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Progress in Scale-up of 2G HTS Wire at SuperPower – Part I

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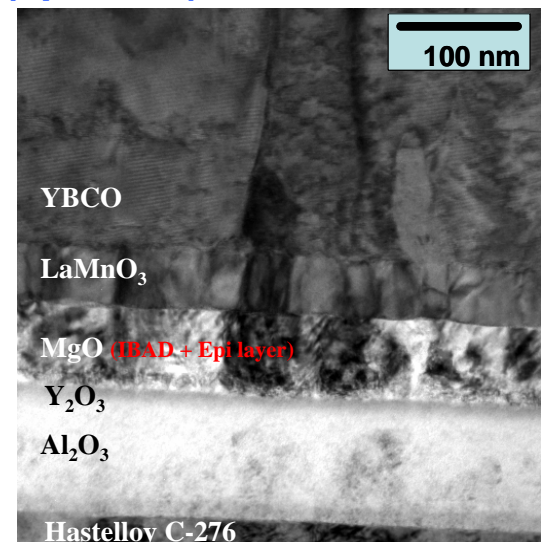
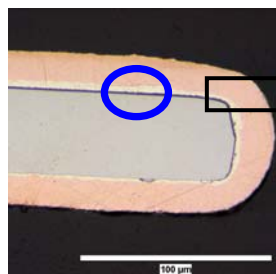
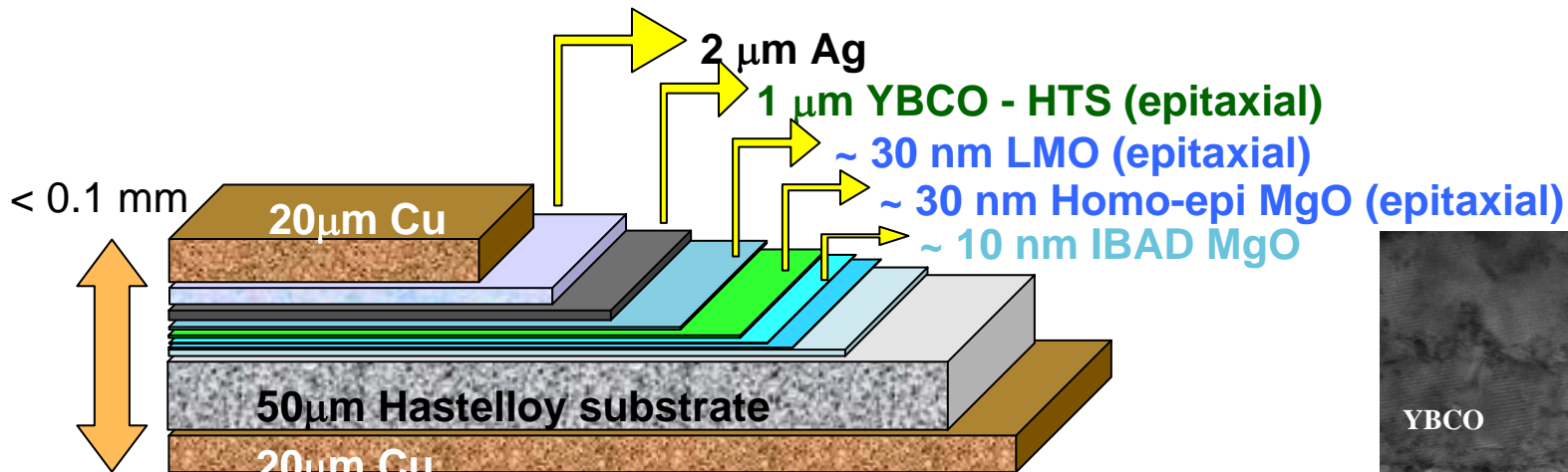
FY2008 Superconductivity for Electric Systems Peer Review, Arlington, VA, July 29 – 31, 2008



SuperPower, Inc. is a subsidiary of Royal Philips Electronics N.V.

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 provides the 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 facility has been operational since 2006

- Majority of investment already made for 1000 km/year capability



Major achievements in FY 2007

- World's first demonstration of pilot-scale manufacturing of 2G HTS wire
- Delivery of 16,000 m of 2G wire to customers including nearly 10,000 m wire delivery to Sumitomo Electric for the Albany HTS Cable project
- Crossed 100,000 amp-meter threshold in long-length wire performance
- Splice-free piece lengths > 500 m
- I_c over 1 meter nearly 600 A/cm
- Linear tape speeds of 180 to 360 m/h* in key deposition processes (IBAD, Buffer, MOCVD)
- I_c of 116 A/cm at 77 K, 1 T (perpendicular to wire) and 180 A/cm at 65 K, 3 T, (perpendicular to wire)
- Reduced wire price to \$65/m from 2006 price of \$100/m

