SRF Material R&D

Claire Antoine
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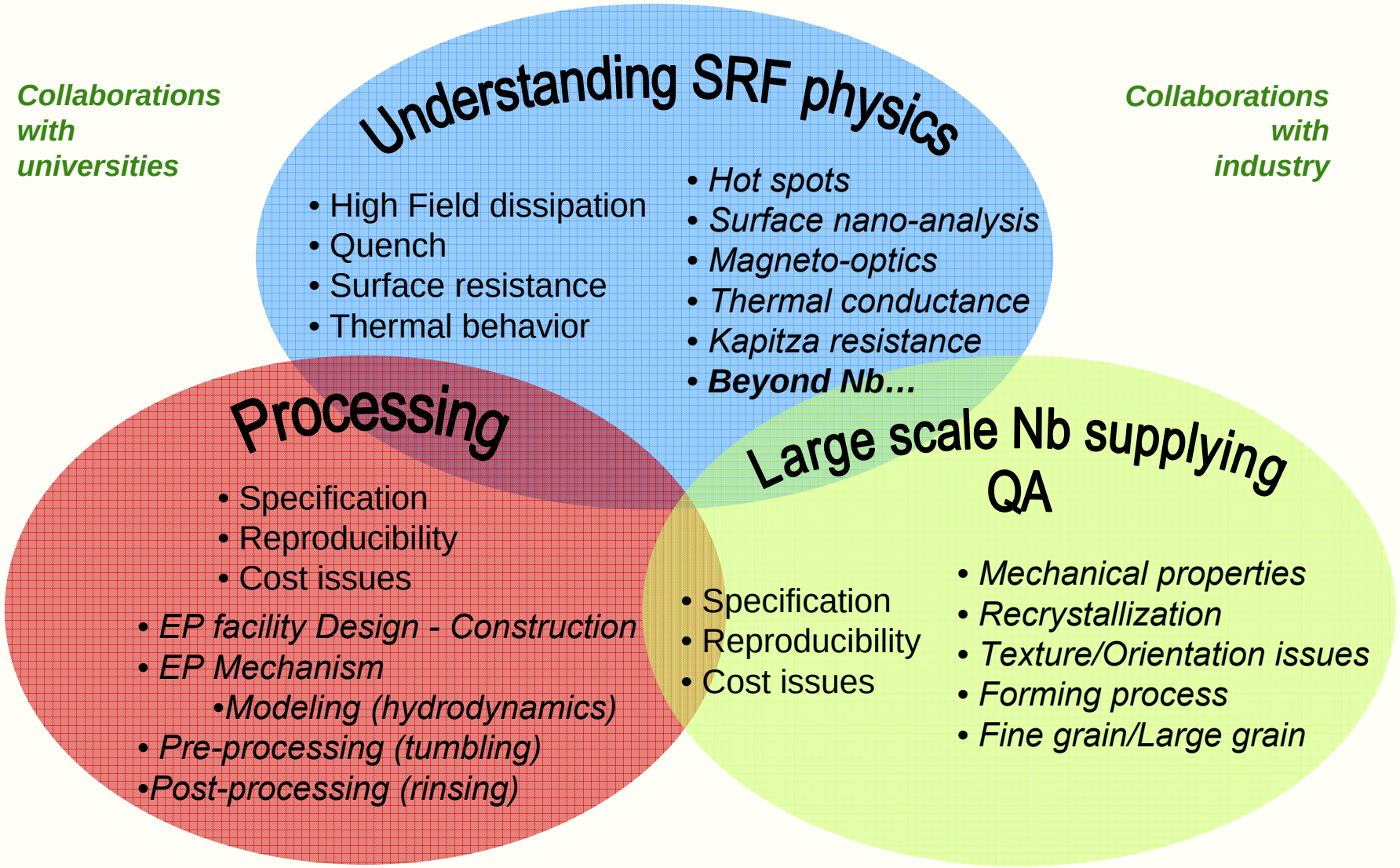
SRF Materials Issues

Fermilab

Collaborations with universities

Collaborations with industry



SRF Materials group

Fermilab

Scientists:	
C. Antoine	***(Processing R&D, University Collab)***
Engineer-Physicists:	
D. Hicks*	***(Cavity 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 (colln MSU)…**
  - **Cutting study**
  - **RRR measurement**
  - ***Plasma cleaning (field emission)***
- *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

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 (at FSU*)**
  - **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 Light Source.***

Process R&D Activities

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- *Ongoing*
  - **Tumbling on samples**
  - **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.**

Priority # 1 Single cell test program

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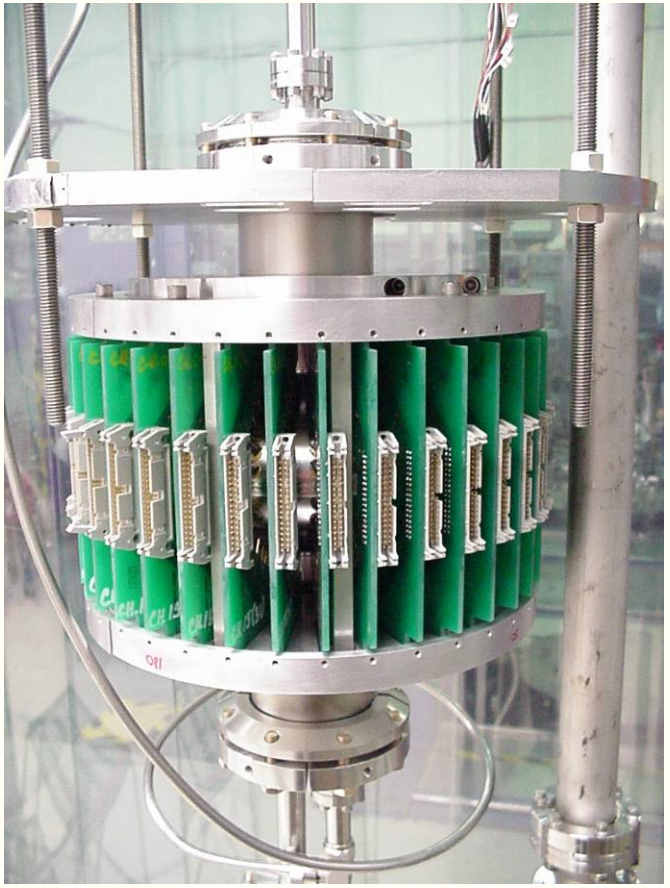
R&D aims at ↑ performances => ultimate test is cavity !

Process R&D (ILC-S0)

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

SRF R&D (6 test in the 1st 2 years)

- 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

Why Should We perform Process R&D ?

