

High Q via N infusion R&D at Jefferson Lab

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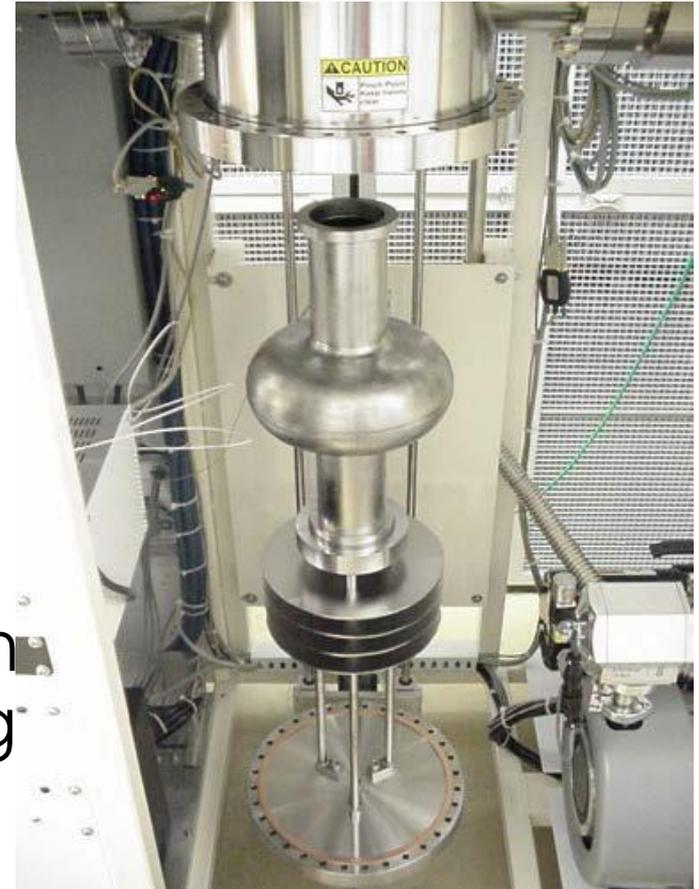


BACKGROUND

- Work started to understand the role of high field Q-slope with hydrogen (niobium hydrides) and **passivation of Nb surface during heat treatment.**
- 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 **heat treatment at 800C and followed by 120C with no post furnace chemical etching.**
- **Surface nitridation for surface passivation (400C, $\sim 10^{-5}$ mtorr N_2)** was attempted and improvement on both Q and E_{acc} was observed.

BACKGROUND

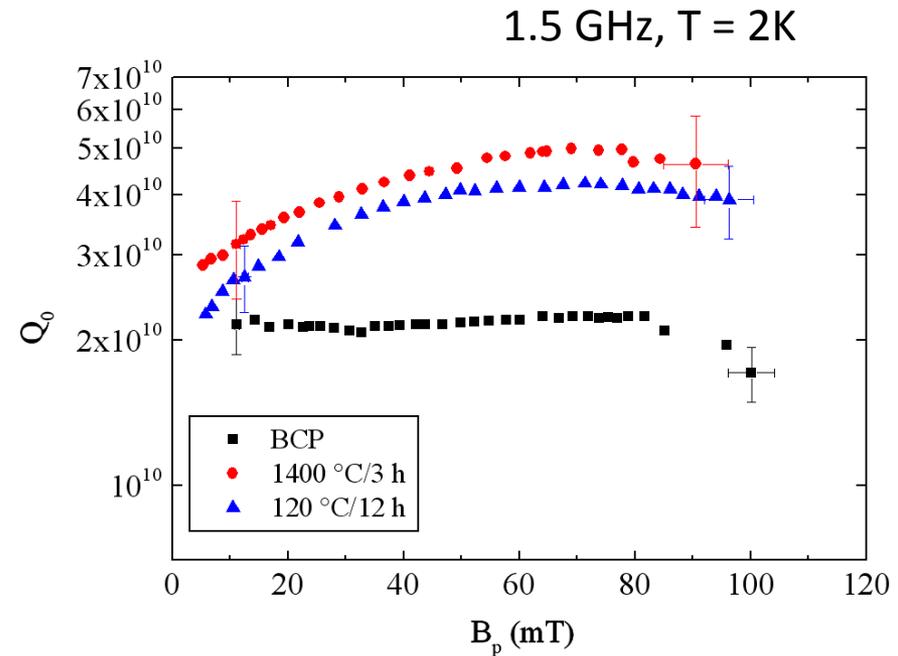
- New dedicated clean induction furnace was designed and installed in order to explore the surface passivation parameters.
- The furnace is capable to going higher than 2000C in UHV environment.
- The furnace is equipped with gas (N₂, O₂, Ar, H₂) handling system.



