Summary of the
SRF Materials Workshop

held 29-31 October at Michigan State Univ.
hosted by MSU, NSCL, and Fermilab
http://meetings.nscl.msu.edu/srfmatsci/

Presented by Lance Cooley
SRF Materials Group Leader, Fermilab
On behalf of the Program Committee

Overview

- Fourth in a series of largely domestic workshops in the spirit of the Gordon Conferences
- General themes: end-use pull, industry achievements, materials science, processing innovations, fundamentals and tutorials
- Attendees are 40% Academic, 40% Lab, 20% Industry / Small Business

- Charge: *Build connections between fundamental materials science and SRF technology to understand limits, validate processes, and seek breakthroughs in performance.*

Program

1. Materials R&D Drivers – updates from ILC, TTC, and other recent cavity tests
2. Removing or Avoiding Extrinsic Performance Limits
   - Focus on possible origins of weld / etch pits: do they originate from sheet forming? Welding? Electropolishing?
3. Understanding and Achieving Intrinsic Limits
   - Overviews of atomic layer deposition and flux-line heating
4. Beyond Niobium
5. Processing Science and Innovations
6. Seamless Forming
   - Tutorial on seamless forming

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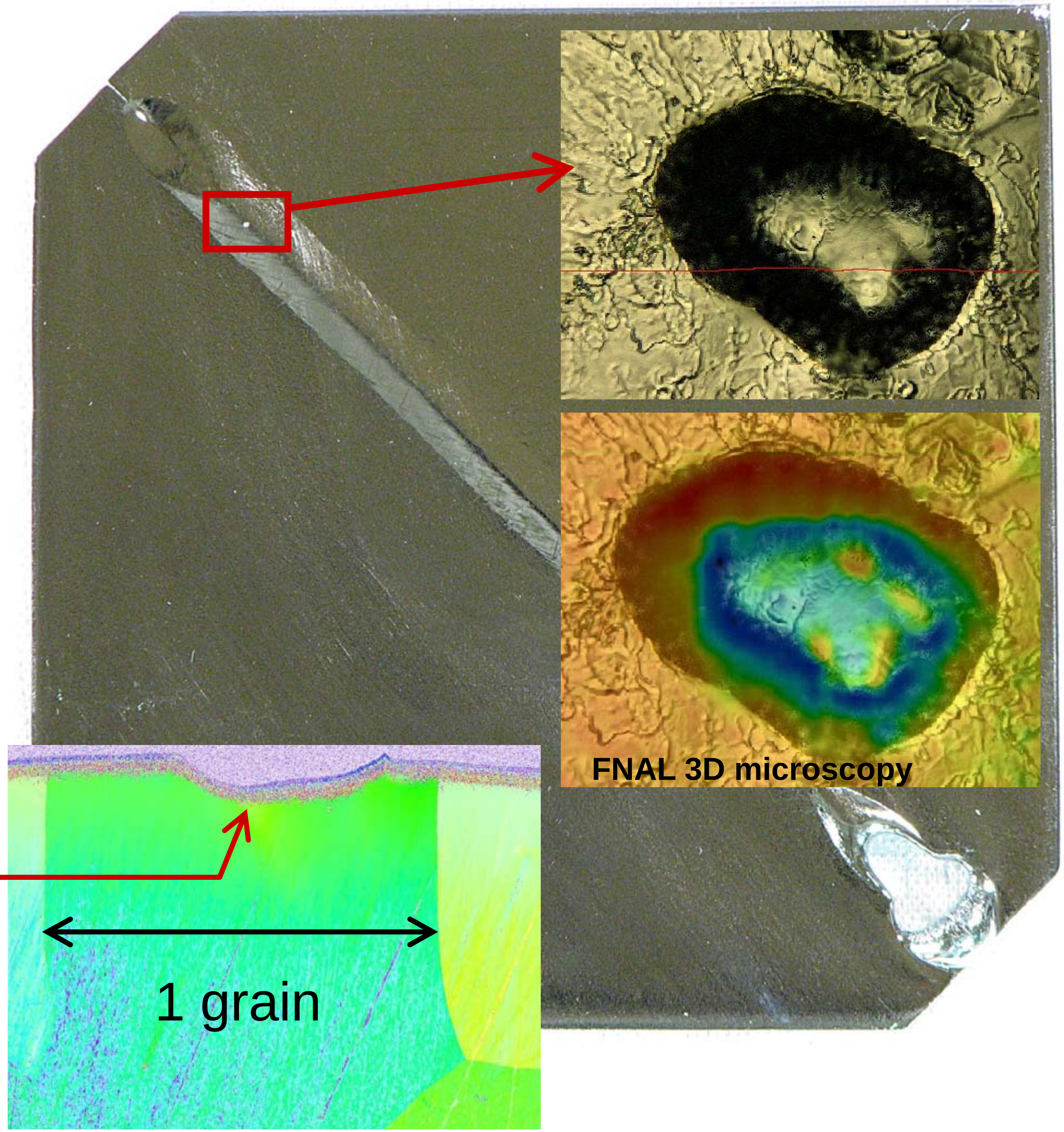
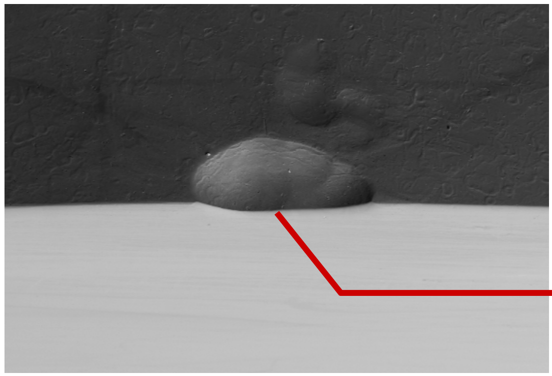
Weld pits have been made in the laboratory

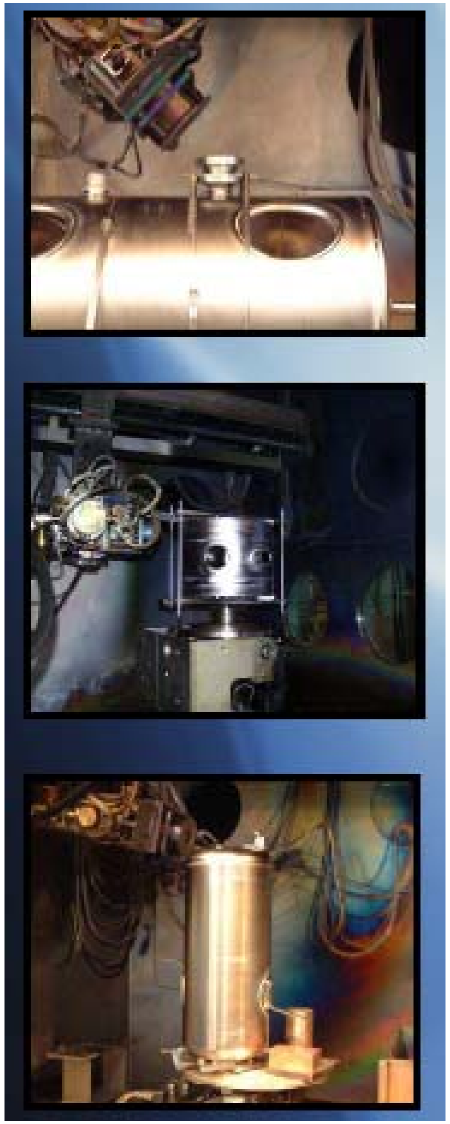
Below: Cross-section of defect cut, polished, and imaged by orientation microscopy at Florida State





Welding

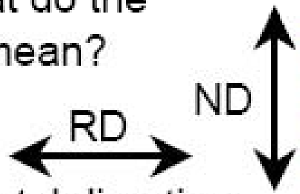
- Bob Salo – Sciaky
- A moving electron gun may be preferred to a moving work piece
- A 50 μm “defect” is not recognized as a defect in post-weld QA. “Weld porosity” is typically quoted in the 0.2 mm range and higher.



