SRF Material R&D

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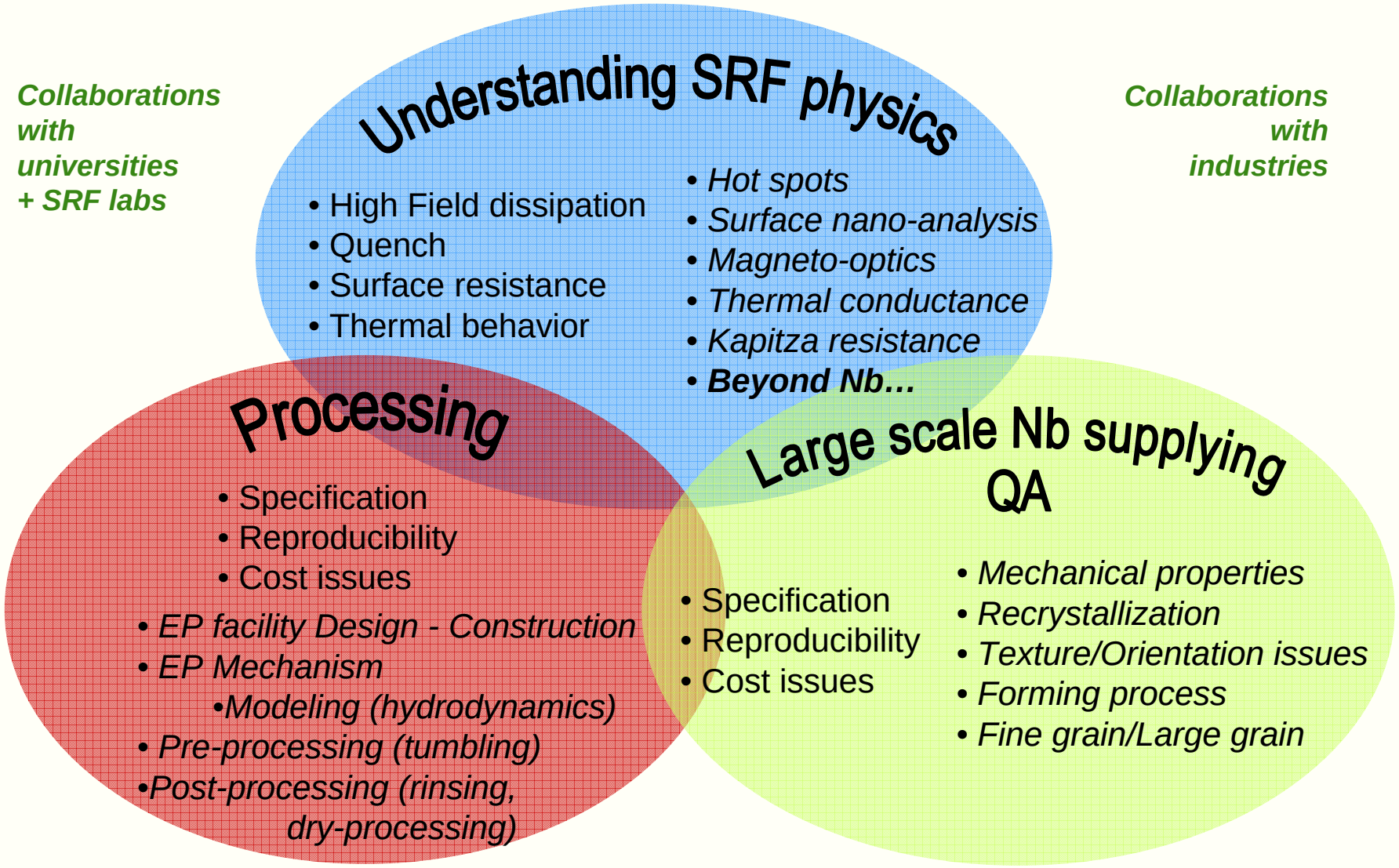
SRF Materials Issues

Fermilab

Collaborations with universities + SRF labs

Collaborations with industries



SRF Materials group

Fermilab

Scientists:	
C. Antoine	***(Processing R&D, University Collab.)***
Engineer-Physicists:	
D. Hicks*	***(Cavity, Nb processing)***
G. Wu	***(Materials R&D, Processing R&D)***
Engineers:	
C. Boffo	***(Processing R&D and Facilities, Materials R&D)***
C. Cooper*	***(Processing Lab Safety, Processing R&D)***
N. Dhanaraj	***(1 Cell Program)***
G. Galasso	***(Processing R&D)***
Designers:	
K. Ewald	***(Processing R&D)***
F. McConologue*	***(FTE Processing R&D)***
Designer 1 cell*	***(1 Cell Program)***
Tech:	
D. Bice	***(Processing R&D @ J-Lab)***
D. Burke*	***(Processing Lab support)***
O. Frianeza	***(Processing R&D, SRF Materials Lab)***
R. Schuessler	***(SRF Materials Lab)***

FTE:
1 SC
5 ENG
3.5 TEC
2 DES

* Not full time

Improvement of QC/QA and Support to projects

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- *Ongoing*
  - **Eddy Current Scanner, microscopy, mechanical measurements (collab. MSU)…**
  - **Cutting study**
  - **RRR measurement**
- *Short term activities*
  - **Cold tensile test (implementation of the Instron Machine)**
  - ***Surface routine analysis****
  - ***Thermal conductivity measurement***
- *Mid-long term activities*
  - ***Squid Eddy Current scanning (sheets, cavities) ? ****.**
  - ***Field emission scanner ? ****

* Investment needed
** developed else where

Process R&D Activities

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- *Ongoing*
  - **Pre-processing (Tumbling) / Post-processing (dry/plasma cleaning)**
  - **Samples R&D *(bath aging, Fluorine monitoring with ISE, process understanding,…)***
  - **3.9 GHz 1-cell EP set-up**
  - **EP modeling *(needs to be reinforced),* BCP *(thermal modeling)***
  - **EP/BCP facility @ ANL & FNAL**
  - **Assembly**
- *Short term activities*
  - **Upgrading the 3.9 GHz EP set-up to 1.3 GHz ?**
  - **Development of nine-cells EP set-up**
  - **Development of single/nine-cells RF test stand with diagnostic *(T-mapping, replicas…)***
- *Mid term activities.* ***They need to be first demonstrated on 1-cell before being applied to 9-cell. It supposes the 1-cell RF test stand to be running.***
  - **Reproducibility of the complete process: EP + HPR + Baking + RF test (1-then 9-cells)**
  - **Alternative rinsing (ethanol, degreasing)**
  - **Baking study**
  - **Feasibility of online F monitoring on the EP set-up.**

Materials R&D Activities

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- *Ongoing*
  - **Surface 3D microprobe analysis (with NU)**
  - **Magnetic characterization, magneto-optic, critical current, influence of grain boundary, baking (with FSU, ex Wisconsin)**
  - **Mechanical characterization, texture analysis (with MSU)**
- *Short term activities*
  - **Recrystallization study, cold and RT mechanical properties (1-2 year post doc)**
  - **Development of large grain/monocrystal cavity fabrication (project, not necessarily within the material's group)**
  - **Magnetometry on monocrystals (e.g. Fermi local PhD program), sensitivity of grain orientation to the processing ***
  - **Rs low field measurement with RF microscope, Theory of SRF (at FSU**)**

Mid/long term activities

- ***nm thin films of e.g. MgB2 on medium/large grain Nb cavities ; collaboration with Argonne, FSU and Penn State U *.***
- ***Superconducting Gap measurement by photoemission and STM ; collaboration with Argonne, IIT *.***

* Investment needed
** developed else where

Why Should We perform Material R&D ?