Cavity loading in the furnace

BACKGROUND

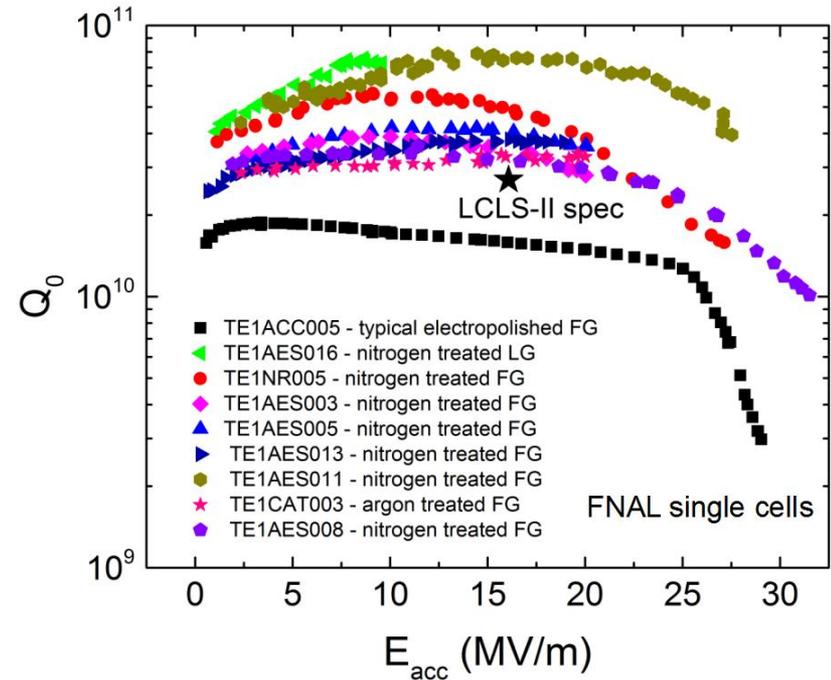
- Exceptionally high Q was observed on 1.5 GHz cavity when cavity was heat treated at 1400C/3hrs.
- Investigation found that ~ 1 at.% of Ti was diffused with in $\sim 2 \mu\text{m}$ on RF surface resulted in the increase in Q and more importantly the positive $Q(E)$ dependence.
- The cavity was made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



