



Recent Progress in Second-Generation HTS Conductor Scale-Up at SuperPower

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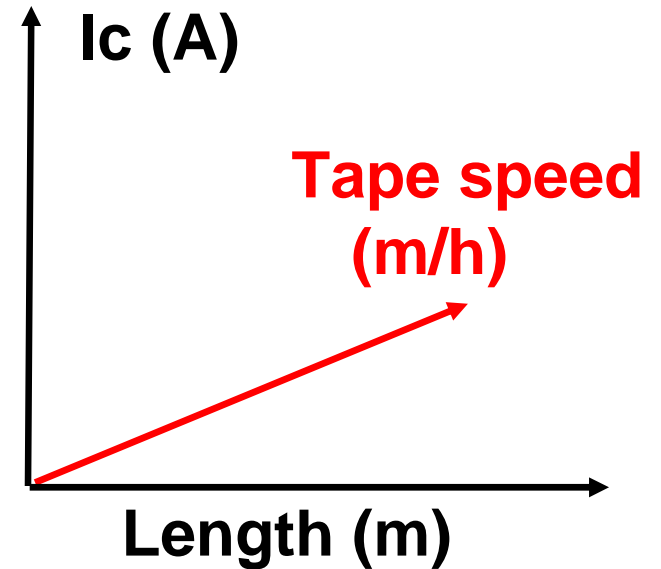
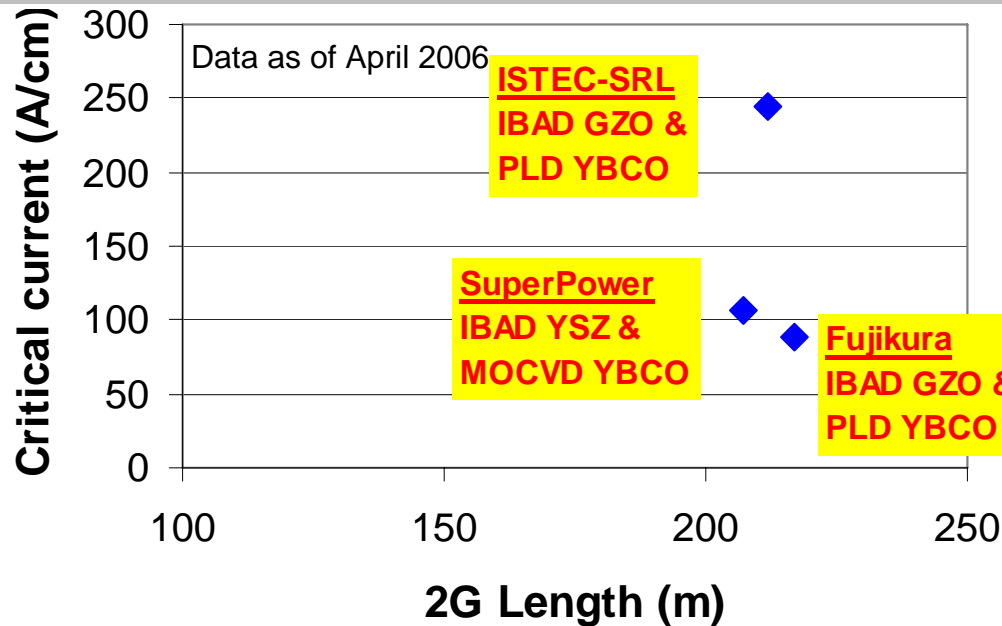
Y. Chen, X. Xiong, Y.Y. Xie, J.L. Reeves, X. Zhang, Y. Qiao, K.P. Lenseth, R.M. Schmidt, D. W. Hazelton, and K. Tekletsadik

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HTS Solutions for a New Dimension in Power

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Tape speed needed to be substantially increased for 2G to be commercially viable



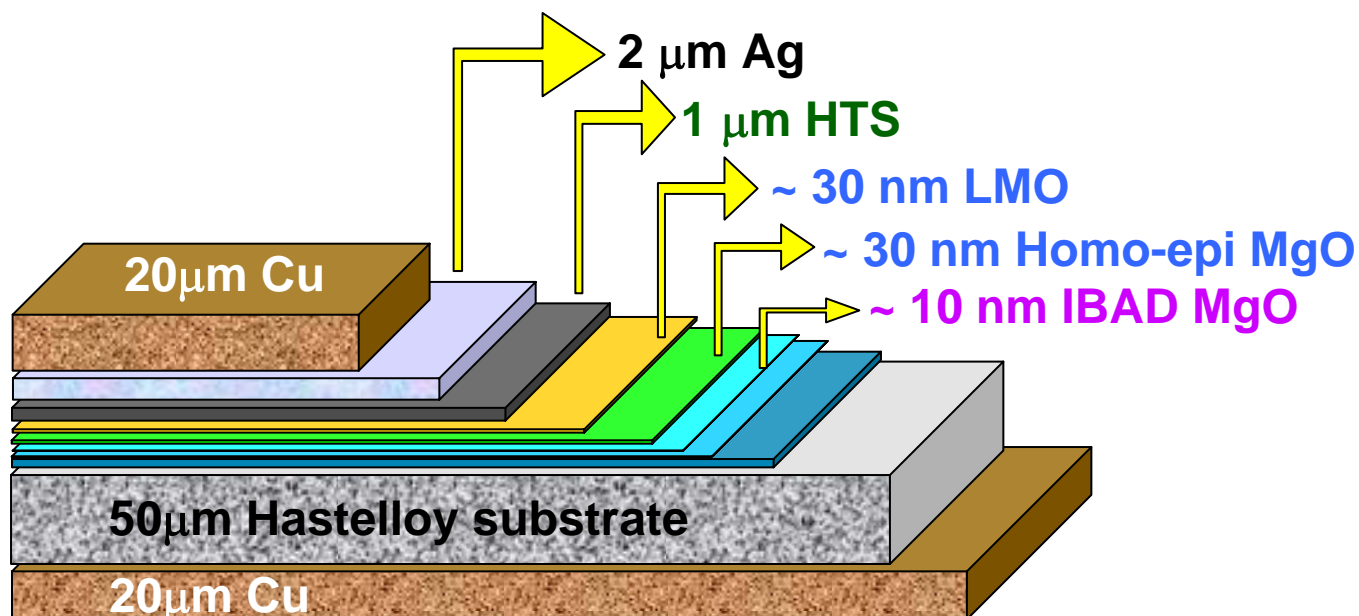
- All 200+m long demonstrations last year used low speeds in buffer & YBCO processes
- Speed of IBAD YSZ & IBAD GZO processes ~ 1 m/h of 10 or 12 mm wide tape
- Effective linear tape speed of PLD processes ~ 3 m/h of 10 mm wide tape
- Effective linear tape speed of MOCVD process = 5 m/h of 12 mm wide tape
- At 5 m/h of 12 mm wide tape, annual production would be less than 100 km/year of 4 mm wide conductor. This is far less than the current 1G market of ~ 700 km/year.

