N-Infusion R&D effort at Jefferson Lab

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Jefferson Lab
EXPLORING THE NATURE OF MATTER

BACKGROUND

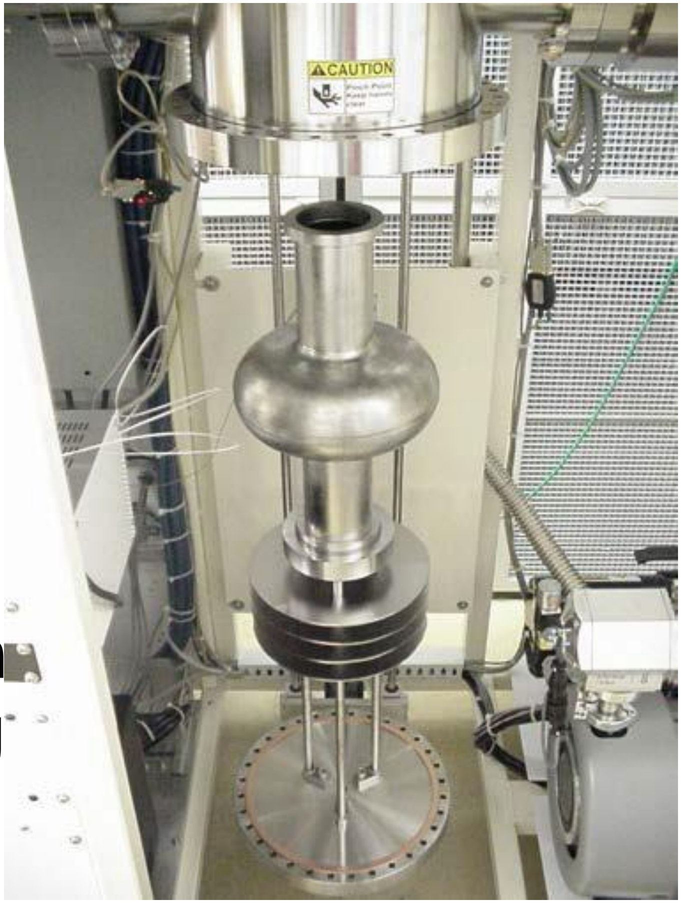
- Work started to understand the role of high field Q-slope with hydrogen (niobium hydrides) and **<u>passivation of Nb surface during heat treatment</u>**.
- The improvement on Q have been observed following the heat treatments with lower hydrogen concentrations.
- Significant improvements on the RF cavity performance of several single cell cavities was obtained after the ***<u>heat treatment at 800C and followed by120C with no post furnace chemical etching</u>***.
- ***<u>Surface nitridation for surface passivation (400C, ~10^{-5} mtorr N_2)</u>*** was attempted and improvement on both Q and E_{acc} was observed.

Passivated niobium cavities
US 7151347 B1

Ciovati et al. Phys. Rev. ST Accel. Beams 13, 022002 (2010) 022002
Ciovati et al., SRF 2011

BACKGROUND

- New dedicated clean induction furnace was designed and installed in order to explore the surface passivation parameters.
- The furnace is capable to going higher than 2000C in UHV environment.
- The furnace is equipped with gas (N2, O2, Ar, H2) handling system.



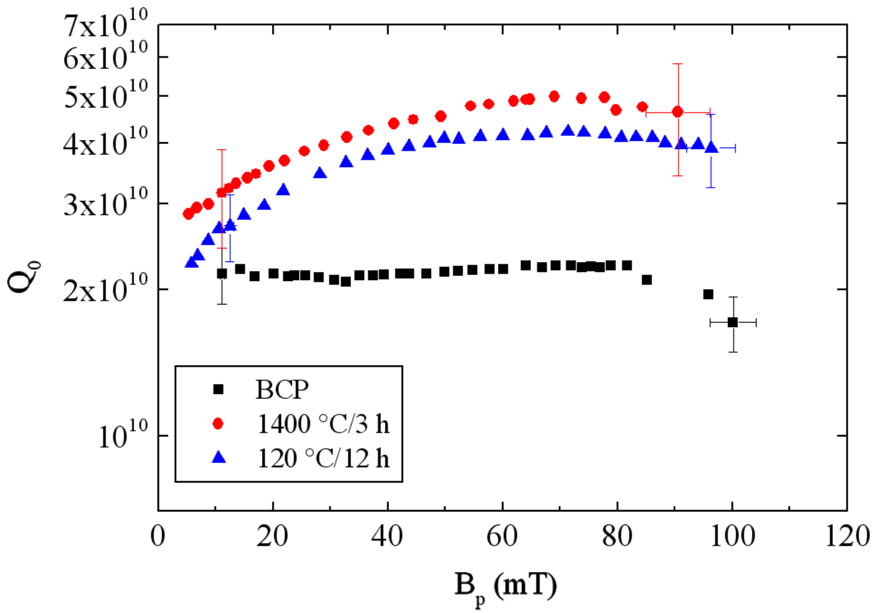
Cavity loading in the furnace

P. Dhakal et al., Rev. Sci. Inst. 83, 065105 (2012)

BACKGROUND

- Exceptionally high Q was observed on 1.5 GHz cavity when cavity was heat treated at 1400C/3hrs.
- Investigation found that ~ 1 at.% of Ti was diffused with in ~2 μm on RF surface resulted in the increase in Q and more importantly the positive Q(E) dependence.
- The cavity was made from medium purity (RRR~100) large grain niobium.

1.5 GHz, T = 2K

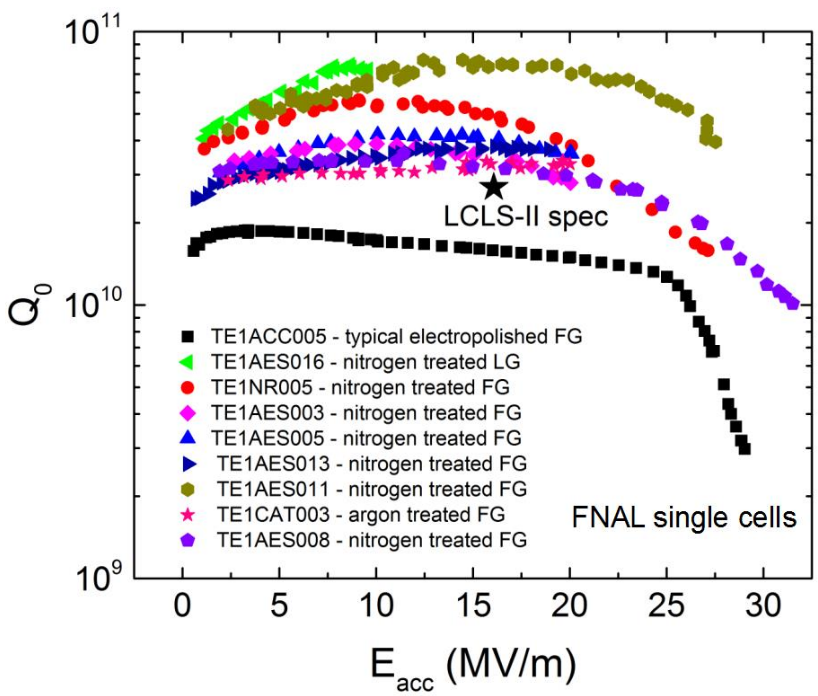


- **First demonstration of Q-rise via doping**
- **No electropolishing after doping**