*4mm wide equivalent

Our main objective in 2008 was to meet market requirements for 2G wire

- *Replace 1G wire in large HTS device demonstration projects in the U.S. and around the world*
 - Key requirements: Long length, availability, I_c , price
- *Supply large volumes of 2G wire to customers who have been waiting to take advantage of the superior performance of 2G*
 - Key requirements: Long length, I_c , additional performance metrics such as in-field I_c , ac losses, joints, insulation, FCL metrics ...
- *Advance towards medium-term goal of replacing copper wire in commercial HTS projects and challenge LTS wire in high-field applications*
 - Key requirements: Long length, availability, I_c , price, in-field performance and other additional performance metrics

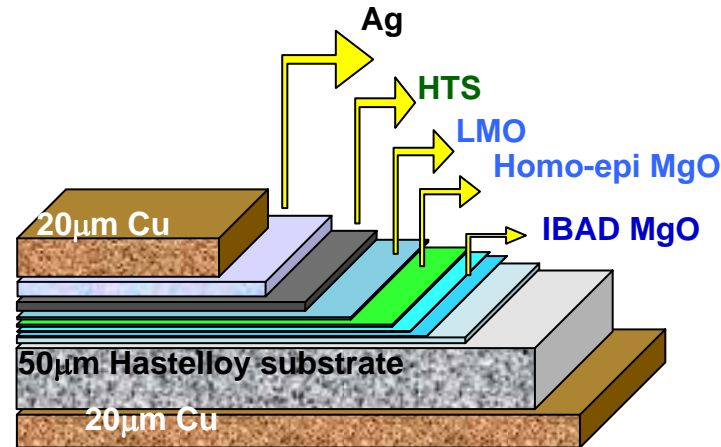
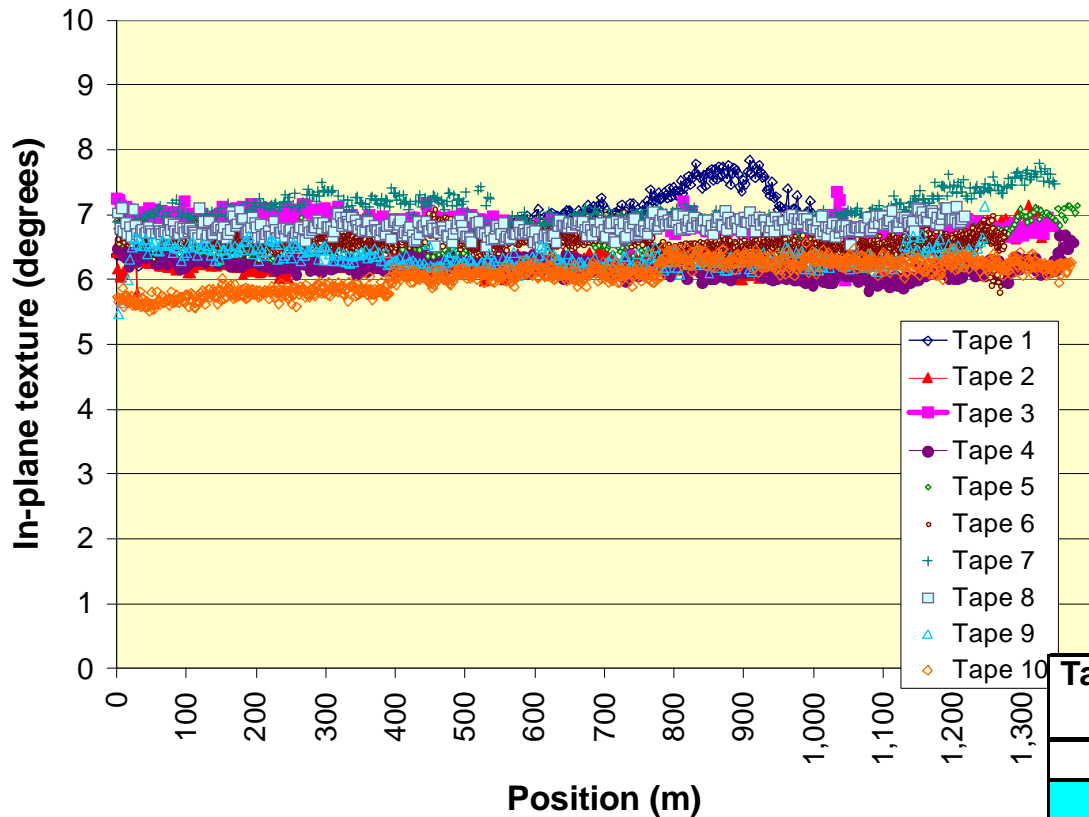
Goals for FY08 were very ambitious & aggressive, and focused towards market requirements