In addition to I_c & Length, high linear tape speed has to be demonstrated in YBCO processes

Pilot Production Equipment was upgraded for high throughput processing of all layers



	2005	2006
IBAD	Helix tape handling YSZ: 1 m/h	Transition to IBAD MgO in Pilot IBAD. Modify hardware accordingly.
Buffer	n/a	New Pilot Buffer system with helix tape handling
MOCVD	Single tape; 5 m/h	Retrofit with helix tape handling; Increase deposition zone length & width

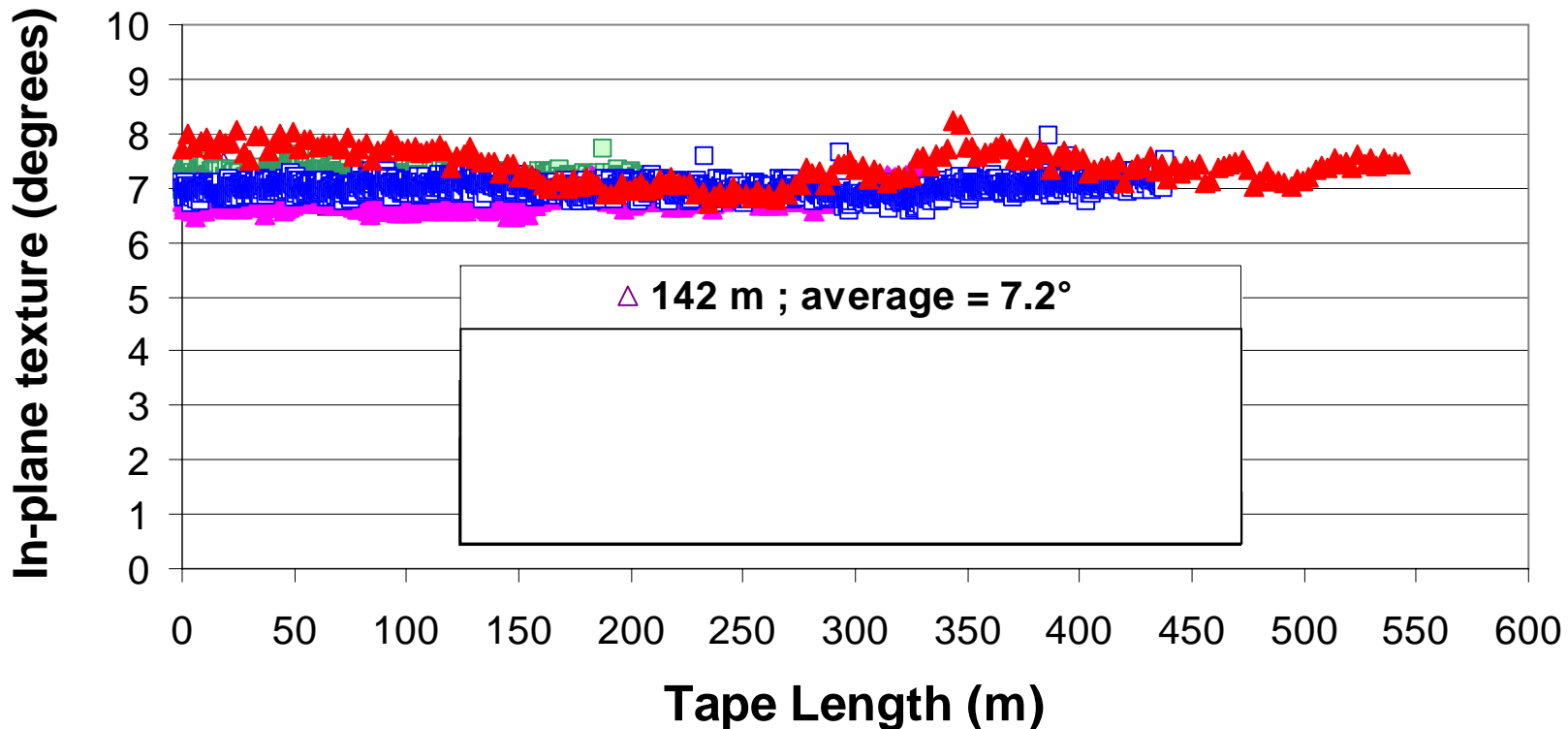


Tremendous challenge to successfully implement modifications in *three* critical equipment *simultaneously* & then routinely produce *10,000 m* of conductor for delivery to Albany Cable project

550 m long tapes have been produced in Pilot Buffer system at linear speeds of 40 m/h



Using only 6 of the 12 tape tracks in helix tape handling in Pilot Buffer system, 40 m/h tape speed is routinely used to produce up to 550 m lengths of homo-epi MgO and LMO on IBAD MgO.



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

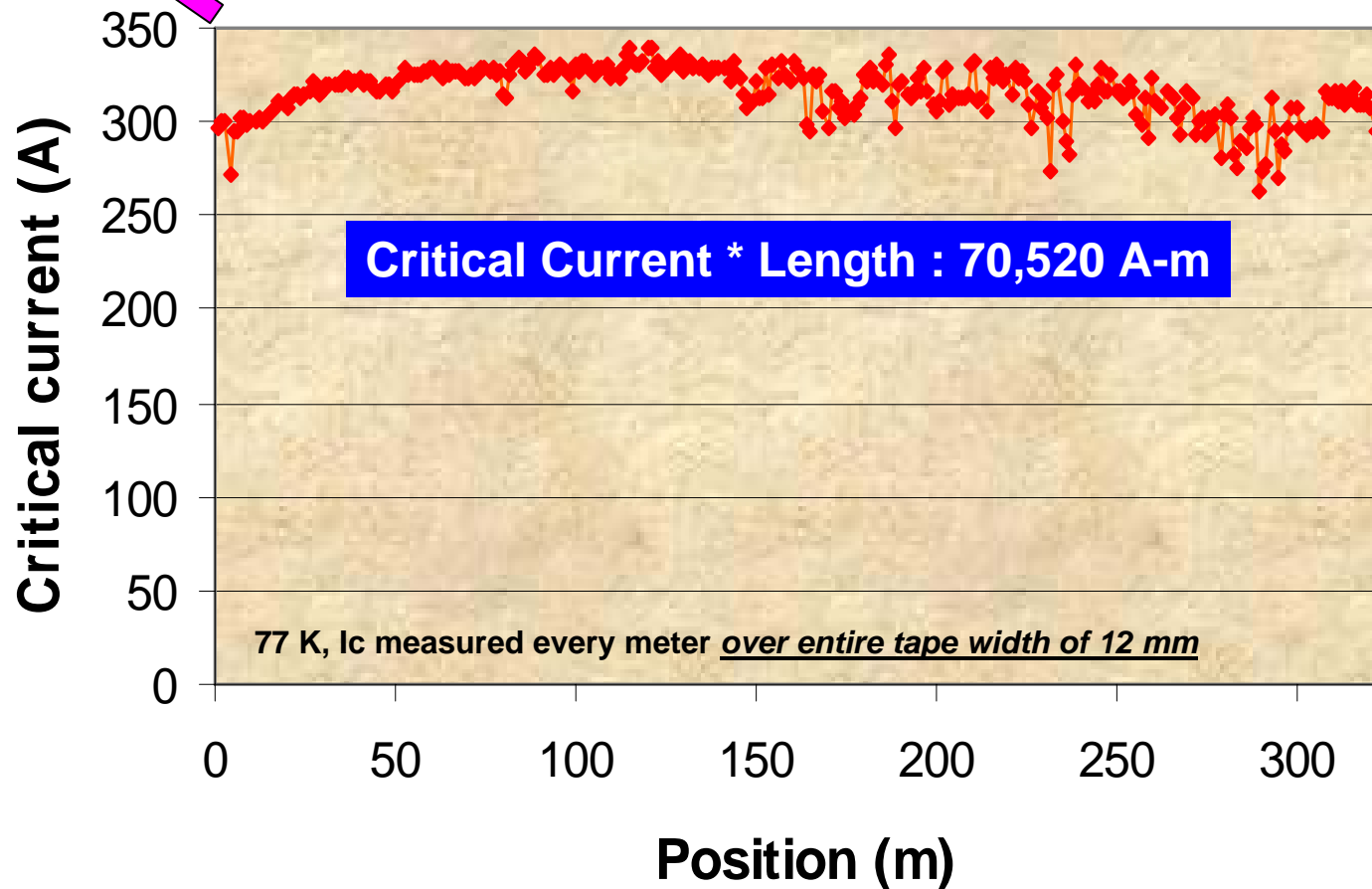
High I_c with excellent uniformity over 300 m by MOCVD in a single pass at 30 m/h on IBAD MgO

