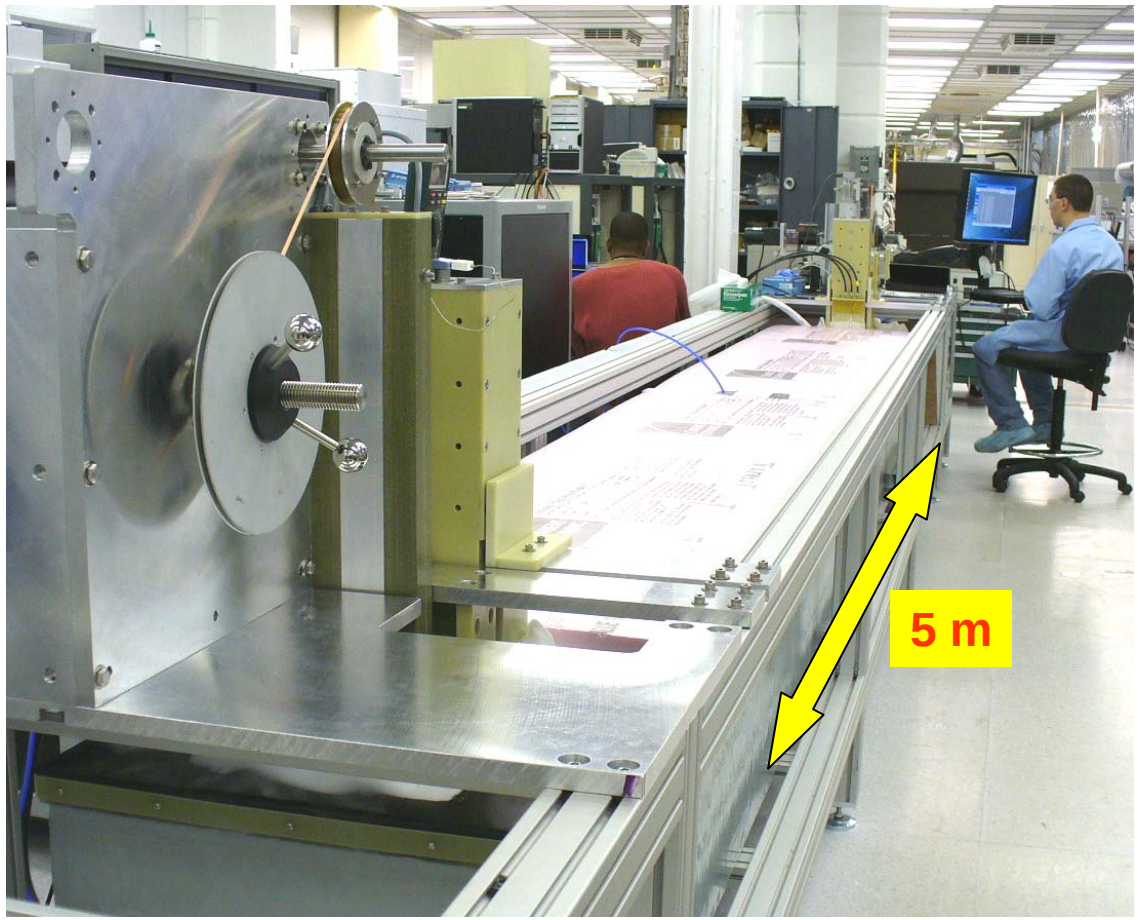
Testing speed enhanced to match speed of processing & longer production lengths

All our reported critical currents are by from I-V curve measurements using by standard transport technique with *continuous dc currents which give reliable Ic and n-value data.*



Meter-by-meter transport Ic measurements took 18 hours to completely test 427 m.

New 5 m transport Ic rig has been constructed. ***Measurement time for a 427 m long tape can be reduced to just 4 hours.***



Substantial improvements made in Ic & speed, & piece lengths of 2G conductors *in the last 2 months*

Attribute	2005	Aug 2006 (ASC)	Oct. 2006 (ISS)	Improvement after ASC 06
Ic (A/cm) – short, reel-to-reel processed	407	557	**721**	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)	1	65	**120**	85%
Buffer speed* (m/h)	n/a	40	**80**	100%
MOCVD speed* (m/h)	5	30	**45**	50%
Ic over 200 m at stated speed	106	246	**227**	**Same Ic level with 50 – 100% higher speeds in all processes**
Ic × L (A-m)	22,000	70,520	**81,550**	100 m longer

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

*12 mm wide tape, single pass

2G conductor is now available in long lengths with excellent properties for prototype demonstrations

- Piece Lengths > 400 m
- Critical Current: 80 – 110 A in 4 mm widths
- Critical current uniformity: < 5%
- High throughput: IBAD – 120 m/h, Buffer – 80 m/h, YBCO – 45 m/h – all single pass of 12 mm wide tape
- Excellent joints, splices & solderability:
  - No degradation in Ic even when joint/splice was bend over 1” diameter and thermal cycled
  - Joint/splice resistance ~ 40 nohmcm^2
  - No problem with soldering to our 2G conductor
- Excellent mechanical & in-field properties: 1.1 T coil at 77 K, 2.4 T at 64 K
- Tested in cable : Two 1 m cables demonstrated with 4 mm wide 2G conductor
- High Power FCL assembly demonstrated: 90 kA prospective fault current limitation demonstrated with our 2G conductor
- Price: $ 600 – 1200/kA-m & dropping. Delivery of kilometers in 4 weeks