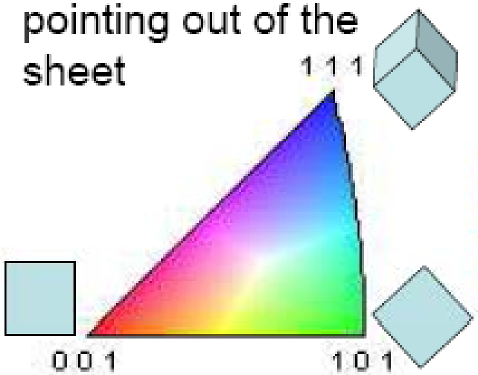
Rolling to make sheet metal … controlling microstructure and texture (grain orientations)

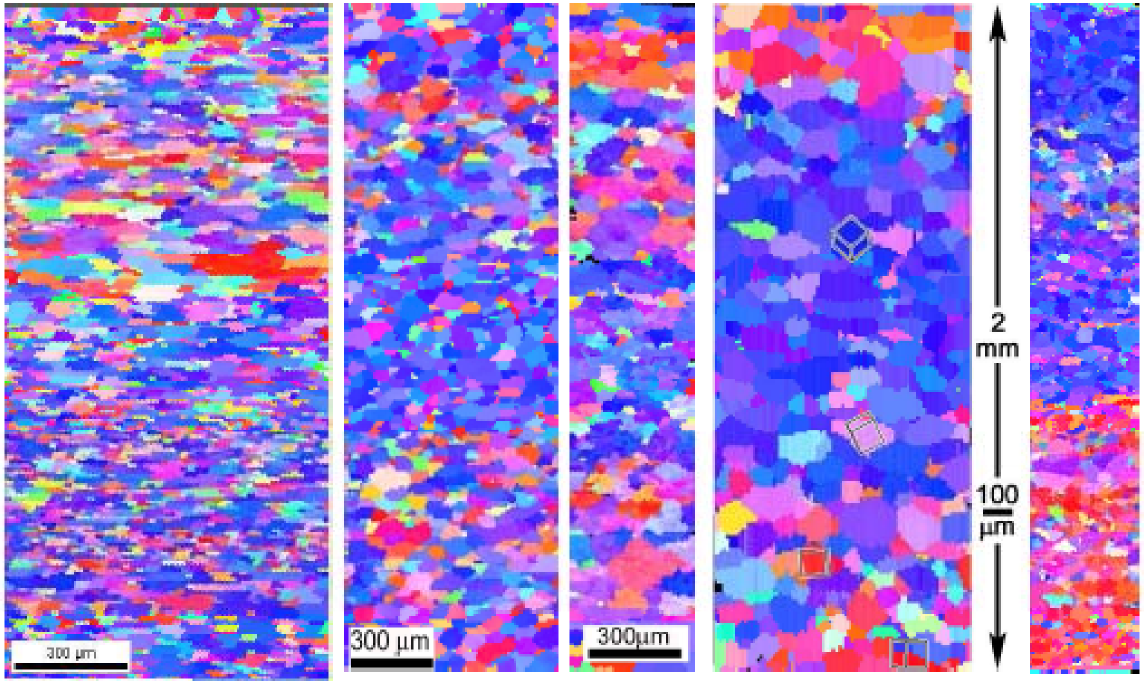
- Consistency is a challenge… Producers start with a hunk of ingot, and then use combination of breakdown forging, annealing, rolling to hopefully get a uniform microstructure
  - does initial ingot orientation haunt the microstructure at the end ?
- We have never seen the same texture/microstructure twice… !

So, what do the colors mean?



The crystal direction pointing out of the sheet





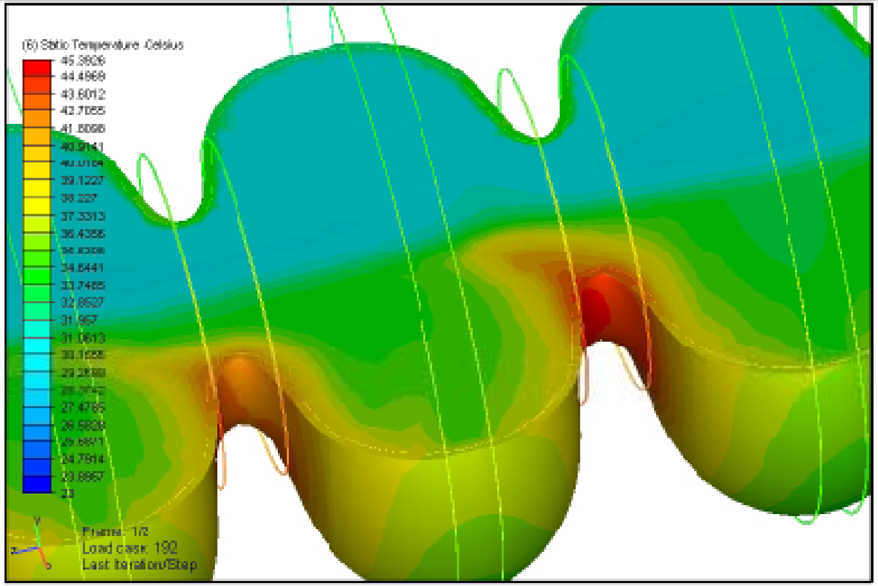
MICHIGAN STATE UNIVERSITY
Prof. Tom Bieler

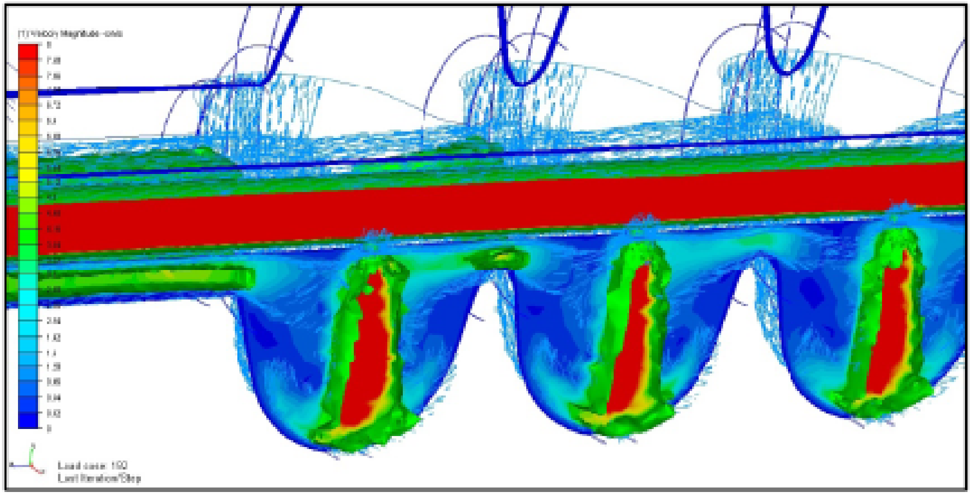
Observations and Speculations

- From making an ingot to final function, dislocations are an omnipresent enabler and suspect,
  - Additional suspects: H, O, impurities, interfaces, magnetic fields, surface energy
  - Dislocations can be removed most effectively by recrystallization;
  - Recovery leaves substructure that is oriented in crystallographic directions
- Does Nb love its dislocations so much that it will not let us take them away?
- Is the perfect cavity a recrystallized single crystal with dislocation segments ***not*** lined up in a radial direction?