YBCO thickness

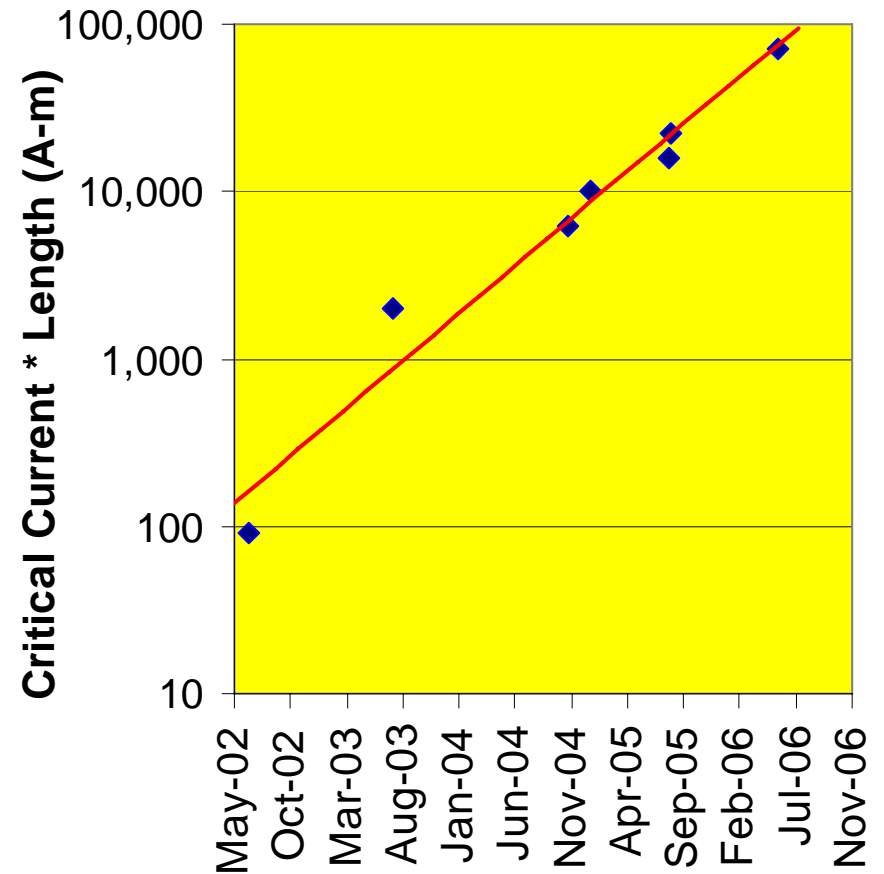
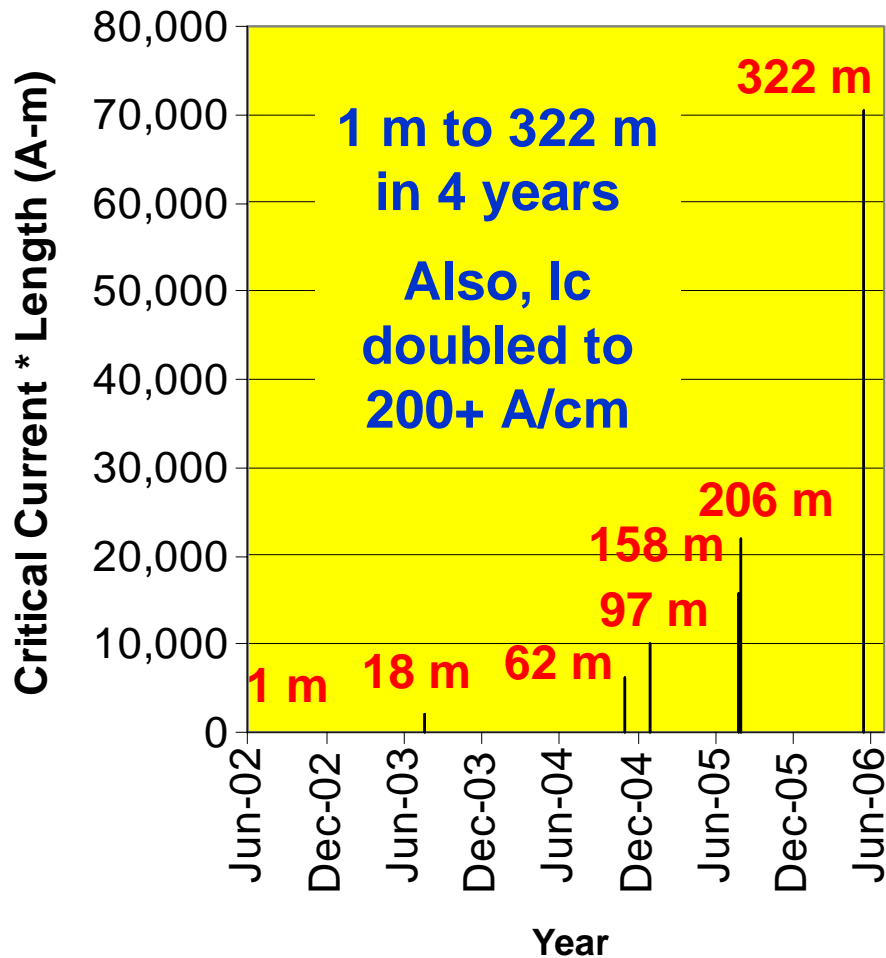
1.2 μm

Min $I_c = 263 \text{ A} = 219 \text{ A/cm}$ over 322 m.
Uniformity of 4.3% over 322 m.

1.2 μm



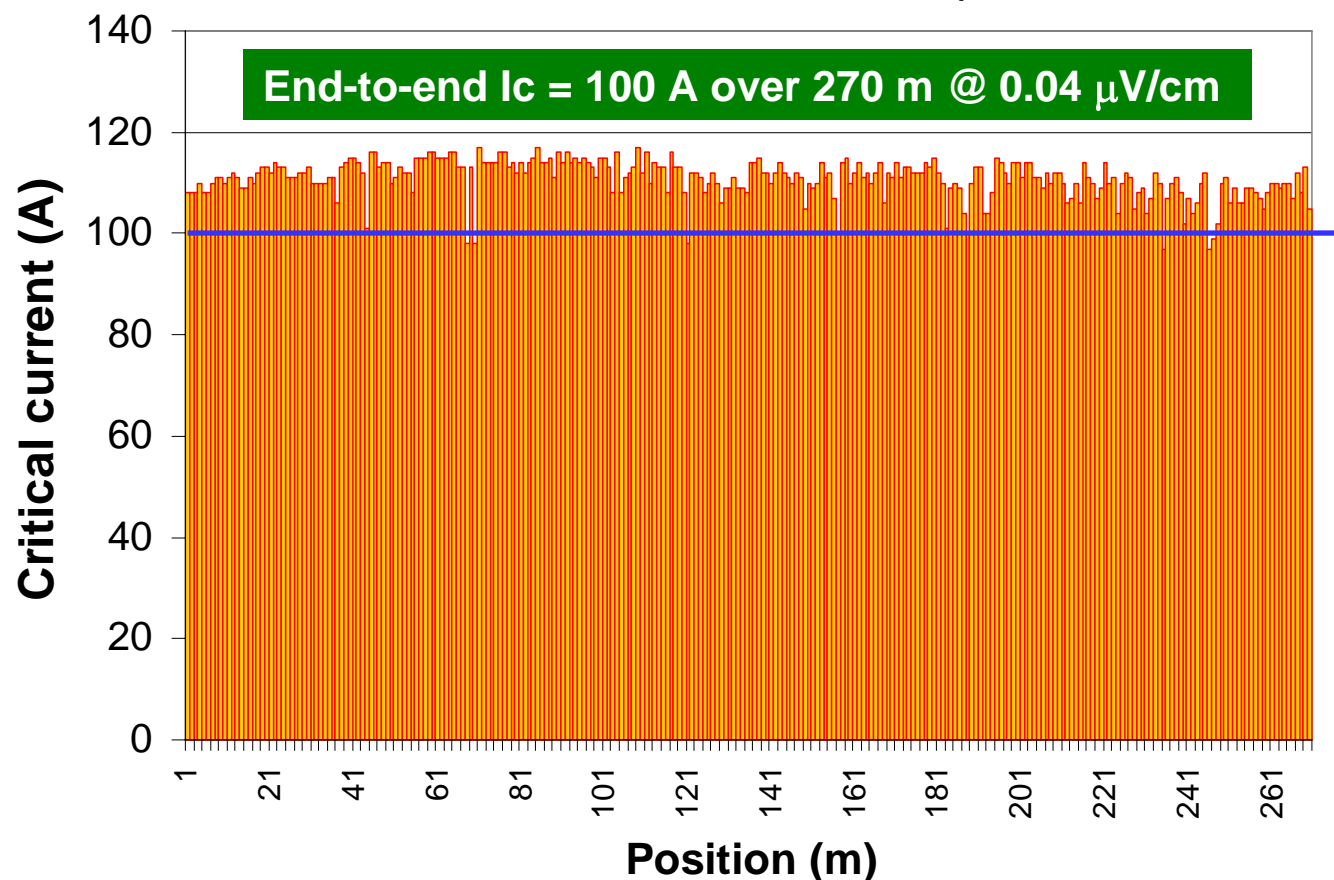
Significant progress in MOCVD scale-up in the last 4 years