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

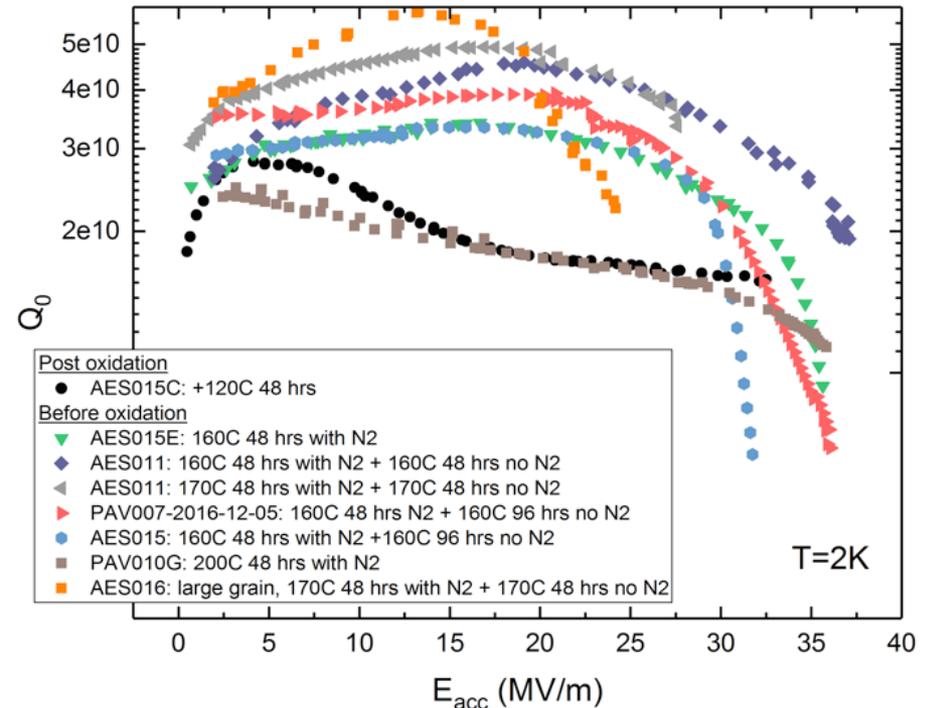
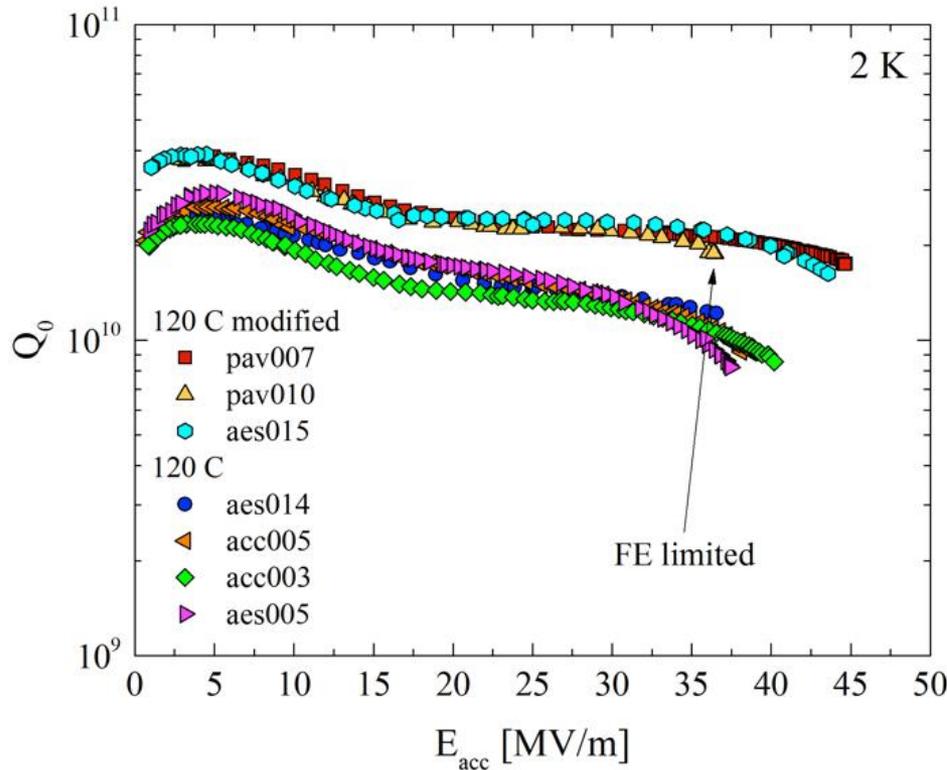
BACKGROUND

- 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.



Recipe for LCLS-II

LOW TEMPERATURE N-INFUSION



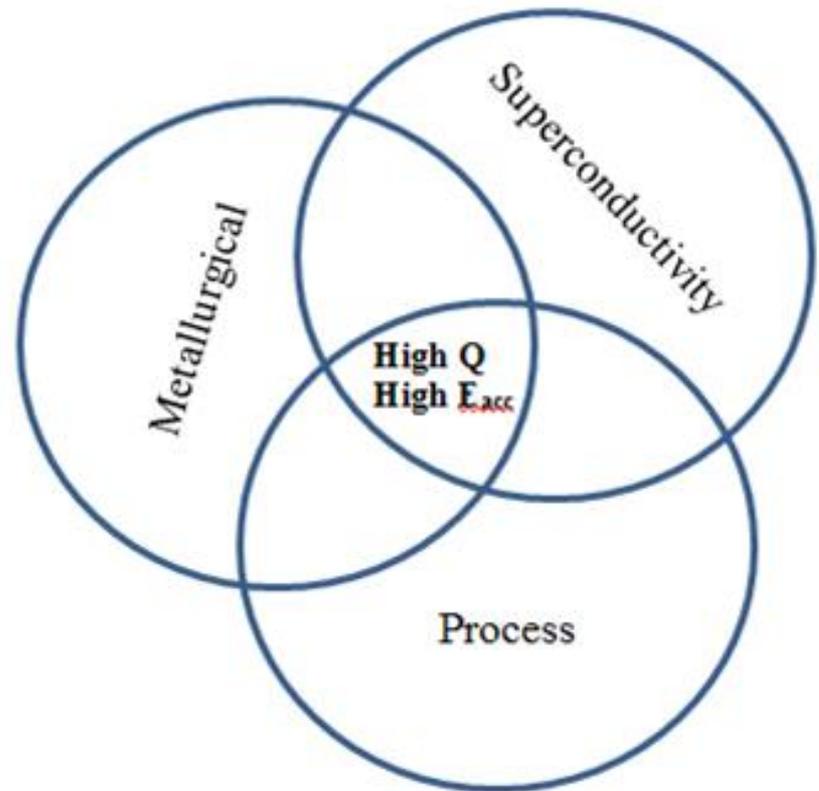
- FNAL reported both increase in Q and E_{acc} when N₂ was infused to furnace during the heat treatment at lower temperature (120C).
- Q-rise phenomenon was observed on cavities when the nitrogen was infused at higher temperature (140-170 C)