Electropolishing?

- There are dramatic variations in temperature and flow conditions on the surface of an "electropolishing" cavity.
- The local parameter sets are well outside those identified as "desired" by small sample tests.
- Historical measurements identified **20-35 C** as producing the lowest surface roughness (under static flow conditions).





Electropolishing?

- At present, there is no bridge from controlled sample tests to the actually-used "electropolishing" parameter set.
  - Temperatures present are well outside of the "recommended" range.
  - Flow rates are variable and in a range not yet characterized via controlled sample analysis.
- Protocols applied to niobium cavities have been found empirically to (often, but not reliably) produce "good" results.
- **There exists minimal technical basis for contending that the transformation of the surface by "electropolishing" is understood and thus predictable or optimized.**
- Is there a significant *etching* component yet in present protocols?

C. Reese

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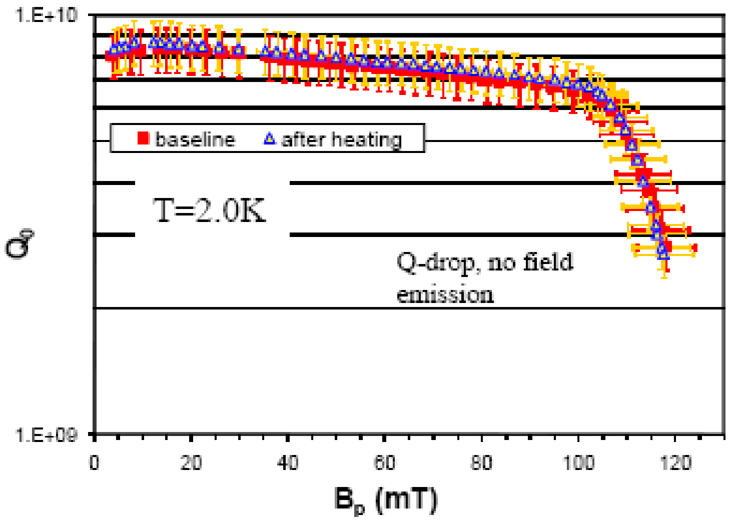
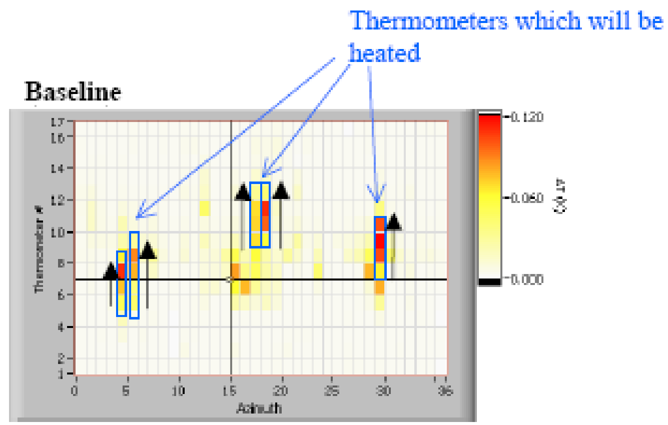
Flux “annealing” redistributes hot spots

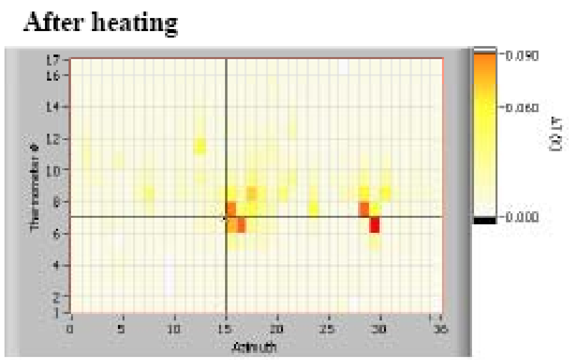
More effective in large-grain cavities due to lower pinning