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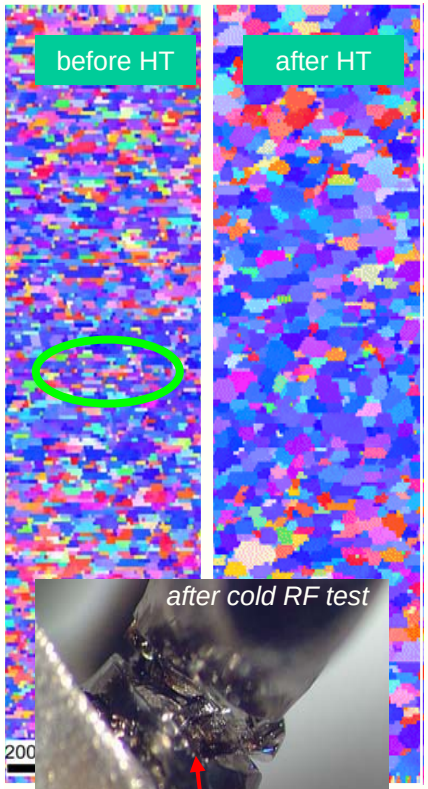
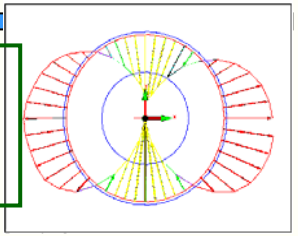


Forming Problems at AES:

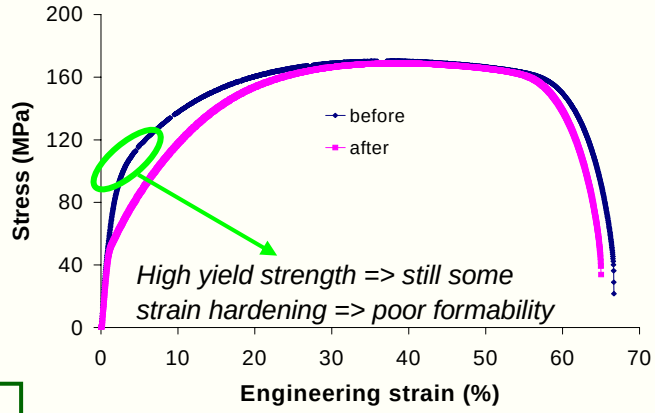
Nb too hard, spring back, 6 passes vs 1, ovalization…



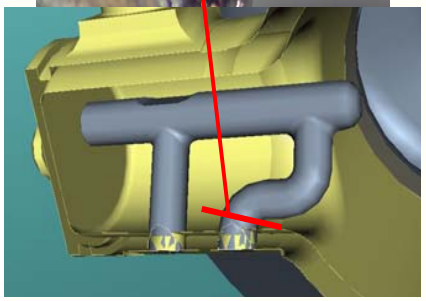
Deviation from circular shape

Microstructure & Mechanical Properties studied (MSU):

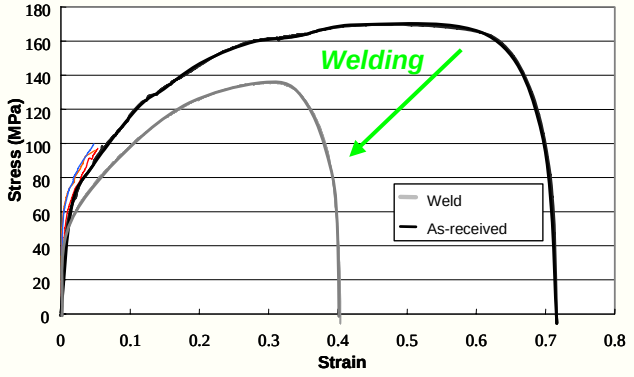
- ***Diagnostic: non fully recrystallized material***
- ***Recommendations***
  - ***Re-annealing of the batch (~ 200 sheets)***
  - ***QA : delivered material should meet tightly specifications***
  - ***We must work with the suppliers to help them to meet specification***



Antenna breaking in HOM coupler



- ***Diagnostic: brittle fracture, but precursor cracks during processing ?***
- ***Recommendation***
  - ***we need to know better cold and room temperature mechanical properties of Nb***



Why Should We perform Process R&D ?

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Surface processing 1

Large spread of results for electropolishing (EP)

Why are EP results are not reproducible ?

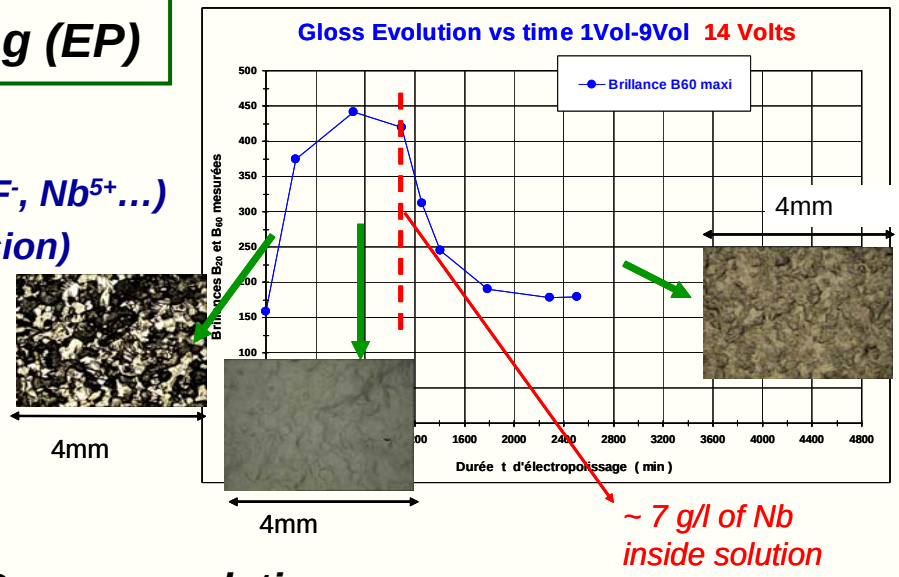
- *Aging of the solution, evolution of the composition (F^-, Nb^{5+}…)*
- *Impurities, particles generation (Sulfur vs field emission)*
- *Variation of the surface composition ?*
- *Variation of the surface roughness ?*

Surface processing 2

Field emission is the major practical limitation

What are the possible sources?