Grassellino et al, arXiv:1701.06077

R&D work at JLAB on High Q

- 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).
- Low temperature N₂ infusion for high Q, high E_{acc} cavities towards ILC.

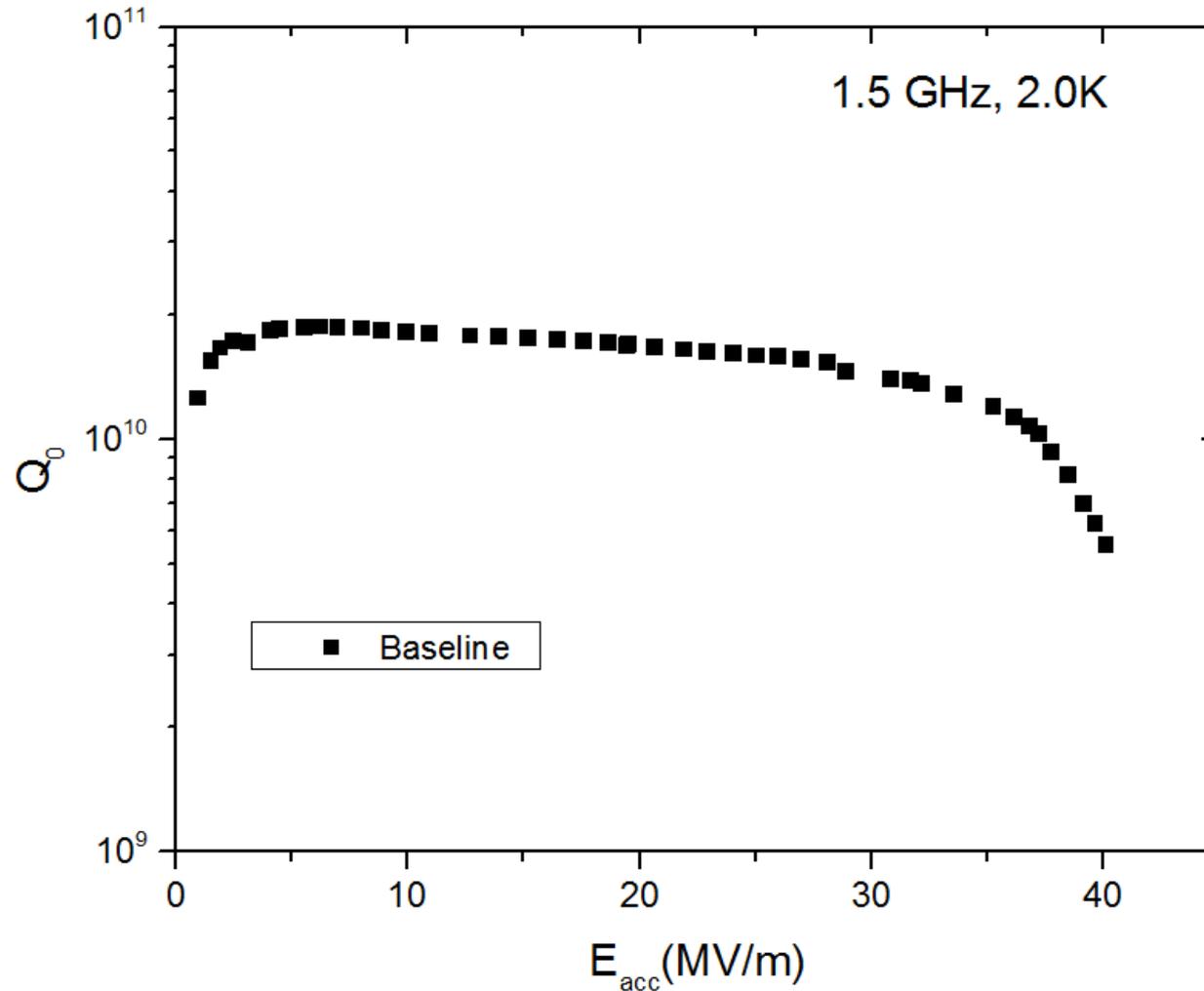
Our approach to achieve high Q, high E_{acc} cavities (**MPS** approach)