2G conductor is now available in long lengths with I_c in the realm of 1G & J_e about 2x better than 1G



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

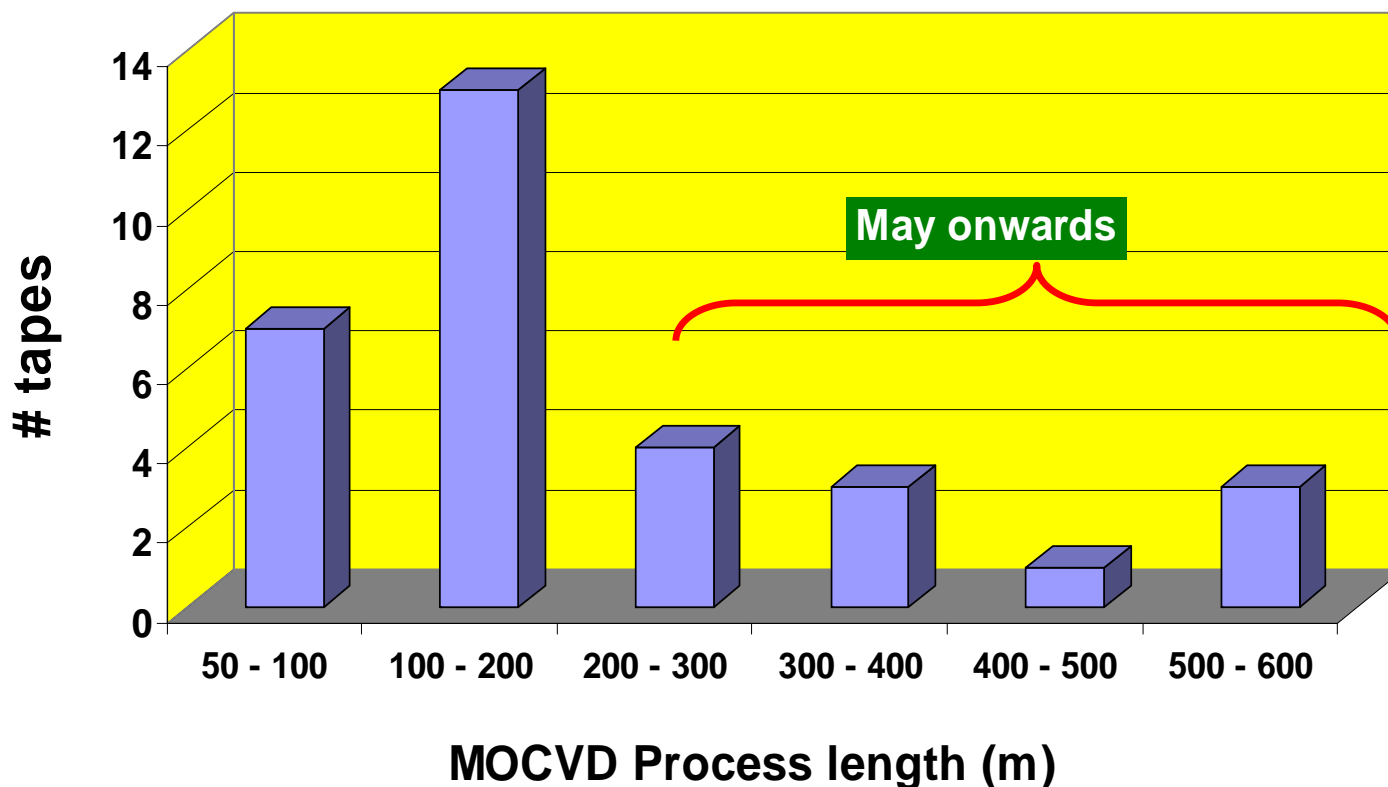


$I_c = 100$ A in a 4 mm wide 2G conductor over 270 m !

$J_e = 26.3 \text{ kA}/\text{cm}^2$ (for a 20 micron surround stabilizer i.e. 40 micron total)

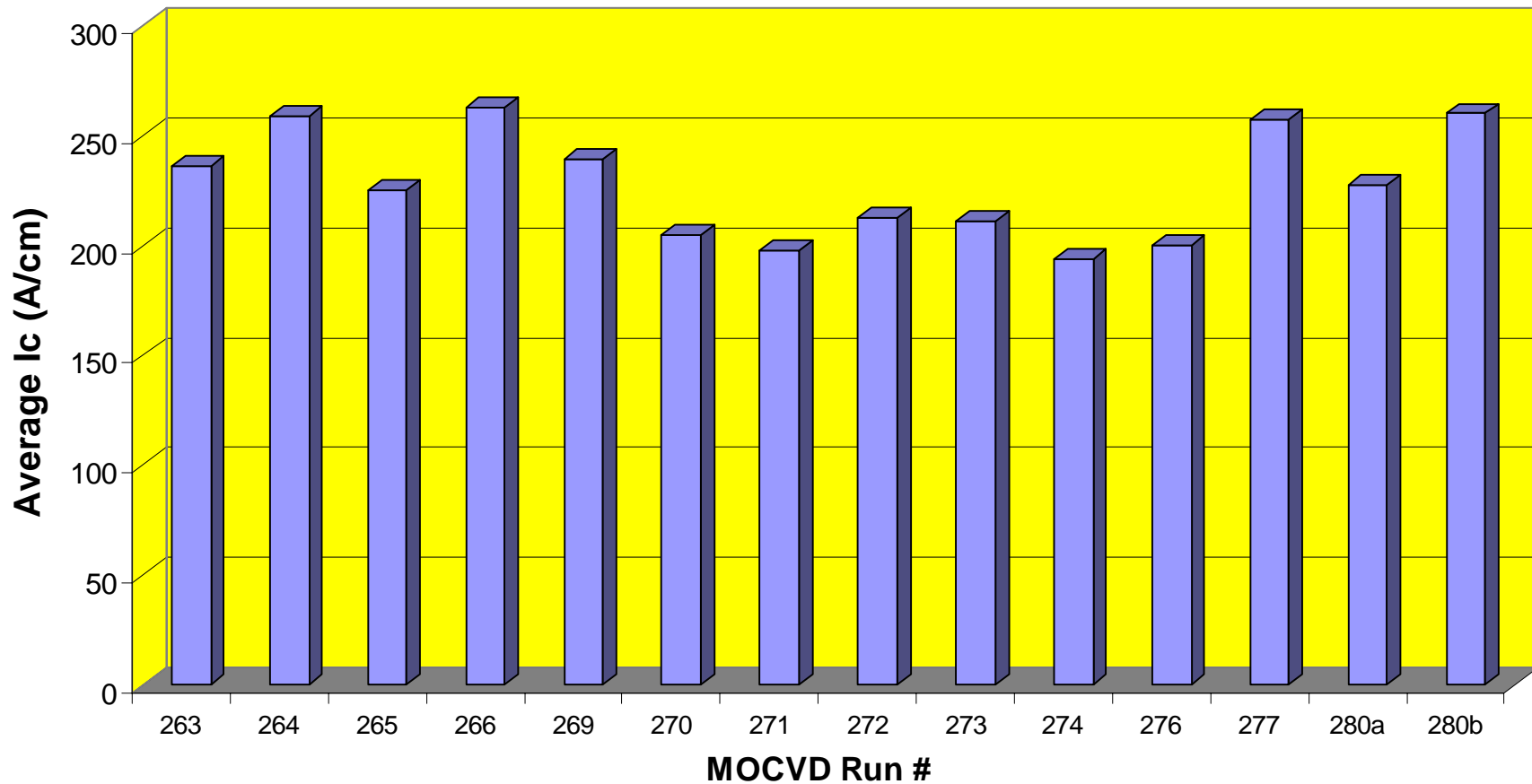
compared to a 1G J_e of $13 \text{ kA}/\text{cm}^2$ to $17 \text{ kA}/\text{cm}^2$