- **Poor control of the wet process : particle counting is not effective**
- **Poor cleaning of the ancillaries : e.g. couplers**
- **Contamination during assembly : long, complex, man-made**
- **Absence of post processing solution**



Recommendations

- ***Need to do R&D on samples, 1-cells before 9-cells***
- ***Developing monitoring (F^-, Nb^{5+}…)***
- ***Modeling***
- ***Surface studies (composition, morphology)***
- ***Develop new designs/tooling to ease assembling (Collabn Jlab)***
- ***Develop post processing applicable to assembled cavities (e.g. Plasma cleaning w ECR plasma)***

Why Should We perform Advance Material R&D? (1/3)

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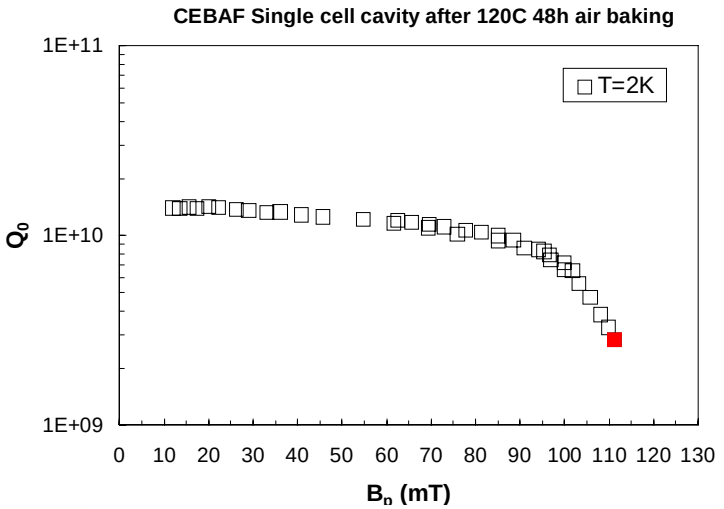
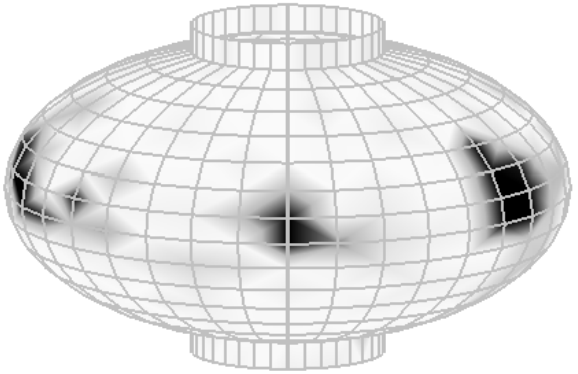
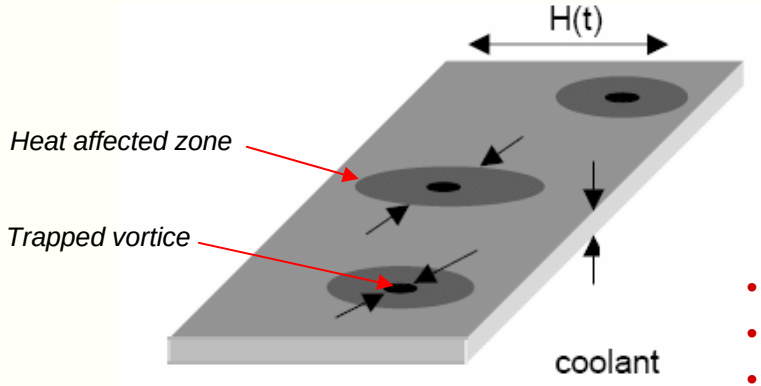
Superconductivity limits

The theoretical limits for RF superconductivity aren't well known

- ***What causes the high field losses/ hot spots ?***
  - ***Morphology ?***
  - ***Grain boundaries***
  - ***Surface contamination (O)***
- ***Recommendations***
  - ***Basic R&D on superconductivity***
    - ***e.g. Hot Spot Model – A. Gurevich (Coll w FSU)***







- ***Effect of trapped vortices***
- ***Heat source ~ can be very small (nm to mm)***
- ***Thermally affected zone: ~ 5 mm and growing with B!***

Why Should We perform Advance Material R&D? (2/3)

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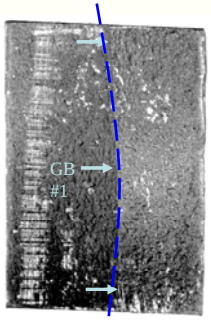
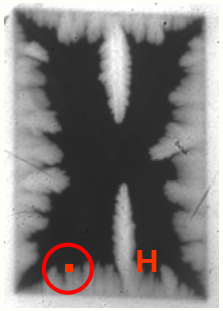
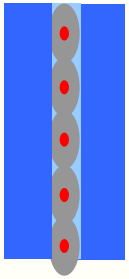
What is the problem with GB ?

Morphological effect or depleted SC ?

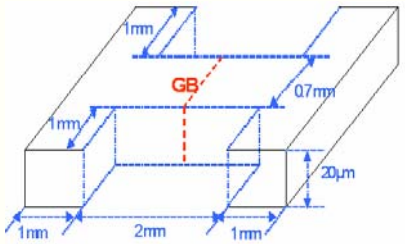
Flux penetration @ GB





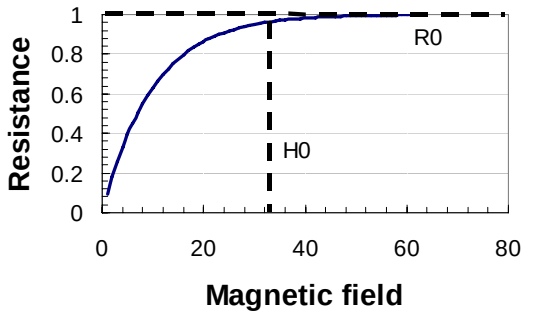


[Collabo. WU/FSU]



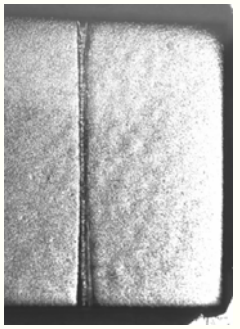
[A. Polyanskii et al, WU/FSU]

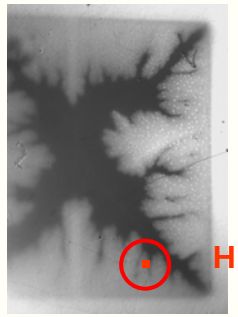
[Sung Hawn]

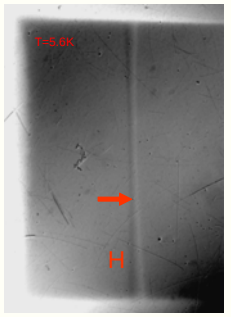


Saturation-field H0 gives information on de-pairing J_d of SC GB

@ artificial notch







There is a local field enhancement due to roughness

Why Should We perform Advance Material R&D? (3/3)

