SuperPower Inc.

superior performance.
powerful technology.

Progress in Coated Conductor at SuperPower

Drew W. Hazelton

Low Temperature High Field Superconductor Workshop ■ LTHFSW 2010
Monterey, CA ■ 11/8/10-11/10/10

celebrating 10 years 2000 ~ 2010

SuperPower Organization

- Wholly owned subsidiary of Royal Philips Electronics, N.V.

2 Facilities –

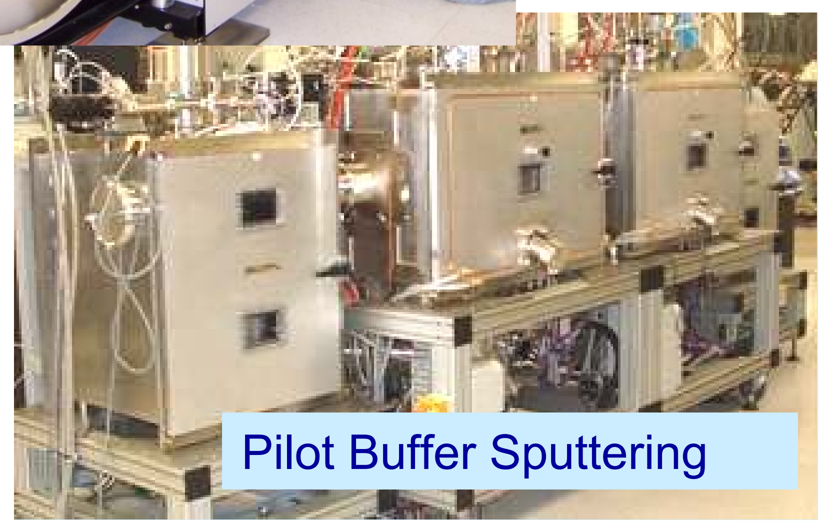
- Headquarters, manufacturing, applications – Schenectady, NY
- 2G HTS R&D – University of Houston
    - Broad scope research agreement with UH / TcSUH

2G HTS wire produced in SuperPower manufacturing facility since 2006


Pilot Substrate Electropolishing

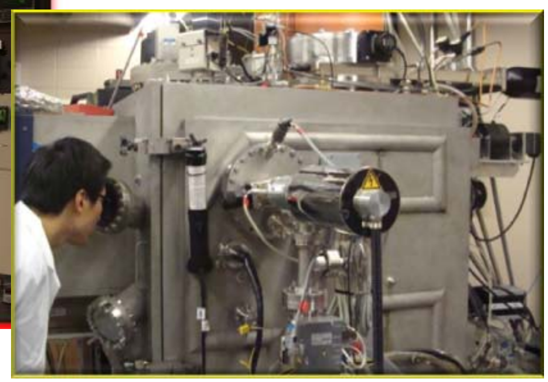

Pilot MOCVD

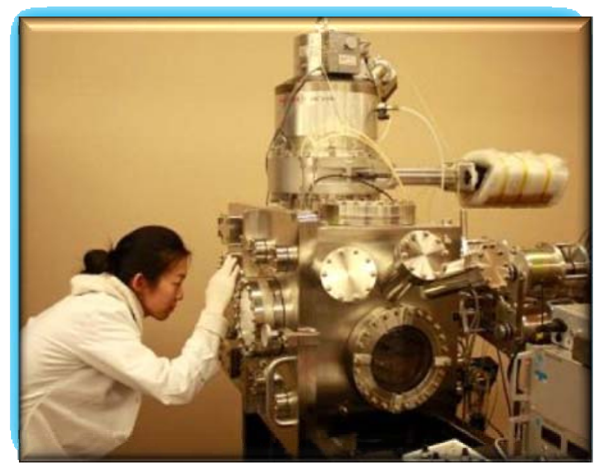

Pilot IBAD

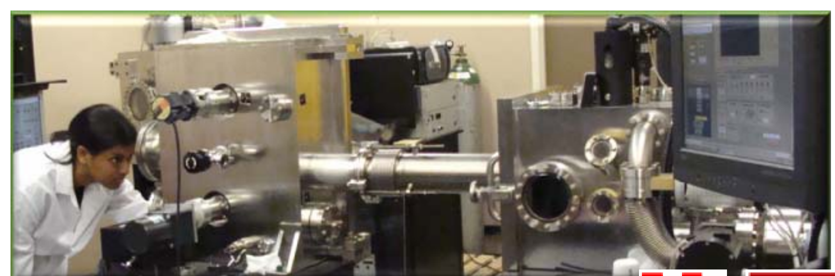

Pilot Buffer Sputtering

SuperPower and UH collaborate to commercialize HTS

- SuperPower has established its R&D operation at the University of Houston with 6 full-time SuperPower scientists
- All HTS research equipment located at UH
- SuperPower is establishing a Specialty Products facility at UH Research Park
- UH received $3.5M from Texas Emerging Technology Fund to establish new facilities and add two faculty specializing in HTS devices & power engineering







