SRF Material R&D

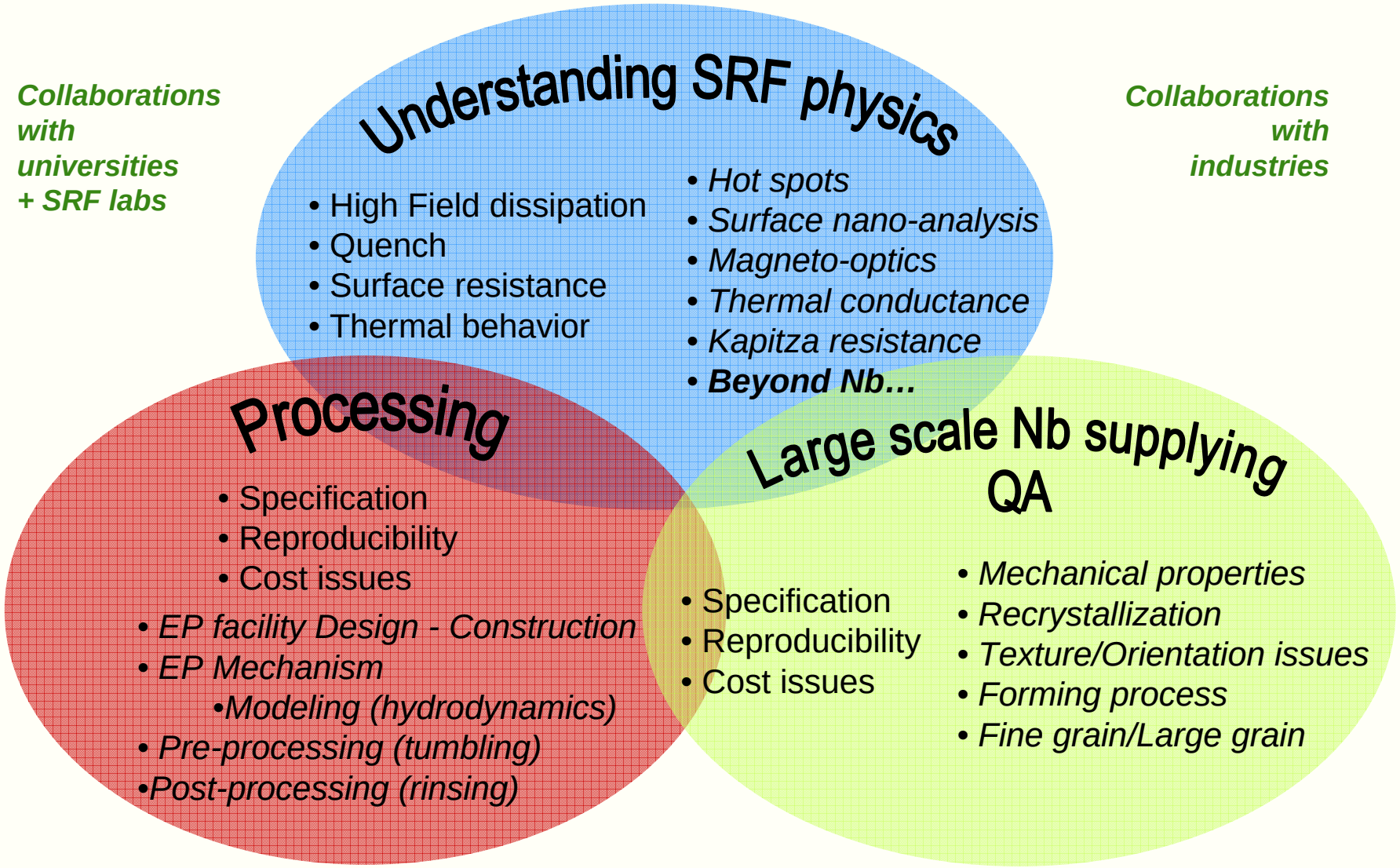
Claire Antoine
Cristian Boffo
Genfa Wu

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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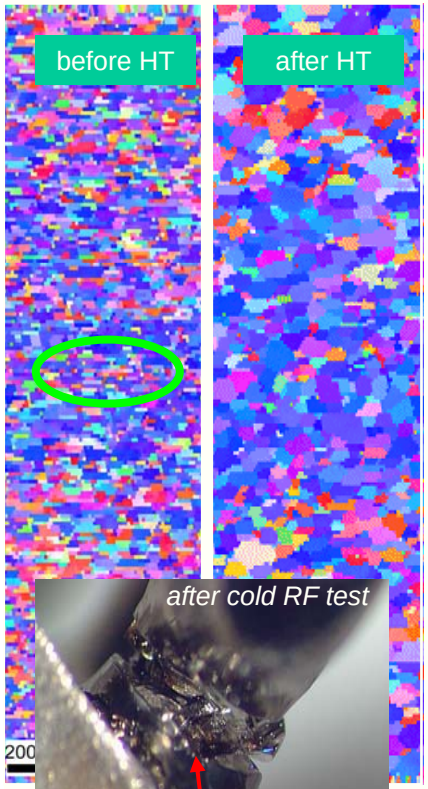
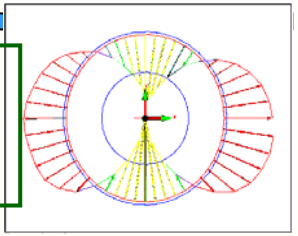