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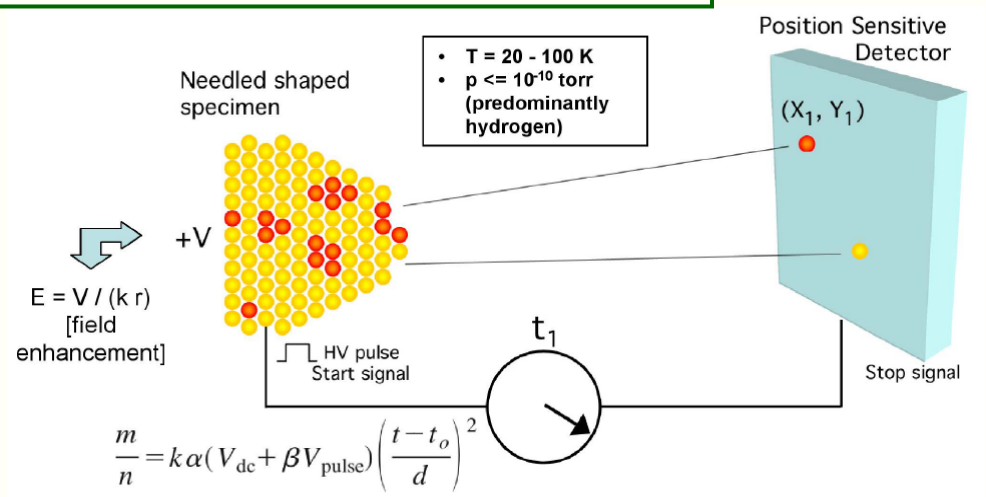
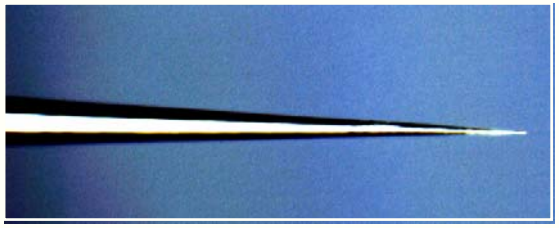
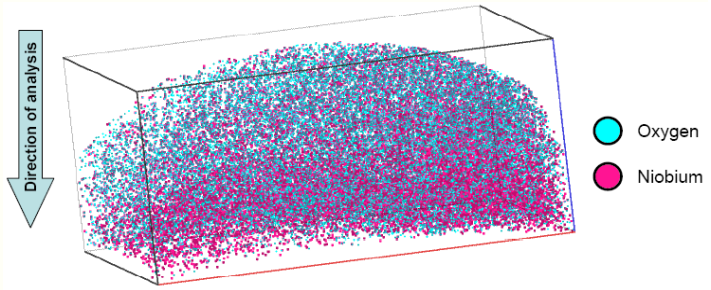
Surface contamination

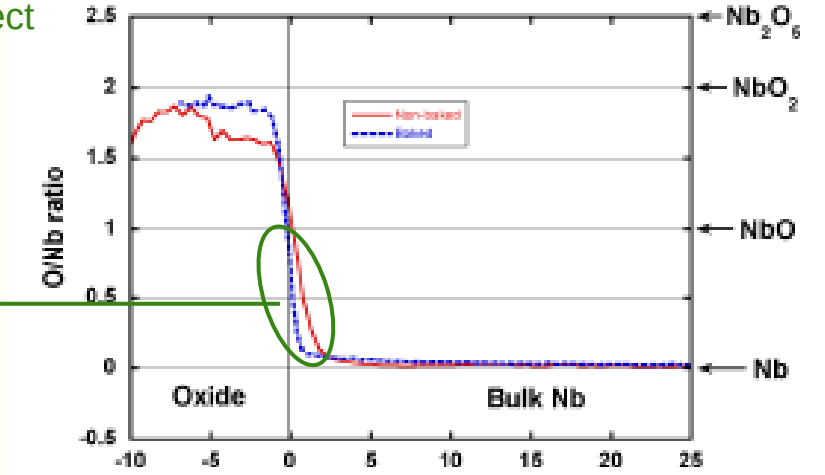
Atom-probe tomography (APT) *[Collbn University]*







Baking effect



Cleaner interface => ≠ SC behavior !

- ***Atomic resolution !!!***
- ***Very sensitive***

But

- ***No direct chemical information***
- ***Complex => low turnover***
- ***Need to be completed with other techniques***

Priority # 1 Single cell test program

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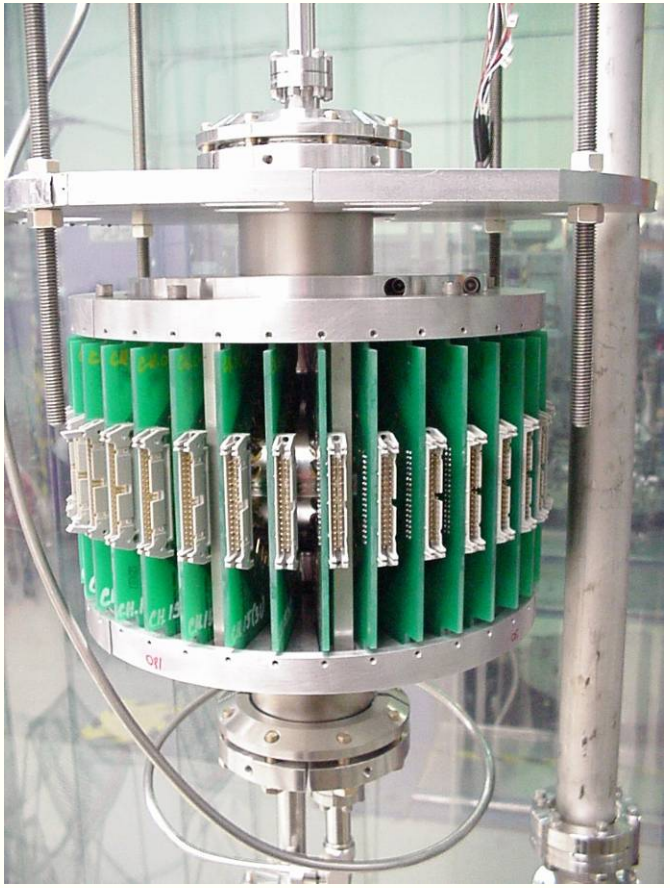
R&D aims at ↑ performances => ultimate test is cavity !

Process R&D (ILC-S0)

- Reproducibility of the tight loop processing
- Alternative rinsing (ethanol, degreasing)
- Pre-processing (tumbling)
- Baking study

SRF R&D (1/5 tests in the 1st 2 years)

- Post processing (plasma cleaning)
- Large grain
  - Grain size, orientation
  - Grain boundary dynamics
  - Processing optimization
- Beyond Nb (2-3 years from now)
  - e.g. MgB_2 on large grain
  - Collaboration W. U
  - Few tests



J-Lab Setup

Single cell test program

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Priority	Description	Manpower @ Fermi	M&S	Time scale	Comments
1	1 Cell test stand • Setup	1.00 FTE ENG 0.60 FTE DES	k$ 250	1 year	Includes 3 1-cell cavities
	• Program ○S0 ○SRF R&D	0.50 FTE TEC 0.75 FTE ENG 0.50 FTE TEC	k$ 100 k$ 60	1 year startup	Helium + small material 3 additional cavities
Total FTE = 1.75 ENG + 1 TEC + 0.6 DES = 3.35					**Total M&S k$ 410**