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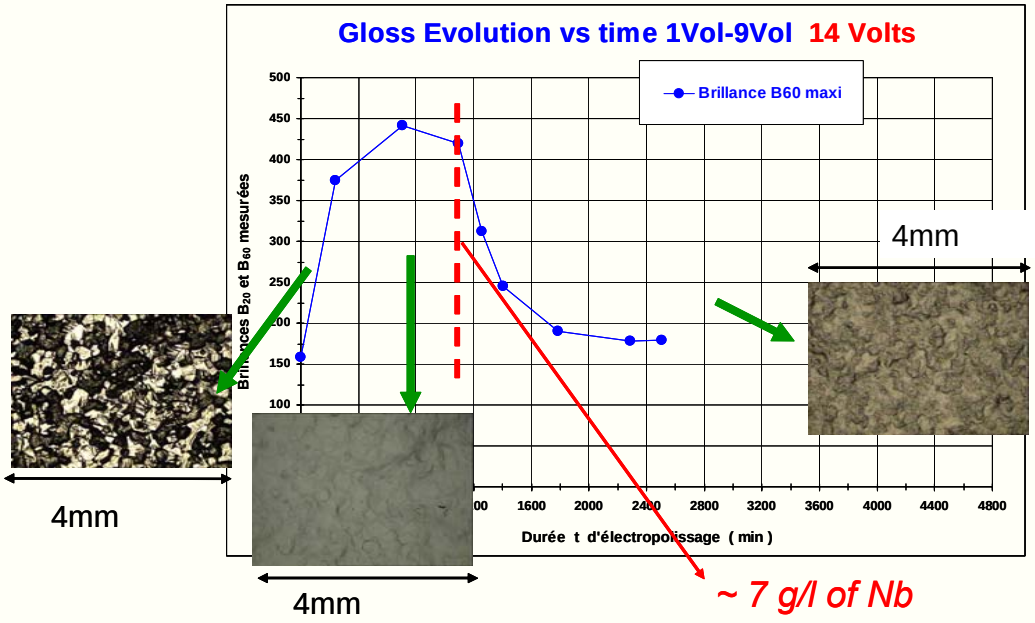
Surface processing 1

Large spread of results for electropolishing (EP)

- ***Why are EP results are not reproducible ?***
  - ***Ageing 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 ?***



- ***Recommendations***
  - ***Need to do R&D on samples, 1-cells before 9-cells***
  - ***Developing monitoring (F^-, Nb^{5+}…)***
  - ***Modeling***
  - ***Surface studies (composition, morphology)***

Why Should We perform Process R&D ?

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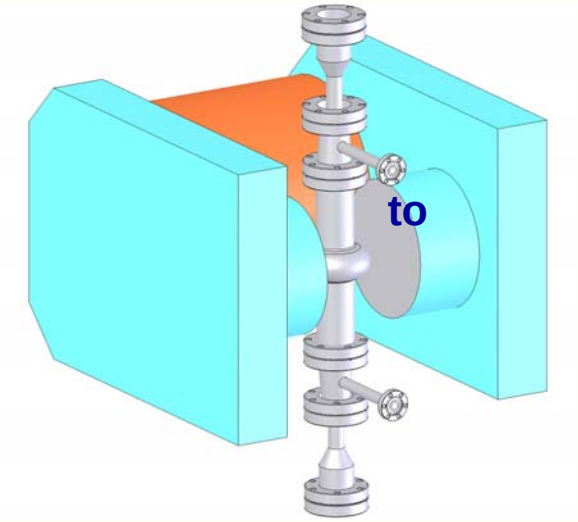
Surface processing 2

Field emission (particle contamination) is still the major practical limitation source

- **What are the possible sources?**
  - **Bad control of the wet process : particle counting is not enough**
  - **Bad control of the ancillaries : e.g. cleaning of couplers**
  - **Contamination during assembly : long, complex, manually made**
  - **Absence of post processing solution**
- **Recommendations**
  - **Develop new designs/tooling to ease assembling**
    - **Collabn Jlab**
  - **Develop post processing applicable to assembled cavities**
    - **e.g. Plasma cleaning w ECR plasma:**



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

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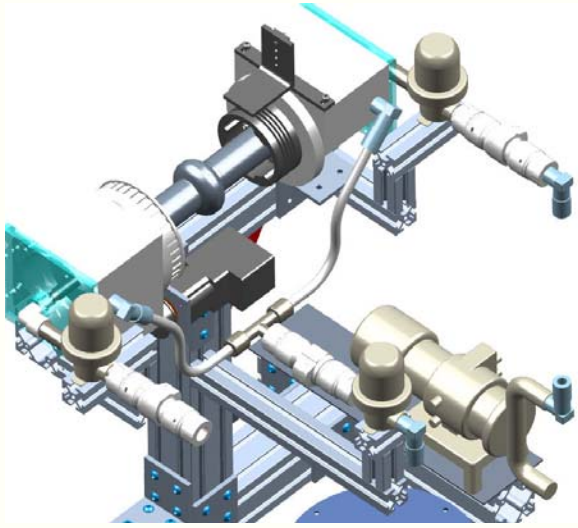
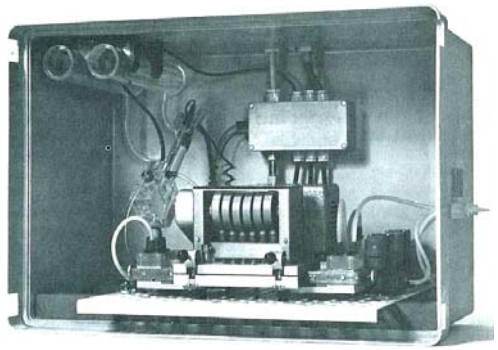
Along with the completion of the EP 9-cell infrastructure design and fabrication at ANL already financed…

- **EP Modeling**

(if HF work at FNAL = authorized…)

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





Why Should We perform Material R&D ?

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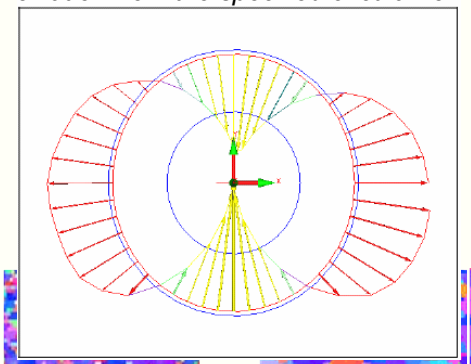
Mechanical Properties 1

Recent Forming Problems at AES: Nb= too hard, spring back, 6 passes vs 1, ovalization….