	2007 Review	Goals for FY08
Splice-free length	595 m, Ic of 173 A/cm	Reach 1,000 m, Ic of 200 A/cm
Critical current over long lengths	300 A/cm over 100 m in Research MOCVD system at linear speed of 15 m/h	Over 300 A/cm & then 500 A/cm over long lengths in Pilot MOCVD system at high tape speeds
Ic in short lengths	595 A/cm over 1 m	1000 A/cm
In-field performance	180 A/cm at 65 K and 3 T (perpendicular to wire)	300 A/cm at 65 K and 3 T (perpendicular to wire)
Capacity	Estimated at 720 km/year based on tape speed	Focus on <i>actual</i> capacity to be comparable with 1G
Customer delivery	Delivery of ~ 10,000 m for Albany cable project	Focus on meeting customer requirements worldwide
Wire cost	\$ 65/m for 4 mm	Focus on Yield, QC & Process Control to drive down wire cost

Outline of Presentation

- Long-length metric
- High-current metric
- In-field performance metric
- Meeting customer performance requirements for 2G wire
 - Ac losses
 - Joints
 - Insulation
 - FCL
- Wire deliveries to customers
- Reducing wire cost
 - Quality Control for high-yield manufacturing
- Production capacity metric
- Performance against plans
- Goals for FY09

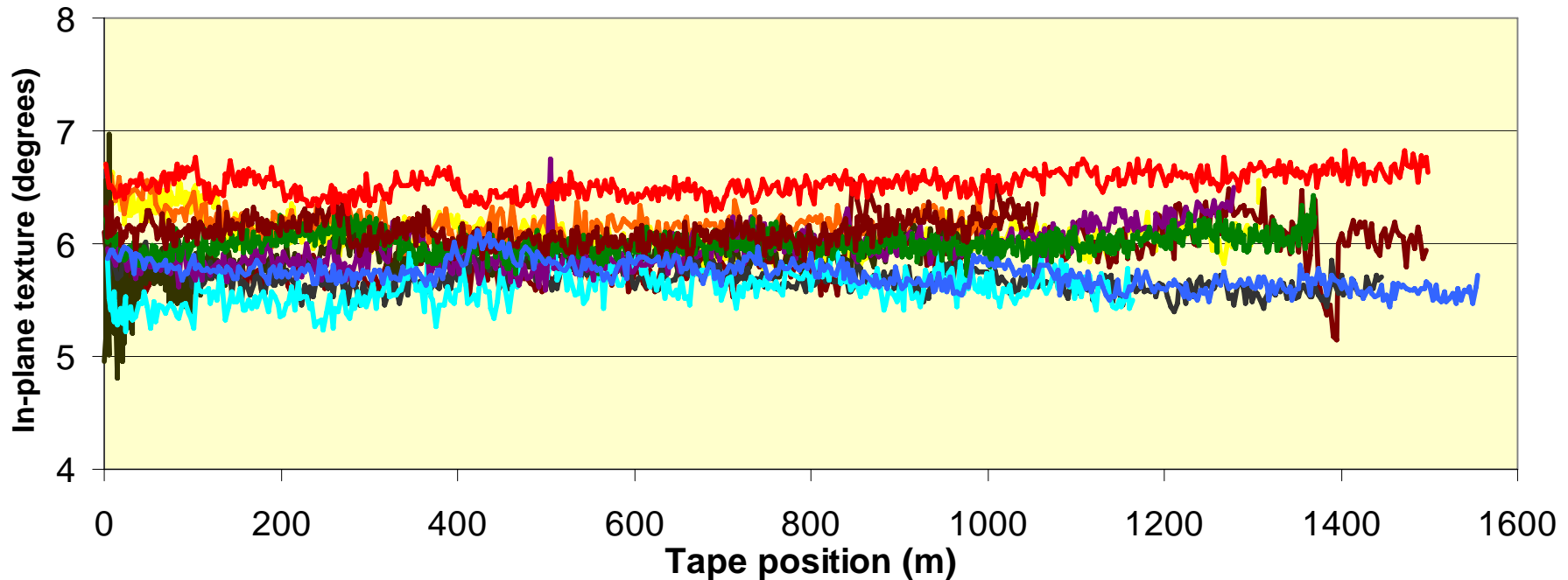
Long-length metric: Routine manufacturing of kilometer lengths of fully buffered tape



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%

As of Dec.07, 12 tapes with complete 5-layer buffer stack were produced in lengths of approximately 1,300 m with in-plane texture of 6–7 degrees and excellent uniformity of ~ 2%

Continued routine manufacturing of kilometer lengths of fully buffered tape in CY 2008