P. Dhakal et al., Phys. Rev. ST Accel. Beams 16, 042001 (2013)
P. Dhakal et al., IPAC'12, p. 2651 (2012)

BACKGROUND

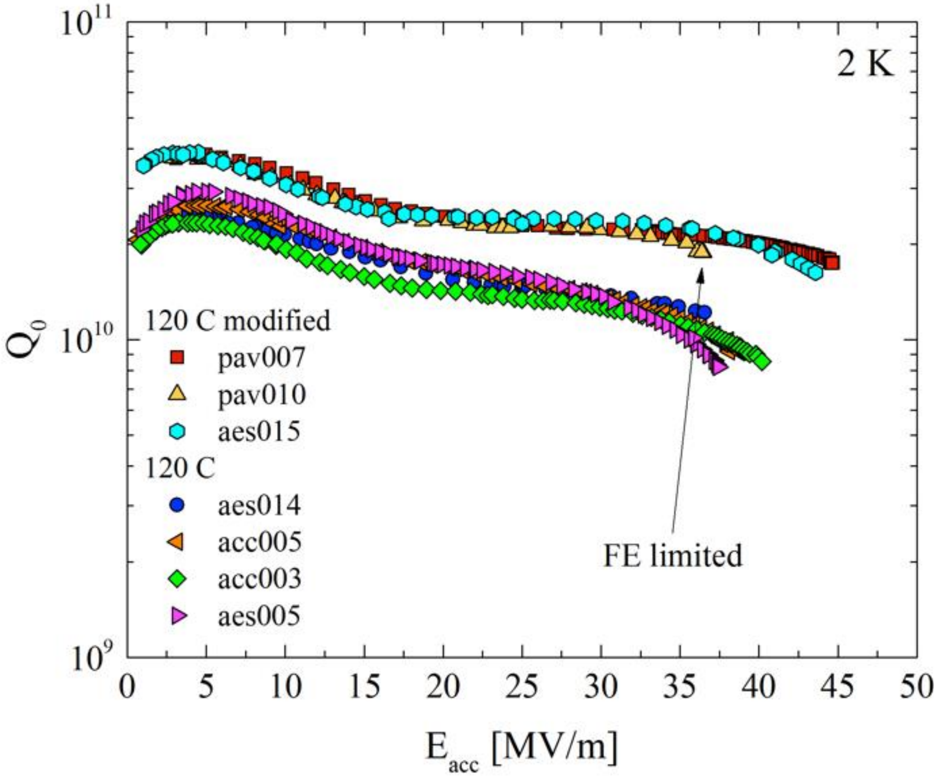
- Fermi Lab explored the surface passivation technique and found that the nitrogen doping followed by surface removal by EP produce the similar results those were obtained via Ti diffusion.
- This has been grown so fast that it became "production recipe" for LCLS-II cavities.
- Even though the dramatic enhancement on Q has been observed the gradient of doped cavities are limited to medium gradient ~20 MV/m.
- Theoretical explanation based on velocity of quasi particle (Xiao model) and broadening of density of state on **dirty superconductor** (Gurevich model) were proposed.

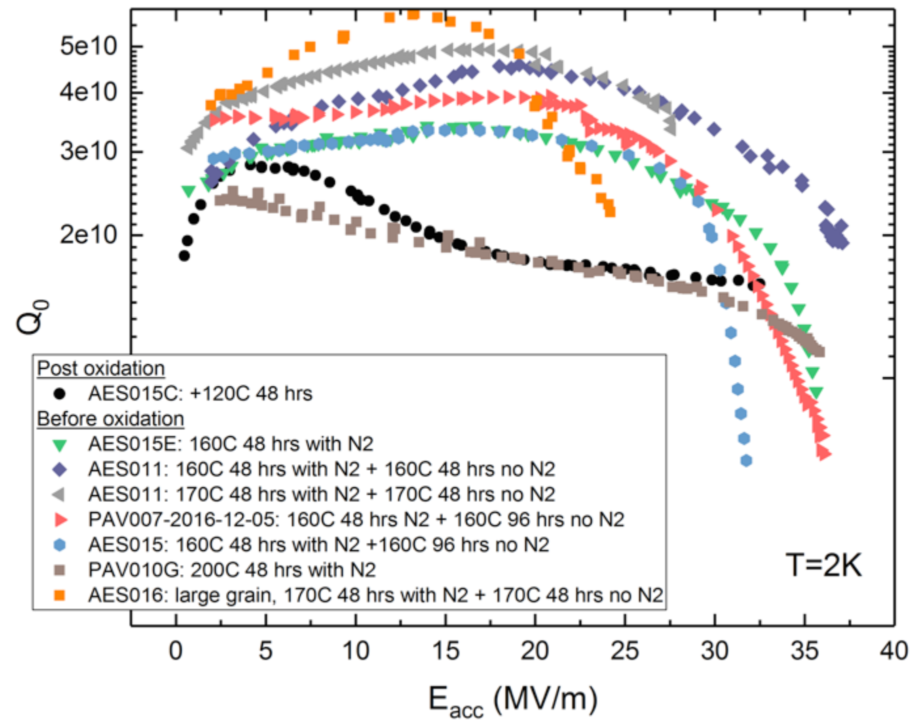


Grassalino et al., SUST 2013

Recipe for LCLS-II

LOW TEMPERATURE N-INFUSION





- FNAL reported both increase in Q and E_{acc} when N2 was infused to furnace during the heat treatment at lower temperature (120C).
- Q-rise phenomenon was observed on cavities when the nitrogen was infused at higher temperature (140-170 C)

Grassellino et al,arXiv:1701.06077

R&D work at JLAB

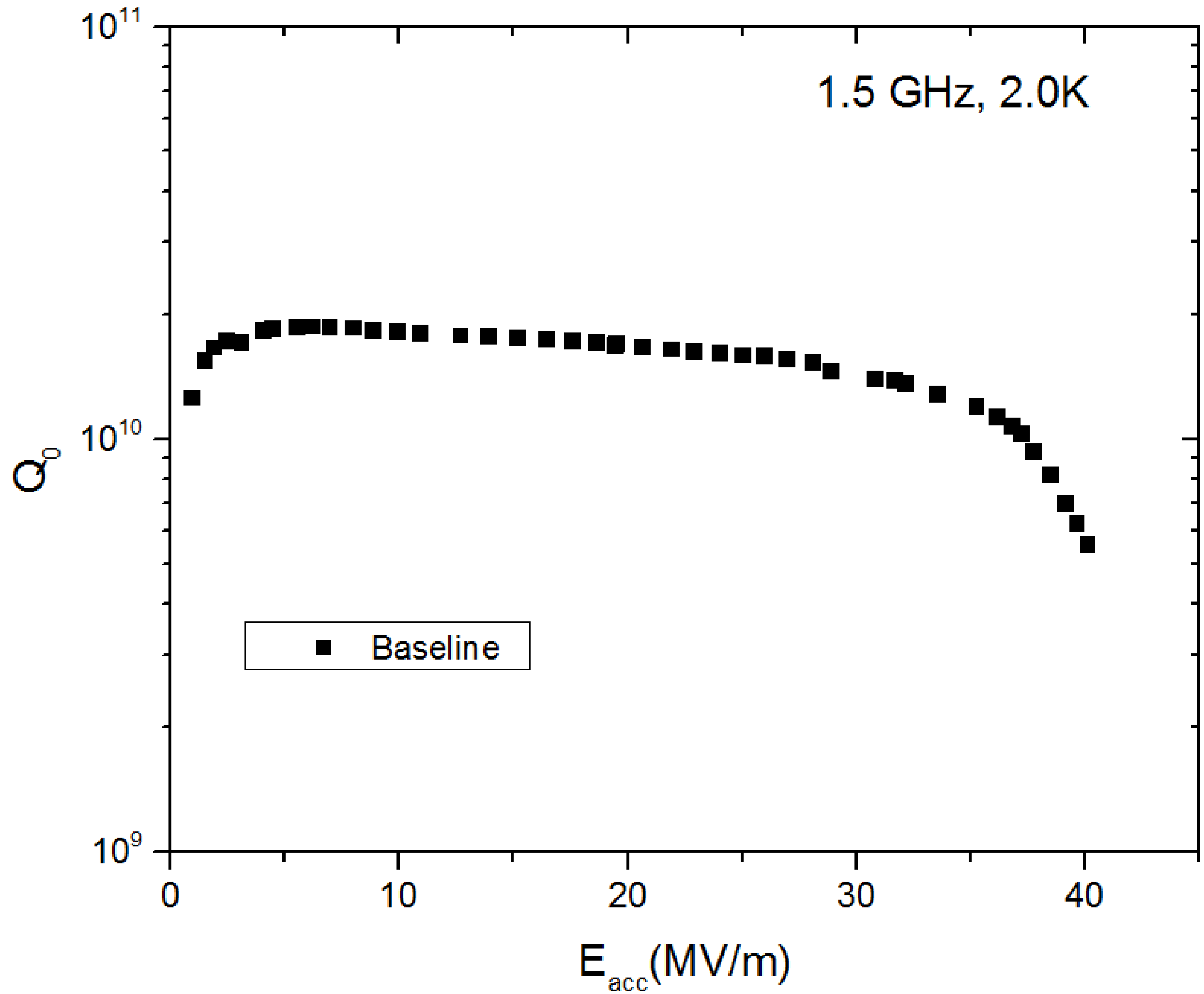
- Mostly high Q R&D in medium field using low/medium purity Ingot Niobium.
- Shape optimization for high Q, high E_{acc} cavity (for example Low Surface Field Cavity).
- Nb_3Sn work on progress with multicell cavities.
- Ongoing Nb on Cu thin film cavities.
- Low temperature N2 infusion for high Q, high Eacc cavities towards ILC.