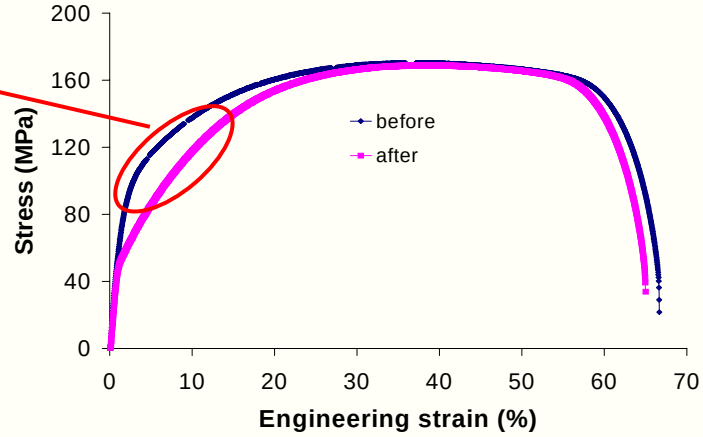
Microstructure & Mechanical Properties studied (MSU):

- ***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***

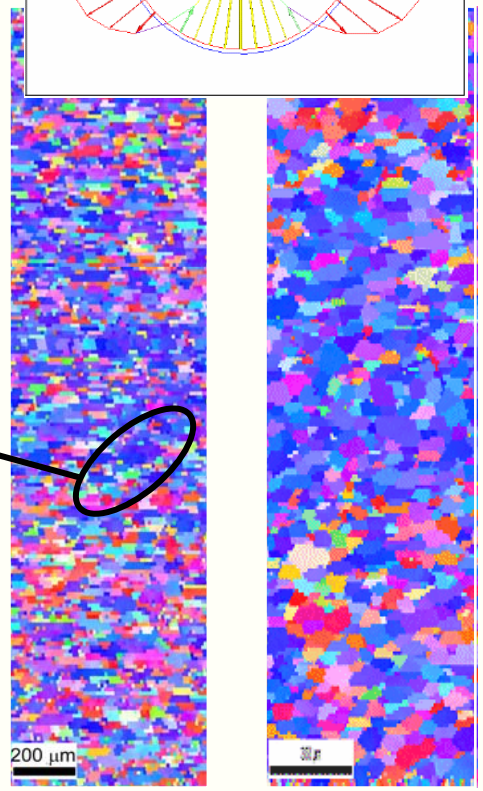
Deviation from the specified circular form



High yield strength => still some strain hardening => poor formability



Non equiaxe grains => recrystallization not completed



before HT after HT

Why Should We perform Material R&D ?

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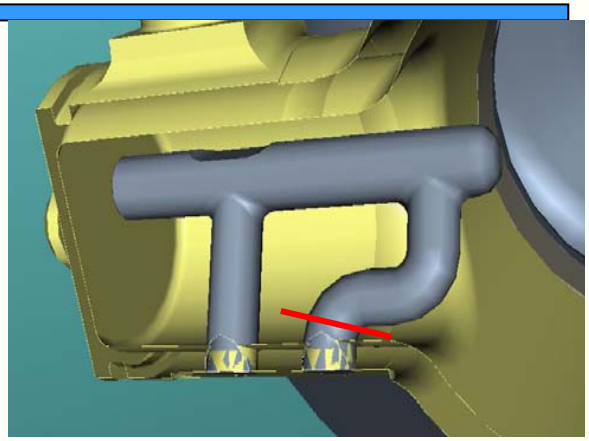
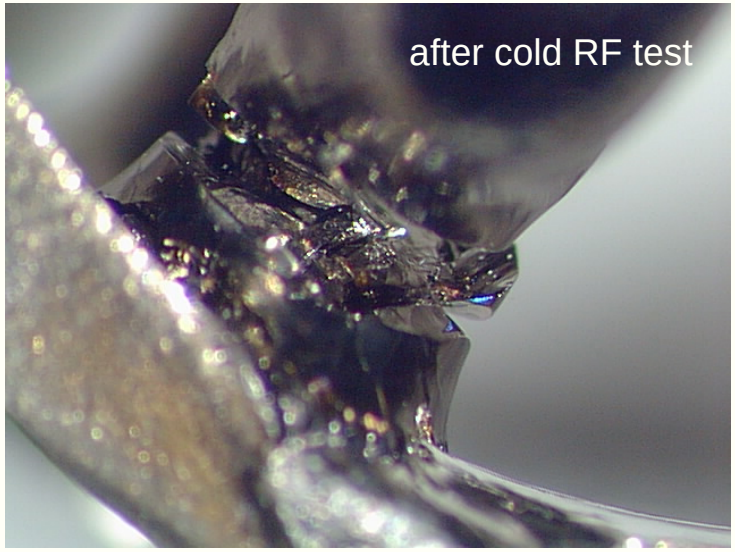
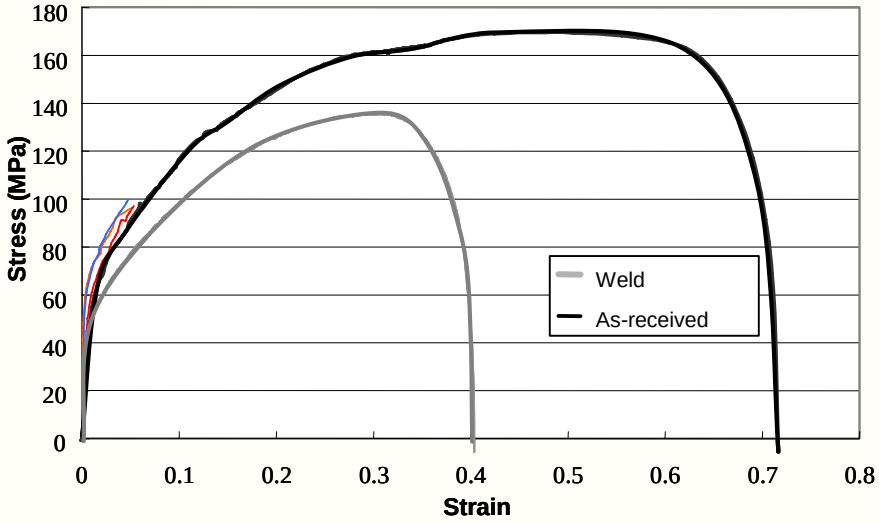
Mechanical Properties 2

Recent breaking of an antenna (3.9 GHz coupler)