Priority # 2 Mid term / Process R&D – EP and…

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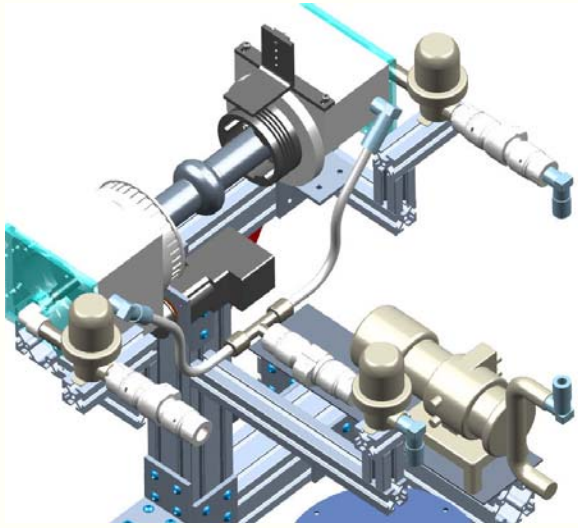
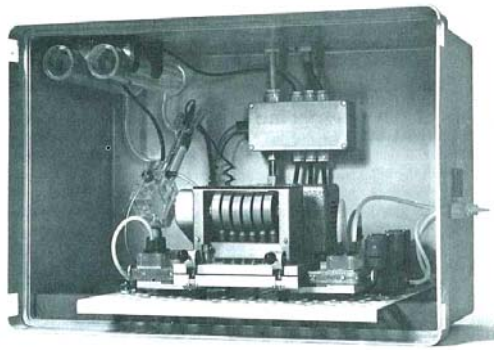
Along with the completion of the EP 9-cell infrastructure design and fabrication at ANL already financed…

- **EP Modeling**

(if HF work at FNAL = authorized…)

- **Upgrading 1cell EP set up from 3.9 GHz to 1.3 GHz**
  - **Issues : e.g. New end parts**
- **Online Fluorine monitoring**
  - **Issues : large volume of consumables + wastes…**
- **9-cell processing facility at FNAL design**
- **tooling, flange design (reduce field emission risk)**
- **Cavity assembly automation**
- **Dry processing (plasma cleaning)**





Process R&D

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Priority	Description	Manpower @ Fermi	M&S	Time scale	Comments
2	Surface processing R&D • EP processing ○Samples R&D	0.50 FTE SCI 0.25 FTE TEC	k$ 5	6 month	Part of program at J-Lab
	○1Cell set up	0.25 FTE ENG 0.25 FTE DES 0.25 FTE TEC	k$ 40	1 year startup	Start 3.9 GHz and design 1.3GHz
	○Modeling	1.00 FTE STU	k$ 5	1 year	Ongoing
	○Tumbling	0.25 FTE ENG	k$10	1 year startup	
	• Processing facilities	1.00 FTE ENG 0.50 FTE DES		2 years	ANL collab. Effort and FNAL facility
	• Field emission reduction ○New tooling for assembly	0.5 FTE ENG 1.0 FTE DES	k$ 30	1 year	J-Lab collab. 1 tech at J-lab for 1 year
	○ Dry processing	1.5 FTE TEC 0.5 FTE ENG	k$ 5	5 month	No basic research, but goal oriented 3.9GHz single test
Total FTE: 0.5 SC + 2.5 ENG + 2 TEC + 1.75 DES + 1STU					**Total M&S k$ 95**

3 Priority : Material Characterization : Mechanical, surface chemistry

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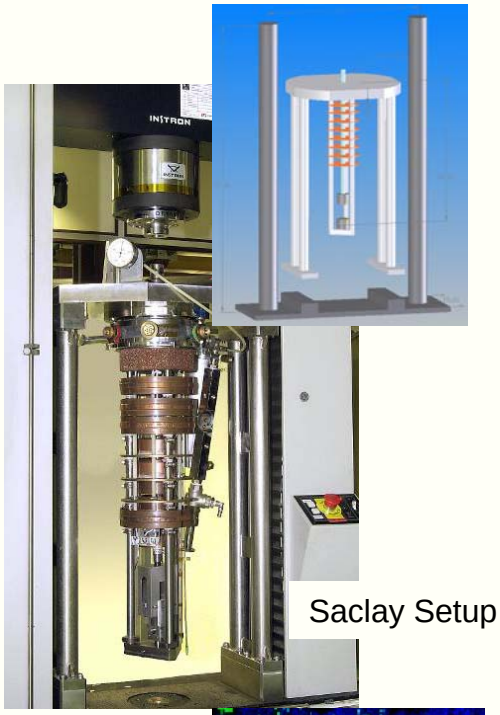
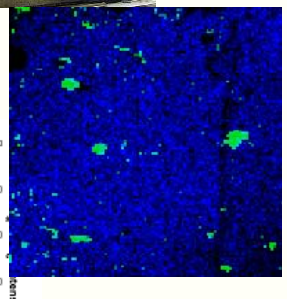
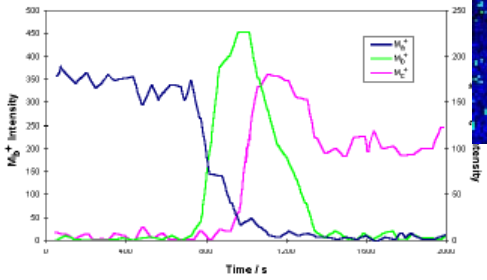
Systematic testing of new batches (QA) + Failure analysis

- **RT and Cold mechanical properties**
  - data for modeling (forming, mechanical resistance , RF behavior…)
  - Recrystallization study (post doc student) => improving specifications for Nb
  - Crystal orientation/texture effects…
- **Rapid SIMS characterization**
  - High detection sensitivity (metal or non-metal)
  - Spatial resolution 10 μm (horizontal) and 1 nm (depth)
  - Large size sample (100 mm round)
  - Very robust/reproducible analysis conditions => allows to gather statistics
- **Additional benefit**
  - Hydrogen, oxygen embrittlement at low temperature
  - Effect of welding (mechanical, chemical)
  - Grain boundary strength, composition
  - Oxide layer study
  - Weaker layer study/Coating study



Saclay Setup





Material testing

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Priority	Description	Manpower @ Fermi	M&S	Time scale	Comments
3	Material testing				
	• Cold test and recrystallization study	1.0 FTE STU 0.25 FTE TEC	$25K	1 year	6 month facility upgrade,
	• Surface analysis	0.25 FTE ENG	$200K		open ended for material study
	• Eddy Current Scanning & RRR	0.25 FTE ENG 1.00 FTE TEC	$10K	ongoing	operation support M&S
Total FTE = 1.0 STU + 1.25 TEC + 0.5 ENG = 2.75					**Total M&S k$ 235**

4 Priority : monocrystal Nb program

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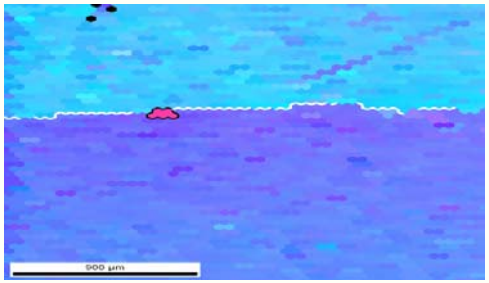
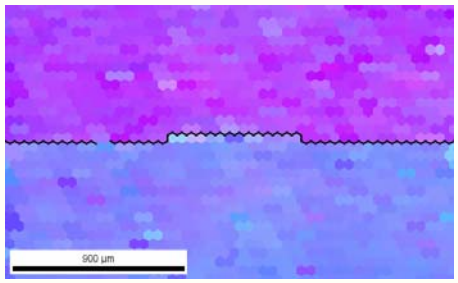
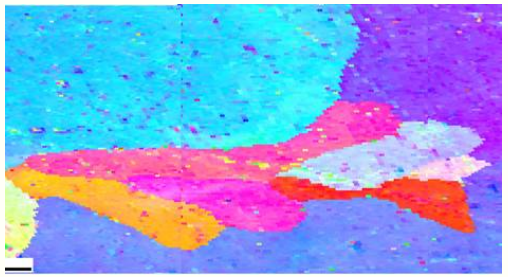
2 complementary goals :