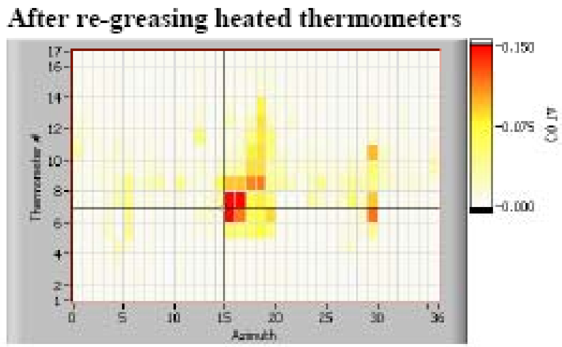


R_{res}=12.9 ± 1.2 nΩ baseline

R_{res}=12.2 ± 1.3 nΩ after heating





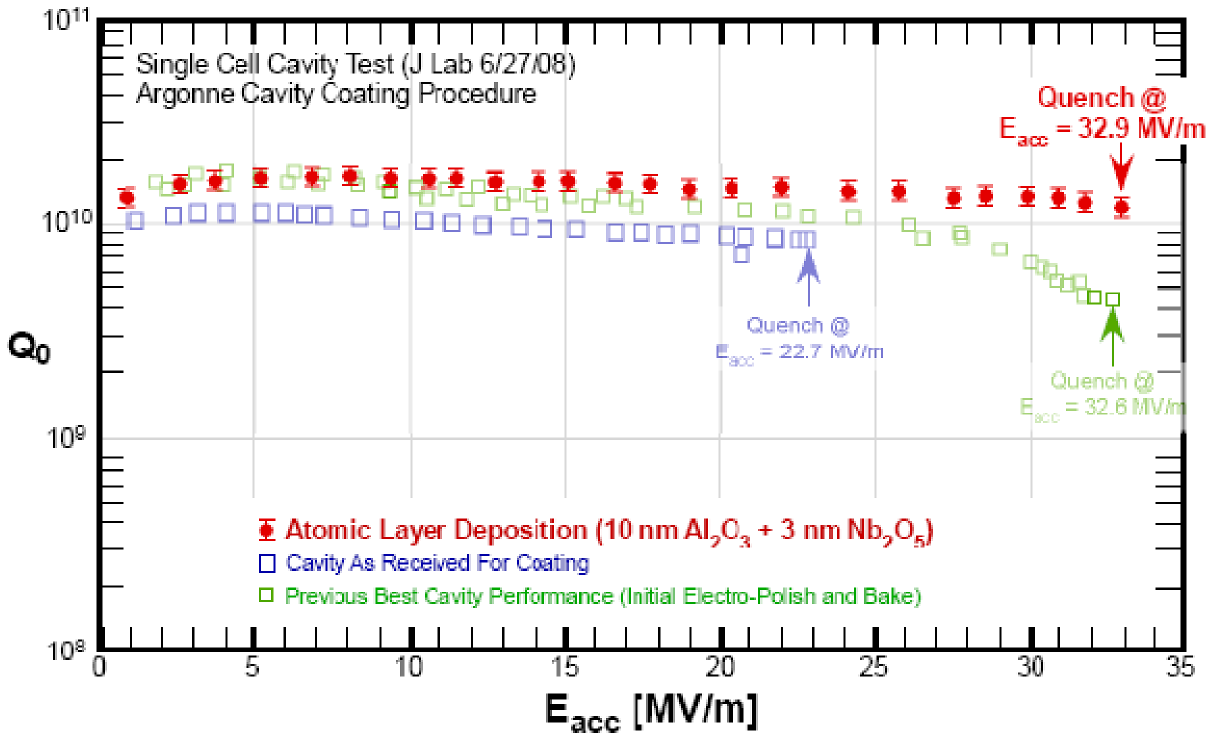


Re-distribution of “hot-spots”

Ciovatti and Gurevich

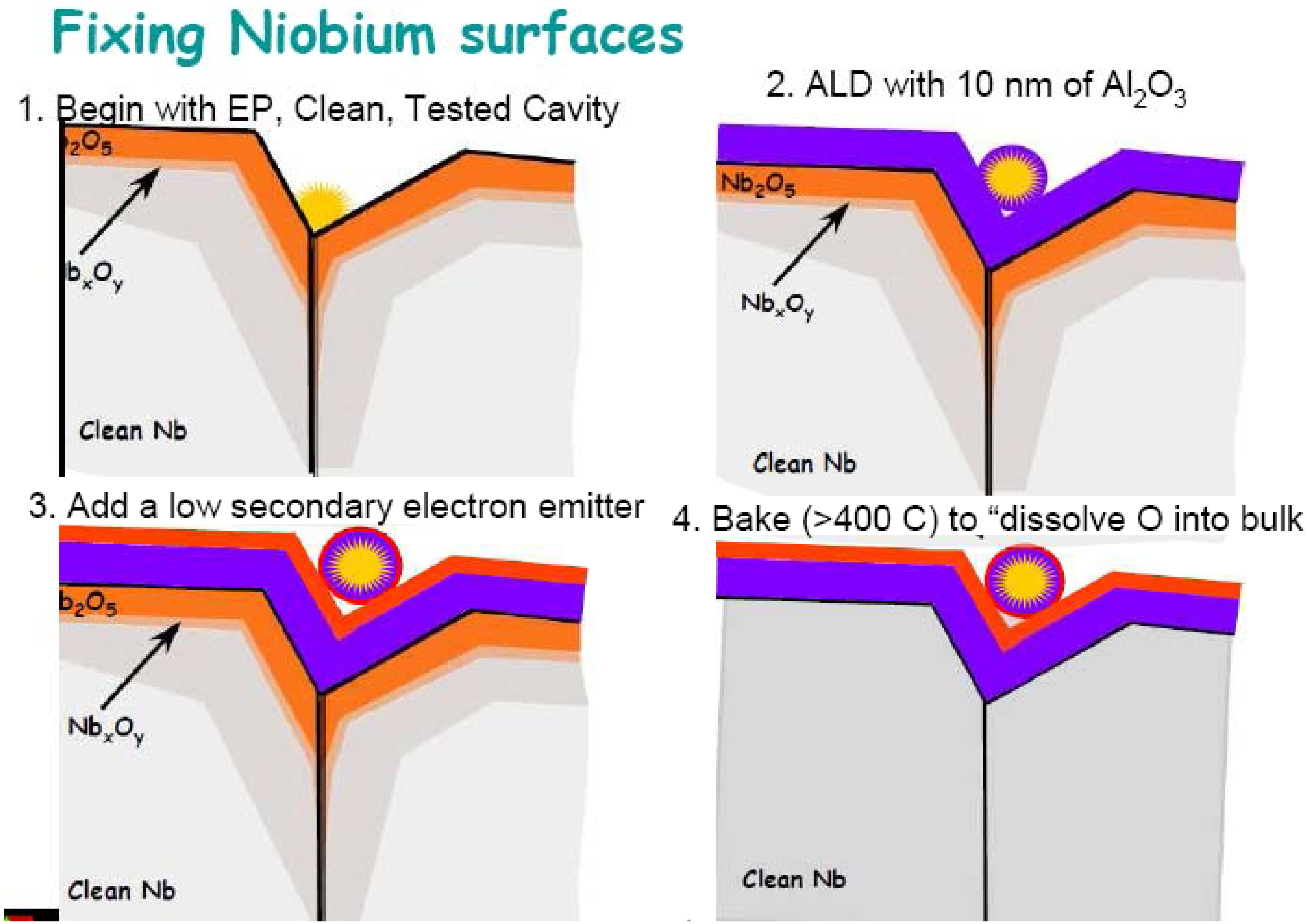
Atomic Layer Deposition appears to work

J Lab Cavity: After ALD Synthesis (10 nm Al_2O_3 + 3 nm Nb_2O_5)



- Only last point shows detectable field emission.
- 2nd test after 2nd high pressure rinse. (1st test showed field emission consistent with particulate contamination)

Permanent cavity coatings?

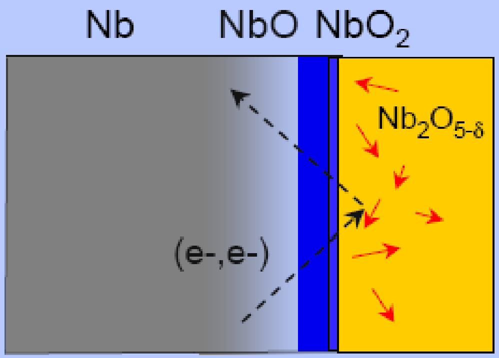


Explanation of the baking effect?

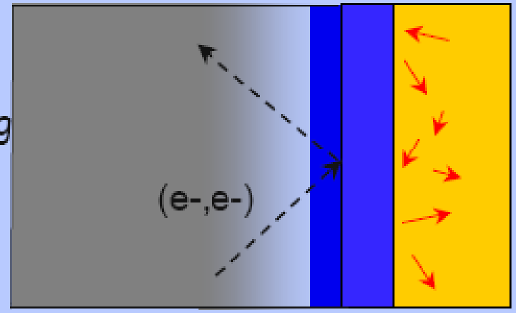
J. Zasadzinski, T Proslier, M Pellin

Oxygen defects in Nb_2O_5 are magnetic, break Cooper pairs when close. But they can be annealed away.