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





3 Priority : Material Characterization : Mechanical, surface chemistry

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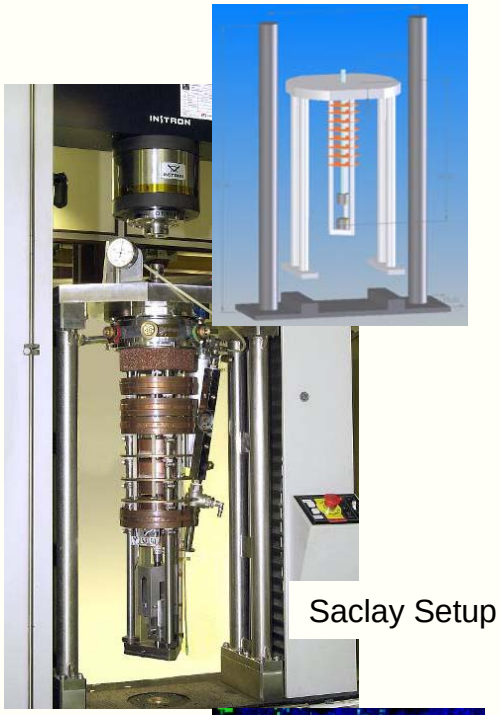
Systematic testing of new batches (QA) + Failure analysis

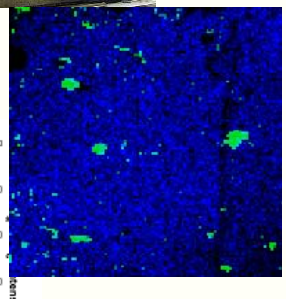
RT and Cold mechanical properties

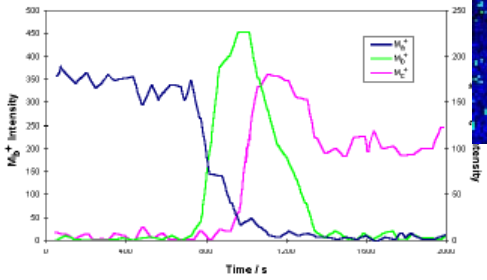
- data for modeling (forming, mechanical resistance , RF behavior…)
- Recrystallization study (post doc student) => improving specifications for Nb
- Crystal orientation/texture effects…

- **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
- **Additionnal 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





Why Should We perform Advance Material R&D ?

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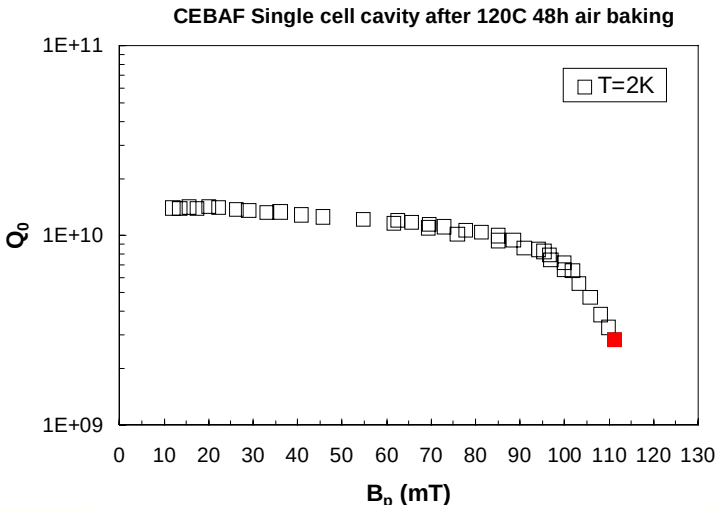
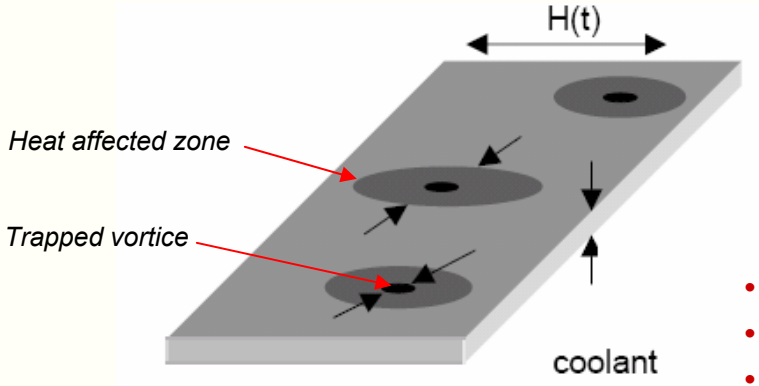
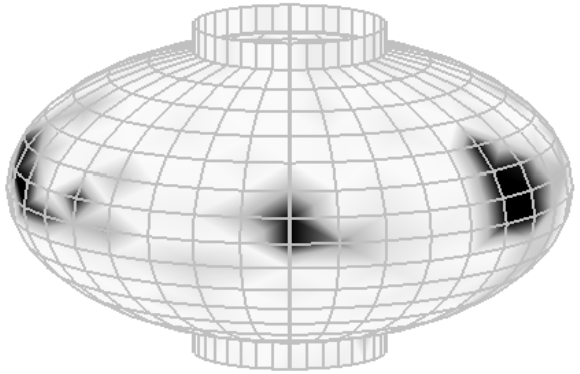
Superconductivity limits

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!***

What is the problem with GB ?

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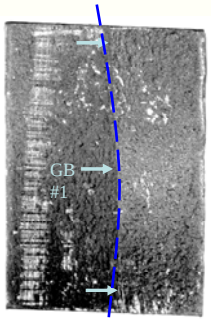
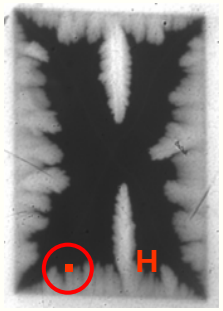
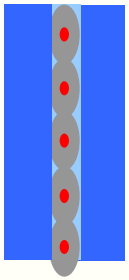
Morphological effect or depleted SC ?