N-INFUSION UPDATE

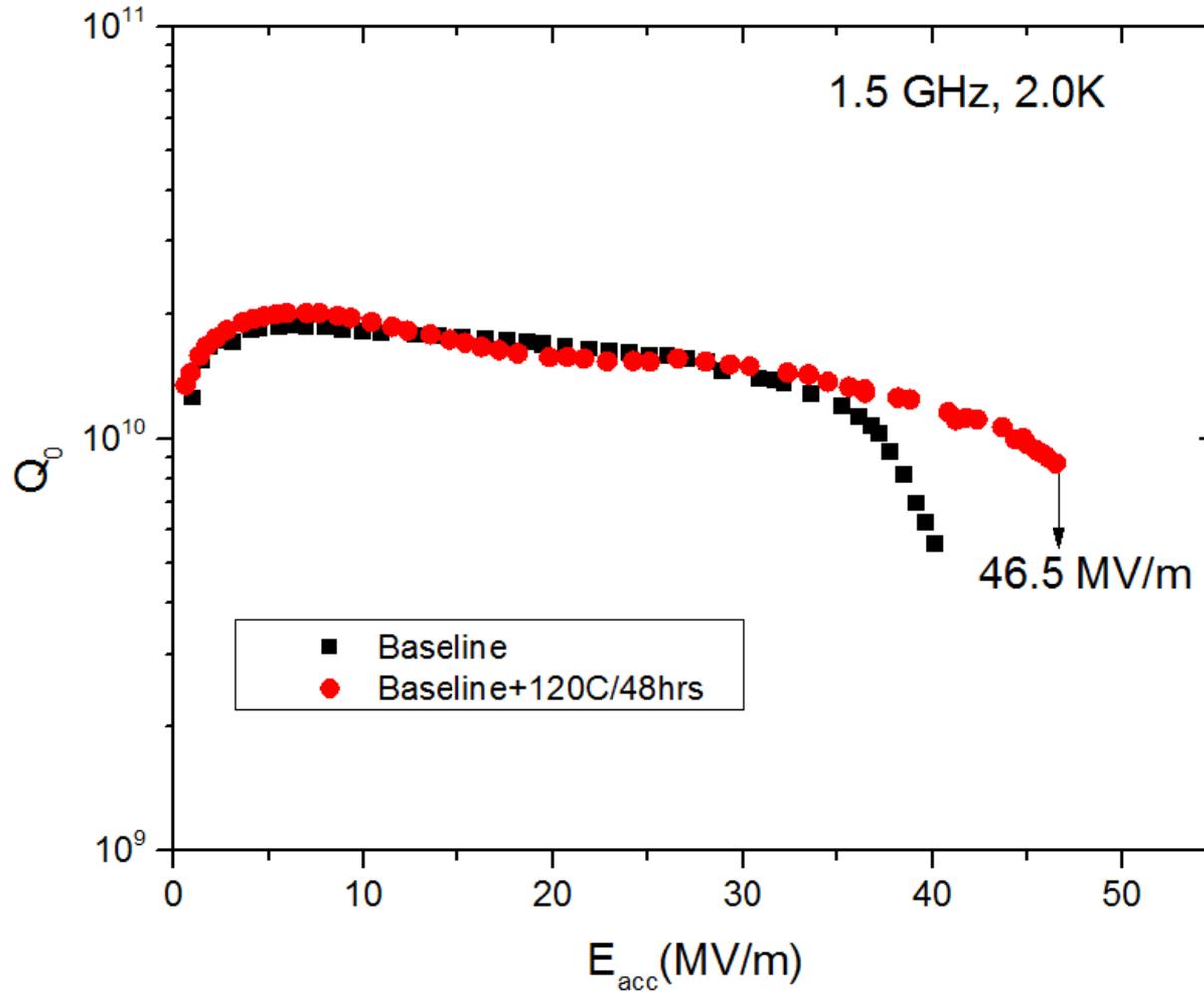
- High purity fine grain Nb Cavity RDL-02: After the fabrication, the cavity was given **standard ILC recipe** of 150 μm EP, 800 $^{\circ}\text{C}$ /2hrs furnace treatment, followed by 20 μm EP.
- Cavity was HPR before loading to the furnace and Nb caps were assembled in clean room.
- After each heat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