Forming Problems at AES:

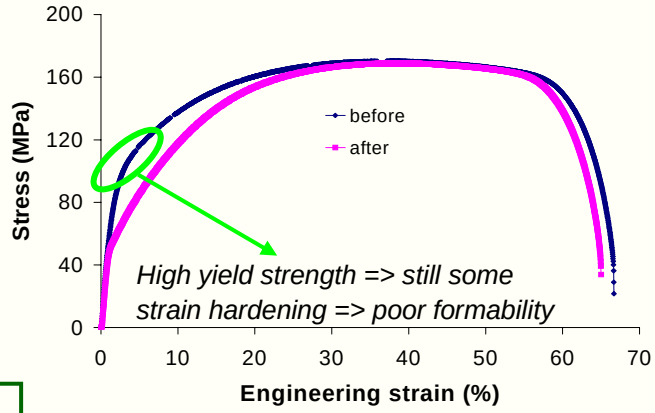
Nb too hard, spring back, 6 passes vs 1, ovalization…



Deviation from circular shape

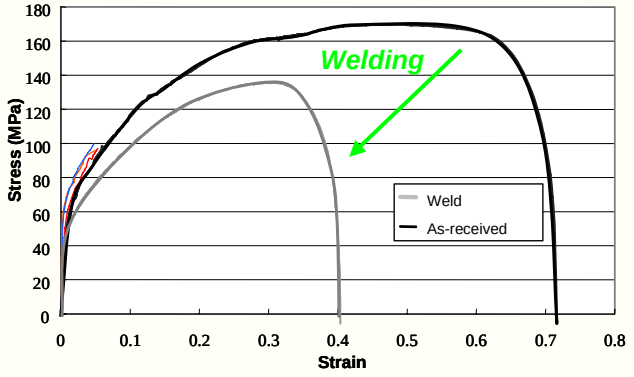
Microstructure & Mechanical Properties studied (MSU):

- ***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 ?

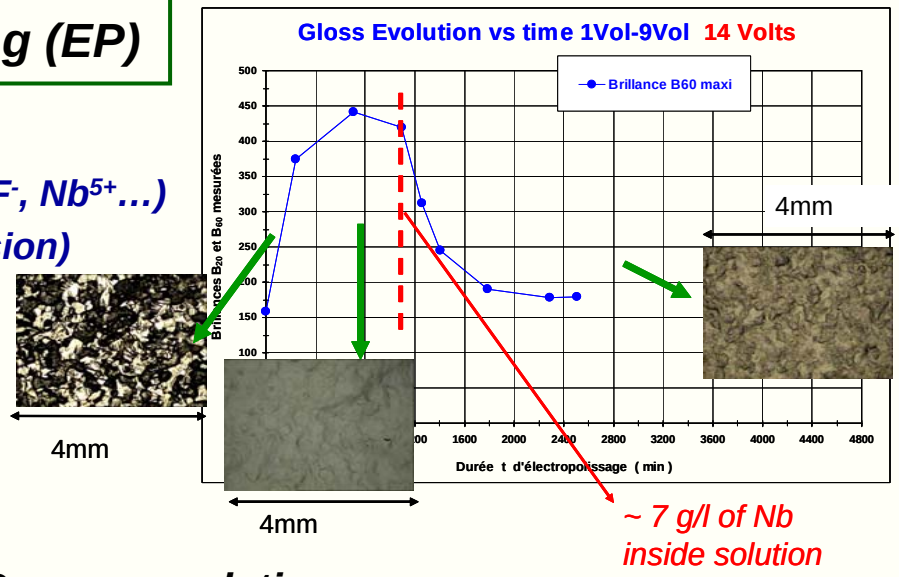
- *Aging of the solution, evolution of the composition (F^-, Nb^{5+}…)*
- *Impurities, particles generation (Sulfur vs field emission)*
- *Variation of the surface composition ?*
- *Variation of the surface roughness ?*

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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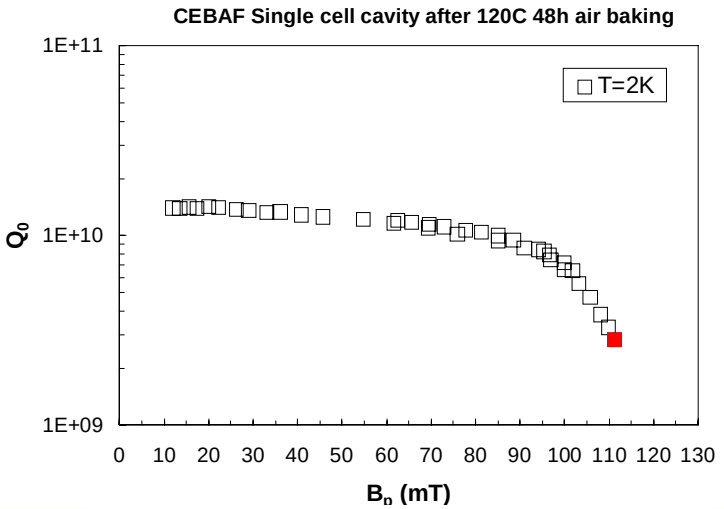
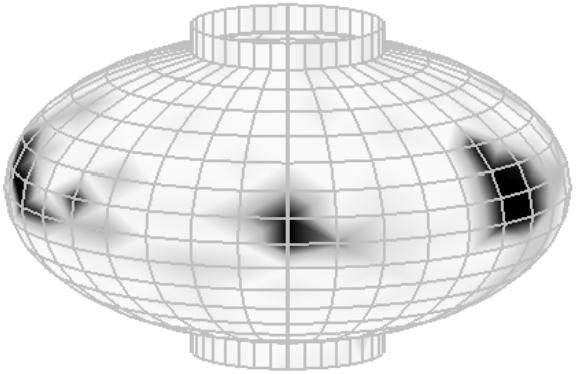
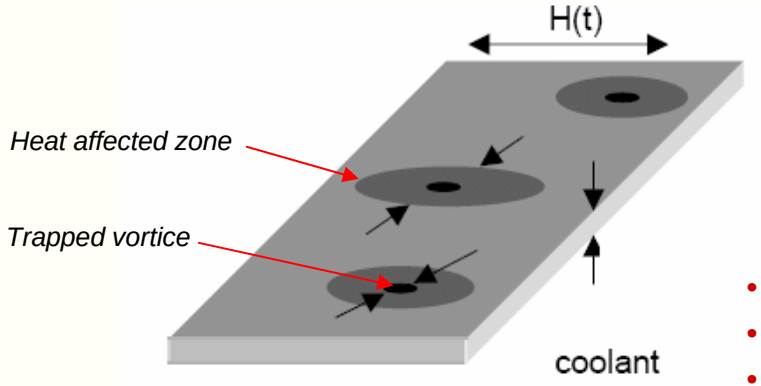
Superconductivity limits