We are now routinely processing MOCVD tapes in lengths over 300 m



- 35% of tape produced by MOCVD are 200+m.
- 71% of tape produced since May are 200+ m and 43% are 300+ m
- 31 production runs yielding 5,720 m of 12 mm wide tape (= 17,160 m of 4 mm wide tape)

Critical currents of 200 to 250 A/cm reproducibly achieved in long lengths from May onwards

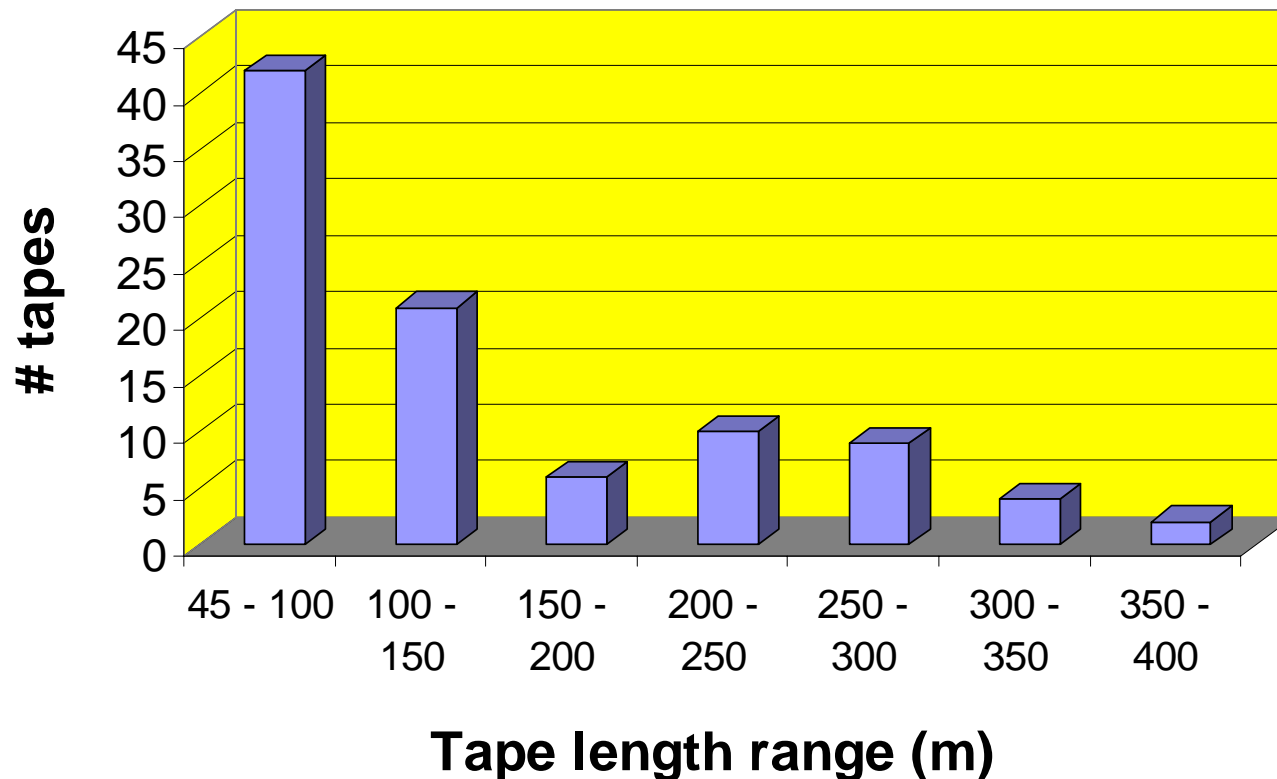


#267 was damaged after MOCVD. #268 & # 275 were experimental runs
Runs #278 & #279 were interrupted.

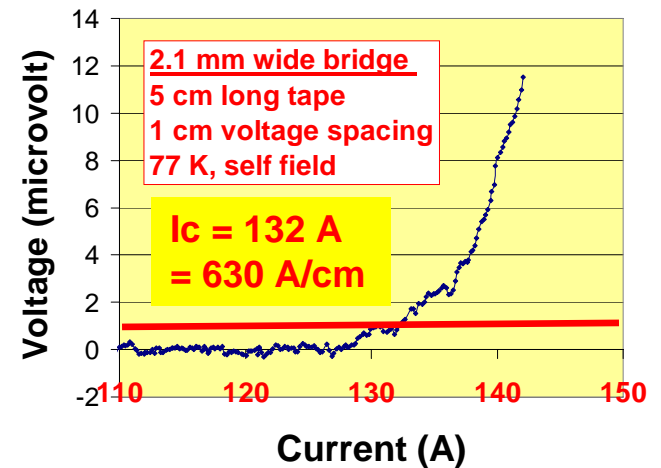
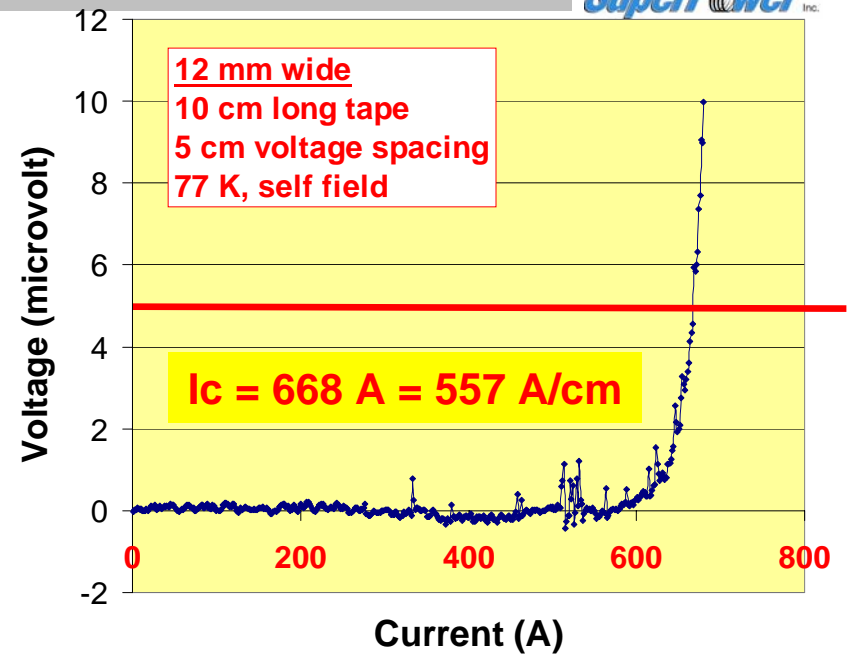
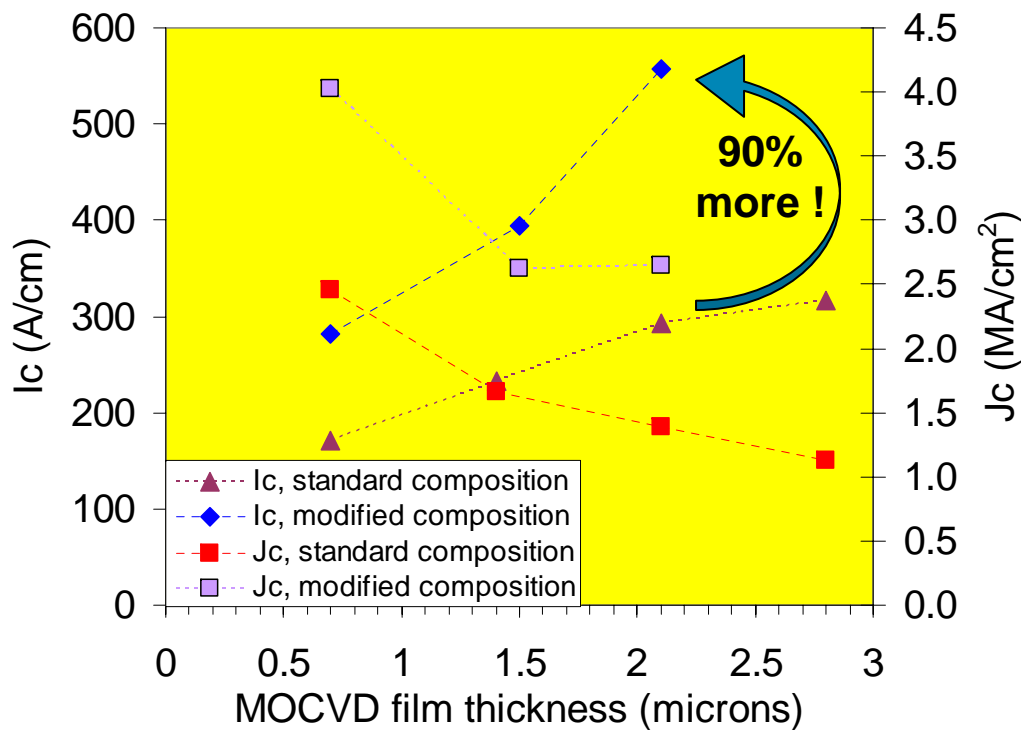
More than **12,000 m** of qualified tape in inventory for Albany Cable Project