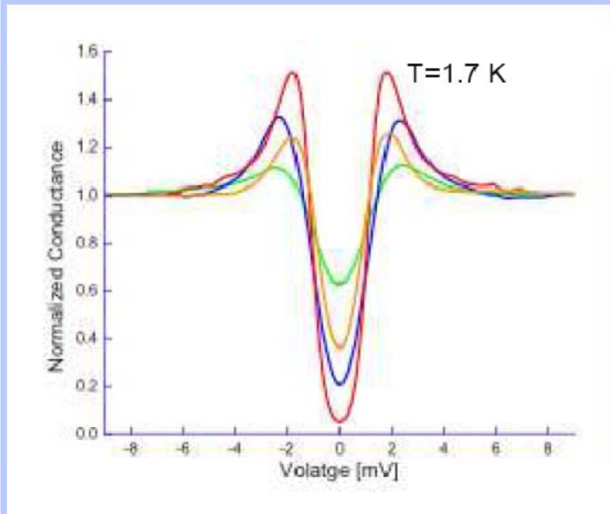
Before baking

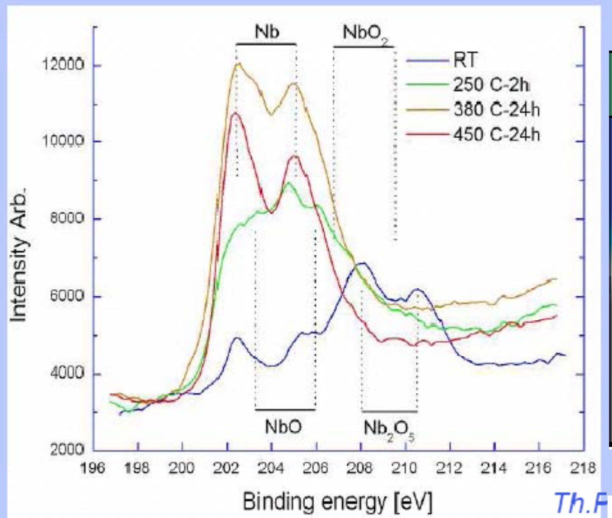


After Mild baking



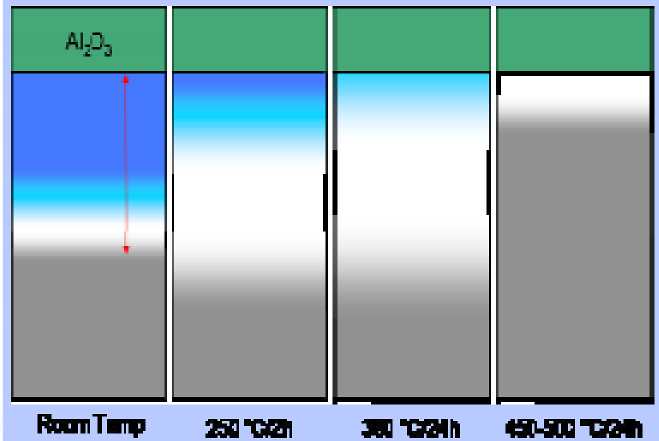
Al_2O_3 Protective layer, diffusion barrier