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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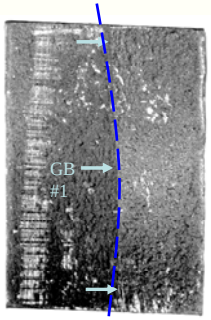
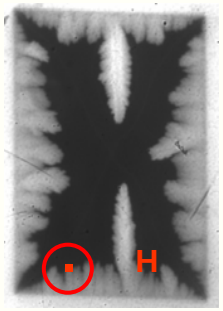
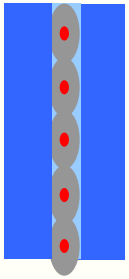
What is the problem with GB ?

Morphological effect or depleted SC ?

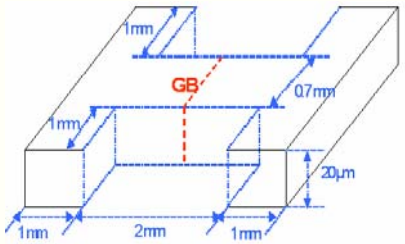
Flux penetration @ GB





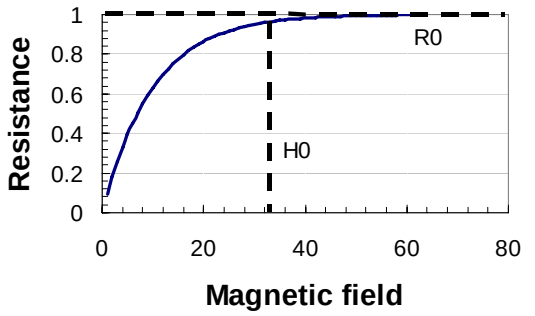


[Collabo. WU/FSU]



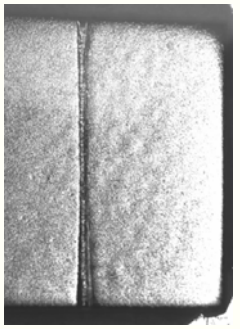
[A. Polyanskii et al, WU/FSU]

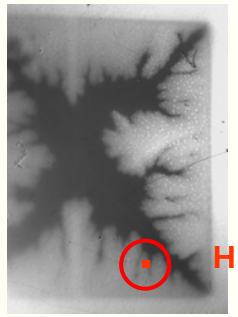
[Sung Hawn]