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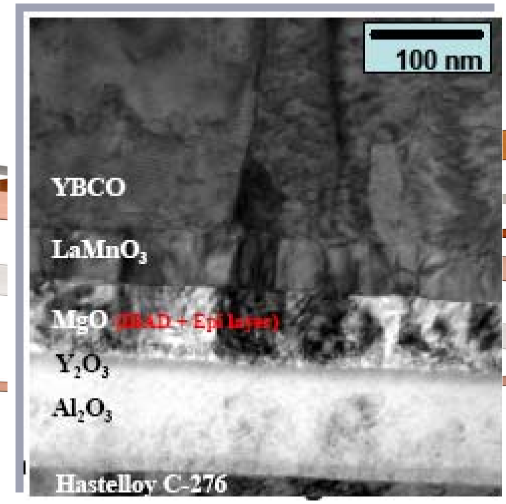
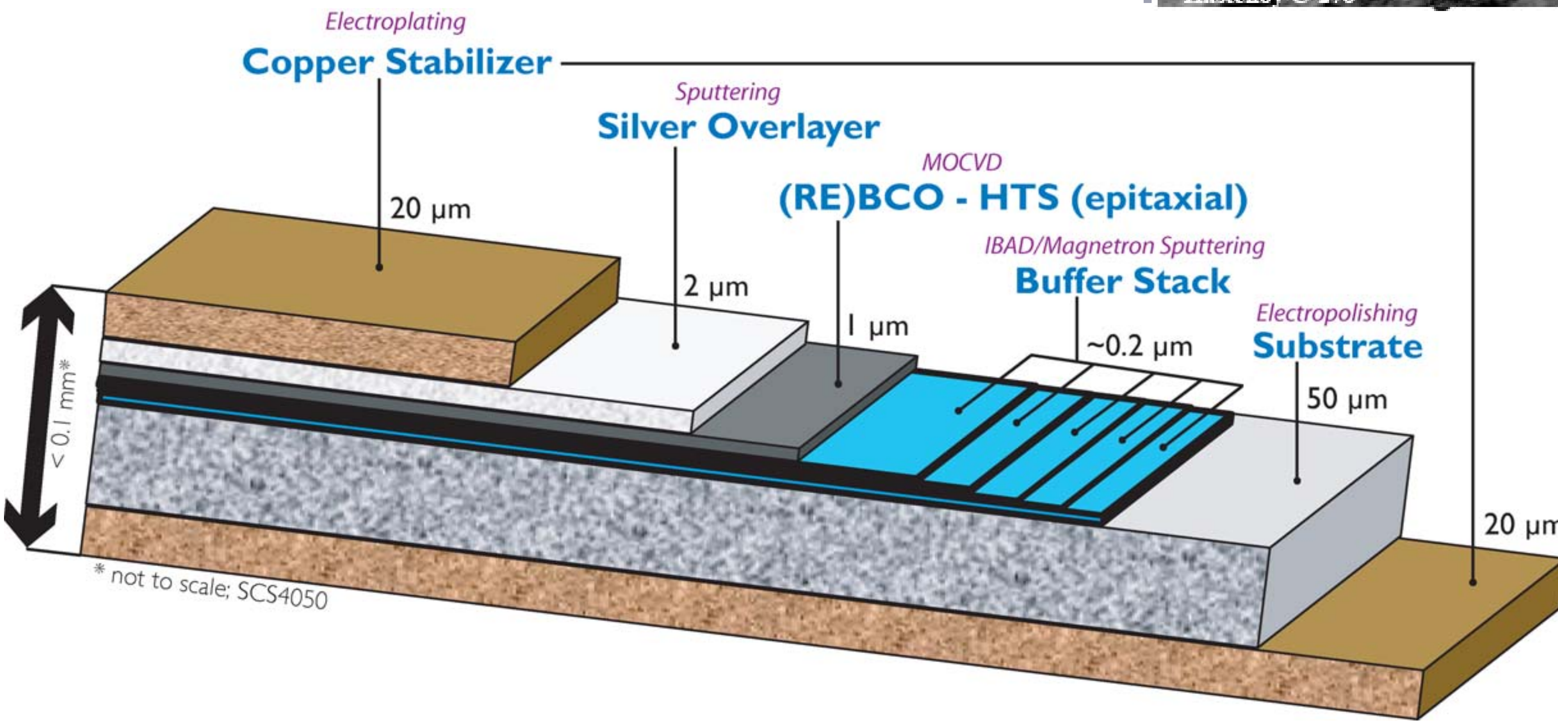
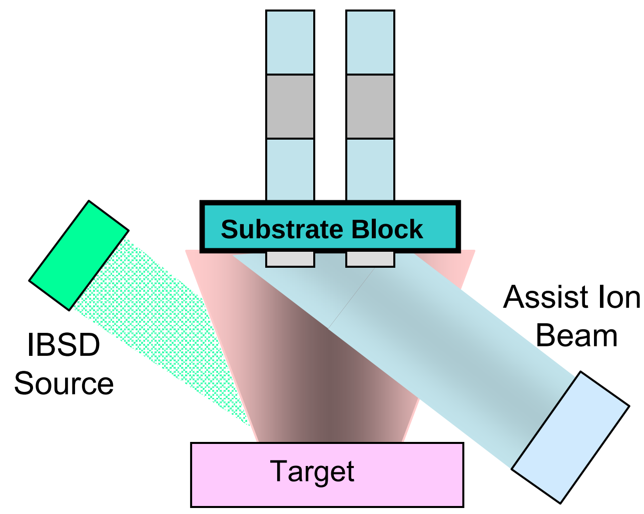
SuperPower 2G HTS Architecture





Advantages of IBAD technology

- Virtually any substrate can be used
  - *High-strength* substrates
  - *Non-magnetic* substrates
  - *Low cost, off-the shelf* substrates (Inconel, Hastelloy, Stainless Steel)
  - *Very thin* substrates (50 μm)
  - *Resistive* substrates – for low ac losses
  - *Easy to handle* – less possibility of defects
- Small grain size – sub-micron range
  - *No issues with percolation* in any length
  - Can pattern wire to *very narrow filaments for low ac loss wire*
- IBAD MgO develops excellent texture within 10 nm thickness
  - *High throughput*



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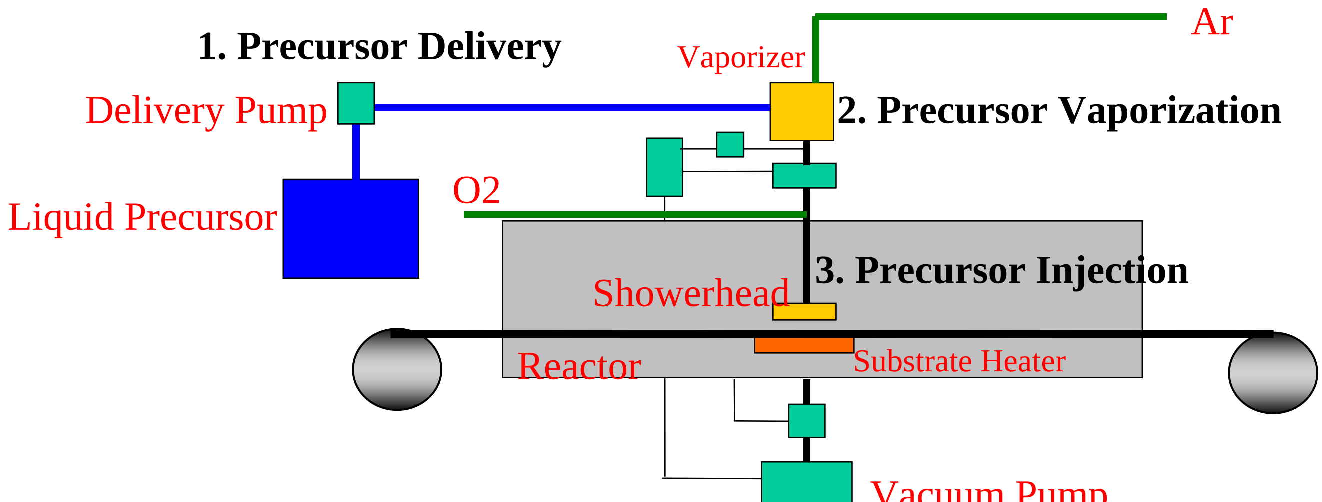
Advantages of MOCVD