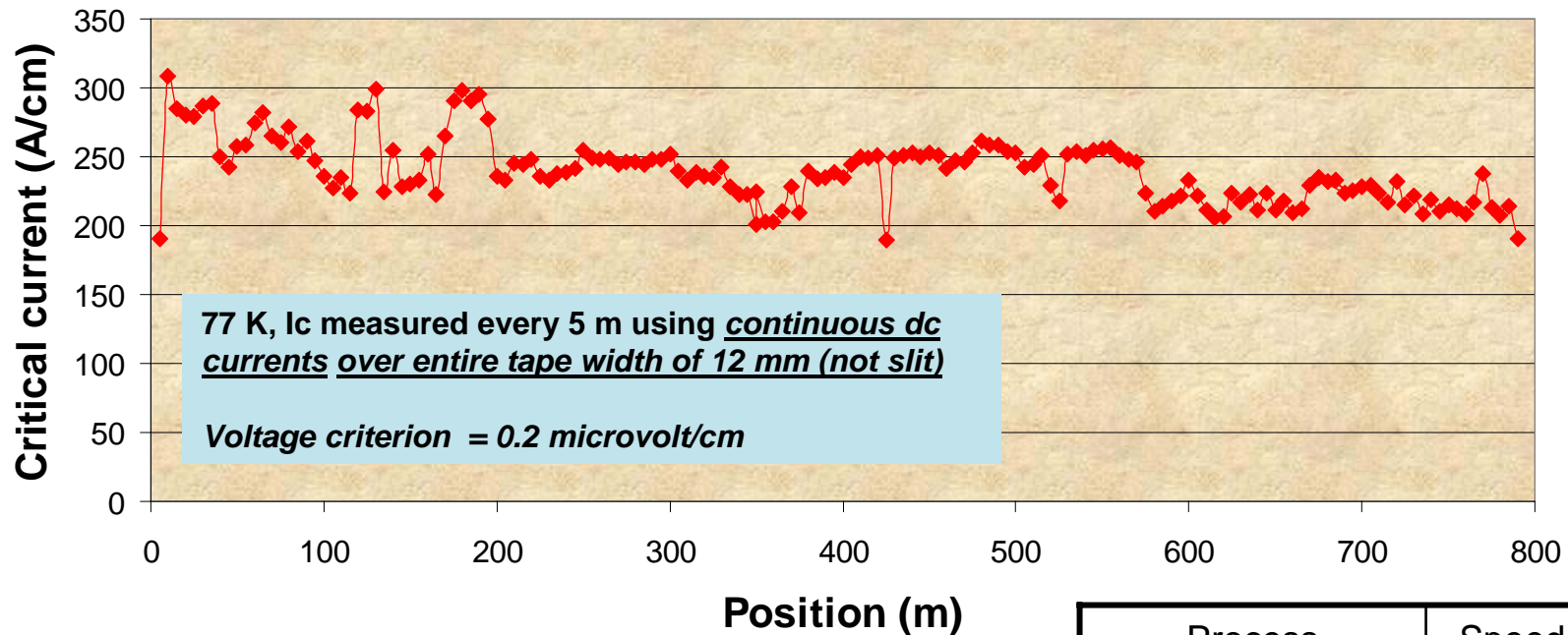


Over **35 tapes** with complete 5-layer buffer stack have been produced in lengths of 1,300 m to 1,500 with in-plane texture of 5 – 7 degrees and excellent uniformity of ~ 2%

Manufacture of kilometer-lengths of high quality, fully-buffered tape was routine throughout FY08