No official R&D project that supports ILC.

N-INFUSION UPDATE

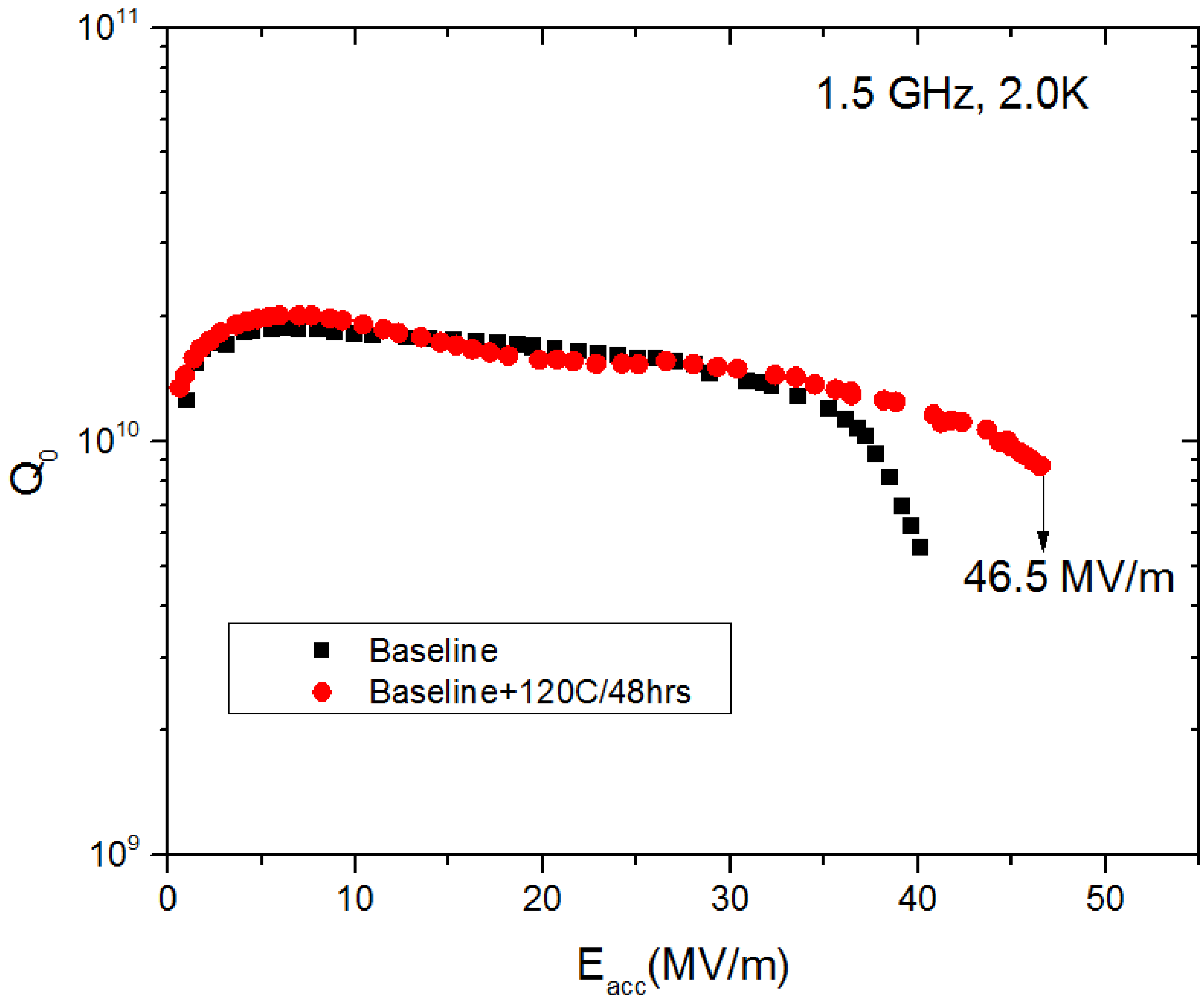
- High purity fine grain Nb Cavity RDL-02: After the fabrication, the cavity was given **<u>standard ILC recipe</u>** of 150 μm EP, 800 □C/2hrs furnace treatment, followed by 20 μm EP.
- Cavity was HPR before loading to the furnace and Nb caps were assembled in clean room.
- After each heat treatments (**with caps**), the baseline measurement was done to surface reset with 10 μm EP.
- Rs vs T data were taken from 4.3-1.5K at B_p~10mT in order to extract the material parameters.
- **<u>No post chemistry after the furnace treatment</u>**.