- Piece length required = 42.4 m
- 55% of tapes > 100 m piece length
- 27% of tapes > 200 m piece length



High critical currents achieved in thick MOCVD films

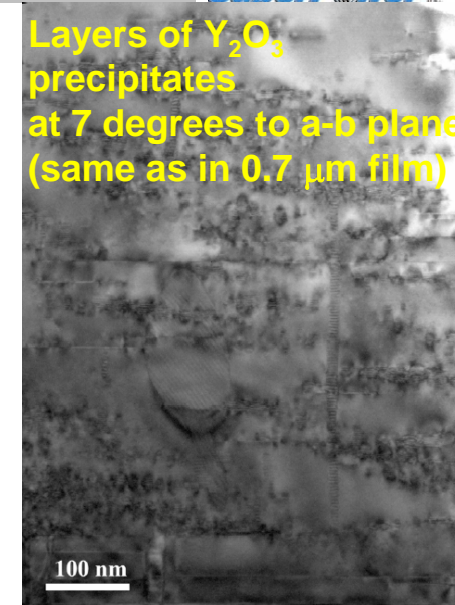
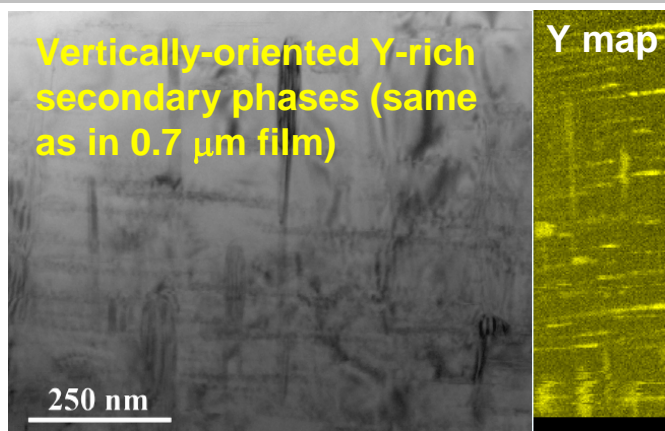
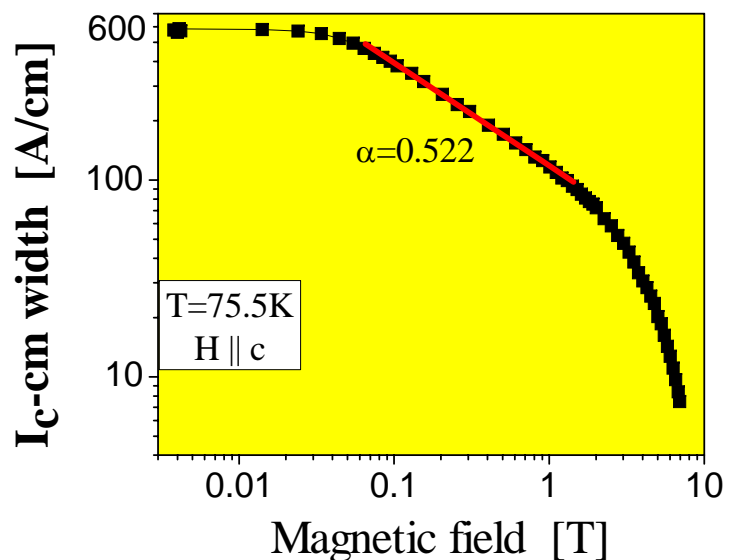


In a **2.1 micron** film made in 3 passes, achieved **Ic of 557 A/cm (Jc = 2.65 MA/cm²)** over 12 mm wide, 10 cm long tape.

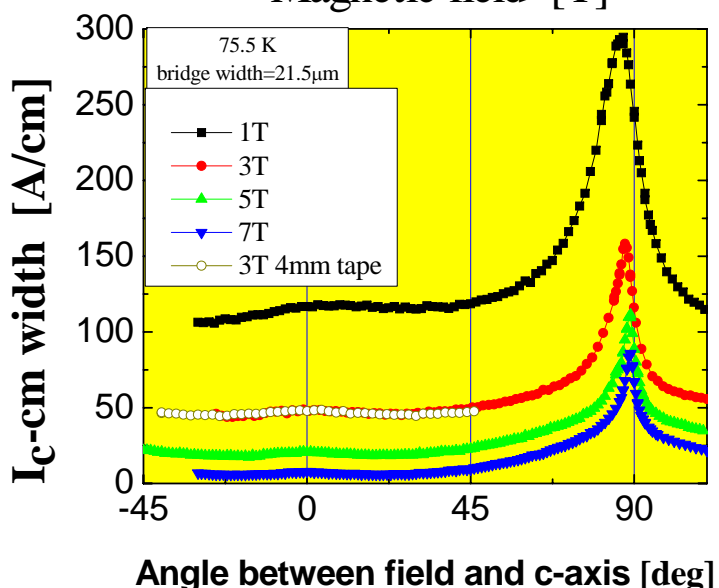
After patterning a 2.1 mm wide bridge, measured **Ic of 630 A/cm (Jc = 3.0 MA/cm²)**

High J_c & J_e measured in 2.1 micron high current conductor at 1 T, 75.5 K

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100+ A/cm conductor at 1 T, 75.5 K, $B \parallel c$!