- Only process with combination of both high deposition rate & large deposition area (= highest throughput)
- Precursors are maintained outside vacuum chamber (refill is simple)
  - Solution precursor improves the reliability of vapor source supply, and makes it easy to control/adjust film composition
- Low vacuum (a few Torr)



HTS Layer by MOCVD

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Advantages of SuperPower 2G HTS in high field magnet applications

- High critical currents with excellent high field performance
  - (RE)BCO layer can be readily doped using MOCVD for added performance advantage
- High current density available in thin tape form
  - Standard thickness ~ 0.1 mm
  - (RE)BCO layer small fraction of total cross-section
- High mechanical strength
  - Strong Hastelloy® C276 substrate

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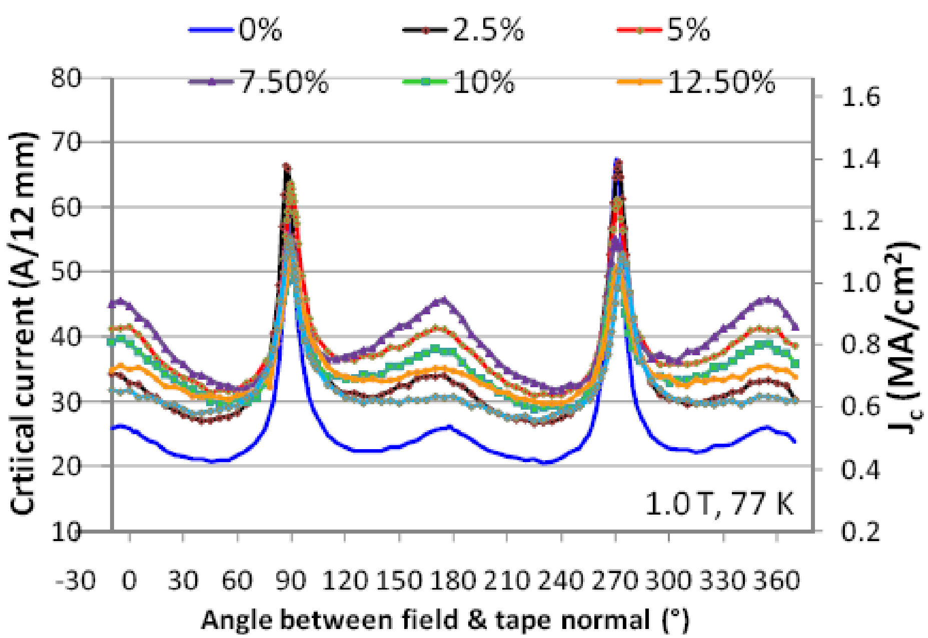
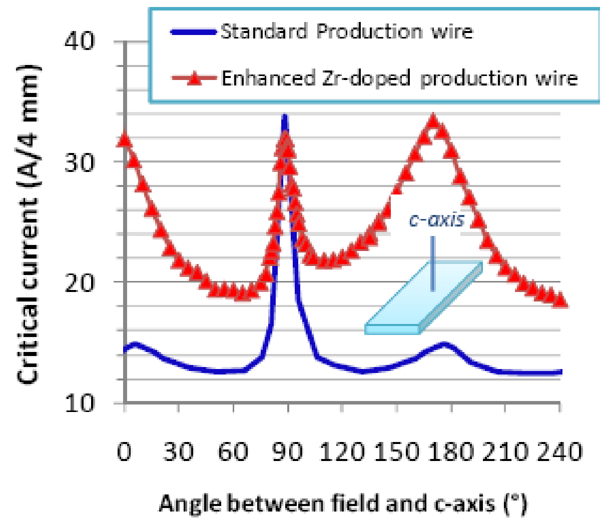
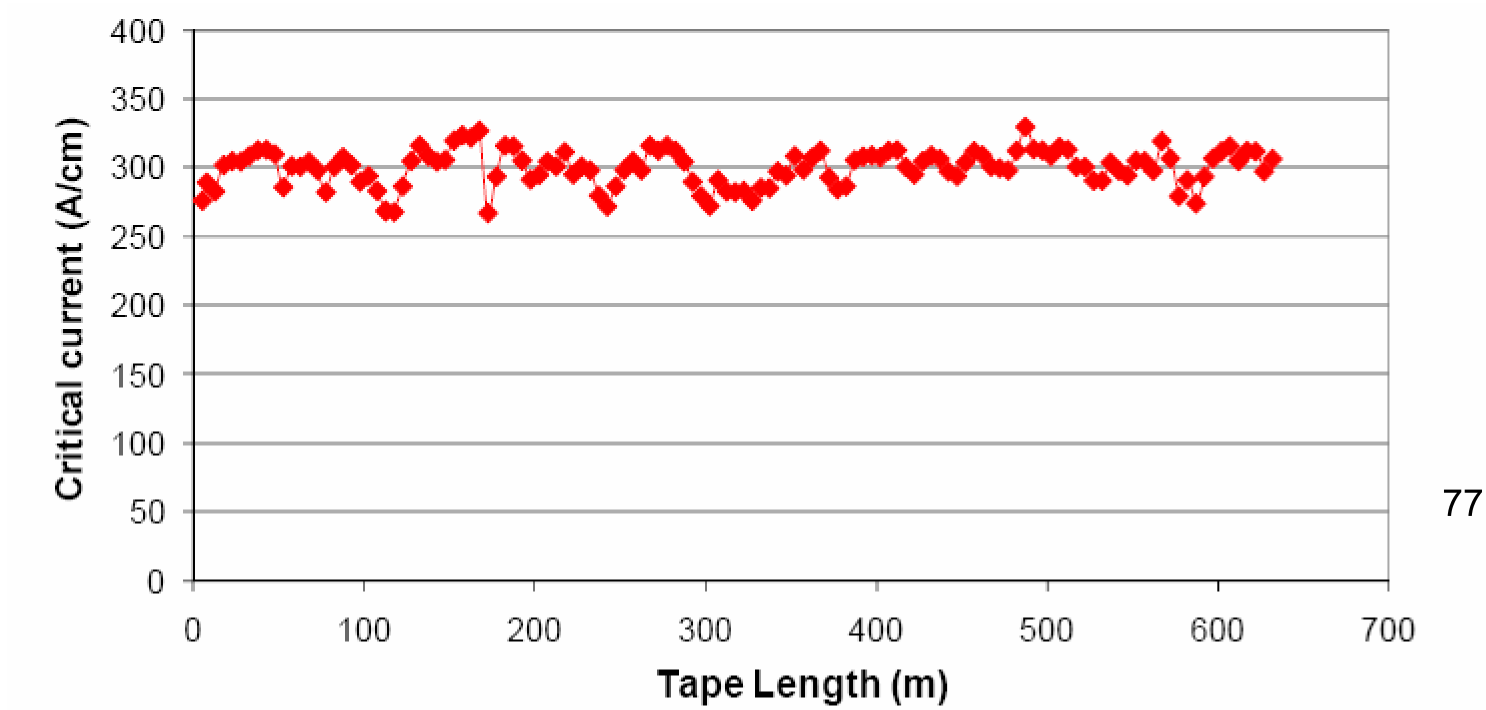
Improved pinning by Zr doping of MOCVD (RE)BCO layer