Targeting kilometer lengths of complete 2G wire

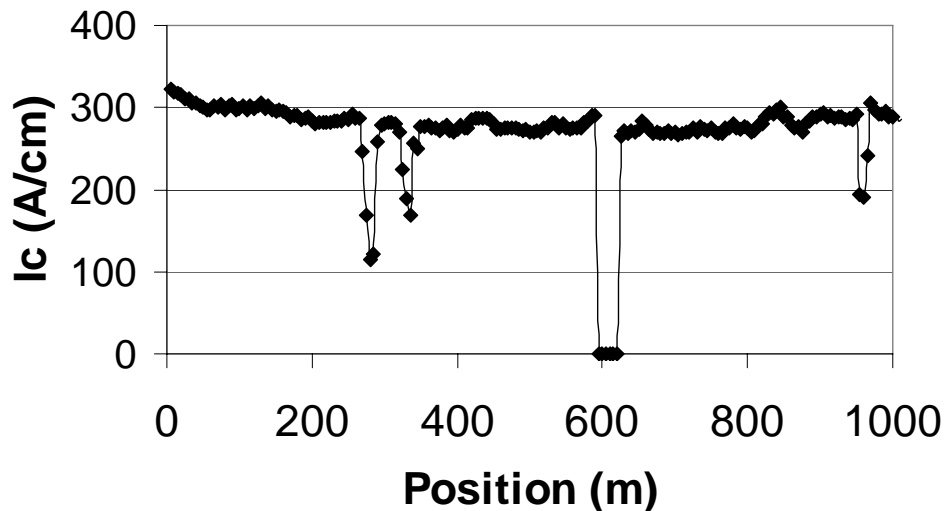
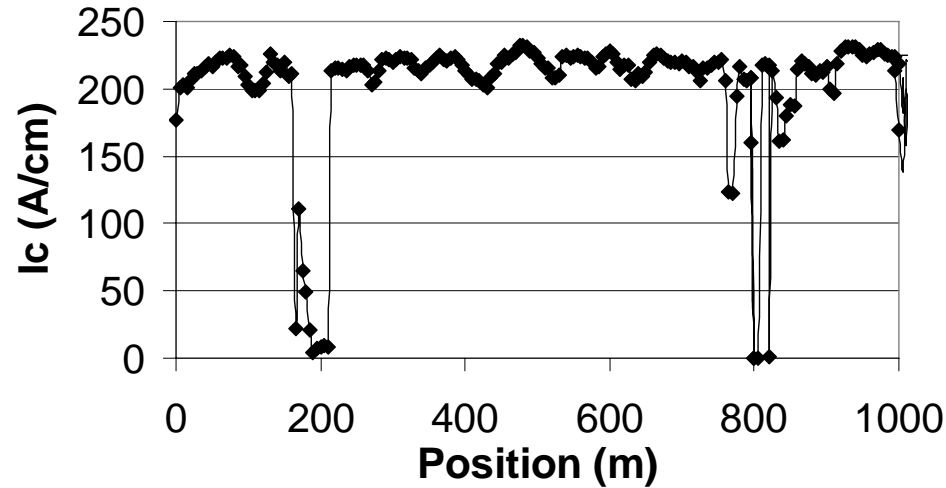
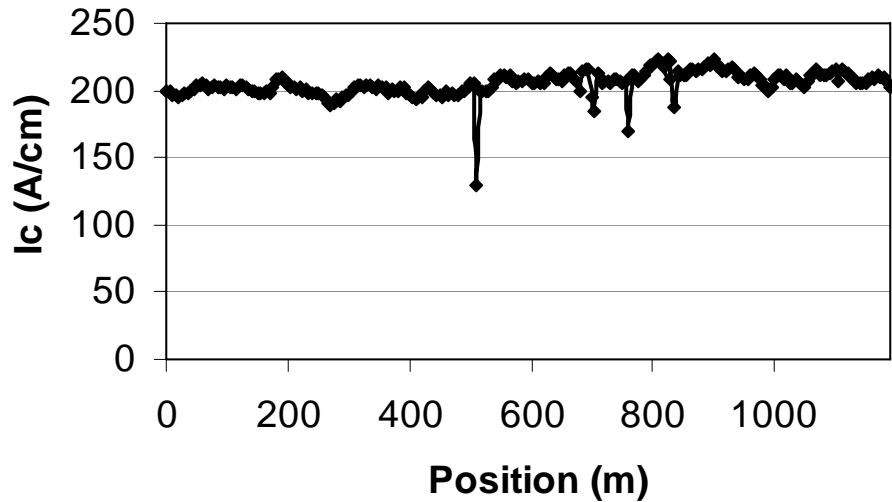
- In FY07, we reported first demonstration of 500+m long 2G wire: 595 m with minimum I_c of 173 A/cm corresponding to 102,950 A-m.
- Demonstrated 790 m long wire in FY08



- Minimum I_c = 190 A/cm over 790 m
- $I_c \times \text{Length}$ = 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