Flux penetration @ GB

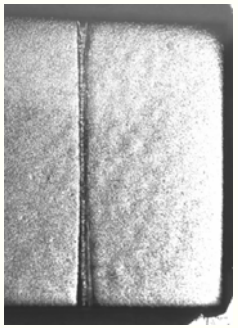


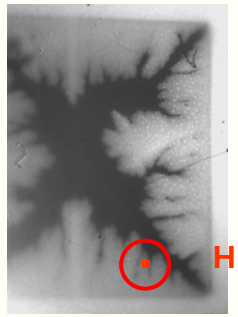


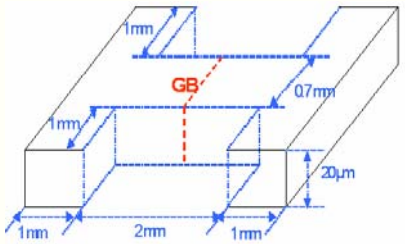


[Collbn WU/FSU]

@ artificial notch

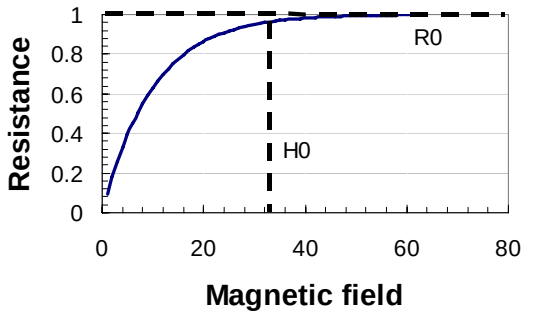




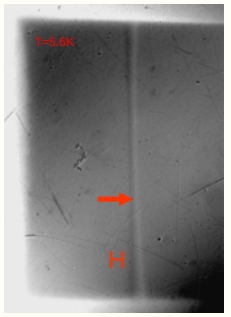


[A. Polyanskii et al, WU/FSU]

[Sung Hawn]



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



There is a local field enhancement due to roughness

Surface contamination

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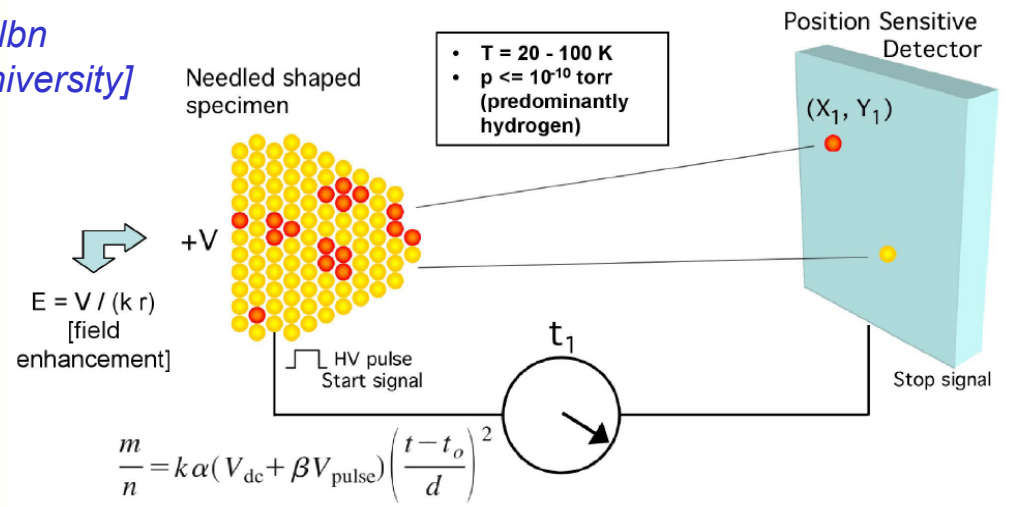
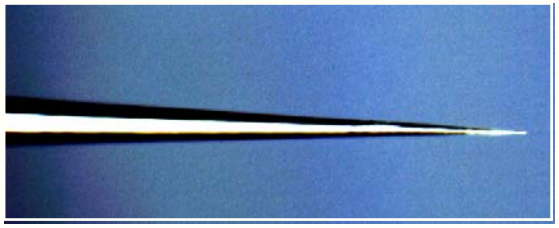
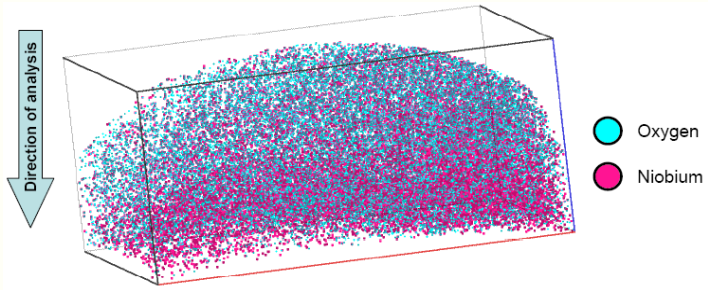
Atom-probe tomography (APT)

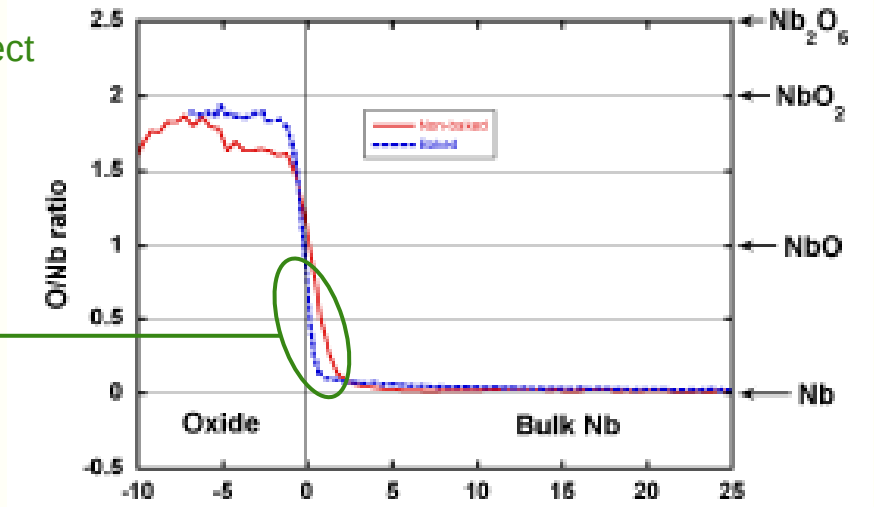
[Collbn NUniversity]