- Systematic study of improved pinning by Zr addition in MOCVD films at UH
- Process "know how" transitioned to SuperPower manufacturing

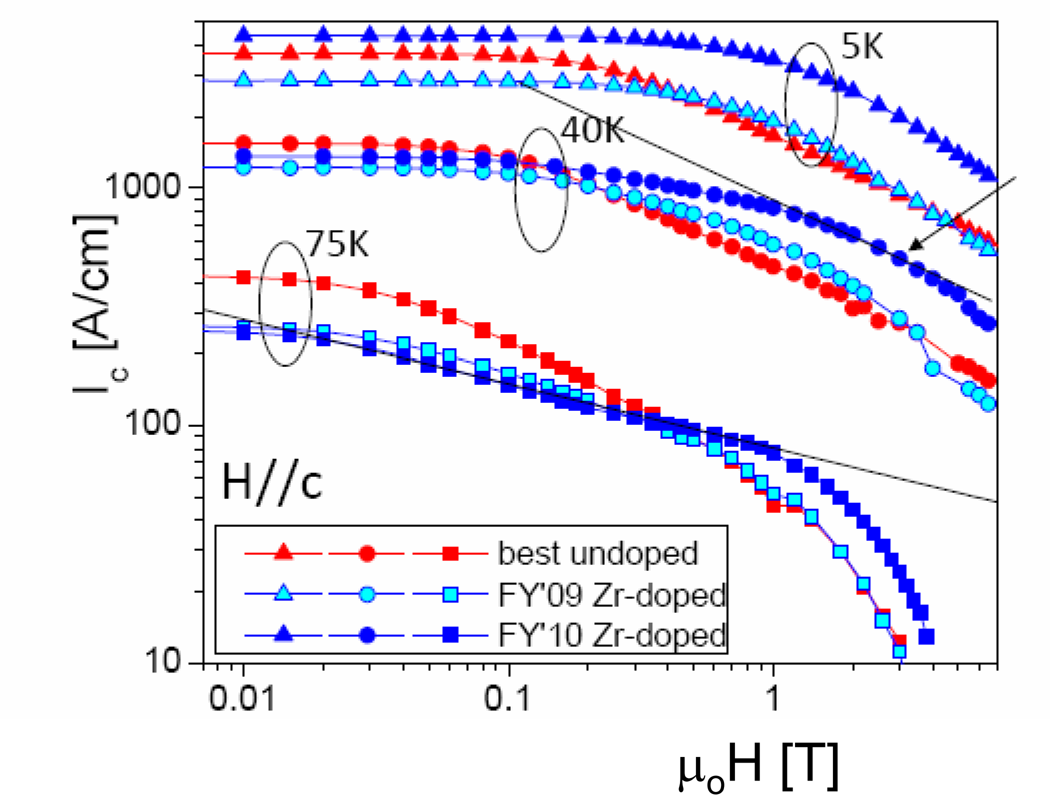
Routine manufacturing of Zr-doped tapes in long length initiated



77 K, sf

Long tapes with Zr-doping exhibit critical currents of 250 to 300 A/cm in tapes run through the manufacturing facility

But what does the Zr-doping do at low temperatures – high fields



2010 Zr-doped production tapes show:

- Large Ic increase at low temperatures
- Absence of α at low T

Measurements by B. Mairov, L. Civale (LANL)

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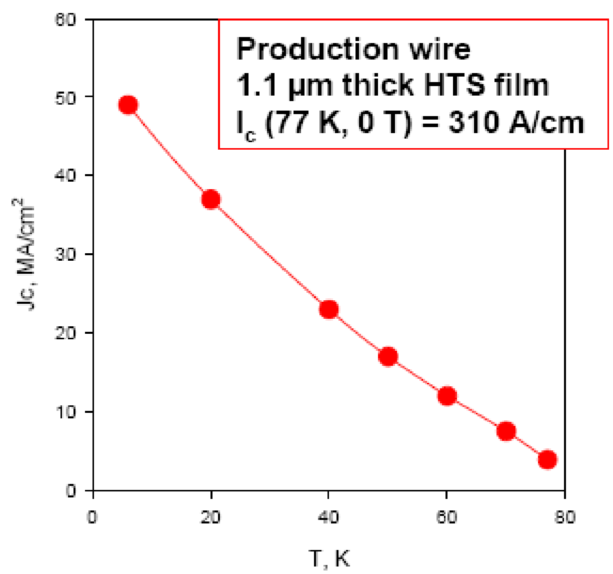
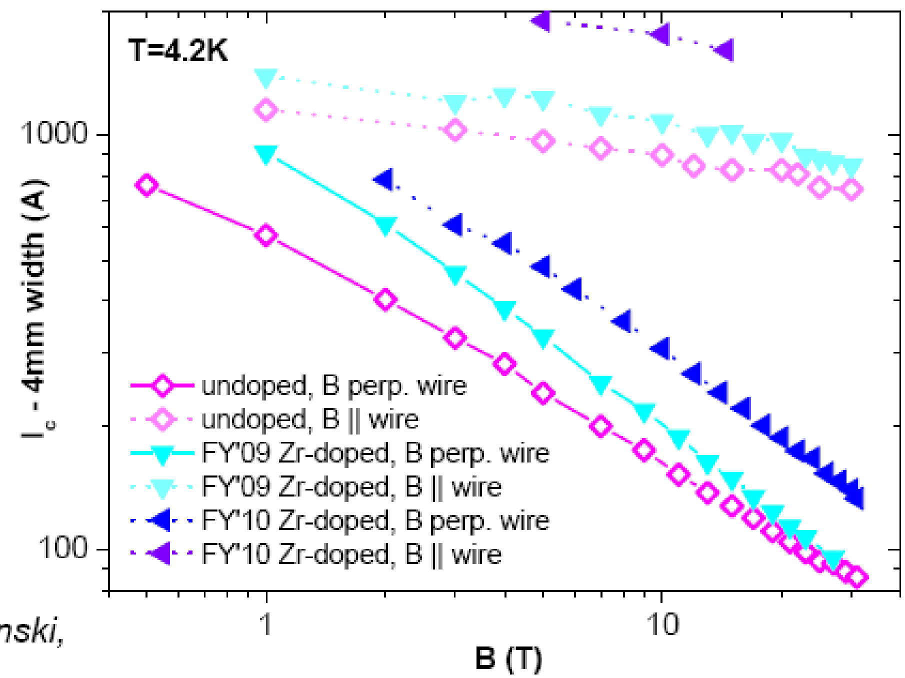
Improvement extends to higher fields