RECENT WORK AT JLAB



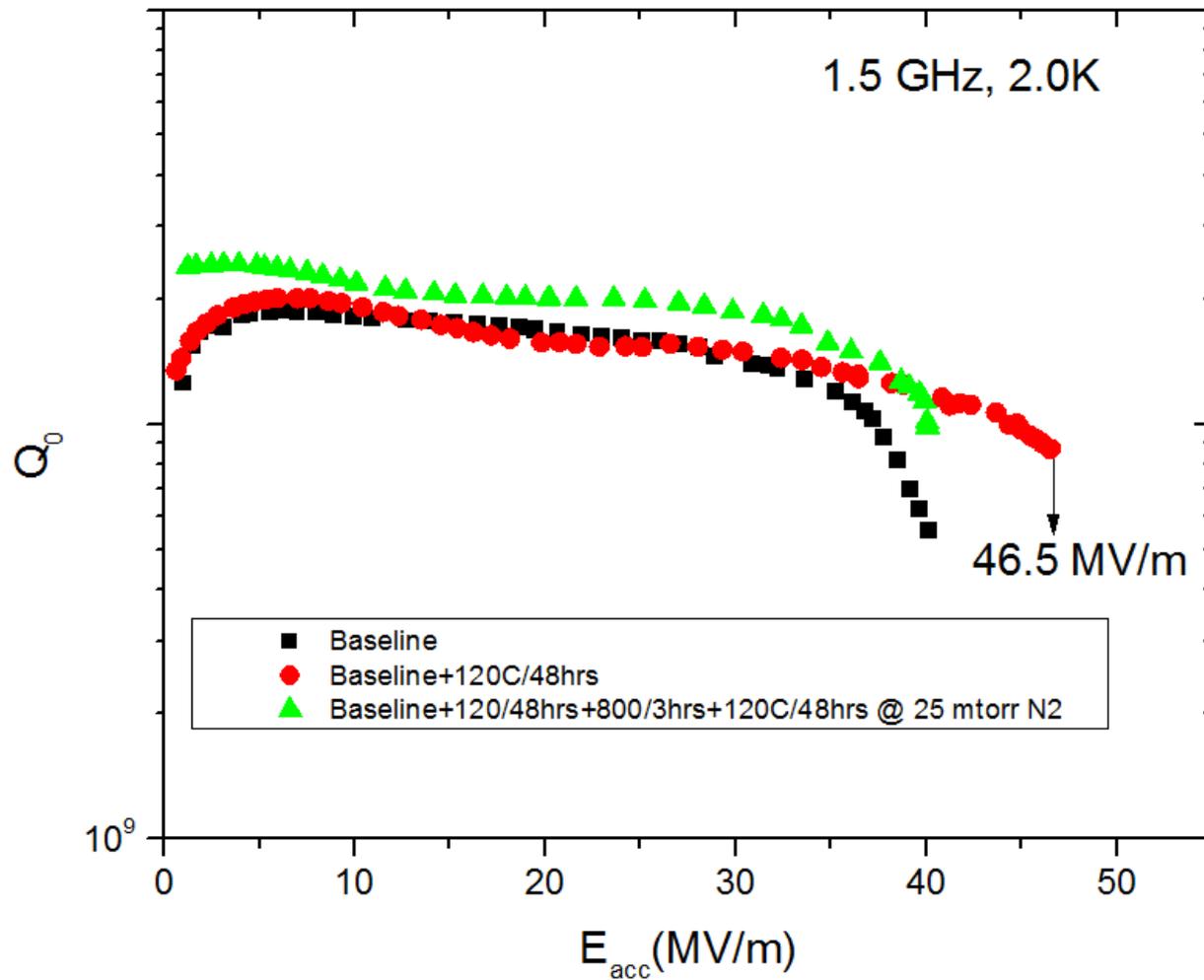
Standard ILC EP recipe