RECENT WORK AT JLAB



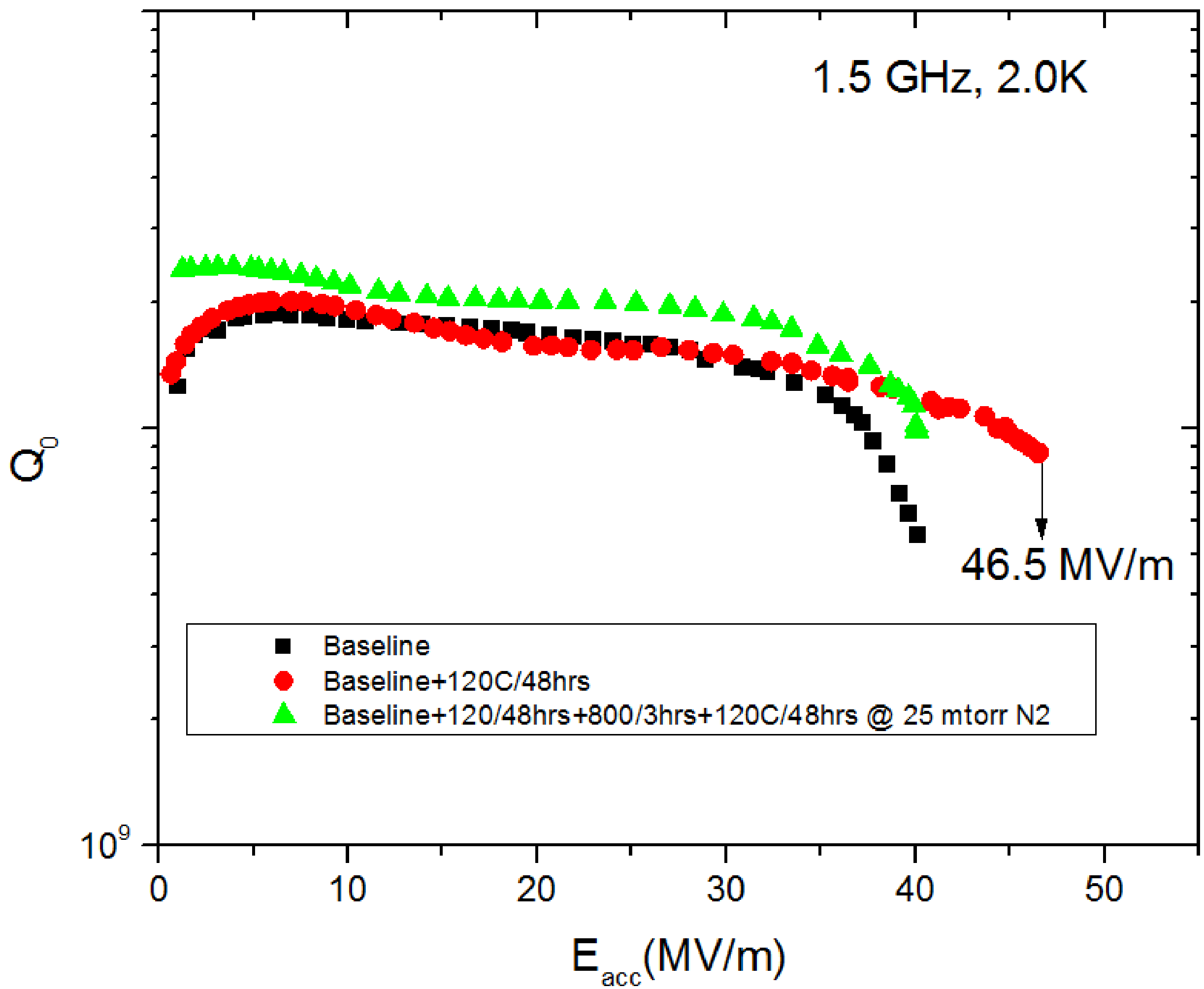
Standard ILC EP recipe

RECENT WORK AT JLAB



Standard ILC EP recipe with Bake

RECENT WORK AT JLAB



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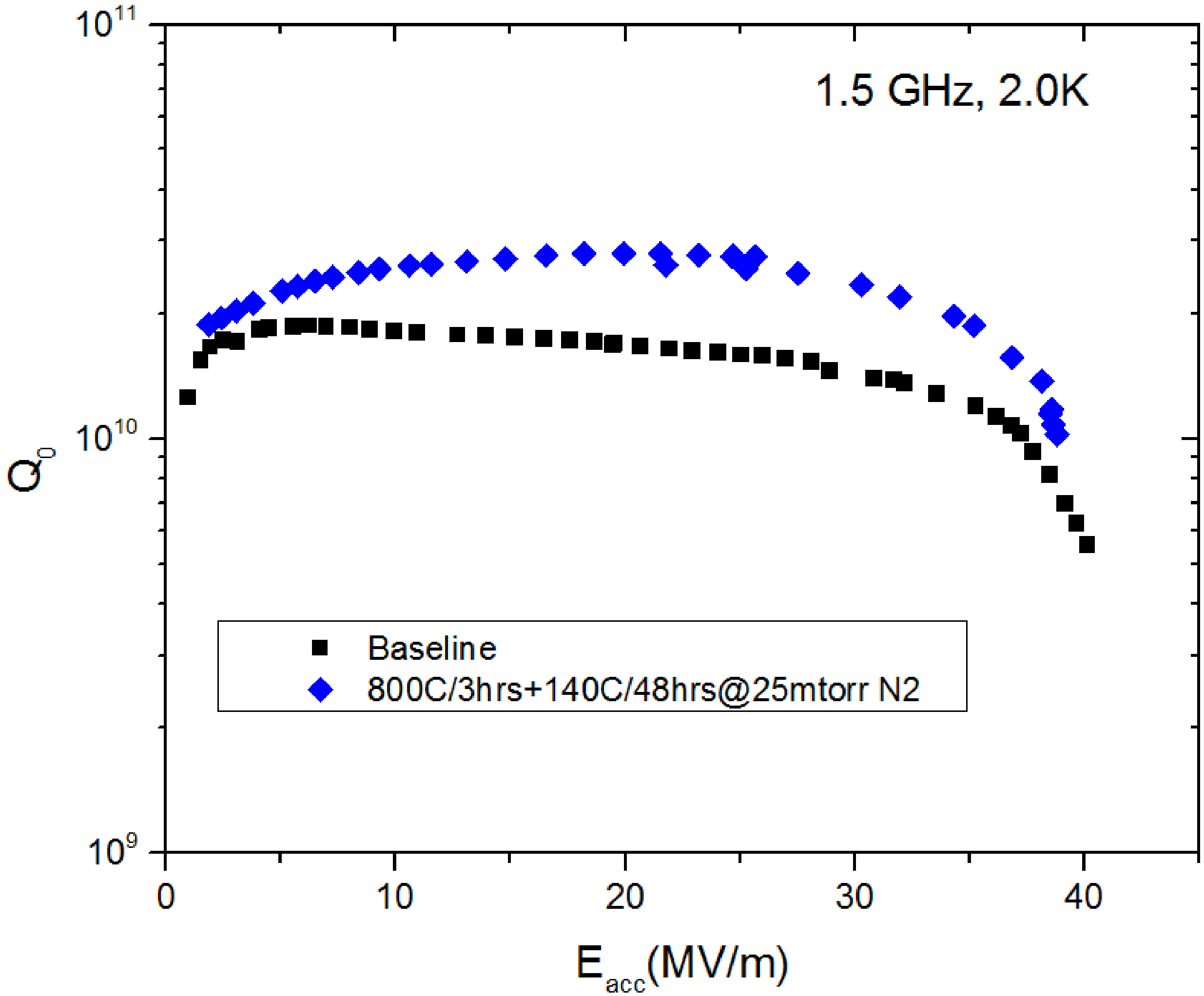
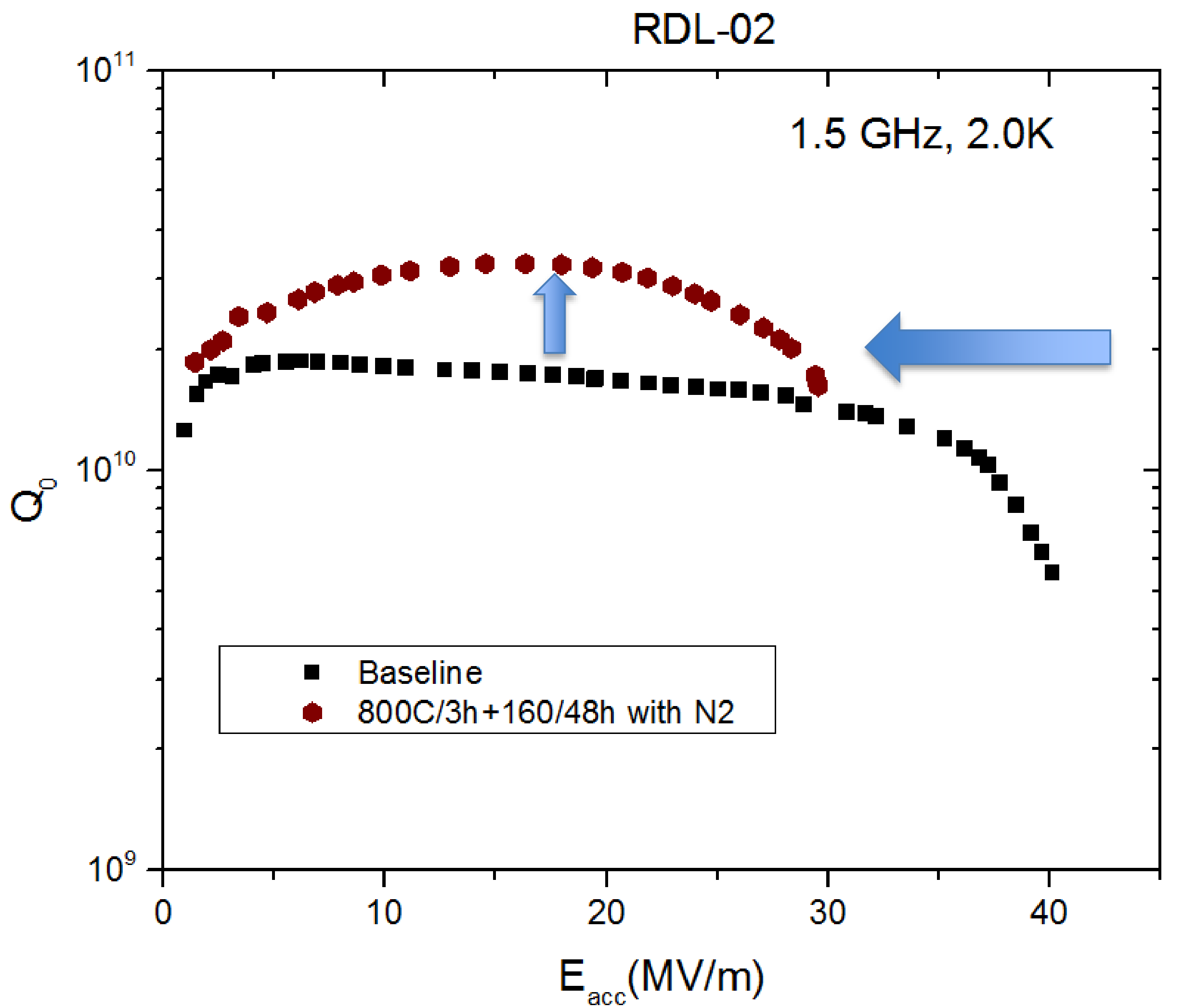