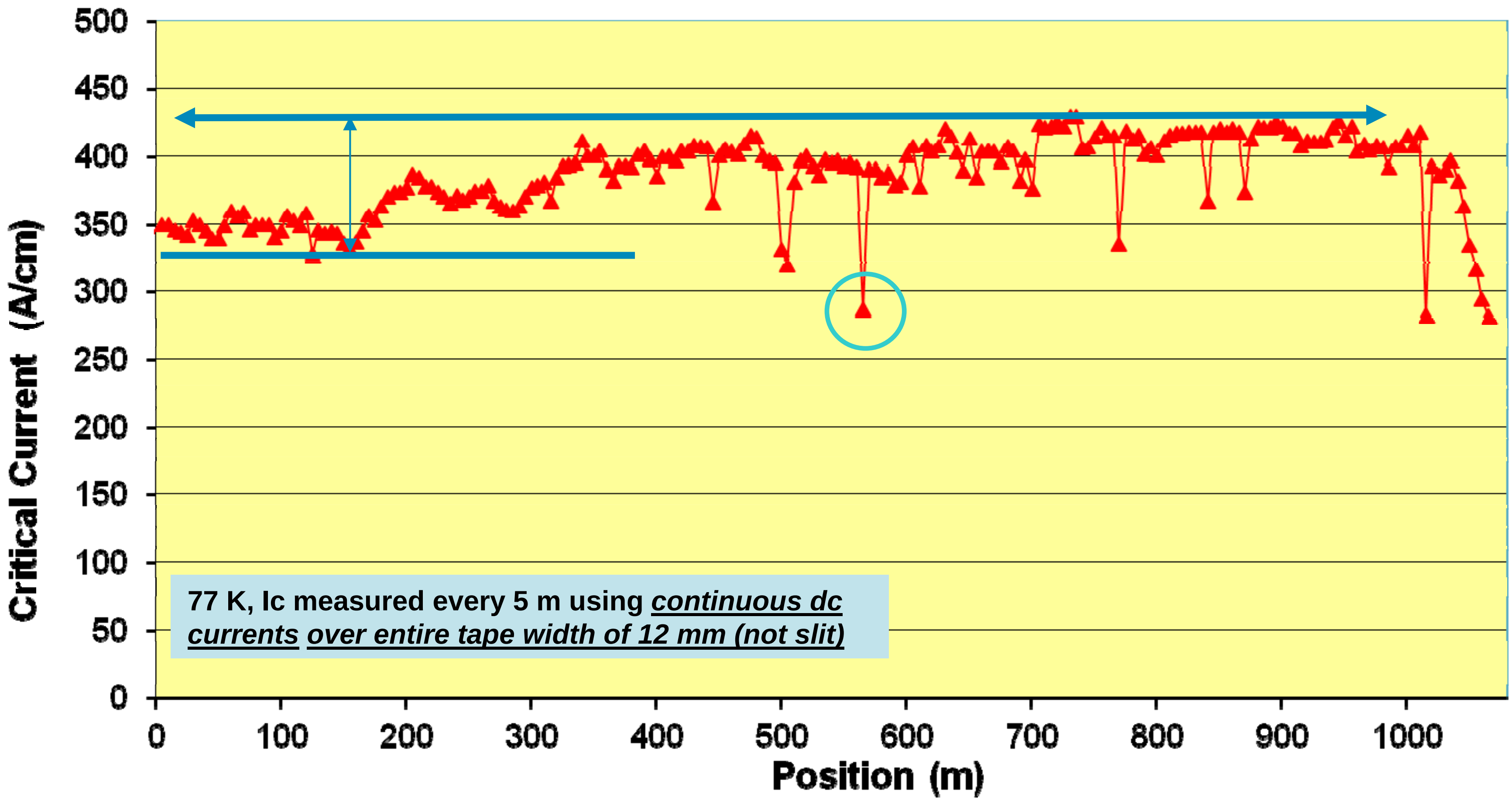
Measurements by V. Braccini, J. Jaroszynski, A. Xu,& D. Larbalestier, NHMFL, FSU

Advances with Zr-doping being locked into production

What further steps are needed for high field magnets?

- Consistent performance
- Repeatable, critical current vs. operating conditions (T, B, Bf)
- Mechanical properties
  - Axial (high strength inherent with Hastelloy substrate)
  - Transverse – more variation – multiple layers
- Joints
  - Joint resistance
  - Standard process
- Geometry control
  - Issue mainly with electroplated stabilization (dog boning)
- Amount of stabilization (copper) and quench require more understanding
- Alternative configurations: high current conductors, cables