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***

4 Priority : monocrystal Nb program

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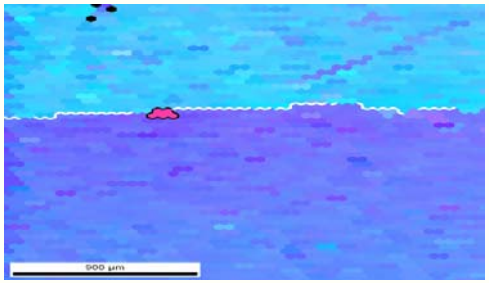
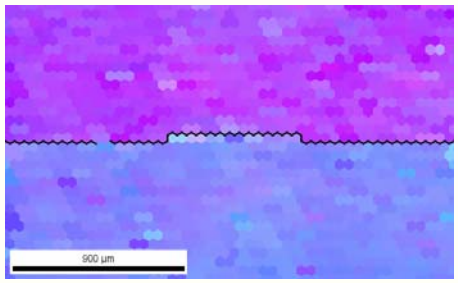
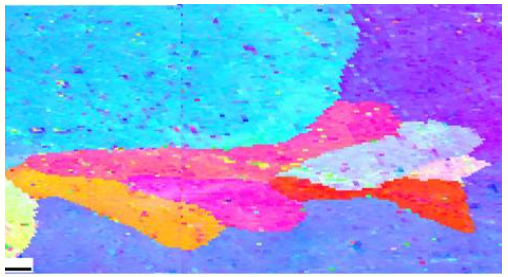
2 complementary goals :

- **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 student)***
  - **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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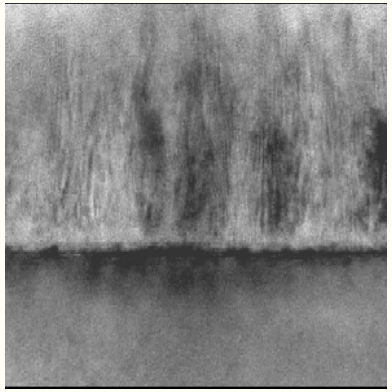
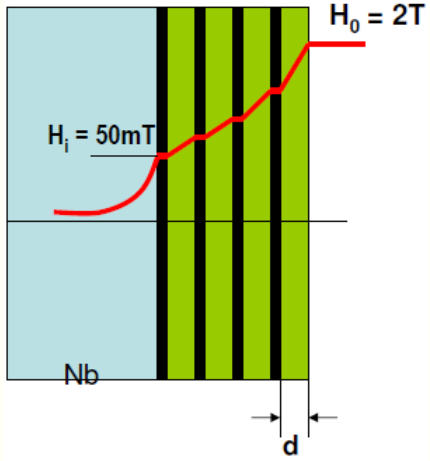
Single cell test program, collaboration with Universities

- **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]***

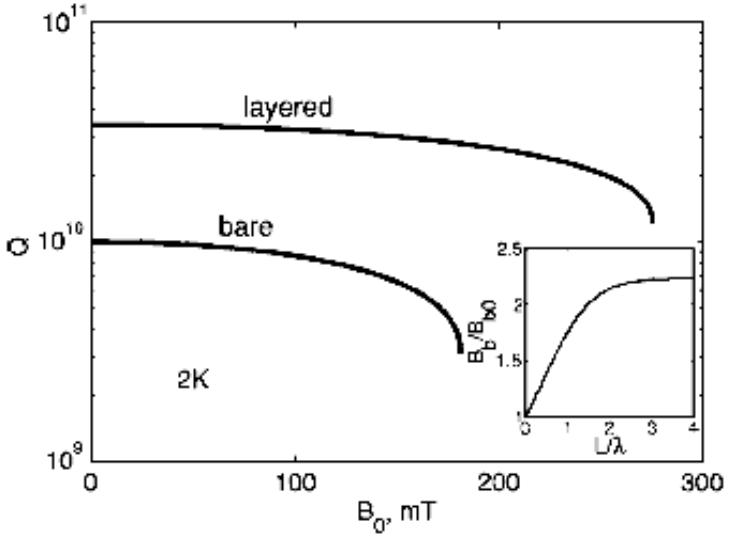


$$B_{c1} = \frac{\phi_0}{2\pi\lambda^2}\left(\ln\frac{\lambda}{\xi} + 0.5\right)$$

Enhanced B_{c1}

Surface barrier

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



[A. Gurevich, manuscript to APL 2005]

Collaborations

- 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 SRF Material workshop @ Fermi (May 2007)*