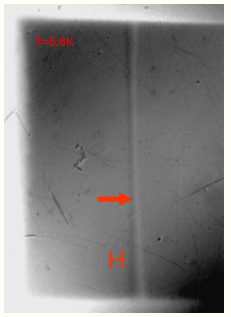


Saturation-field H0 gives information on de-pairing J_d of SC GB

@ 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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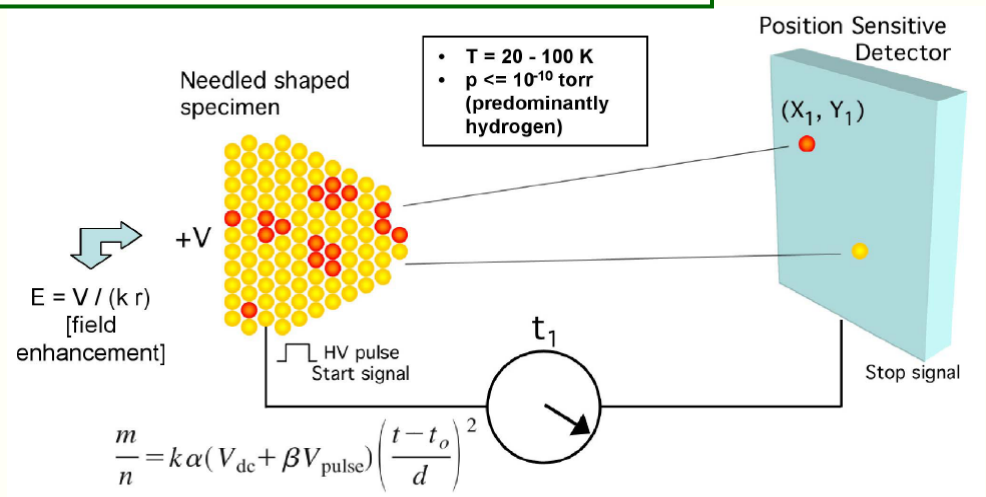
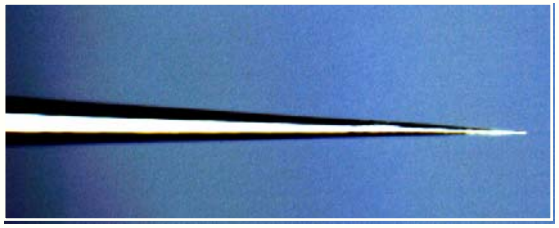
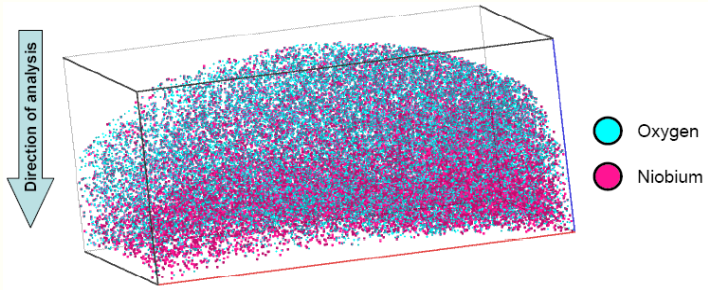
Surface contamination

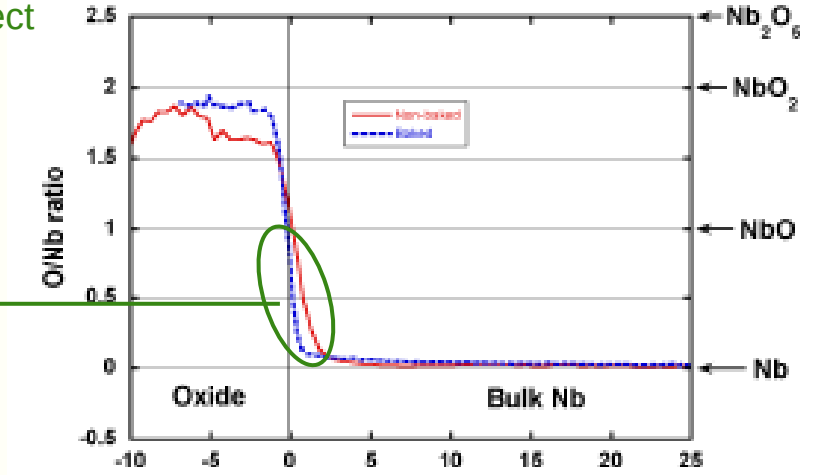
Atom-probe tomography (APT) *[Collbn University]*







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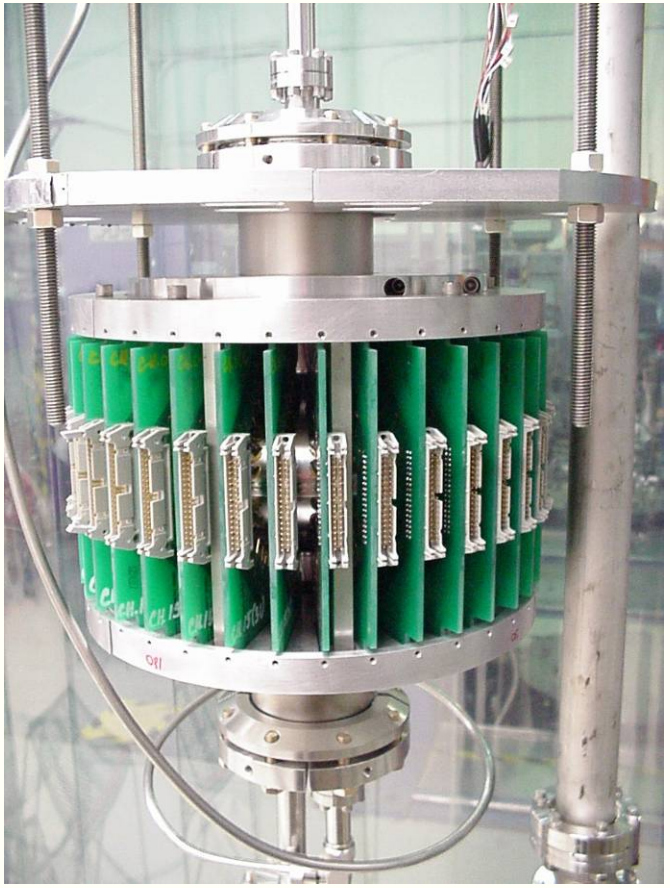
R&D aims at ↑ performances => ultimate test is cavity !