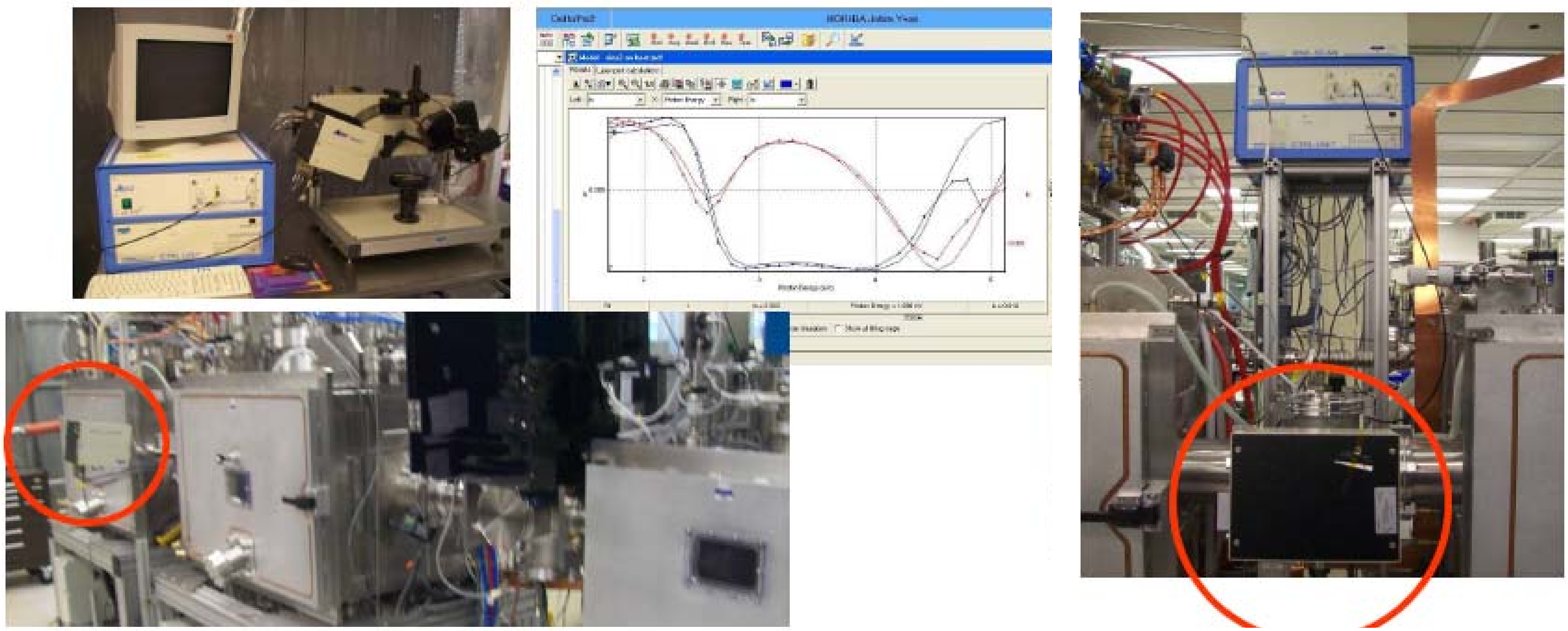
2G HTS wire production processes are routinely conducted in kilometer lengths



- Need to control Ic variability over length – MOCVD process control
- Need to understand cause of “drops” – overall process control

On-line ellipsometry system introduced in buffer deposition

- Thickness of alumina buffer is critical to avoid diffusion of substrate species
- New in-situ ellipsometry system installed to measure real time thickness of alumina and other buffer layers



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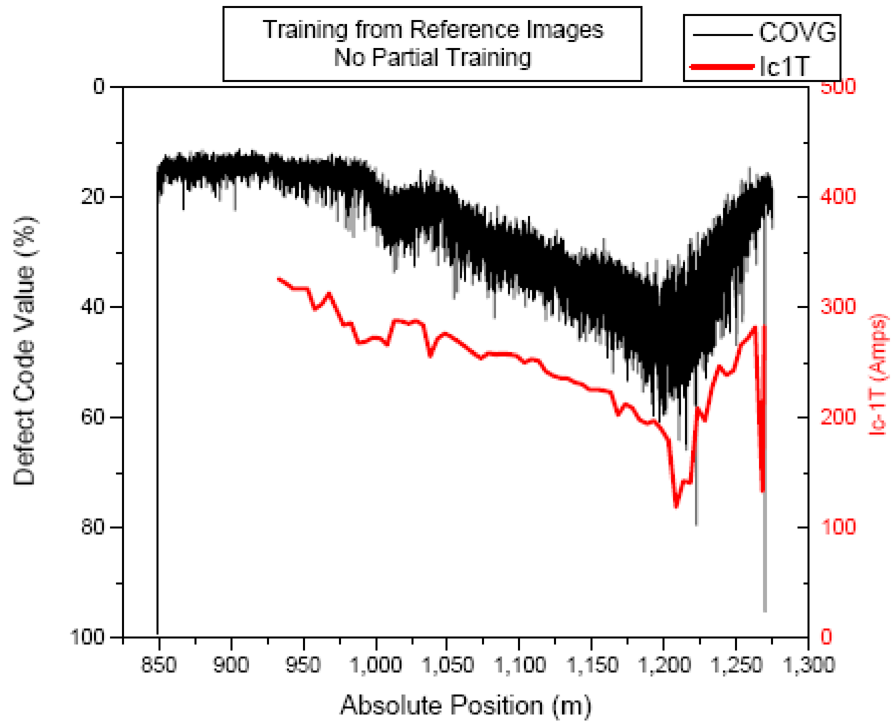
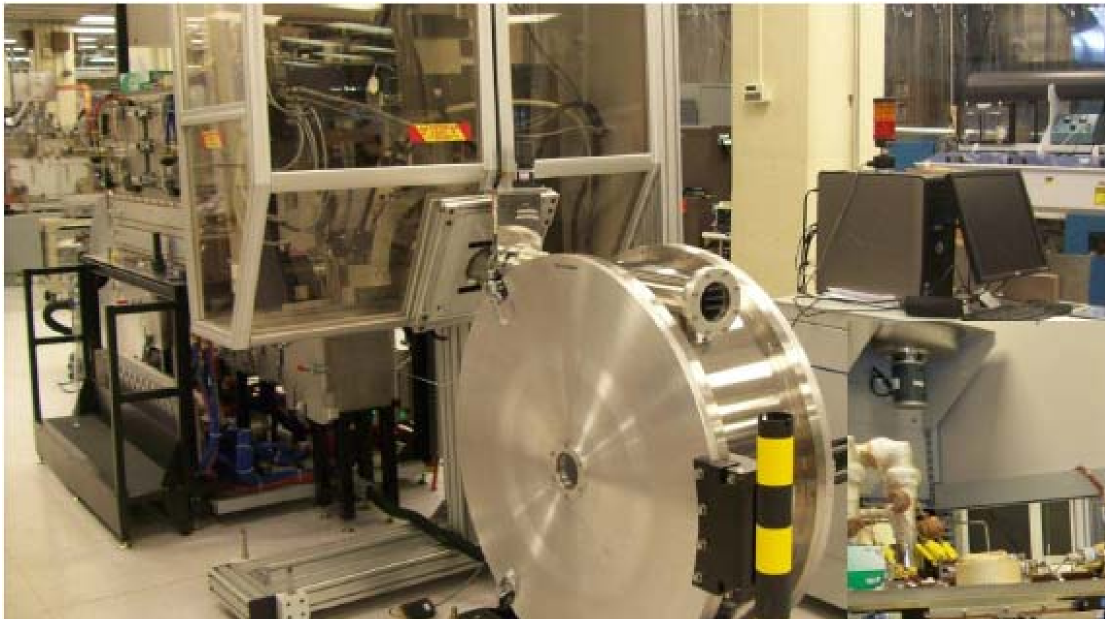
In line quality control vision system being added to improve MOCVD process feedback

- Reference images used from a previously inspected MOCVD tape with known good Ic
- Comparisons of quality maps a good predictor of critical current performance
- Process drift can be discerned in real time
- Learning how to use this data to feedback into process parameters