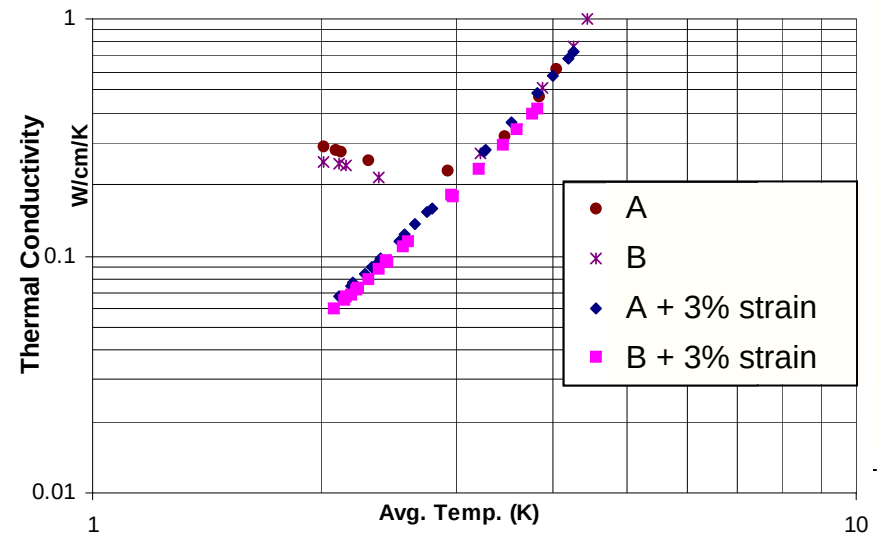
Summary

Priority	Description	Manpower @ Fermi	M&S	Time scale	comments
1	1 Cell test stand	1.00 FTE ENG	$200K	1 year	
	• Setup	0.60 FTE DES			
	• Program	0.50 FTE TEC	$100K	1 year startup	Helium + small material
	○ S0	0.75 FTE ENG	$60K		3 additional cavities
	○ SRF R&D	0.50 FTE TEC			
2	Surface processing R&D				
	• EP processing				
	○ Samples R&D	0.50 FTE SCI	$5K	6 month	Part of program at J-Lab
		0.25 FTE TEC			
	○ 1Cell set up	0.25 FTE ENG	$40K	1 year startup	Start 3.9 GHz and design 1.3GHz
		0.25 FTE DES			
		0.25 FTE TEC			
	○ modeling	1.00 FTE STU	$5K	1 year	Ongoing
	○ Tumbling	0.25 FTE ENG	$10K	1 year startup	
	• Processing facility	1.00 FTE ENG		2 years	ANL collab. Effort and FNAL facility
		0.50 FTE DES			
	• Field emission reduction				
	○ New tooling for assembly	0.5 FTE ENG	$30K	1 year	J-Lab collab. 1 tech at J-lab for 1 year
		1.0 FTE DES			
	○ Dry processing	1.5 FTE TEC			No basic research, but goal oriented 3.9GHz single test
		0.5 FTE ENG	$5K	5 month	
3	Material testing				
	• Cold test and recrystallization study	1.0 FTE STU	$25K	12 month	6 month facility upgrade, open ended for material study
	• Surface analysis	0.25 FTE TEC			
	• Eddy Current Scanning & RRR	0.25 FTE ENG			operation support M&S
			$10K	ongoing	
		0.25 FTE ENG			
		1.00 FTE TEC			
4	Advanced R&D	1.0 FTE SCI	$50 K	2 years	Collaborations (external funding?)
	• Superconducting Properties	0.25 FTE TEC			Fermi contribution:
	○ Dissipation sources				Sample and small material @ short term
	○ Superconducting gap	1.0 FTE STU ?			1-cell testing @ mid term
	• Surface fine studies				
	○ 3D probe				
	○ Prime				
	• Support to monocrystals prog		$250K		magnetometer (external funding?)
	• Multilayer S-I-S				
Total FTE: 1.5 SC + 5 ENG + 4.25 TEC + 2.4 DES			**Total M&S $490 K +$ 300K AARD**		

Conclusion

- 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)

Thermal behavior

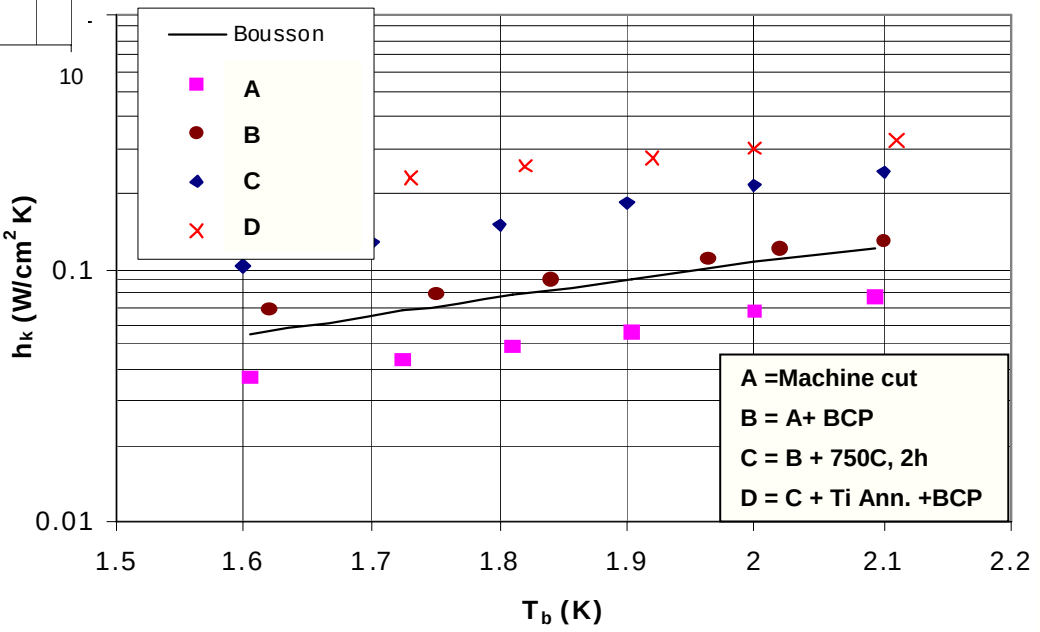


- **Thermal conductivity @ 2 K decreases dramatically with strain (80%!)**
- **It is not recovered with 750C, 2h**
- **It is recovered with Ti annealing (1300-1400 C)**
- **Intermediate temp need to be tested**

Unexpected results !!!!!

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

[CollnMSU]



Surface Topology

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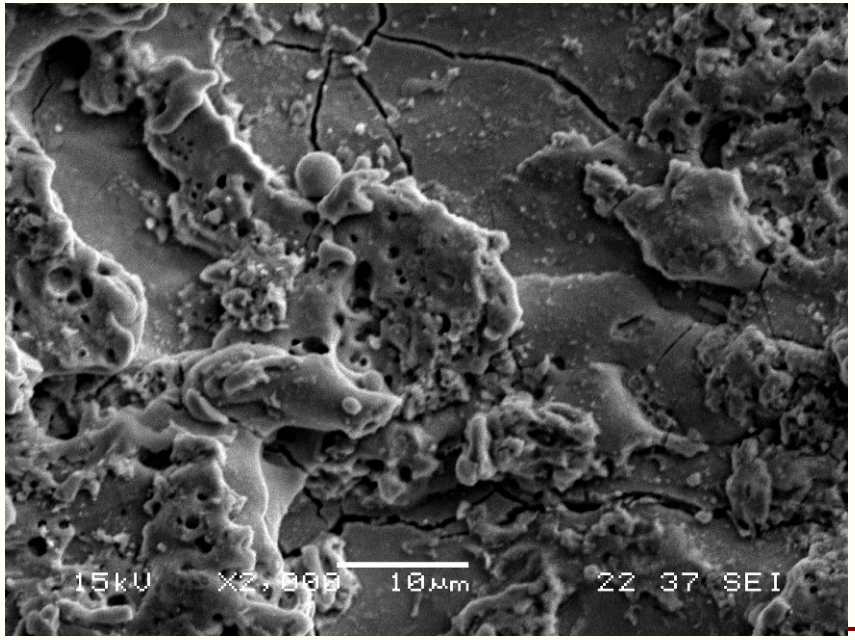
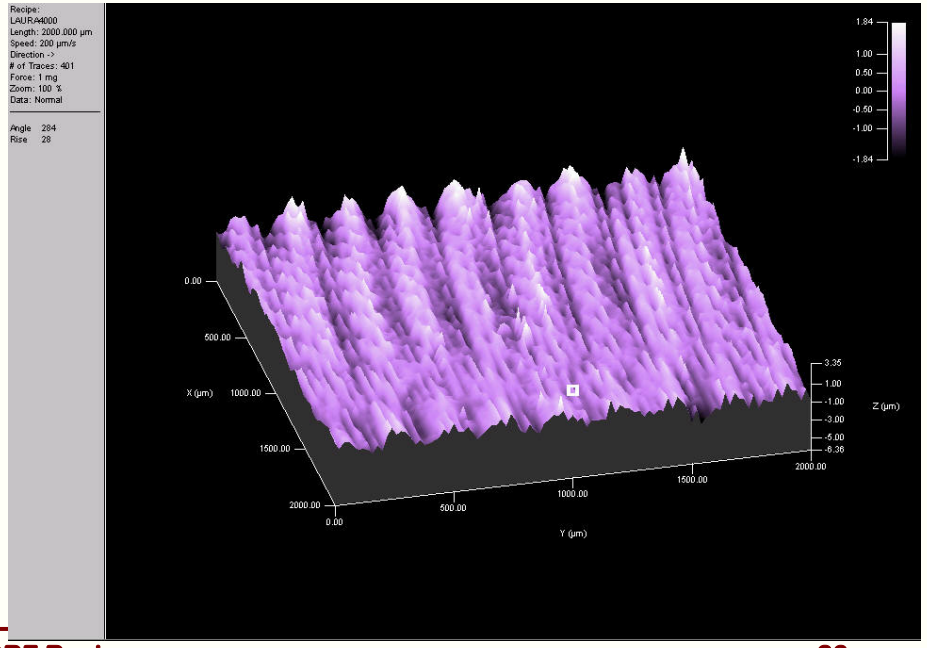
Surface Roughness and Chemistry:
Example: Study of different cutting techniques by C. Cooper / Fnal