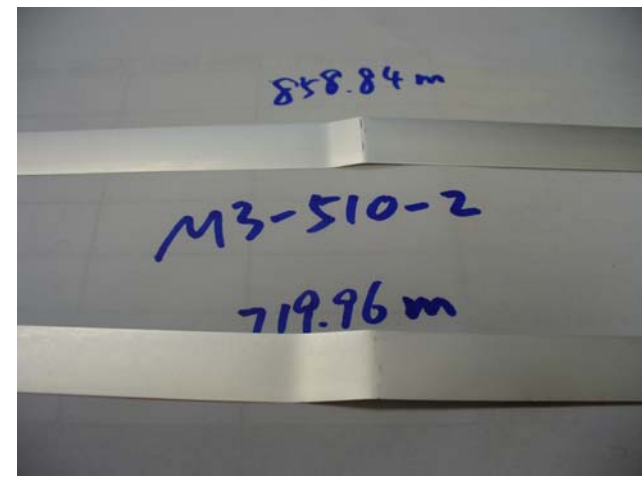
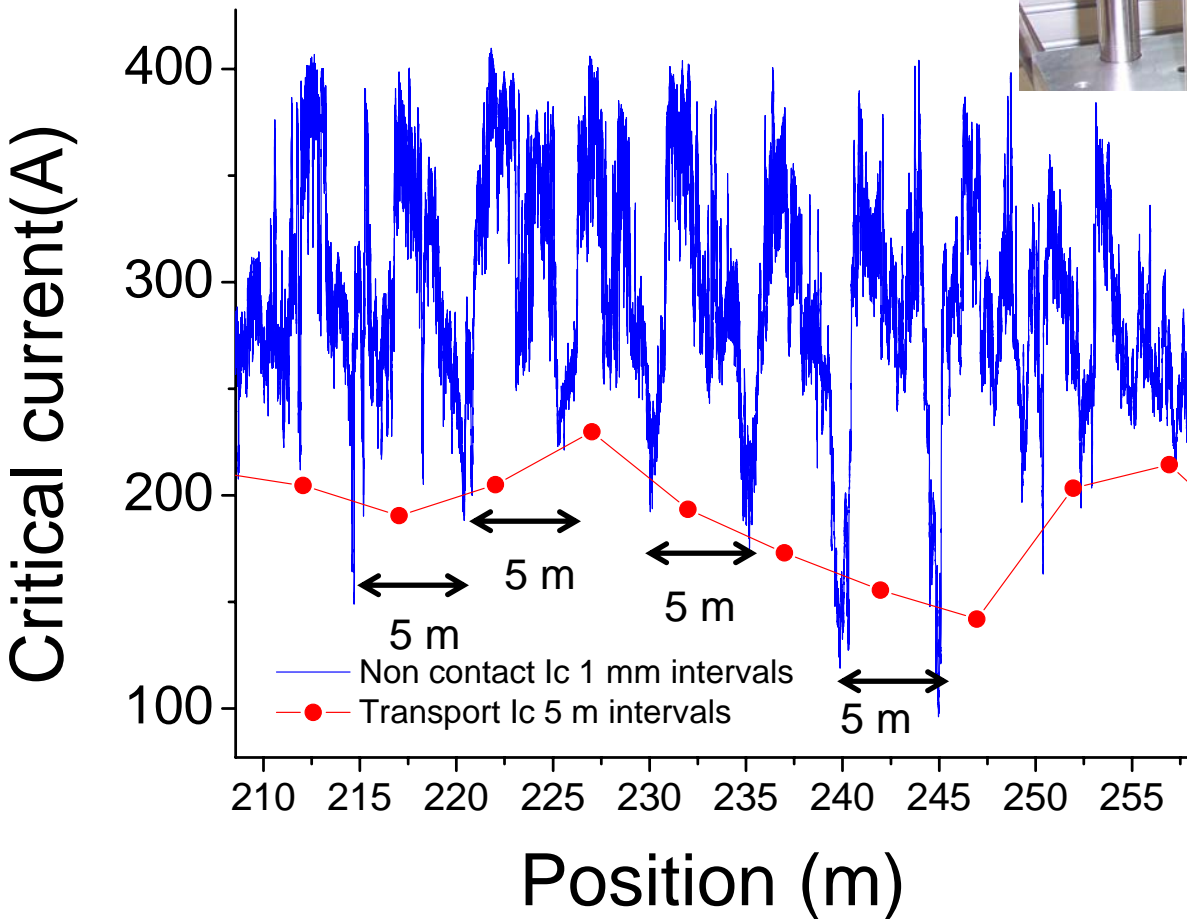
Challenges in fabrication of complete, kilometer long 2G wire