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	$235K	1 year	Includes 3 1-cell cavities
	• Program ○S0 ○SRF R&D	0.50 FTE TEC 0.75 FTE ENG 0.50 FTE TEC	$100K $60K	1 year startup	Helium + small material 3 additional cavities
Total FTE = 1.75 ENG + 1 TEC + 0.6 DES = 3.35					**Total M&S $395**

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

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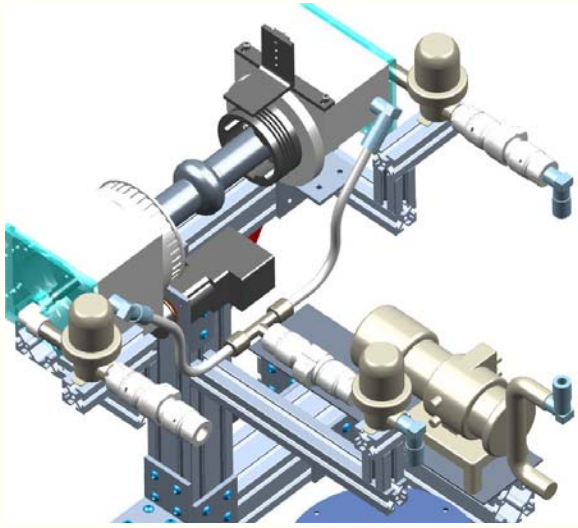
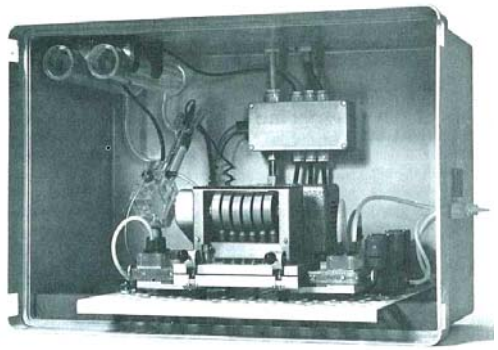
Along with the completion of the EP 9-cell infrastructure design and fabrication at ANL already financed…

- **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	$5K	6 month	Part of program at J-Lab
	○1Cell set up	0.25 FTE ENG 0.25 FTE DES 0.25 FTE TEC	$40K	1 year startup	Start 3.9 GHz and design 1.3GHz
	○Modeling	1.00 FTE STU	$5K	1 year	Ongoing
	○Tumbling	0.25 FTE ENG	$10K	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	$30K	1 year	J-Lab collab. 1 tech at J-lab for 1 year
	○ Dry processing	1.5 FTE TEC 0.5 FTE ENG	$5K	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 $95K**

3 Priority : Material Characterization : Mechanical, surface chemistry

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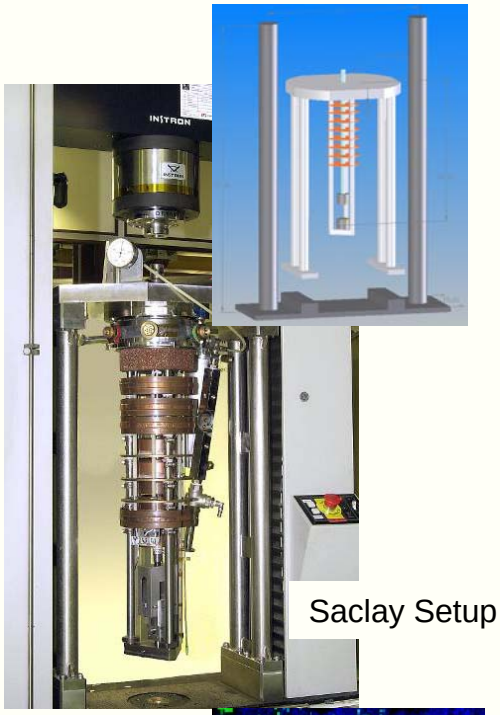
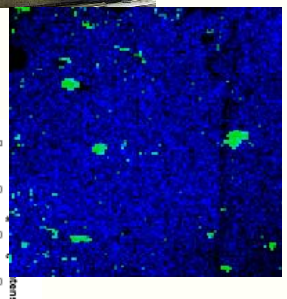
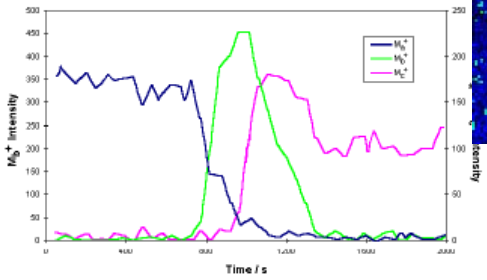
Systematic testing of new batches (QA) + Failure analysis

- **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 $235**

4 Priority : monocrystal Nb program

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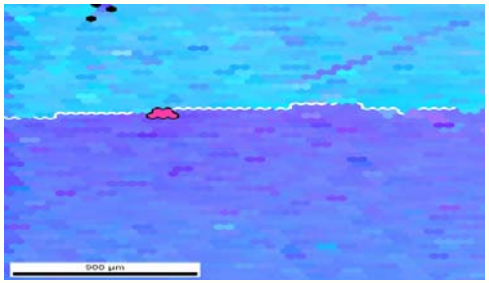
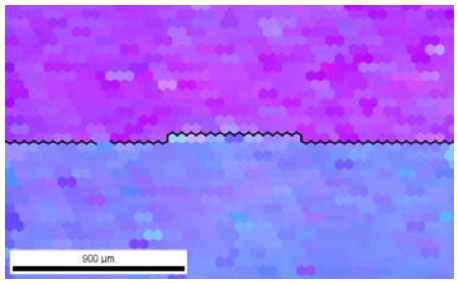
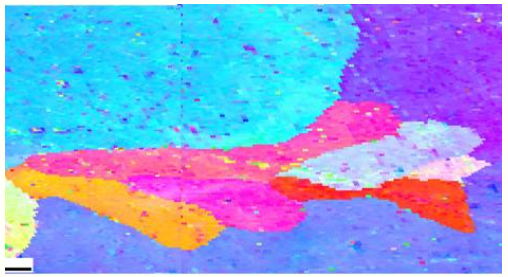
2 complementary goals :