"Ic1T" refers to "first transport Ic" measurement Over the length of the conductor run

In-line XRD in new pilot-MOCVD line (M4) for real-time quality control



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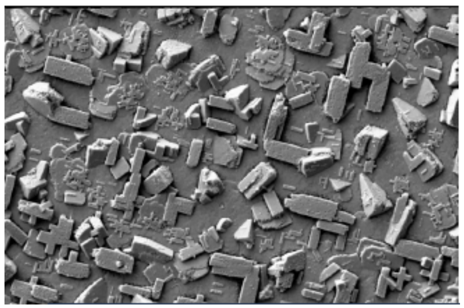
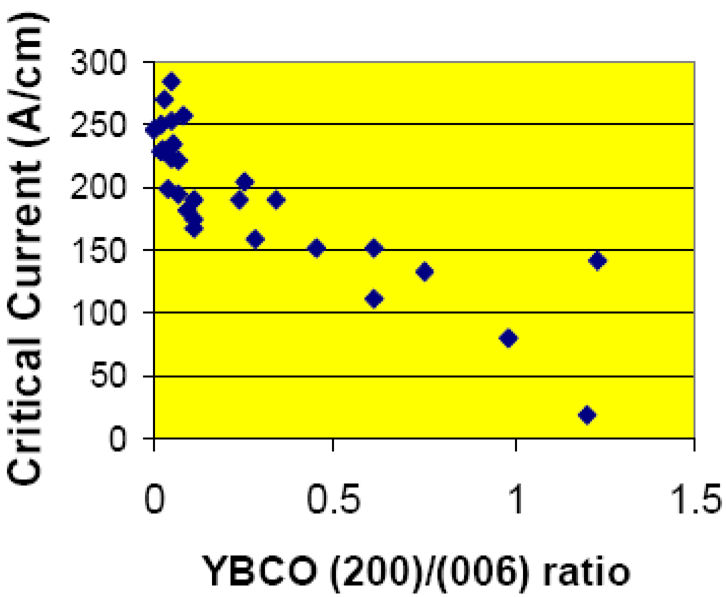
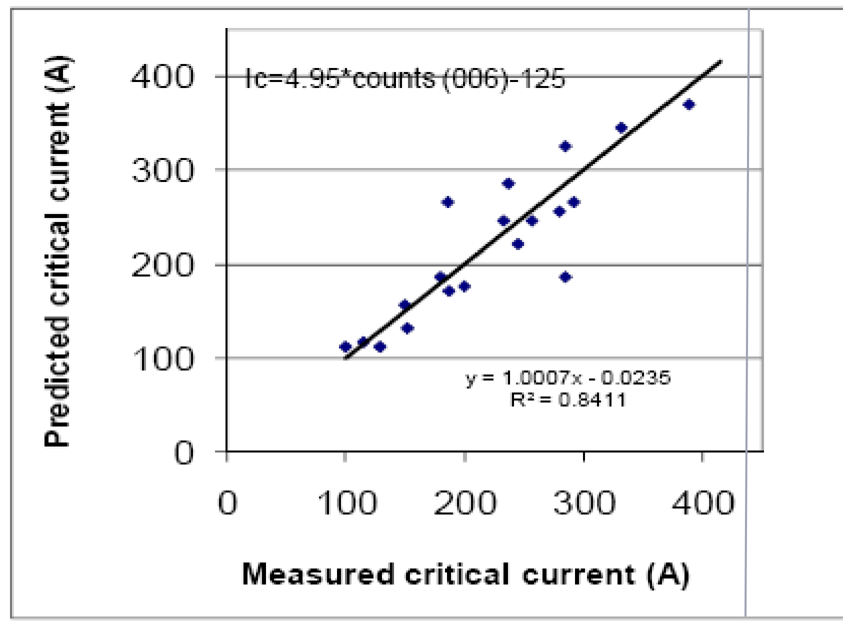
Early detection of a-axis growth during MOCVD is valuable in controlling 2G tape Ic