Kilometer lengths limited by a few bad regions in an otherwise uniform wire

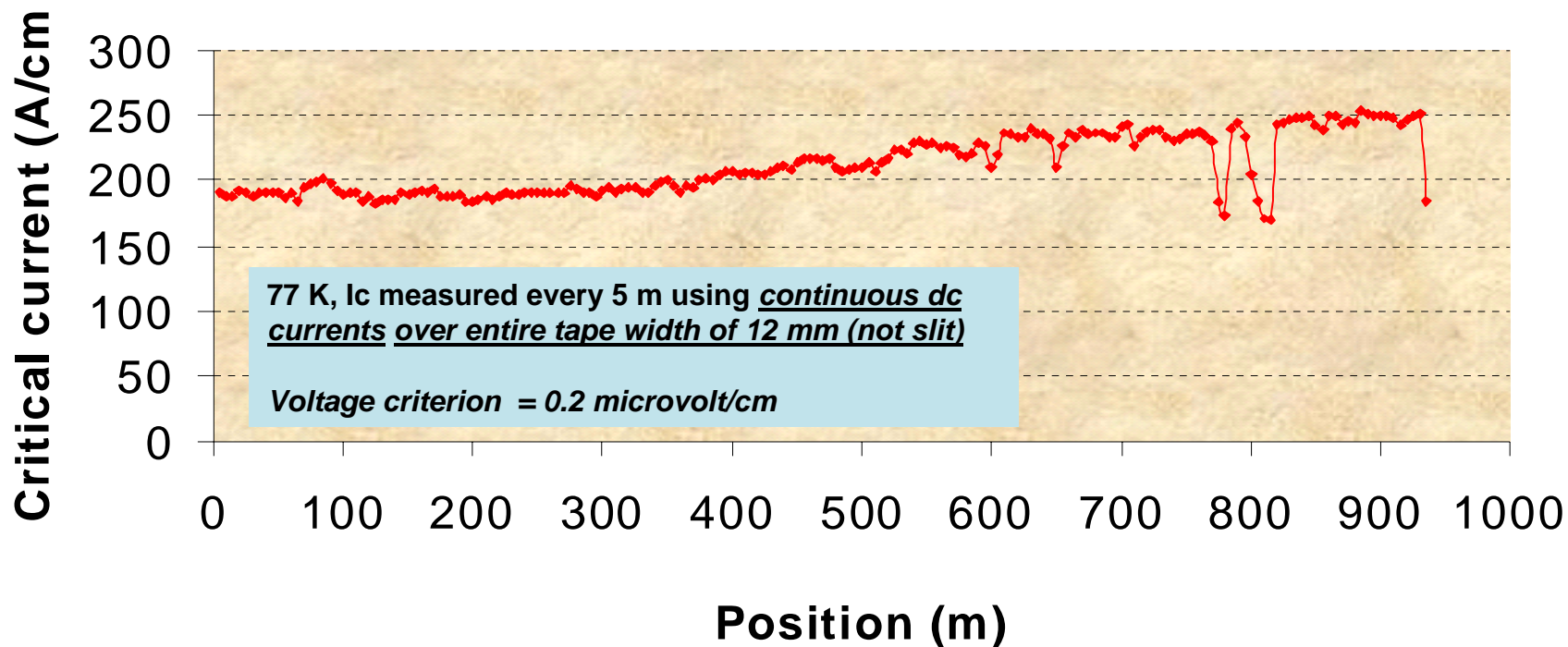
Major sources of problems responsible for Ic drops in kilometer tapes have been identified

Ic drop over a broad distance (few meters) traced to fluctuations in MOCVD process



Z-bend mechanical defects caused by sudden increase in tape tension result in sharp Ic drop (few mm)

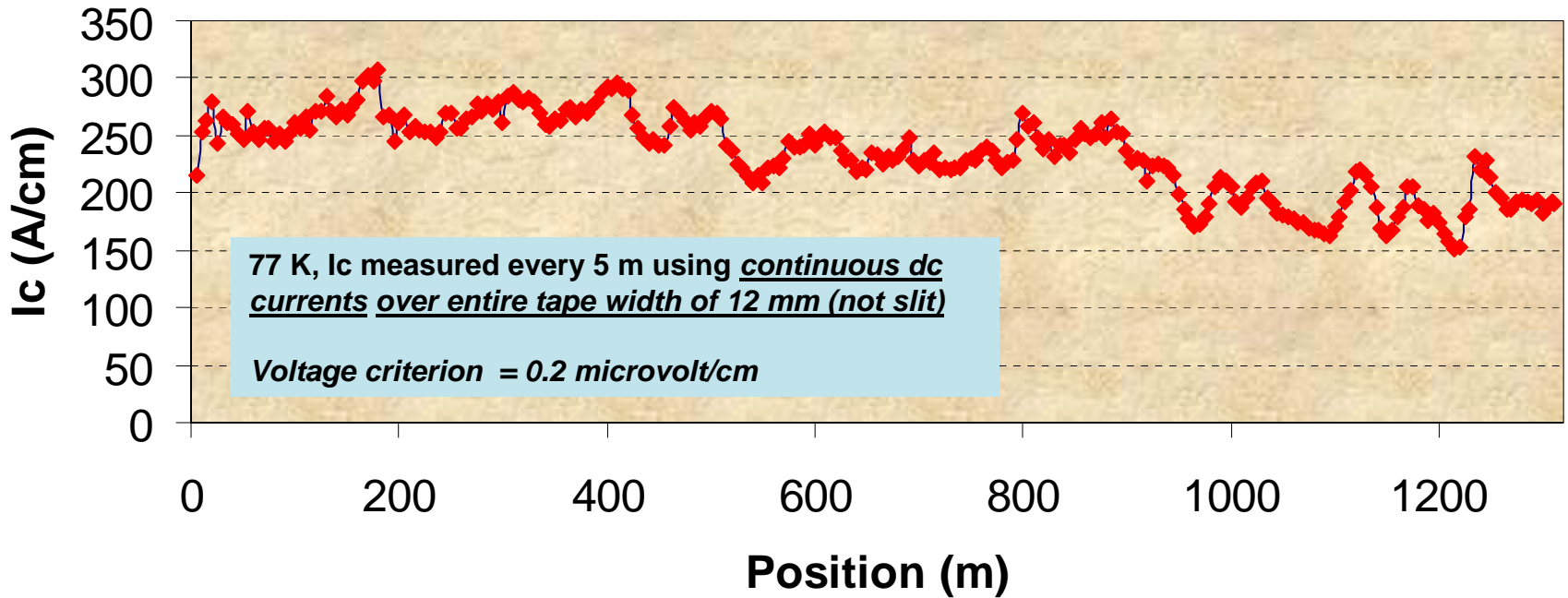
Reached kilometer-class lengths of 2G wire