- **Developing local expertise on the fabrication process:**
  - **~ 10-15 1-cell cavities project**
  - **3.9 GHz then 1.3 GHz :**
- **R&D program on sample:** ***(PhD or post Doc students)***
  - **Sensitivity of the crystalline orientation to :**
    - **Hydrogen loading**
    - **Formability ? e.g. (111) = more favorable for small grain textures**
    - **EP vs BCP, Oxygen diffusion ? (111) = close packed/ (001) = loose packed**
    - **EP vs. BCP, Oxide thickness ? (idem)**
    - **Surface B_C ? (B_{C3}), Superconducting gap ?**
    - **Recrystallization @ welding…**
  - **Can/ should be completed w surf Analysis**

grain orientations: *asymmetric* ↓ *symmetric* ↓ *triple point* ↓ ***[collabn, MSU]***







Longer term / SRF R&D: S-I-S Multilayer

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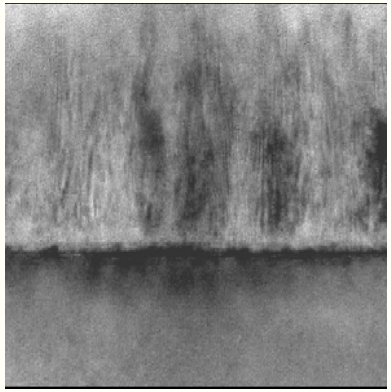
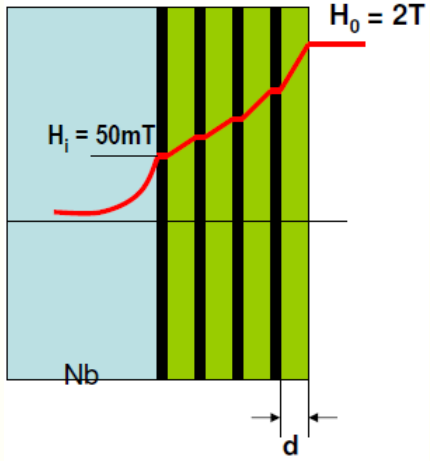
Single cell test program, collaboration with Universities

- **Theory (FSU-National High Magnetic Field Lab)**
- **MgB_2 (ANL, Penn State)**
- **NbN (ANL, JLAB)**
- **Nb_3Sn (ANL, JLAB)**



MgB_2 ***[X. Xi. Penn State]***



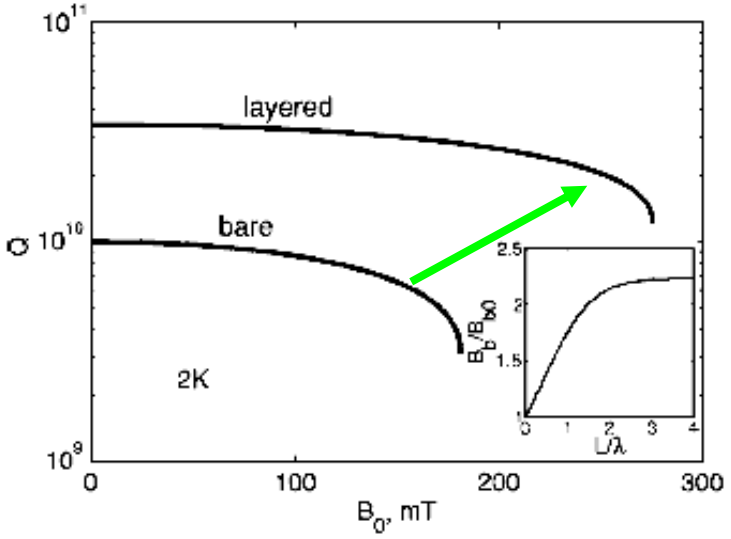
[A. Gurevich, APL 2005]

$$B_{c1} = \frac{\phi_0}{2\pi\lambda^2}\left(\ln\frac{\lambda}{\xi} + 0.5\right)$$

Enhanced B_{c1}

Surface barrier

$$B_{c1} = \frac{\phi_0}{\frac{1}{2}\pi d^2}\left(\ln\frac{d}{\xi} - 0.07\right)$$



Advanced SRF R&D

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Priority	Description	Manpower @ Fermi	M&S	Time scale	Comments
4	Advanced R&D			2 years	
	•Support to monocrystals prog	1.0 FTE STU ?	$250K		Magnetometer (external funding?)
	•Superconducting Properties ○Dissipation sources ○Superconducting gap	1.0 FTE SCI 0.25 FTE TEC	$50 K		Collaborations (external funding?) Fermi contribution: •Sample and small material @ short term •1-cell testing @ mid term
	•Surface fine studies ○3D probe ○Prime				
	•Multilayer S-I-S				
Total FTE: 1 SC + 1 STU + 0.25 TEC			**Total M&S k$ 300**		

Collaborations

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- Cavity Processing, assembling... (S0 for ILC …)
  - **Jlab, Cornell, ANL**
- Chasing Hot Spots

  Micro & macro scale
  - **Local variations in SC properties?**
    - **Magneto-optics and Transport / ASC-FSU**
  - **Defects, Impurities?**
    - **Local nano-chemistry – 3DAP / NU**
    - **Local superconducting gap - ANL+ IIT**
  - **Thermal Properties?**
    - **Thermal conductivity and Kapitza – MSU**
- Beyond Niobium
  - **Fundamentals of SC, theory / ASC-FSU**
  - **Multilayers SIS**
    - **Deposition process ANL/ Penn state**
    - **Local nano-chemistry – 3DAP / NU, ANL**
- *Organization of the 1rst extended SRF Material workshop @ Fermi (Spring 2007)*

Summary

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Program	Total FTE	Infrastructure M&S	Total M&S
1-Cell RF test stand	1.75 ENG + 1 TEC + 0.6 DES = 3.35	k$ 250	k$ 410
Surface processing R&D	0.5 SC + 2.5 ENG + 2 TEC + 1.75 DES = 4.75	k$ 85	k$ 95
Material testing	1.0 STU + 1.25 TEC + 0.5 ING = 2.75	k$ 235	k$ 235
Advanced SRF R&D	1 SC + 1 STU + 0.25 TEC = 2.25	k$ 300	k$ 300

Total FTE: 15.10

1.5 SC + 4.75 ENG + 4.5 TEC + 2.35 DES + 2 STU

(*comp. with present: 1 SC + 5 ENG + 3.5 TEC + 2 DES* **)**

Total M&S:

k$ 740 K + k$ 300 AARD

Conclusion

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- SRF material issues affect all kind of SRF projects
- 3 main activities for the material group
  - Support to project : QA, failure analysis
  - Process R&D
  - Advanced SRF R&D
- Advanced SRF R&D is done mainly /collaborations
  - Grouped AARD proposal (ANL, FSU, MSU, NU…)
- Fermi needs to expand its advanced SRF R&D program:
  - Benefit from advanced knowledge on SC
  - Scientific leadership in SRF
  - Improvement of projects (cost, reliability, performance)
- The material group needs to be reinforced (Sc/Eng, Tec, Des)

Additionnal slides…

bcd:main_linac:cavity_package:material_fundamental ILC Wiki

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Fundamental Materials R&D

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Overview

Over the last decade a set of procedures has been developed for the fabrication, surface treatment and assembly of superconducting niobium cavities, which lead to high performance cavities, if applied properly. These procedures include improved material QA by

R&D investigations (ongoing or under consideration)

The overarching goals of fundamental R&D should be to understand and thereby remove performance limits, ultimately leading to cost reduction.