RECENT WORK AT JLAB



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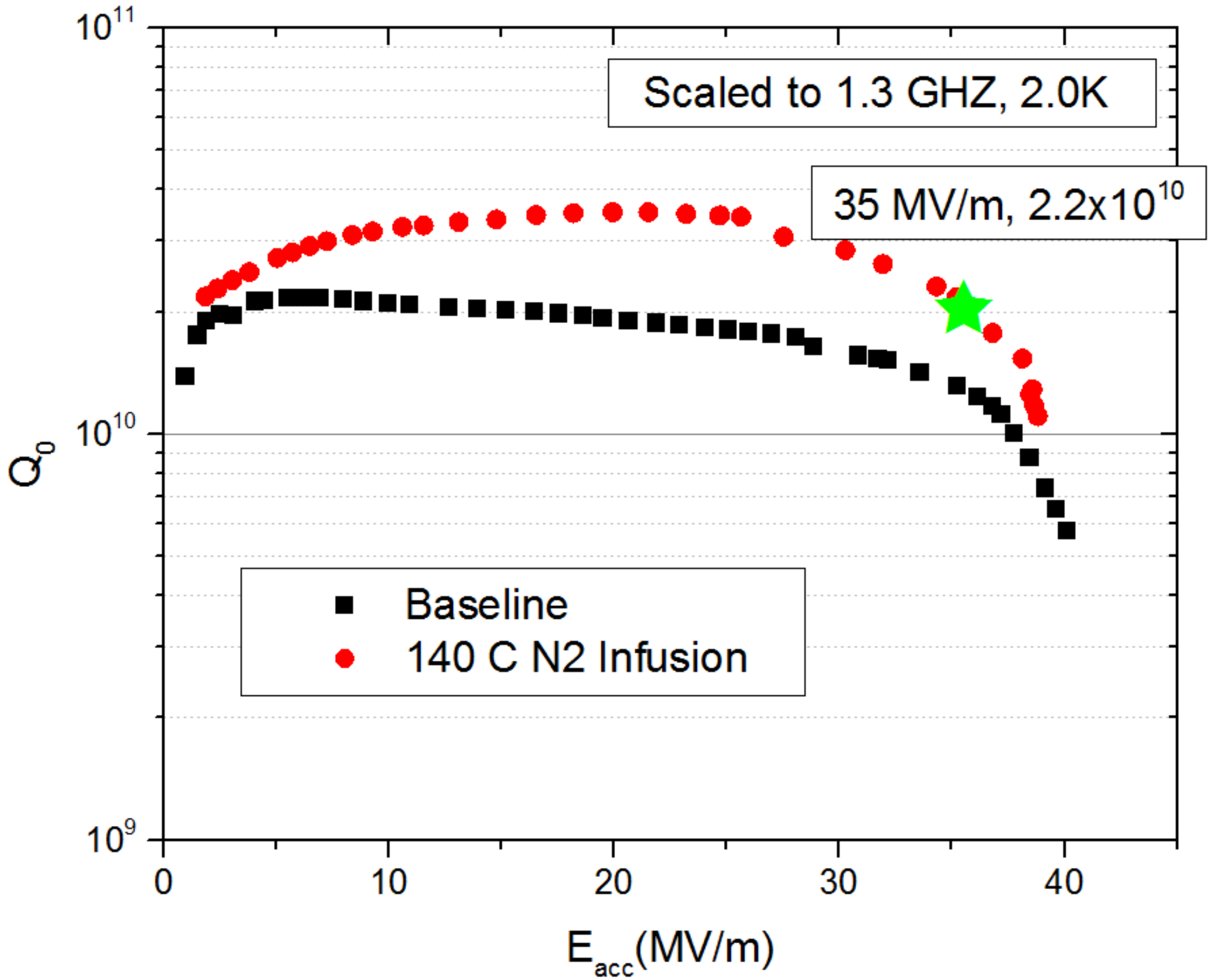
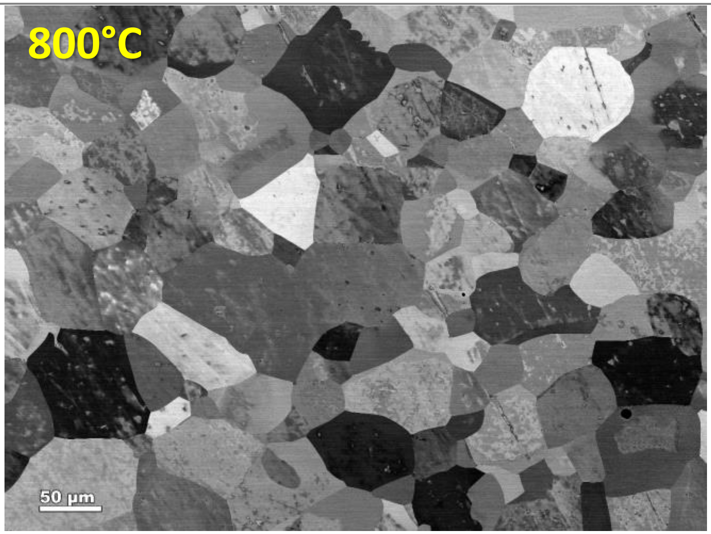
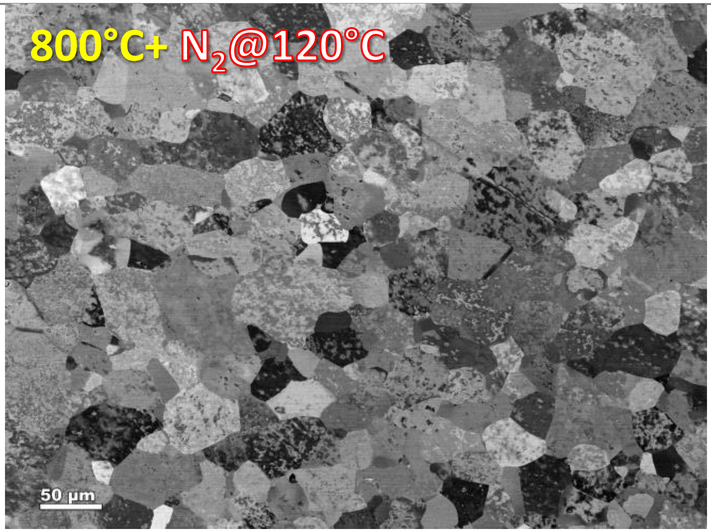