- Minimum current (I_c) = 170 A/cm over 935 m
- $I_c \times \text{Length} = 158,950 \text{ A-m}$
- Uniformity over 935 m = 10.6%

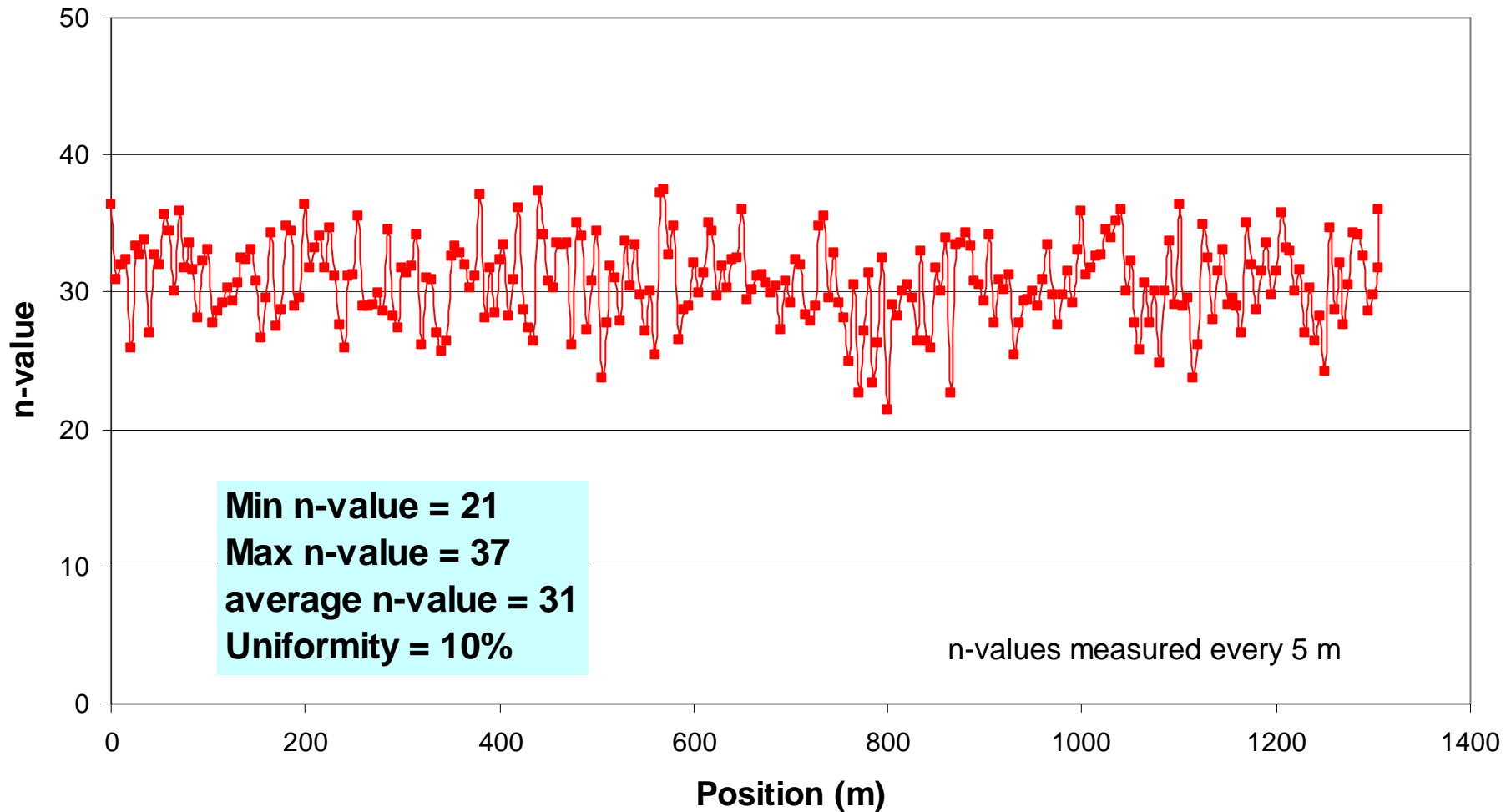
Process (single pass)	Speed of 4 mm tape (m/h)
IBAD MgO	360
Homo-epi MgO	345
LMO	345
MOCVD	135

Crossed kilometer threshold in July 2008



Length	Minimum I_c (A/cm) (0.2 $\mu\text{V/cm}$)	$I_c \times \text{Length}$ (A-m)
945	200	189,000
1,205	163	196,415
1,311	153	200,580

Excellent & uniform n-values over kilometer lengths



Remarkable progress in 2G HTS wire scale-up over the last 6 years