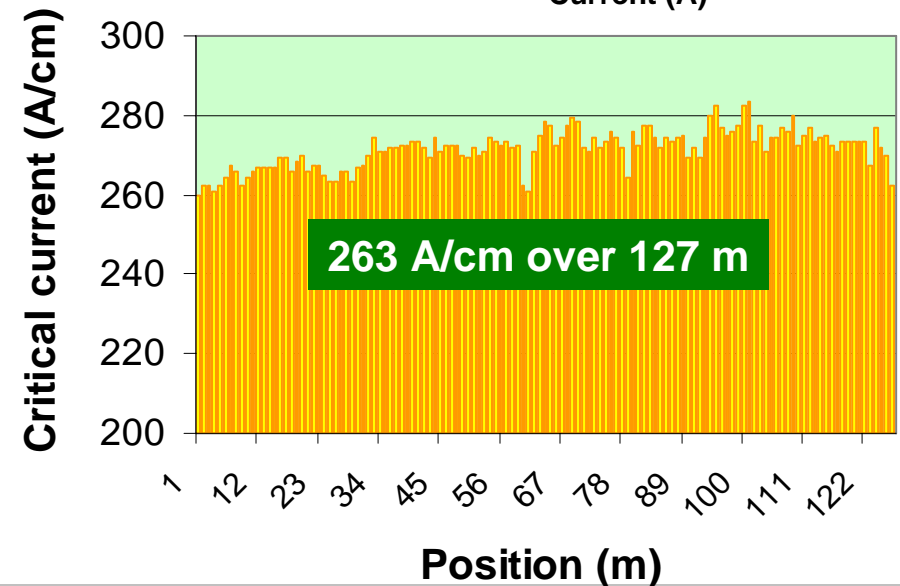
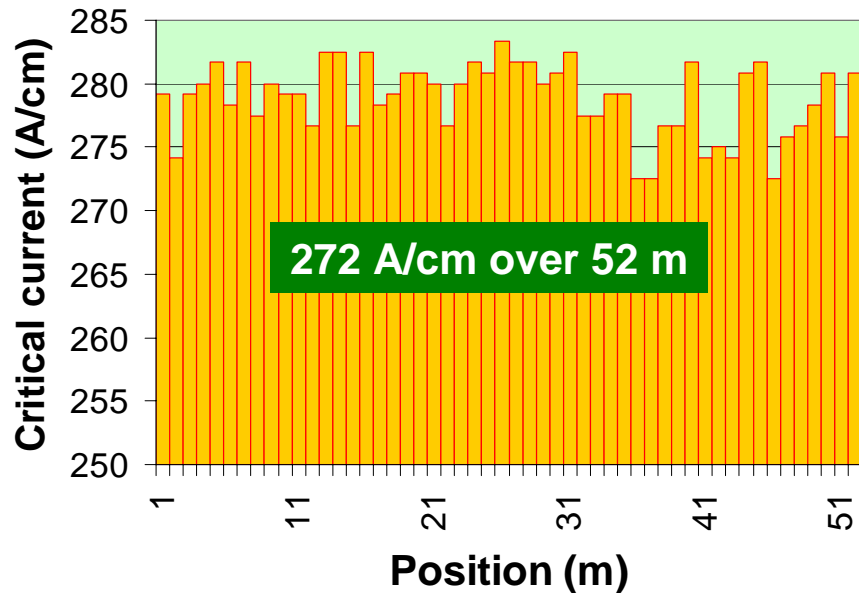
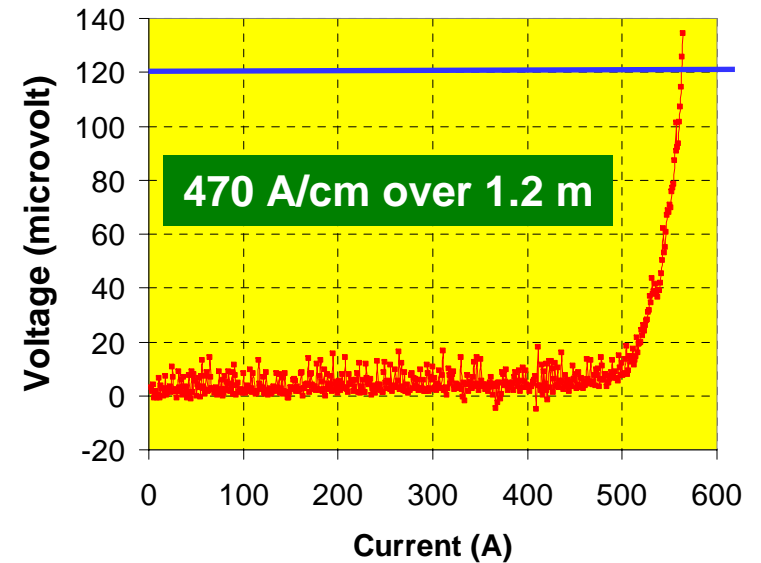
1 T, 75.5 K	I_c (A/cm)	J_c (MA/cm ²)	J_e (kA/cm ²)
$B \sim \parallel a-b$	294.4	1.4	50.5
$B \parallel c$	116.7	0.56	21.1
$B \parallel c$, 2005	61	0.2	11
2006 improvement	90%	175%	82%

Significant improvement in in-field properties for a 45% increase in I_c at self field

High currents with excellent uniformity have been achieved by MOCVD over a range of conductor lengths



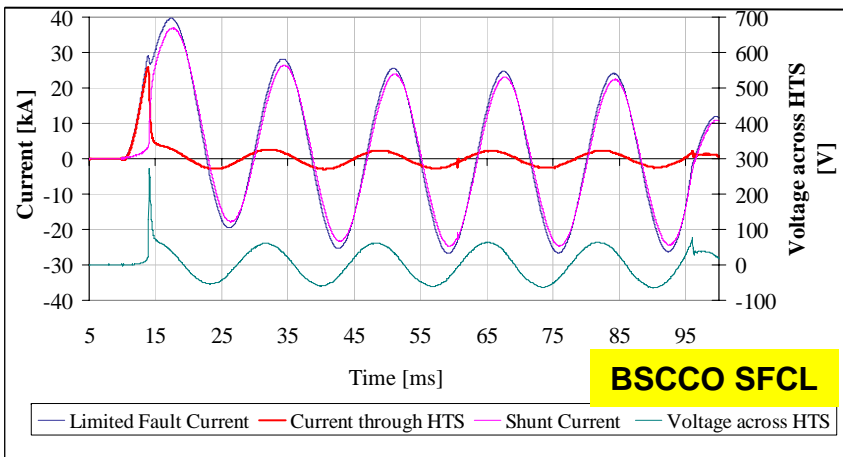
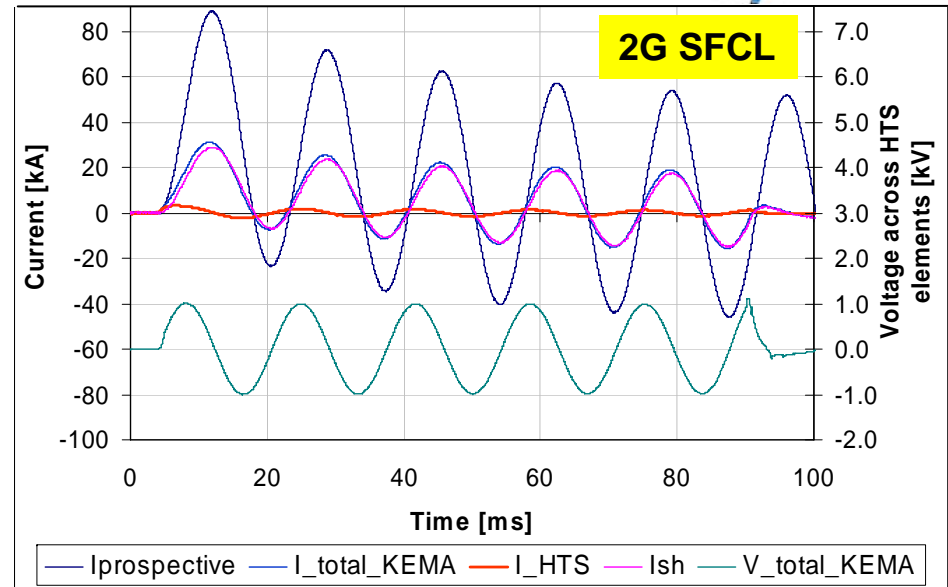
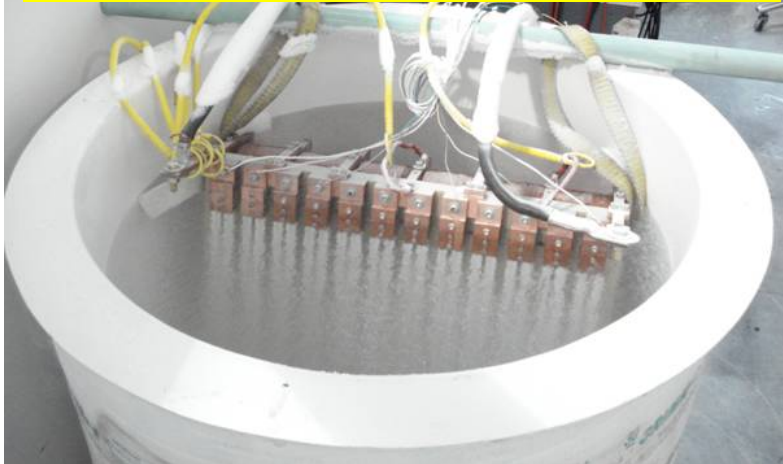
Length (m)	0.05	322
I_c (A/cm)	557	219
Thickness (μm)	2.1	1.2
J_c (MA/cm ²)	2.65	1.83
Uniformity (%)		4.3