- Theoretical studies on the RF critical magnetic field
- Measurements of the RF critical field
- Preparation of field emission free surfaces
- Studies to reduce field emission including emitter processing.
- Improvements in scanning methods to pre-screen defects
- Theoretical and experimental studies on the high field Q-slope and its reduction by baking.
- Theoretical and experimental studies on the medium field Q-slope.
- Surface analytical studies of niobium using state-of-the-art instrumentation such as XPS, Auger, SIMS, 3DAP and others.
- Studies to delineate the role of impurities (e.g. O, N, C, H, Ta...) on the superconducting RF performance of Nb
- Studies to delineate the role of grain boundaries and other mechanical imperfections on the superconducting properties of niobium.
- Studies to improve understanding of chemical treatment processes such as electropolishing.
- Basic studies (similar to those describe above) on large grain and single grain niobium.

bcd/main_linac/cavity_package/material_fundamental.txt · Last modified: 2005/12/02 15:52 by main_linac

Thermal behavior

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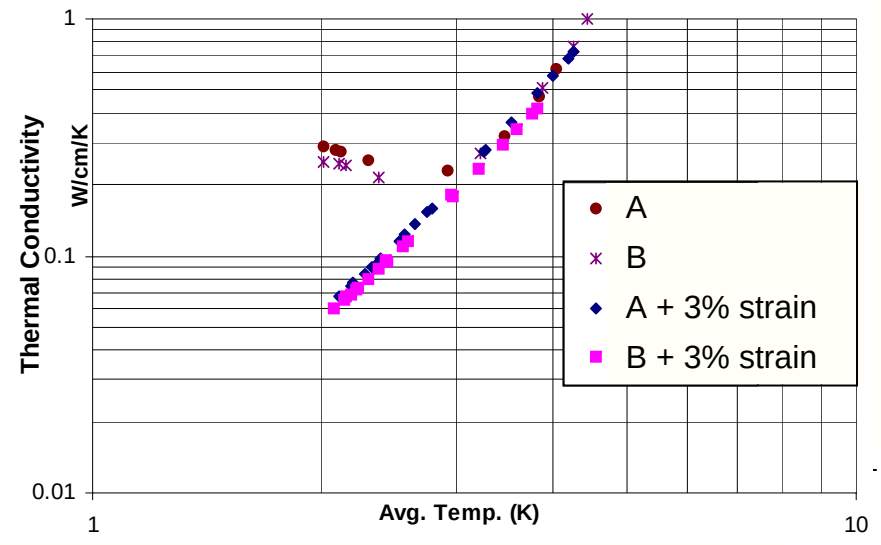
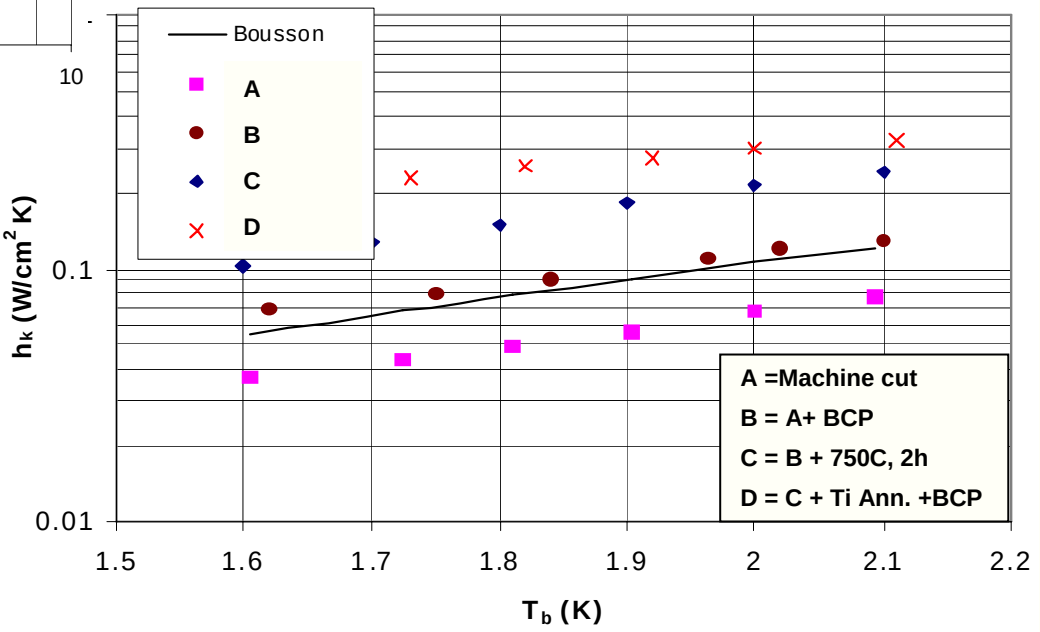


- **Thermal conductivity @ 2 K decreases dramatically with strain (80%!)**
- **It is not recovered with 750C, 2h**
- **It is recovered with Ti annealing (1300-1400 C)**
- **Intermediate temp need to be tested**

Unexpected results !!!!!

- **Kapitza conductance is improved with annealing**
- **It is not much affected by roughness**

[CollnMSU]



TIG Welding Study

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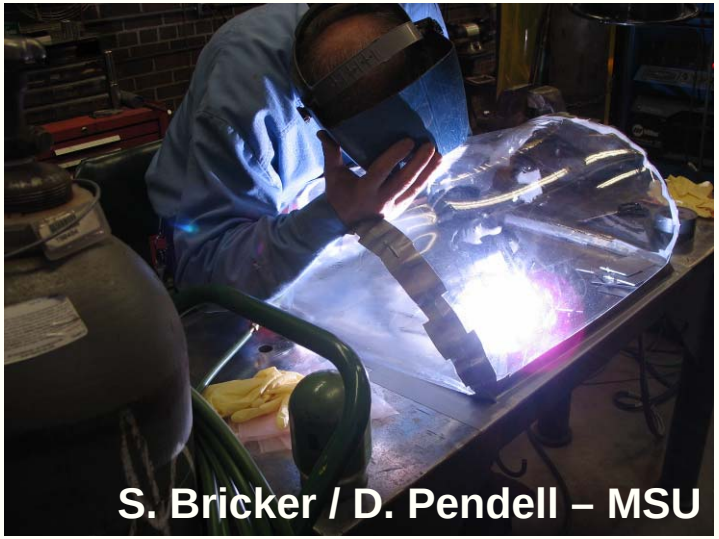
Innovation:

Tig Welding experience @ MSU
+
Ultra pure Ar developed @ FNAL

NSCL



Surface Morphology

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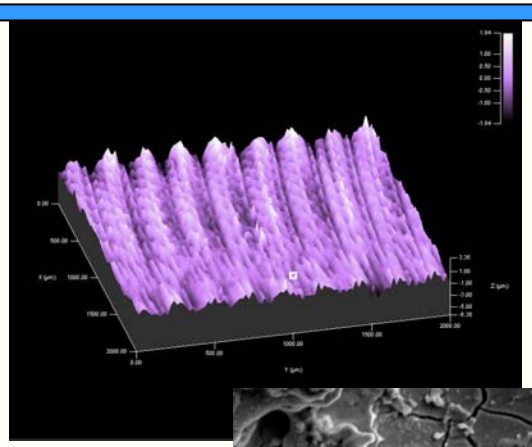
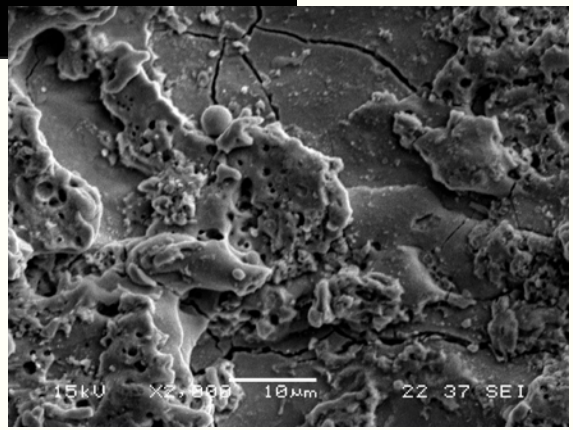
from QA to quench analysis

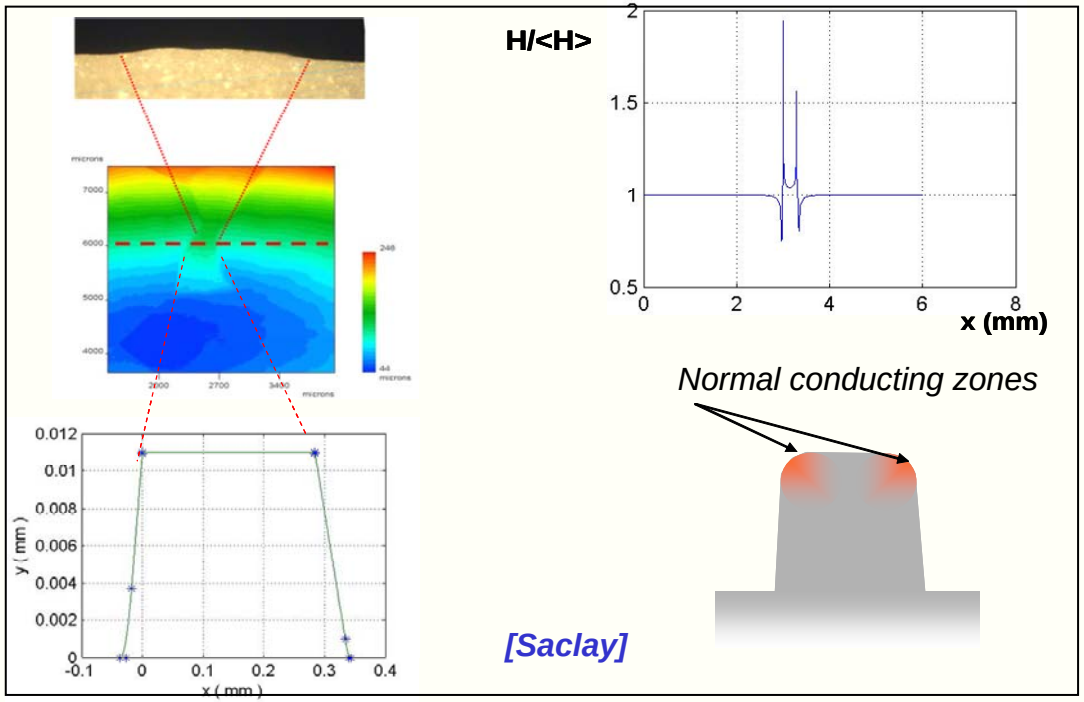
- **Cutting study**
  - **–Roughness and chemical contamination on surface (damage layer)**
  - **–Replica @ the quench site**



Milled Surface Topology



EDM Cut Surface SEM



morphology influence needs to be better estimated

Others ideas …?

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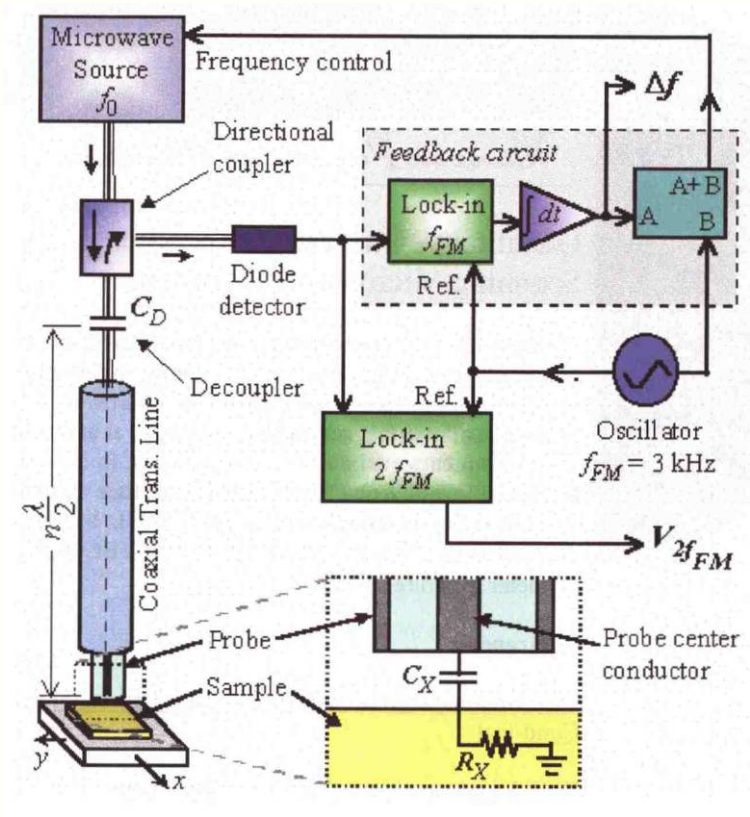
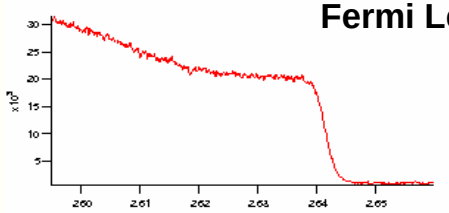
RF microscopy

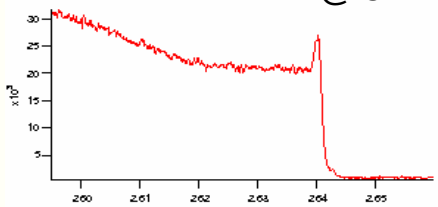


Superconducting gap measurement *(Photoemission)*

Fermi Level @ 10K



@ 5K => SC Δ



Δ @ 5K + BAKING !