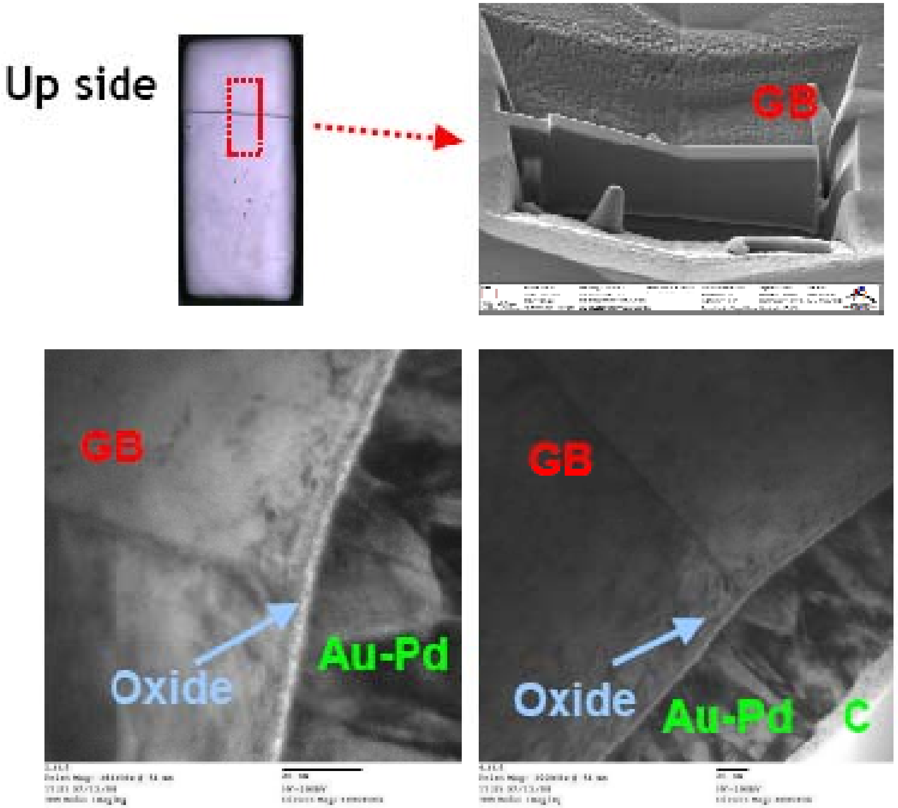


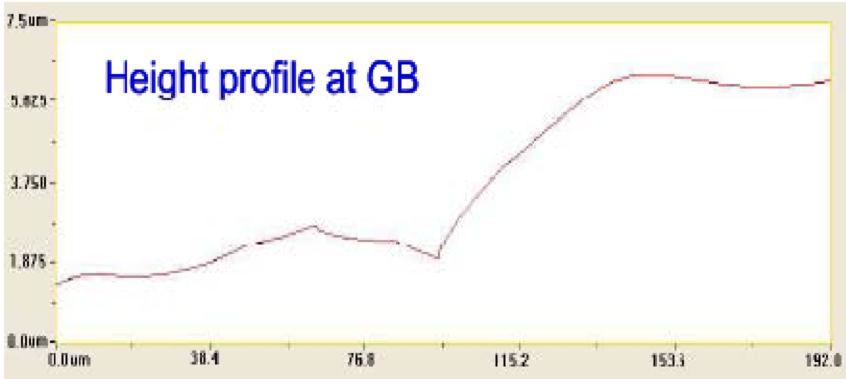
Th.F

Schematic oxide evolution



Evaluation of flux penetration into a grain boundary





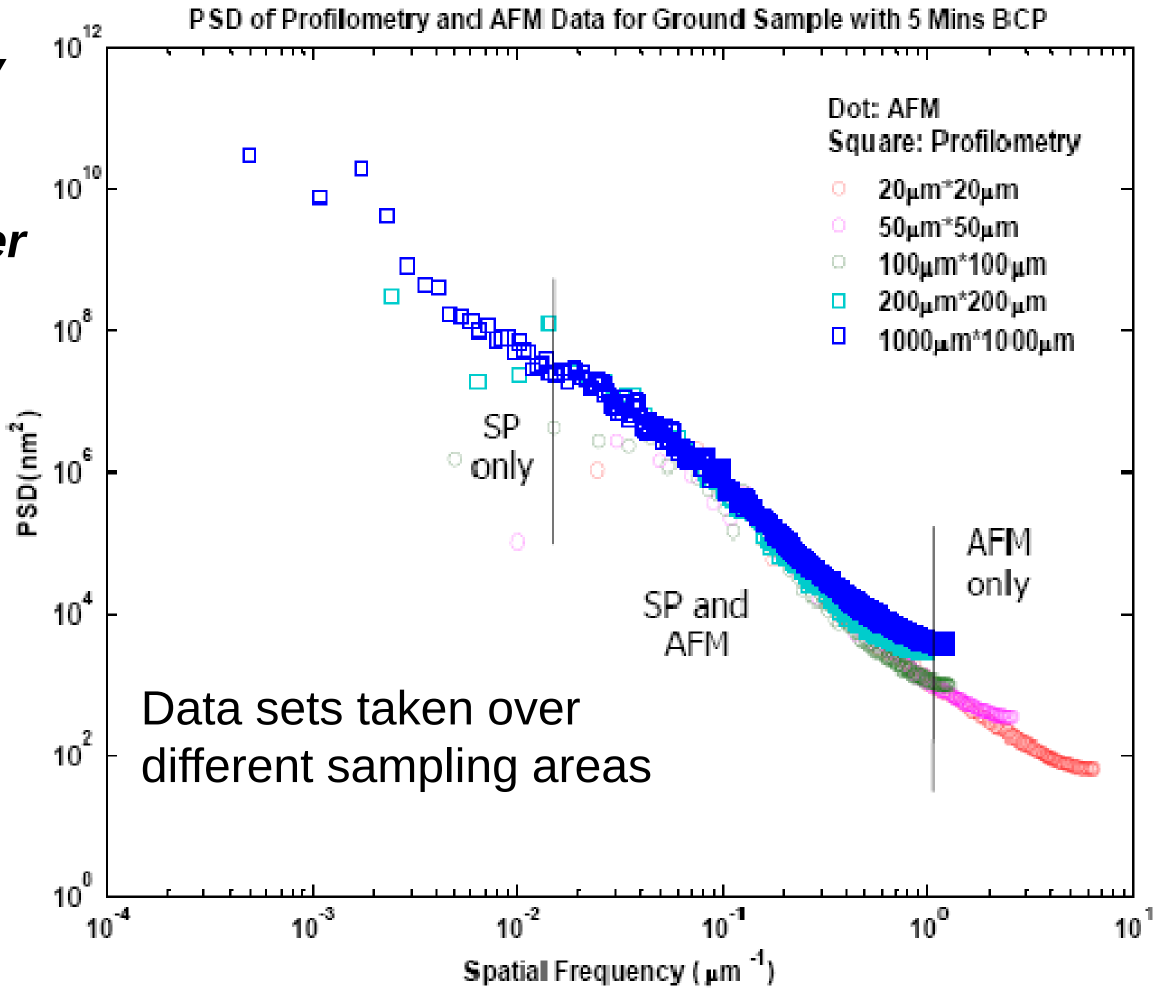
BCP caused a groove to form in the isolated grain boundary, which caused it to admit magnetic flux

Z.H. Sung

A better way to assess roughness

Power spectral density incorporates roughness data from nanometer to millimeter scales

Why is scaling observed over 4 decades?



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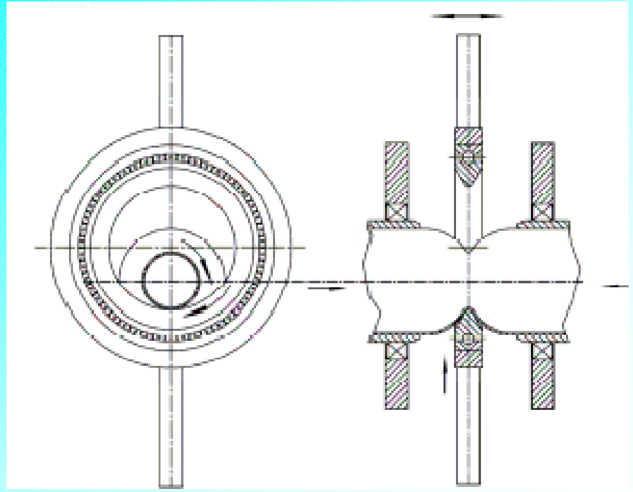
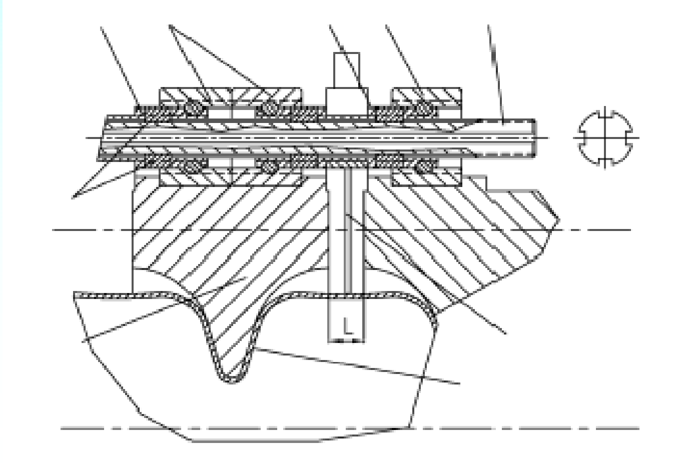
Seamless cavity forming - avoid welds

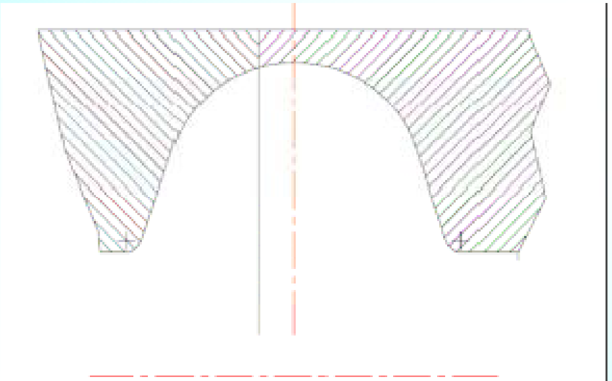
Some key ideas contributed to hydroforming success