Successfully completed high-power testing of a 2G SFCL assembly at KEMA high-power test facility



12 elements, 40 cm long with 4 2G tapes in parallel per element



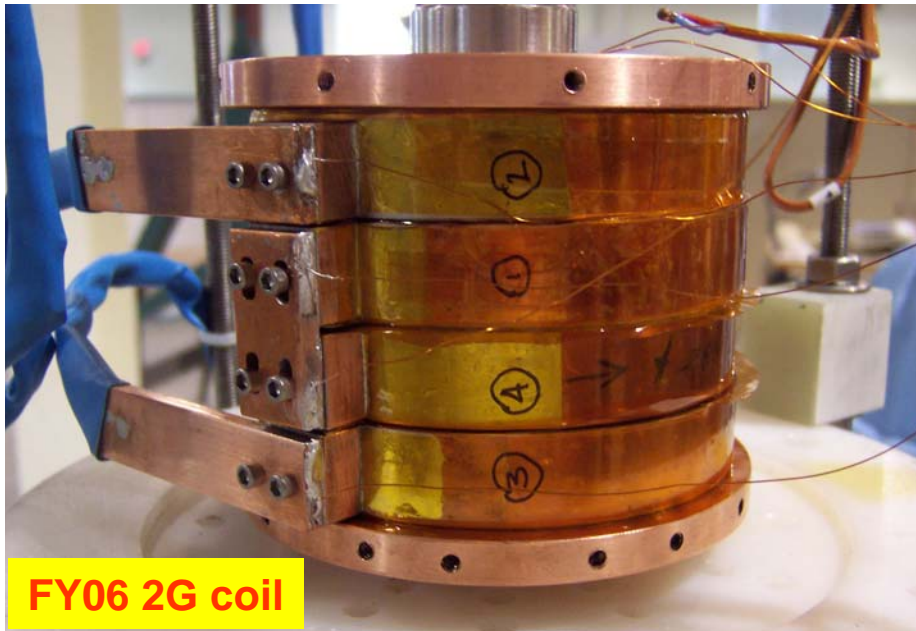
High-power SFCL test	2G
Prospective current	90 kA*
Limited current	32 kA
Current through element	3 kA
Response time	< 1 ms
Element quality range	Narrow

*AEP's requirement of 26 kA rms (70 kA peak) fault condition is satisfied with this 2G performance

Superior performance in all respects using 2G SFCL in High-power tests

High-field coil with ~ 3x better performance demonstrated

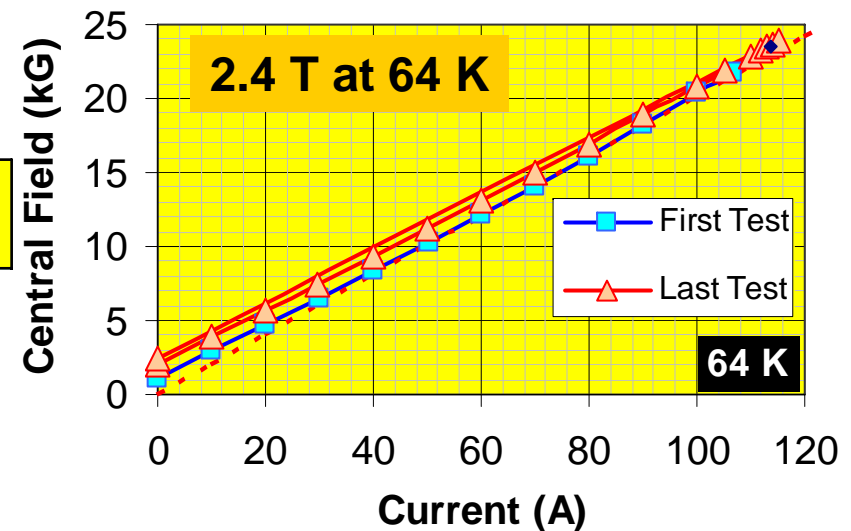
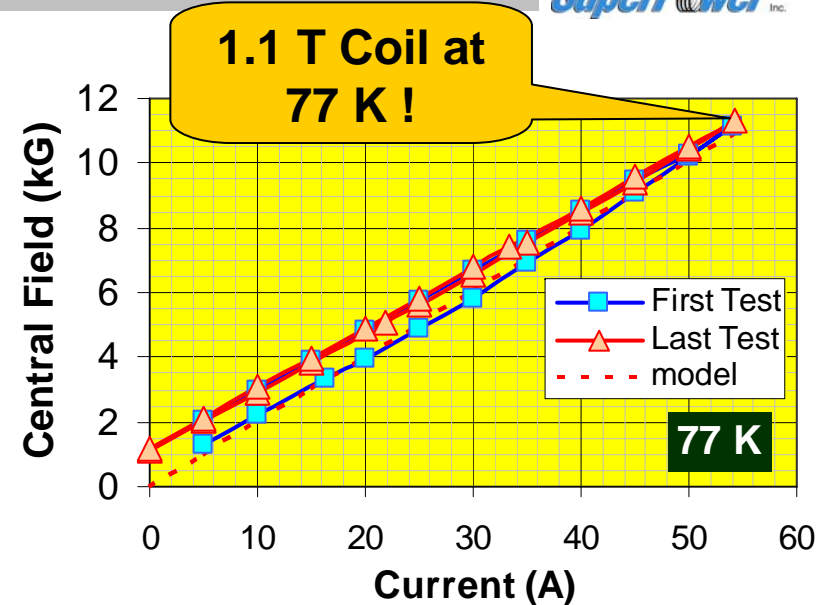
In FY06, we demonstrated a 2G coil that generated 0.4 T at 77 K and 0.87 T at 64 K



Coil ID (mm)	10.92
Winding ID (mm)	12.70
Winding OD (mm)	75.2
Height (mm)	57.2
2G Tape Used (m)	159.6
# Turns	1156

Avg Ic of Tape in Coil (A)	246
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SuperPower Inc.



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



- 👤 **Piece Lengths ~ 300 m**
- 👤 **Critical Current: 80 – 100 A in 4 mm widths**
- 👤 **Critical current uniformity: < 5% over 300 m**
- 👤 **Excellent mechanical properties**

2MX05, Tuesday 5 p.m.: *Design and Properties of SuperPower's Practical 2G HTS Conductor for Electric Power Applications*

- 👤 **Tested in cables**

4LW01, Thursday 4 p.m.: *Testing of Single-Phase Short Sample Cable Core Made with YBCO Conductors*

- 👤 **Very suitable for FCL**

2LX04, Tuesday 5 p.m.: *2G HTS Conductors for Fault Current Limiter Applications*

- 👤 **High throughput**

4MA03, Thursday 10:45 a.m.: *High Throughput Processing of Long-Length IBAD MgO and Buffer Templates at SuperPower*