SEM Images of EDM Wire Cut Sample at Various Magnifications

EDM Cut Surface SEM



Milled Surface Topology



TIG Welding Study

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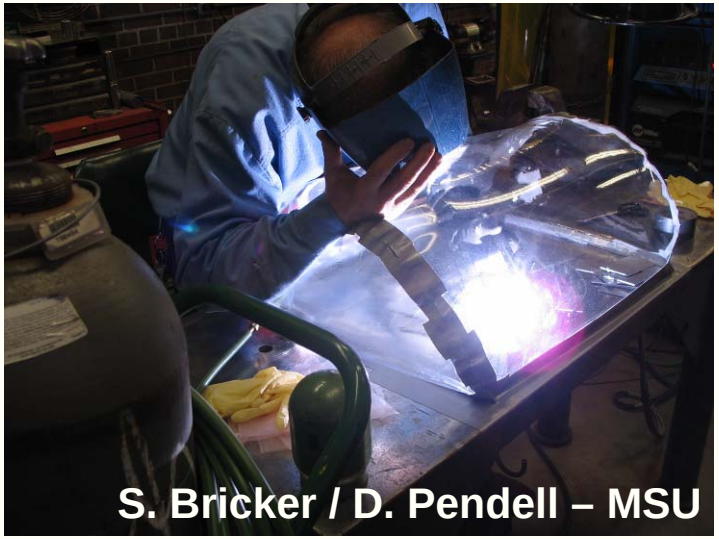
Innovation:

Tig Welding experience @ MSU
+
UPure Ar developed @ FNAL

NSCL



Others ideas …?

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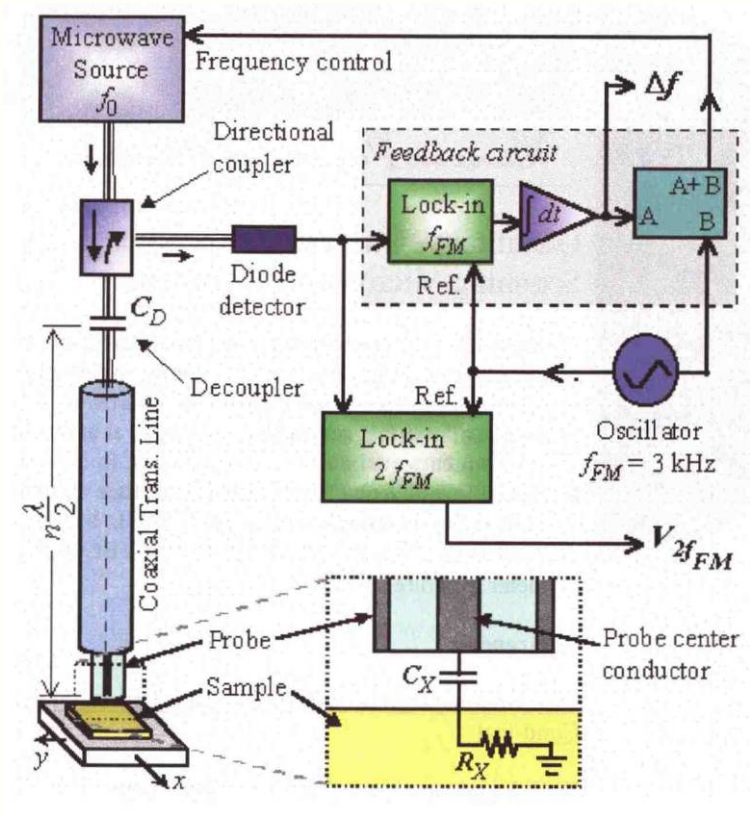
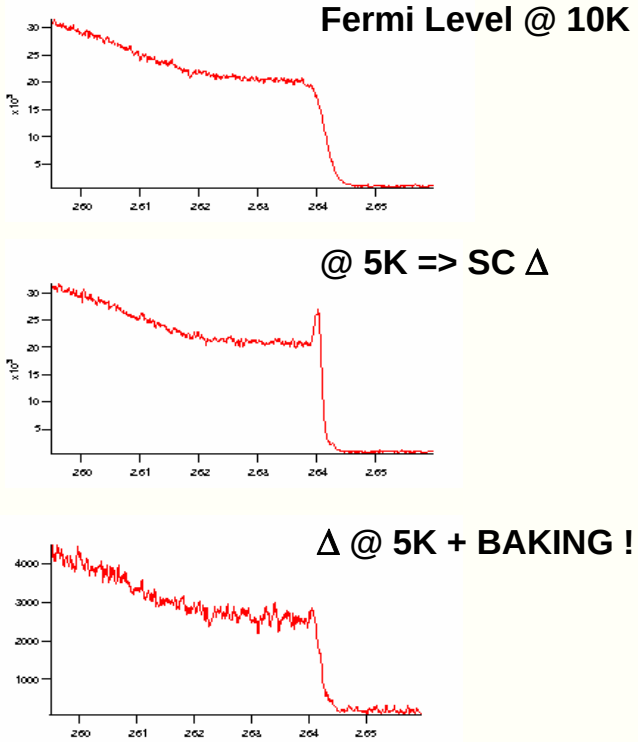
RF microscopy



S. Anlage - UM

Superconducting gap measurement *(Photoemission)*



C. Antoine - CEA

Conclusions

- Great closing arguments
- Allow time for questions !

Your Slides

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- Major items
  - Detail
    - Tiny detail…. Don't use very often
  - 2nd Detail
- Another item
- 3rd item