Principle of diameter reduction in the tube end and in the tube middle



Synchronization mechanism for the final step of hydroforming



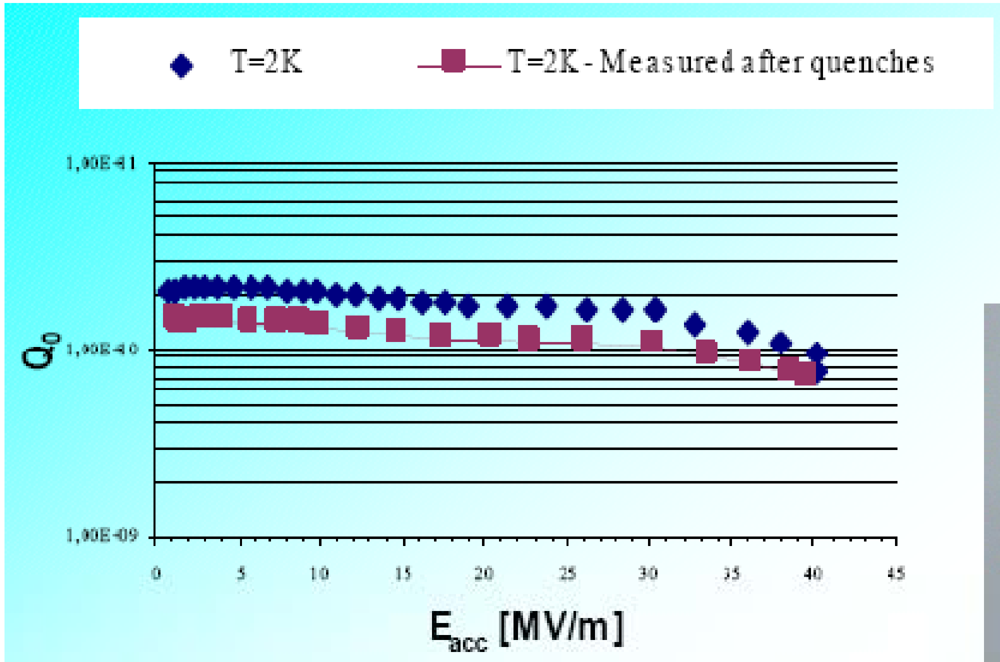
Nonsymmetrical mould for hydroforming

Developed ideas summarized in the patent.

W.Singer, I.Jelezov; No. 10 2007 037 835 ; 18 September 2008

Niobium tubes

Flow forming of niobium spun tubes at MSR (Germany). Precise wall thickness after flow forming. Tolerances within of +/- 0,1 mm

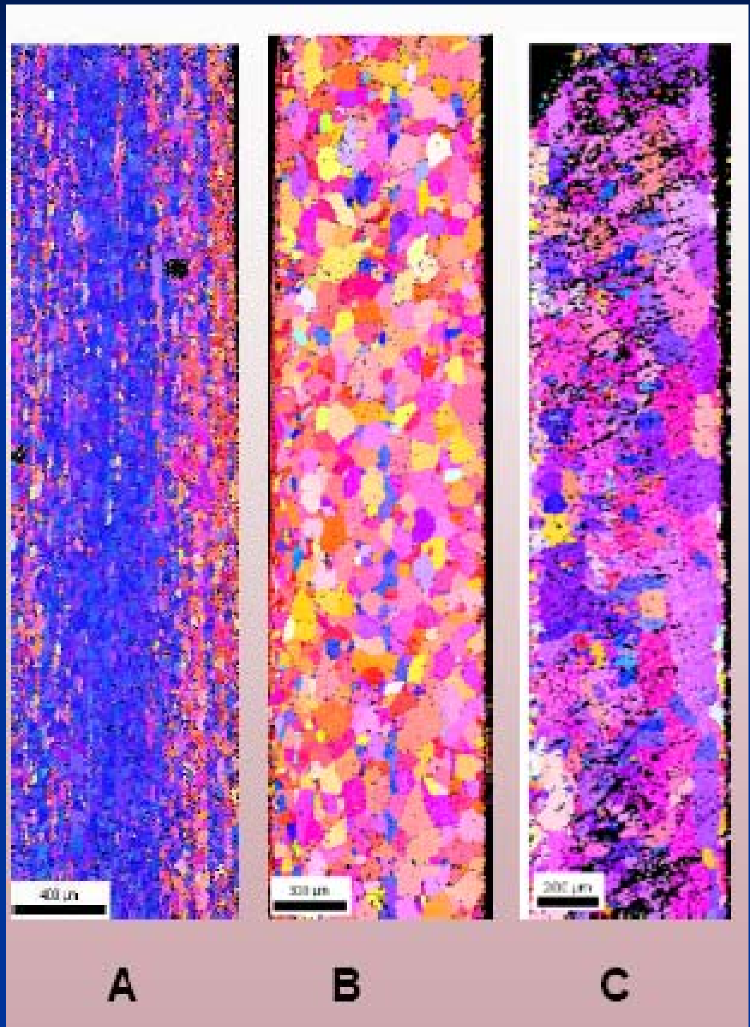


NbCu single cell cavity 1NC2 produced at DESY by hydroforming from explosively bonded tube. Preparation and HF tests at Jeff. Lab: 180 μm BCP, annealing at 800°C, baking at 140°C for 30 hours, HPR (P. Kneisel).

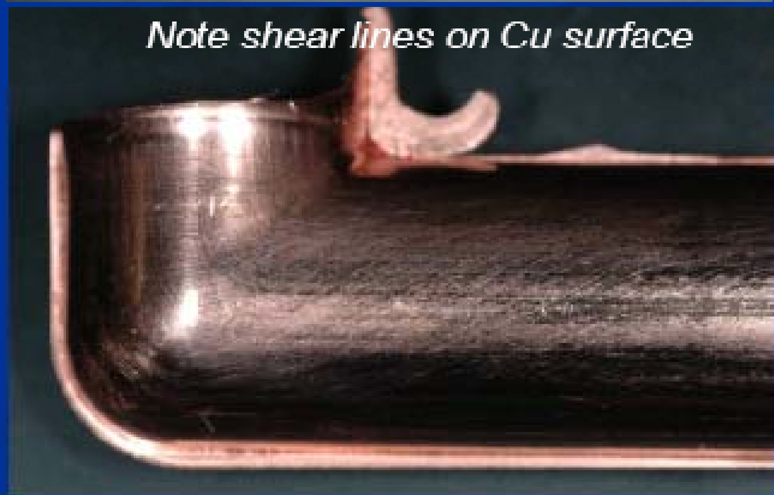
NbCu cavities hydroformed from explosively bonded tubes at DESY.