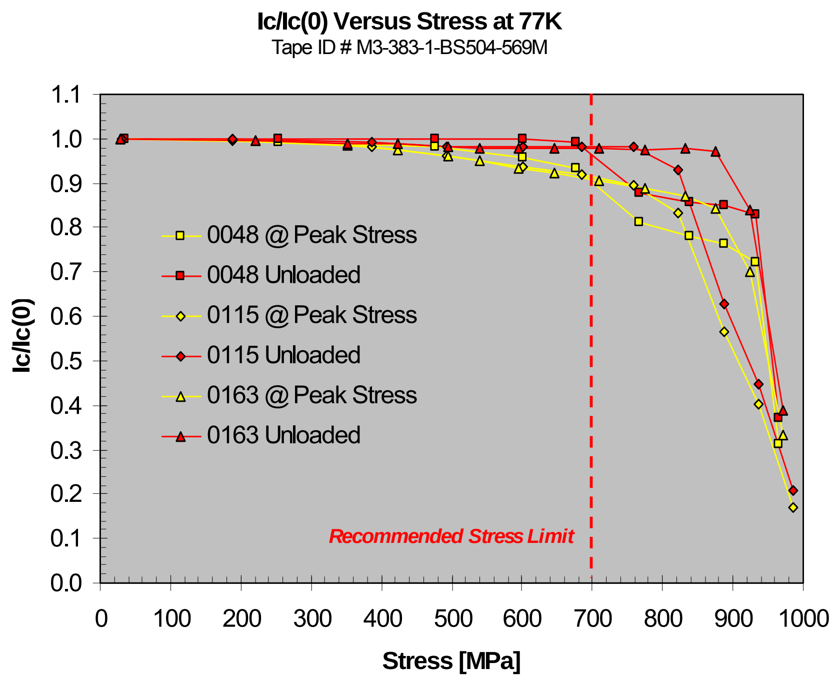


Critical current predicted based on (006) XRD peak intensity



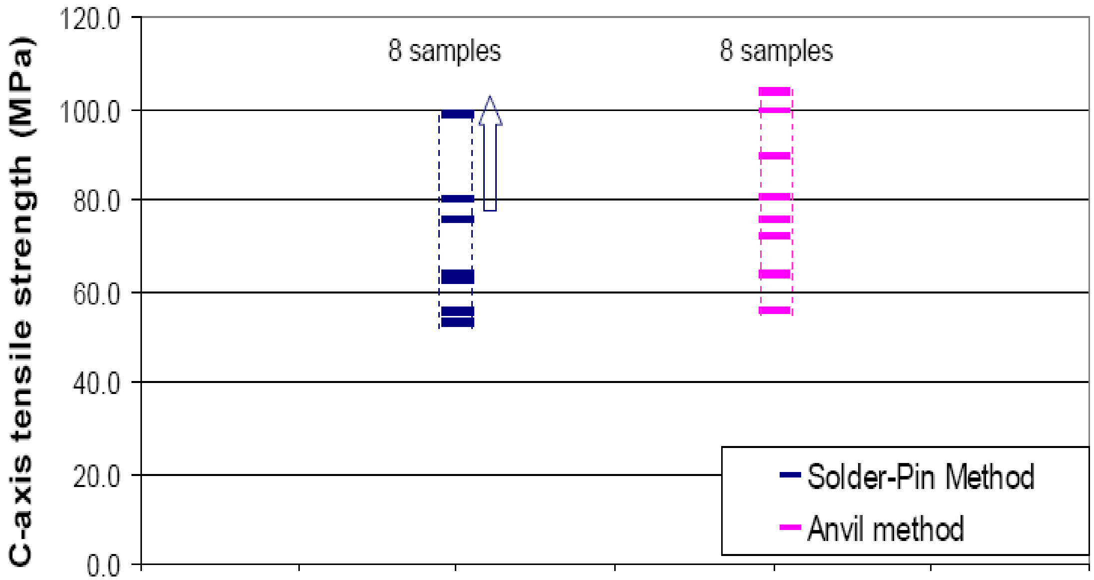
Mechanical strength very high along tape axis

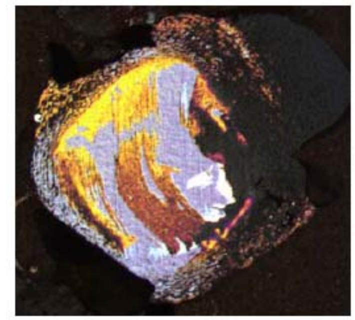
Yield Stress (77K)	970 MPa (140.7 ksi) @ 0.92 % strain
Stress Limit (77K) 98% Ic reversibility 90% Ic (zero strain) at limit	700 MPa (101.5 ksi) @ ~ 0.6 % strain
Modulus (77K)	~120 GPa
Fatigue Limit (77K)	> 100,000 cycles, ~ 680 MPa tensile



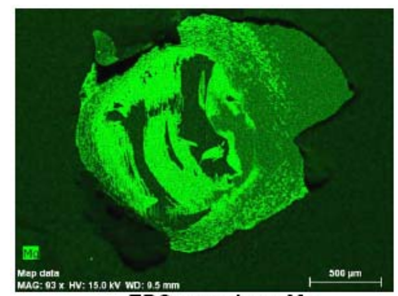
Data from Ron Holtz, NRL

C axis tensile strength evaluated by two methods





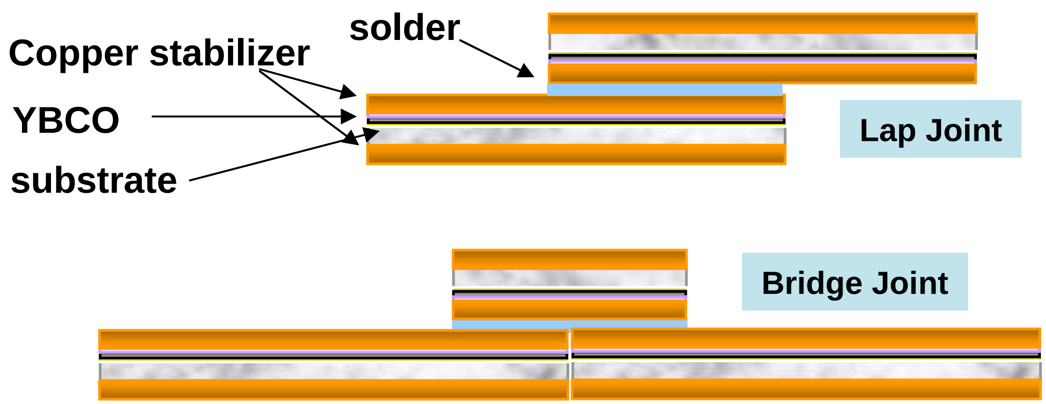
OM photo of delaminated region

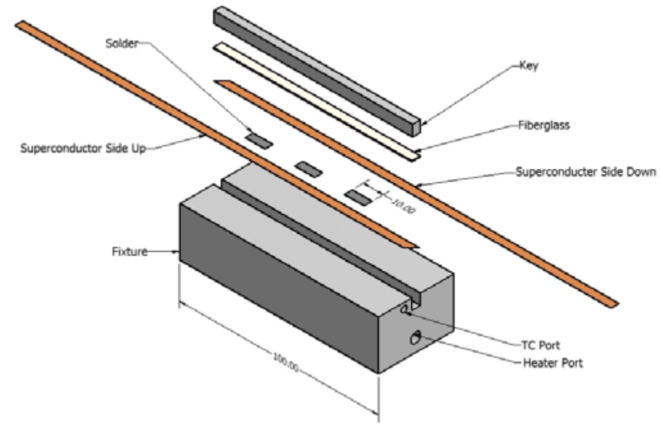


EDS mapping - Mg

- Two methods of testing the c-axis tensile strength are used. Both indicate some variation in the c-axis tensile strength (test variability vs. tape variability)
- Interfaces at the debond zone are evaluated to identify the source of the variation of the c-axis tensile strength

Joint resistance - an ongoing area of development





- Fixturing developed for repeatable joint fabrication
  - Temperature control – T, duration
  - Alignment
  - Pressure during soldering step
  - Preform solder
- No degradation in Ic (1 μV/cm) over the joint or splice
- No degradation in Ic and resistance when joint or splice is bent over 25 mm diameter and thermal cycled three times
- Joint or splice resistance = **10-25 nano-ohm typical** (100 mm long overlap)
  - Variation is seen between conductor production runs
  - Variation within production runs much tighter
  - **Both variation and level of joint resistance are areas of ongoing investigation**

Summary

- 2G HTS will play a key role in pushing high field magnet technology to higher field levels
- Superior Ic performance achieved with advanced pinning techniques, including low temperature high field operating conditions
- Parallel focus areas being pursued
  - Continued performance improvements through technology developments to be introduced in a controlled manner to the commercial product
  - Manufacturing focus to provide reliable, consistent performance conductor
    - Predictable, uniform performance characteristics within and between production runs
    - In-line QC tools being put in place
    - Continued investigations to mitigate variability in
      - C-axis tensile strength
      - Joint resistance

- The need to move from a “developmental” conductor to a “manufactured” conductor is recognized

Questions?

Thank you for your interest!

For further information about SuperPower,

please visit us at: www.superpower-inc.com

or e-mail: info@superpower-inc.com