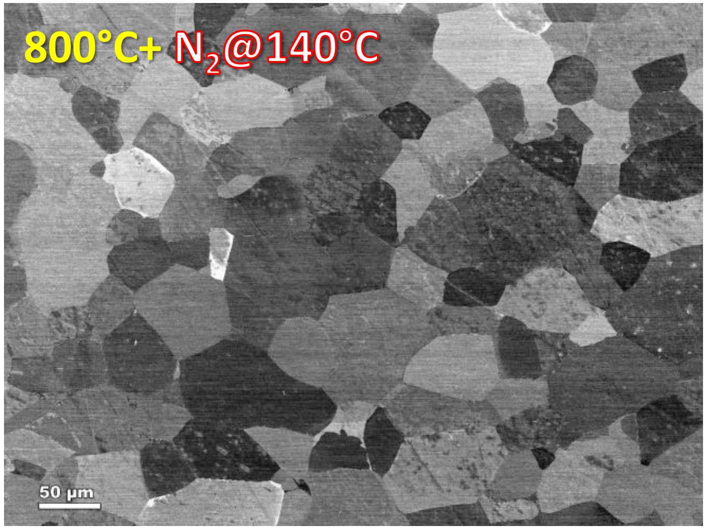
Work in Large grain cavities as well as process control are in progress.

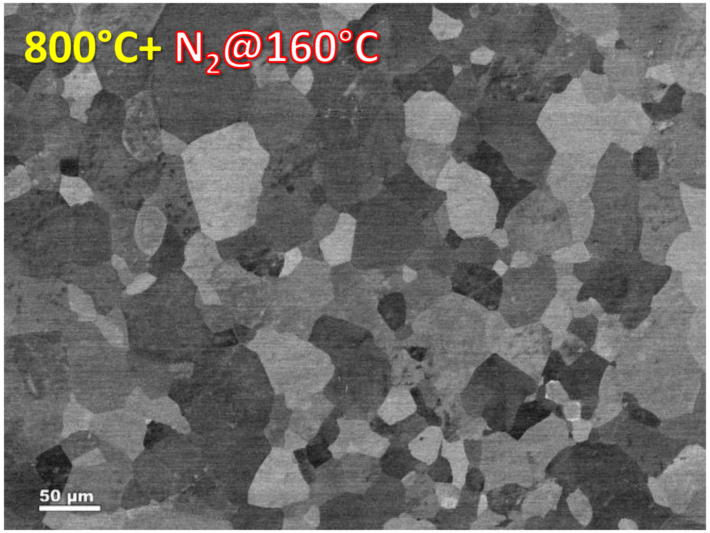
Sample Coupons Study

FSU/ASC





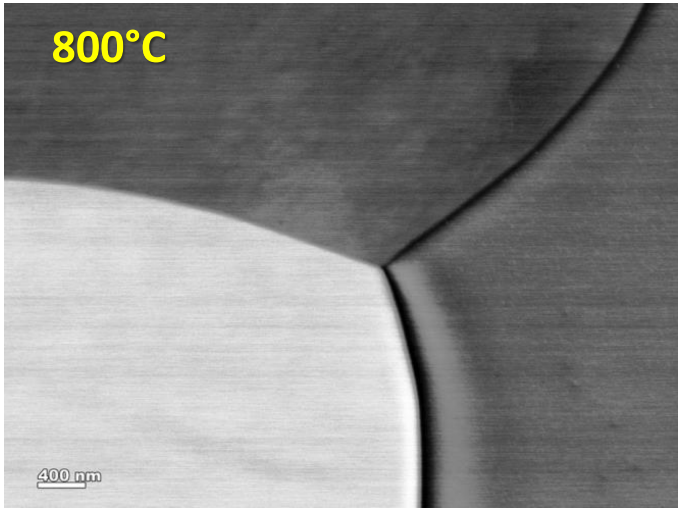


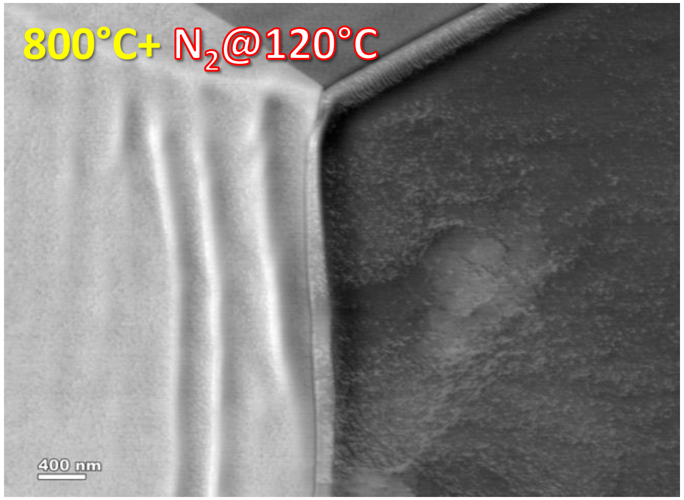


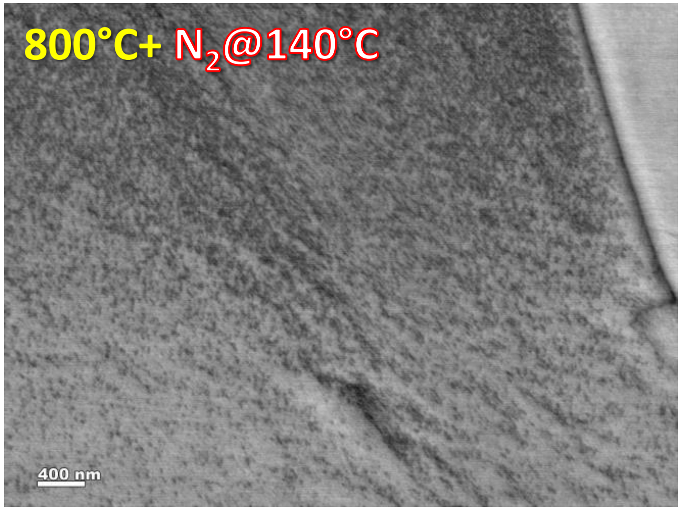
The material looks non-uniform. Grain sizes vary between 10-70µm