- **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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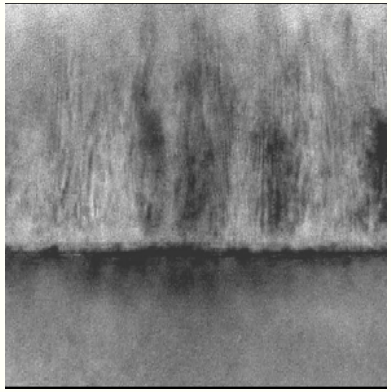
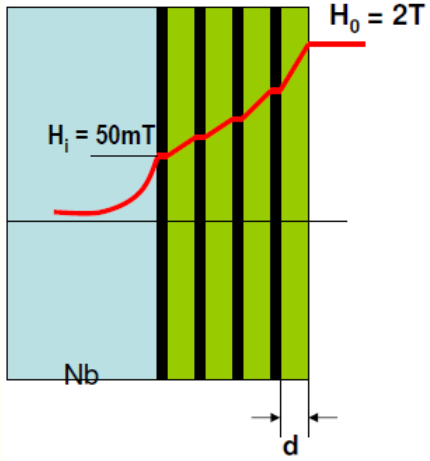
Single cell test program, collaboration with Universities

- **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]***



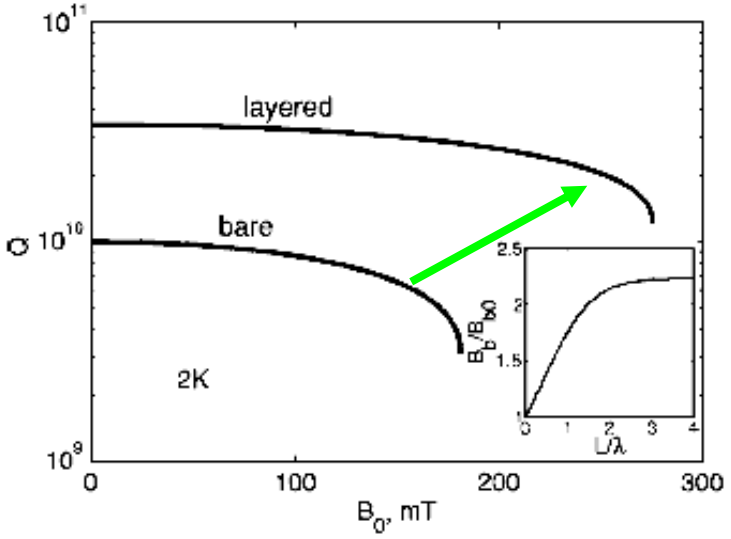
[A. Gurevich, APL 2005]

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

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:
	•Surface fine studies ○3D probe ○Prime				•Sample and small material @ short term •1-cell testing @ mid term
	•Multilayer S-I-S				
Total FTE: 1 SC + 1 STU + 0.25 TEC			**Total M&S $300K**		

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	Total M&S
1-Cell RF test stand	1.75 ENG + 1 TEC + 0.6 DES = 3.35	$395
Surface processing R&D	0.5 SC + 2.5 ENG + 2 TEC + 1.75 DES + 1 STU = 4.75	$95K
Material testing	1.0 STU + 1.25 TEC + 0.5 ENG = 7.75	$235
Advanced SRF R&D	1 SC + 1 STU + 0.25 TEC = 2.25	$300K

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:

$690 K +$ 300K 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…

Thermal behavior

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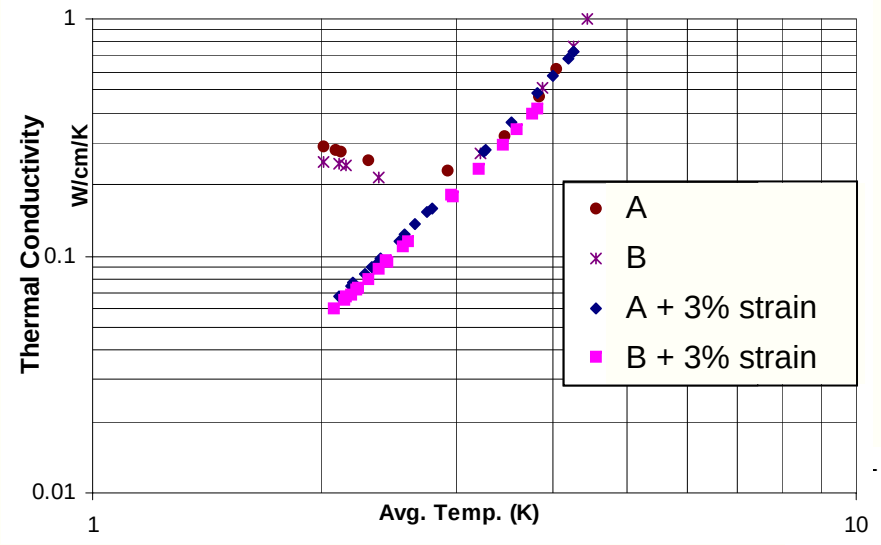
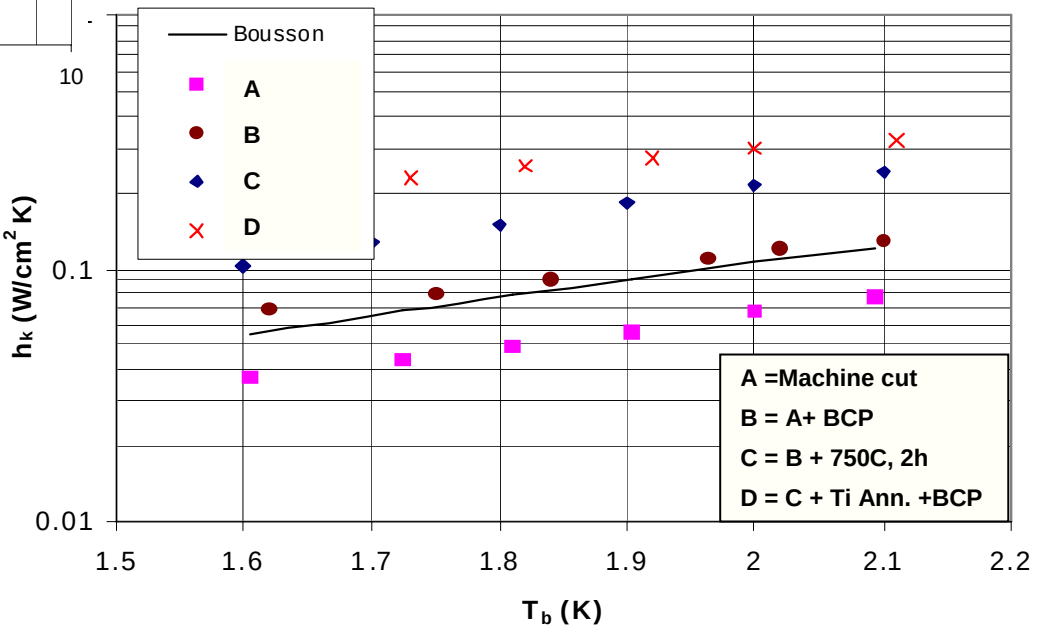


- **Thermal conductivity @ 2 K decreases dramatically with strain (80%!)**
- **It is not recovered with 750C, 2h**
- **It is recovered with Ti annealing (1300-1400 C)**
- **Intermediate temp need to be tested**

Unexpected results !!!!!

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

[CollnMSU]



TIG Welding Study

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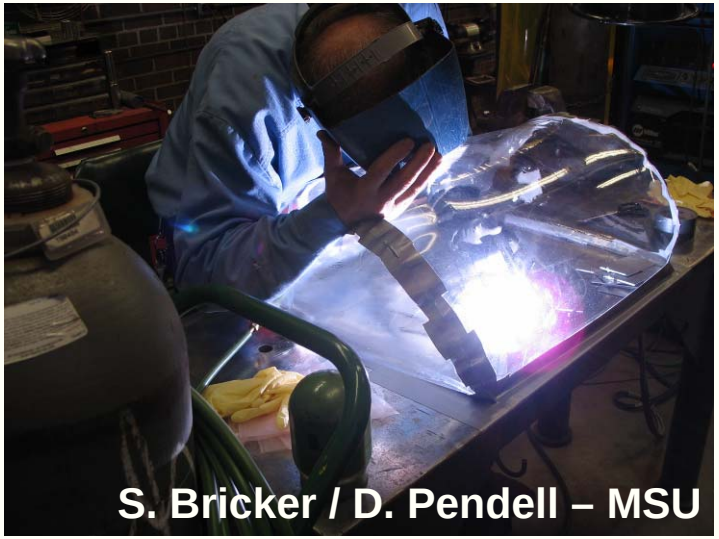
Innovation:

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

NSCL



Surface Topology

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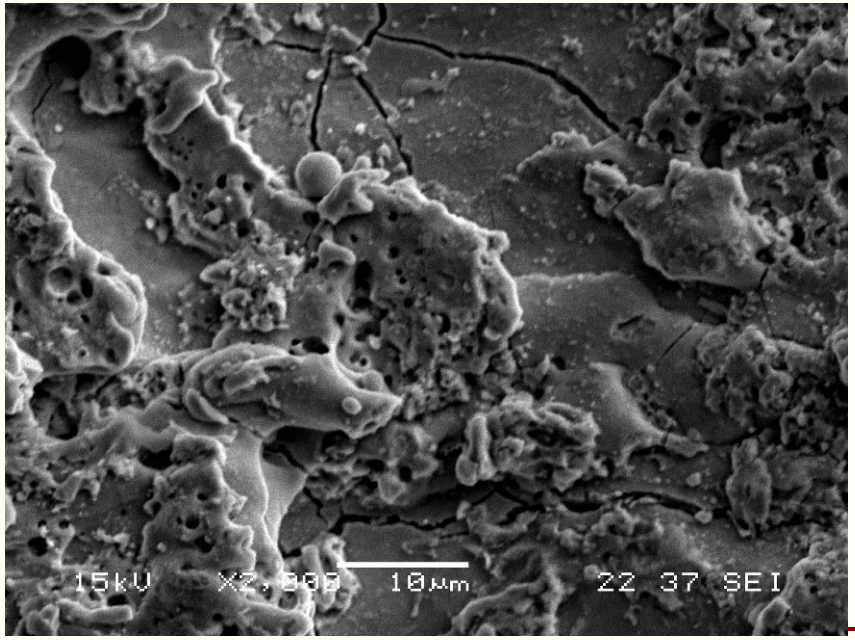
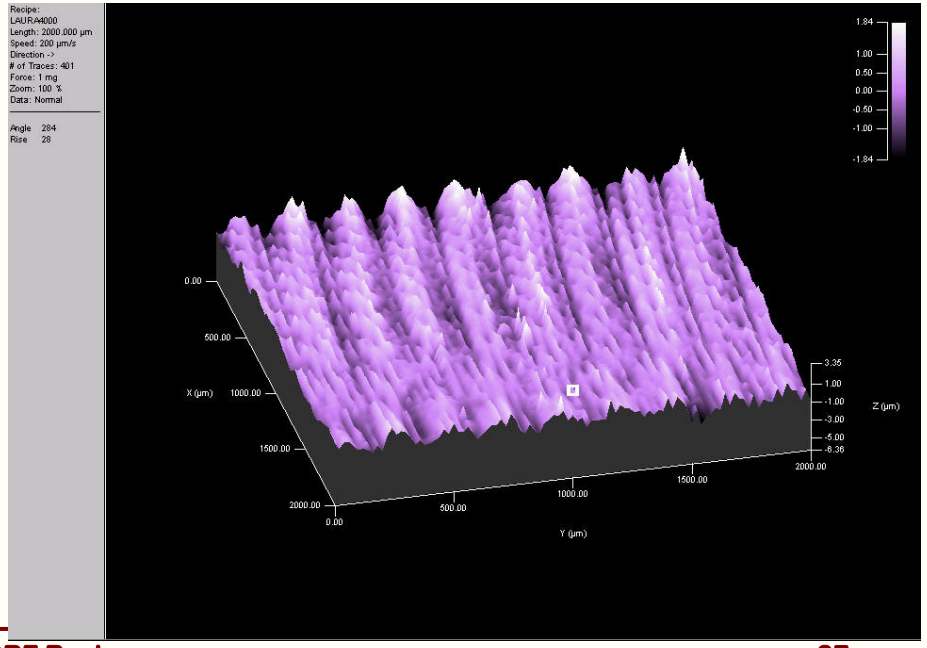
Surface Roughness and Chemistry:
Example: Study of different cutting techniques by C. Cooper / FNAL

SEM Images of EDM Wire Cut Sample at Various Magnifications

EDM Cut Surface SEM



Milled Surface Topology



Others ideas …?

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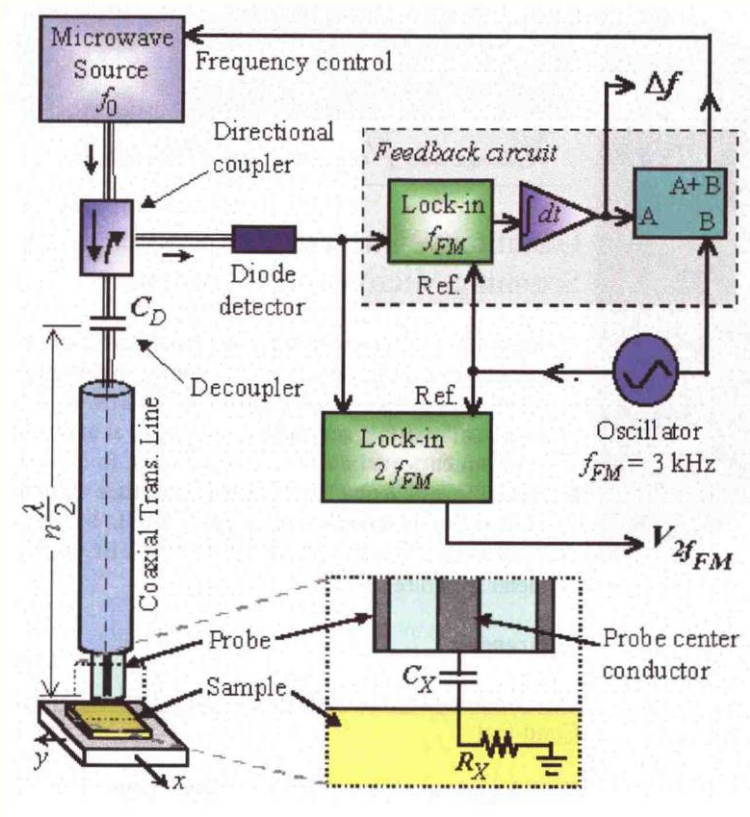
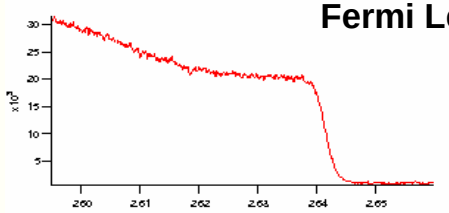
RF microscopy

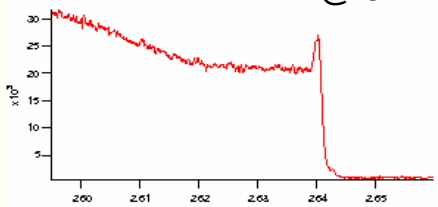


Superconducting gap measurement *(Photoemission)*

Fermi Level @ 10K



@ 5K => SC Δ



Δ @ 5K + BAKING !