40 MV/m without EP

Ultra Fine Grain Processing/ECAE



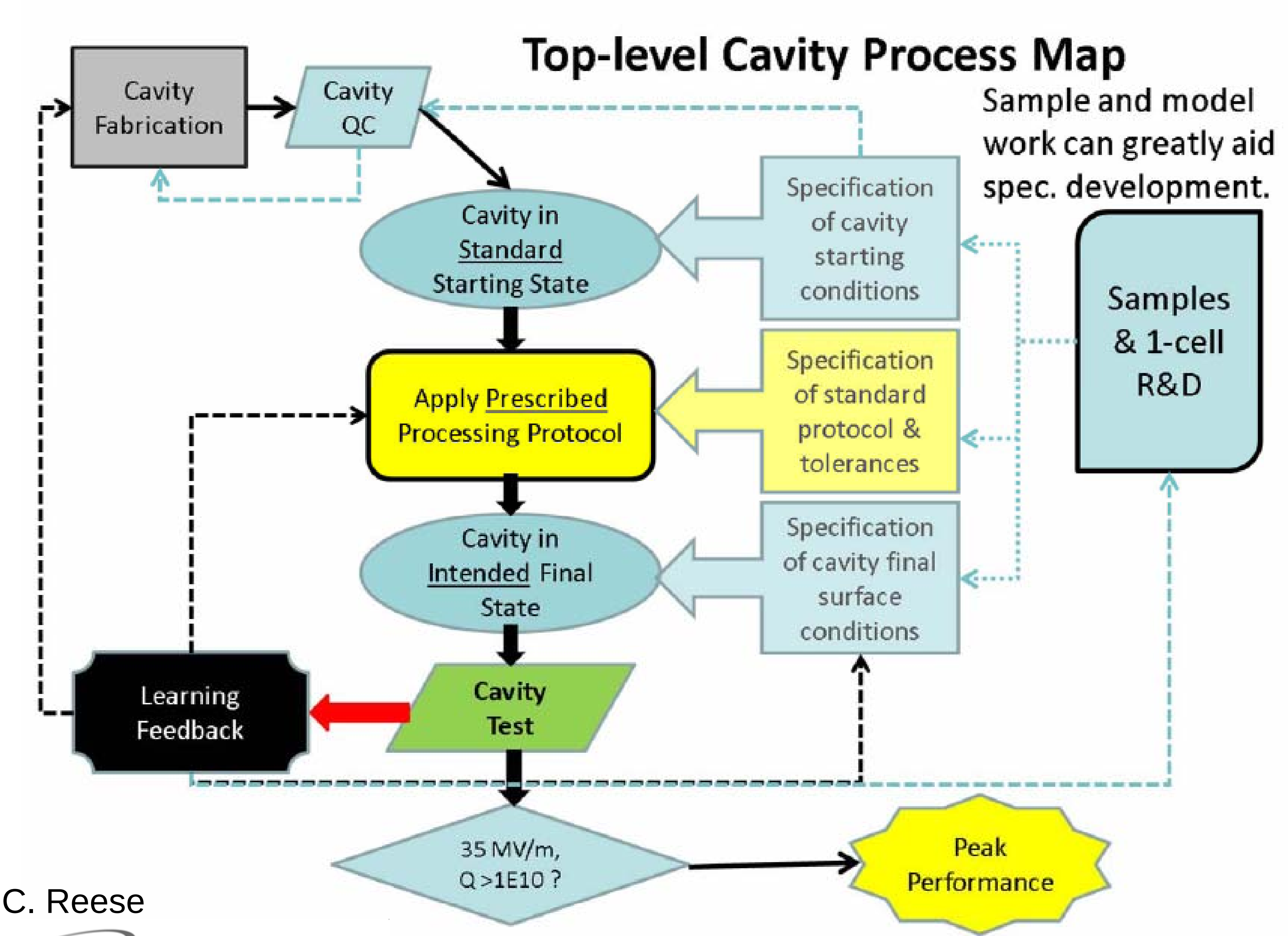
Bare 12.7 mm Niobium without Cu cladding



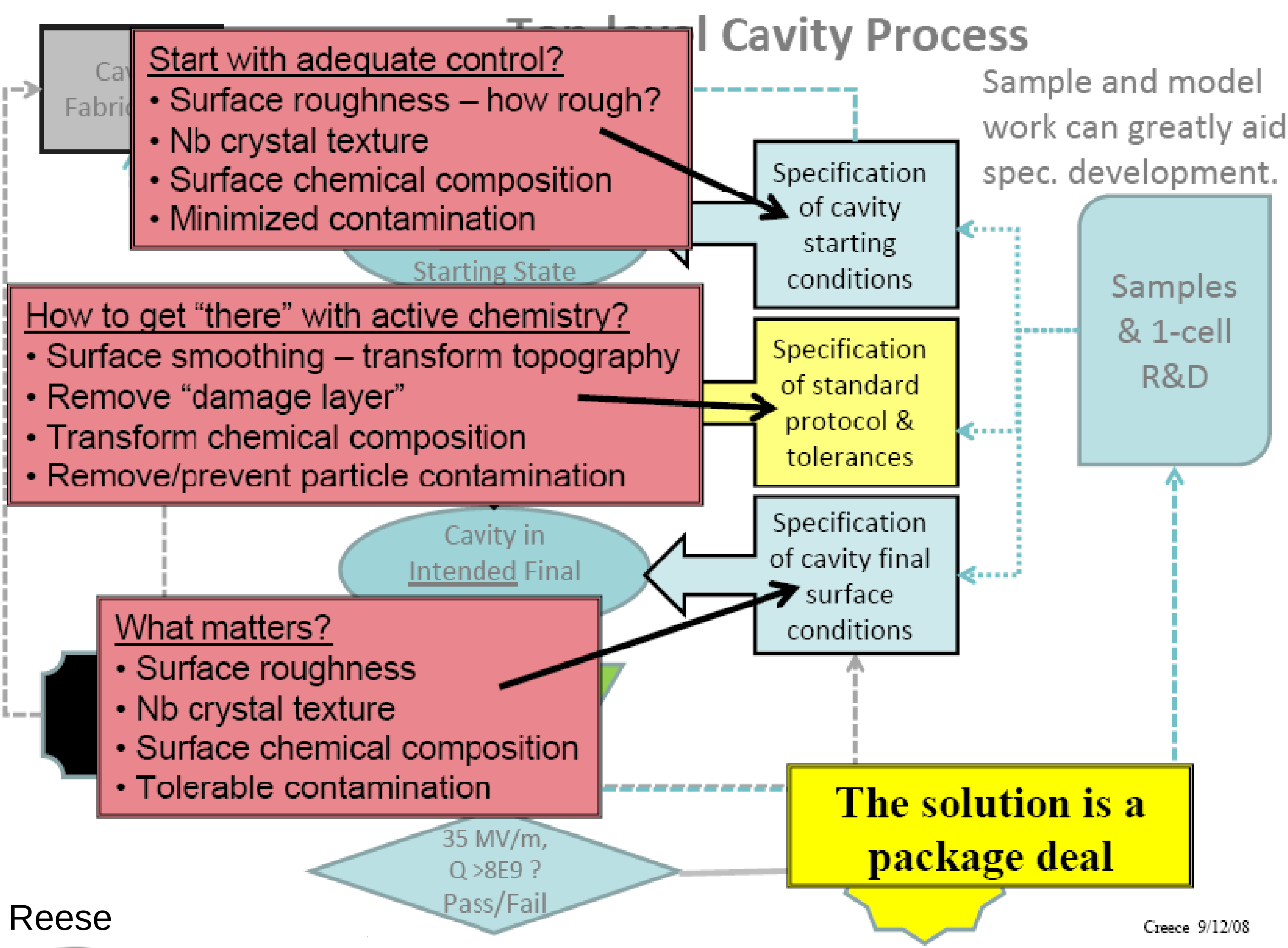
Complete at 104,000 psi

Hartwig – TAMU, Crooks – Black Labs

Summary


Top-level Cavity Process Map
Sample and model work can greatly aid spec. development.
Cavity Fabrication
Cavity QC
Cavity in Standard Starting State
Specification of cavity starting conditions
Apply Prescribed Processing Protocol
Specification of standard protocol & tolerances
Samples & 1-cell R&D
Cavity in Intended Final State
Specification of cavity final surface conditions
Learning Feedback
Cavity Test
35 MV/m, Q >1E10 ?
Peak Performance

C. Reese



C. Reese

Jefferson Lab
Thomas Jefferson National Accelerator Facility