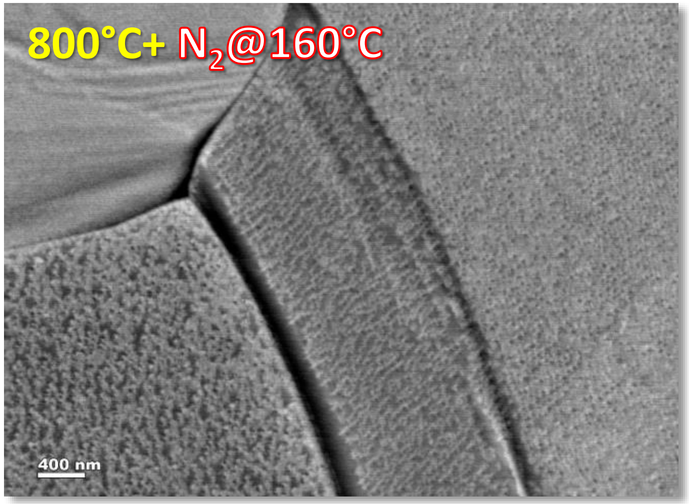
SAMPLE COUPONS STUDY

FSU/ASC





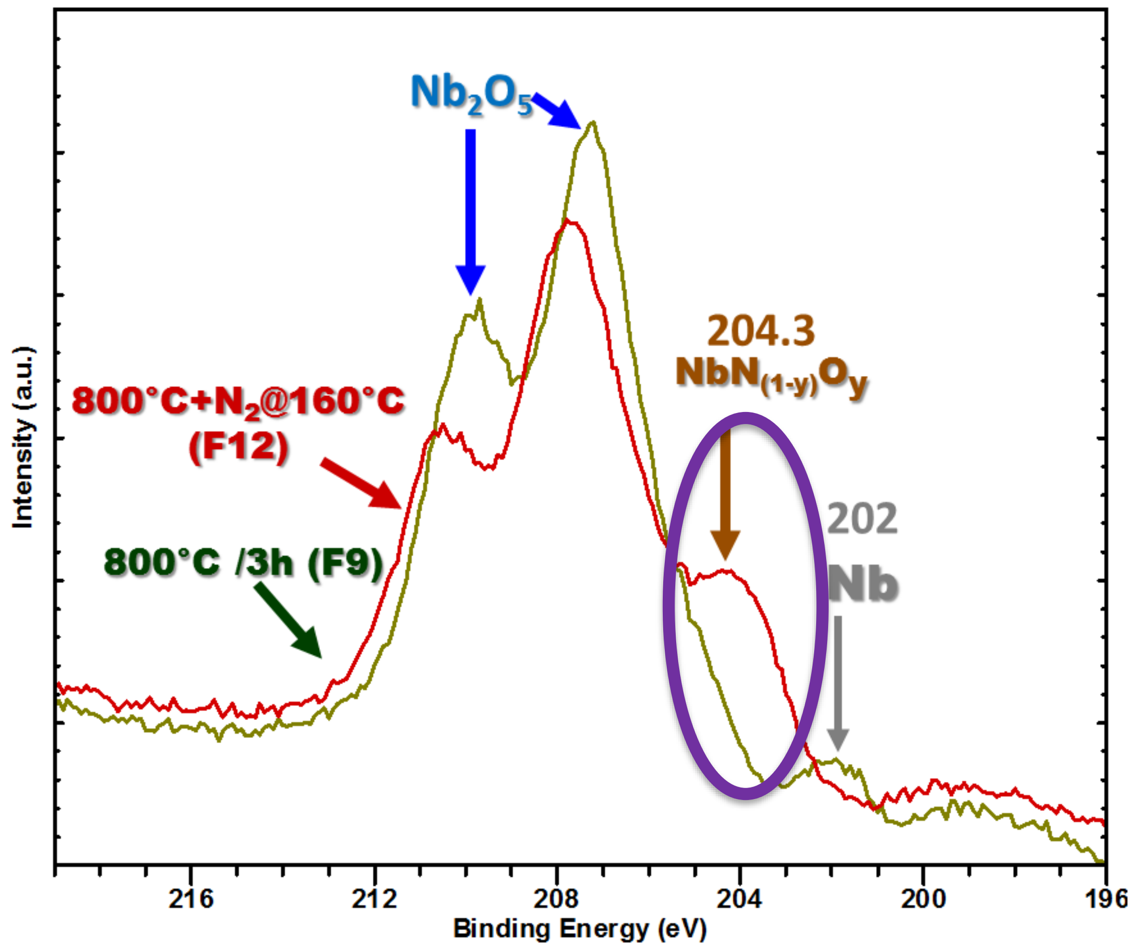




Granular surface morphology on low temperature N doped samples

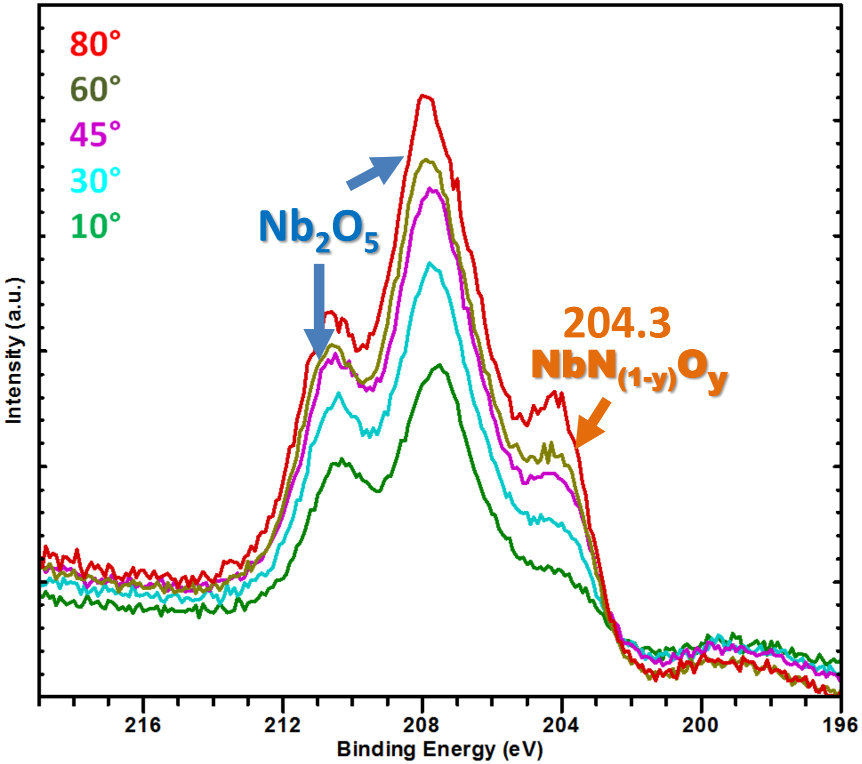
Sample Coupons Study

FSU/ASC

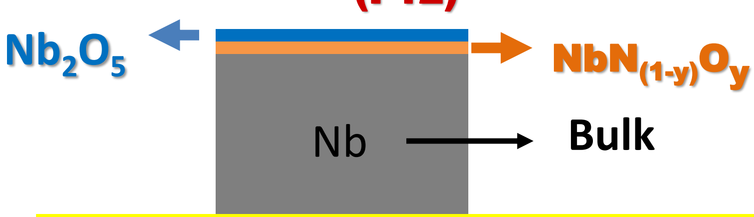


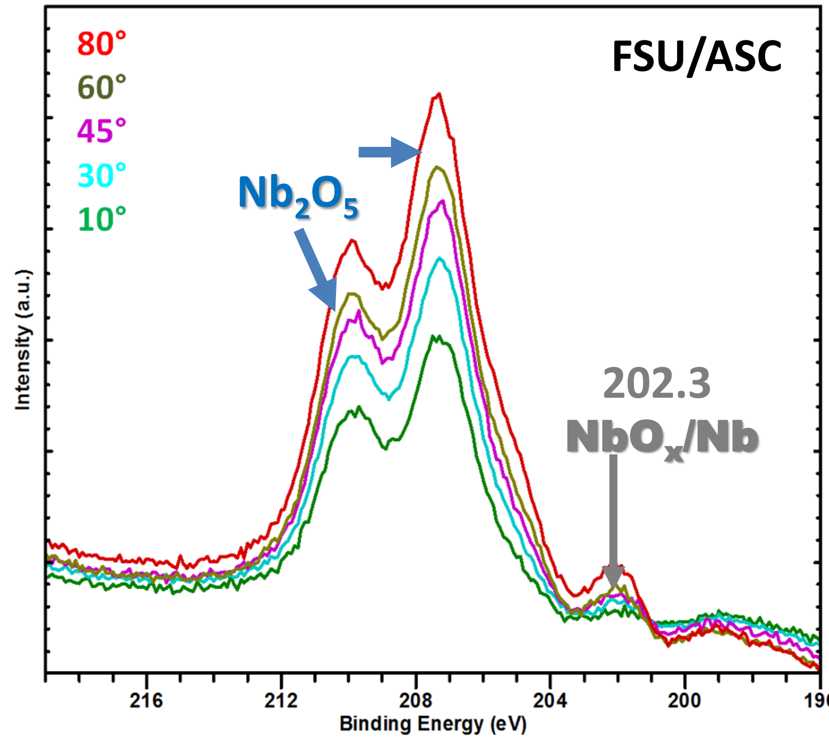
Preliminary XPS Result: Presence of a NbNO peak in low temperature N doped sample

Sample Coupons Study

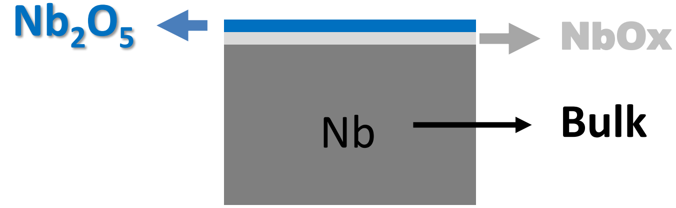


800°C+N_2@160°C
(F12)



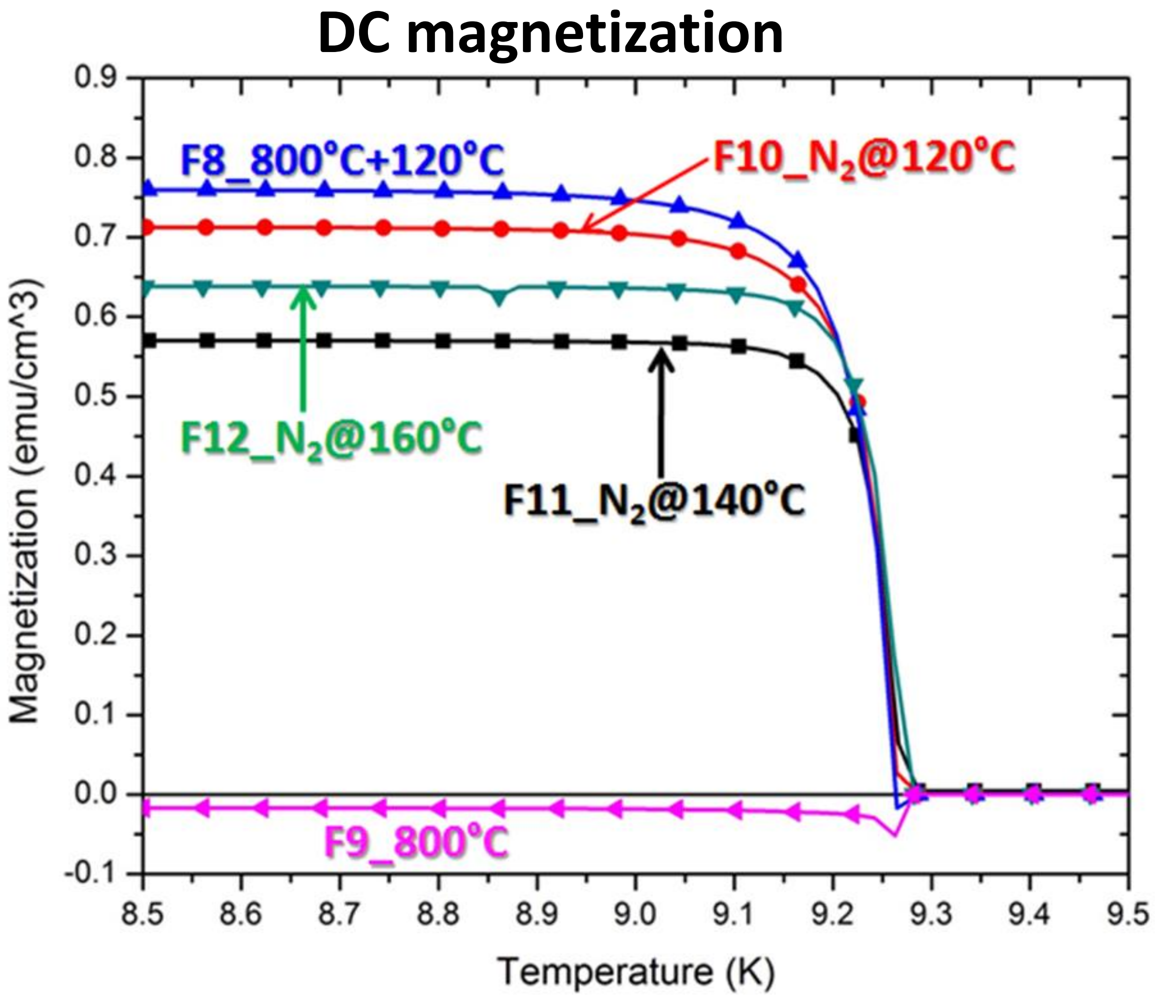


800°C /3h (F9)



Nb_2O_5, and $NbN_{(1-y)}O_y$ exists within first 10nm in low temperature N infused sample

SAMPLE COUPONS STUDY



- **Field cooled sample in an external field of 1mT to below Tc (8.5K).**
- **Field is removed**
- **Magnetization measurement during warmup gives qualitative behavior of flux trapping.**
- **Nitrogen infused and 120C bake samples show flux trapping**

CONCLUSIONS

- **Nitrogen Infusion at low temperature works and can be ideal processing recipe to achieve high Q, high gradient cavities.**
- **Low temperature N-doping of Nb affects the surface properties significantly**
  - **Increase in H_{c3} value, an indication of reduced electron mean free path on surface.**
  - **Different baking temperature in N_2 atmosphere leads to different surface condition.**
  - **Preliminary XPS on low temperature nitrogen infused sample shows a presence of $NbN_{(1-y)}O_y$ and a protective Nb_2O_5 within the first 10nm. The presence of other sub-oxides cannot be ruled out. XPS analysis is in progress.**
- **But the bulk properties remains unaffected**
  - **T_c is unchanged**
  - **Number of pinning sites (evident from magnetization loop) are almost same. The effect is different from high temperature N-doping.**
  - **Sample study shows higher flux trapping efficiency, similar to conventional nitrogen doping. The flux expulsion/trapping in N-infused cavities are work in progress.**