RECENT WORK AT JLAB

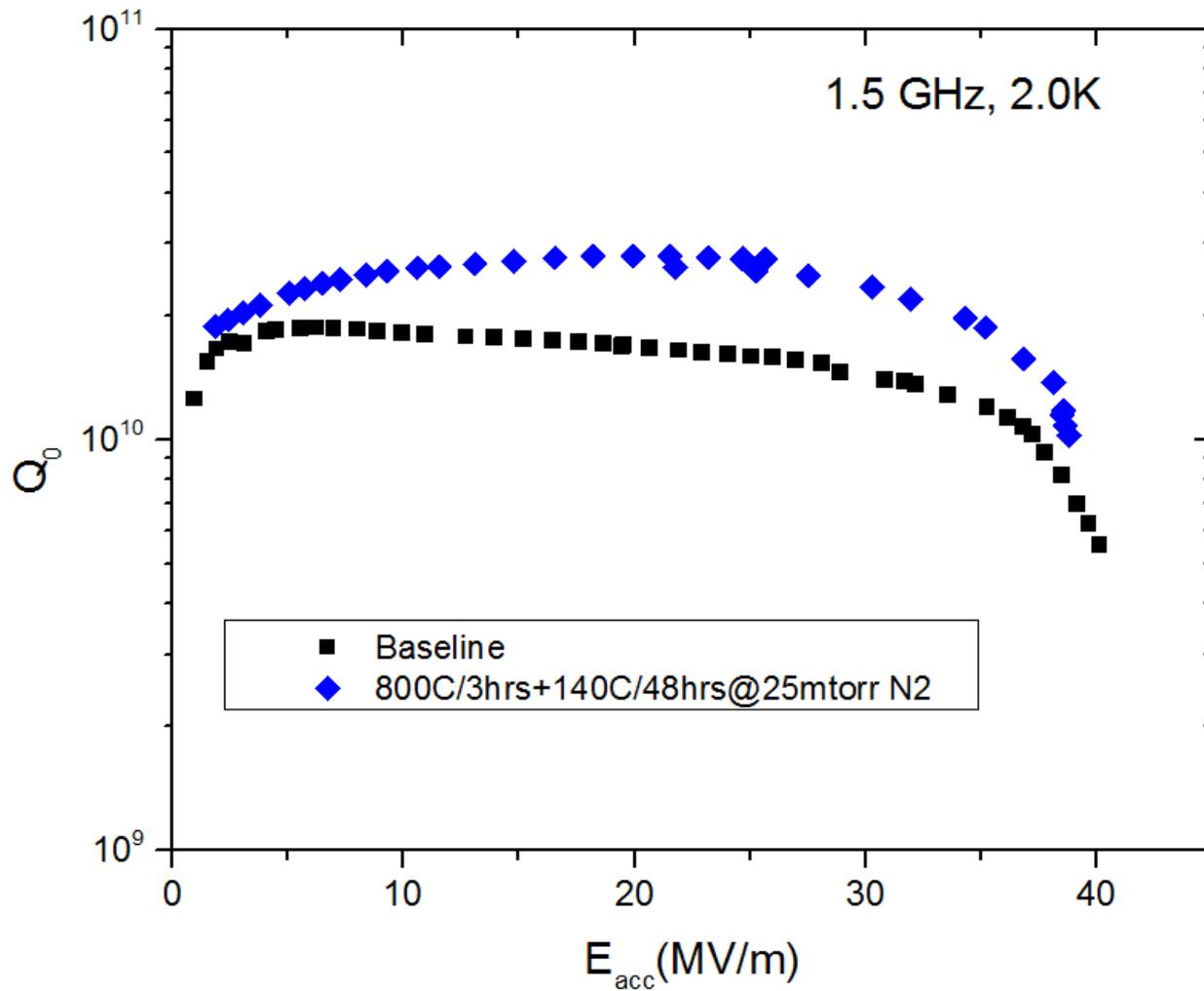


Standard ILC EP recipe with Bake

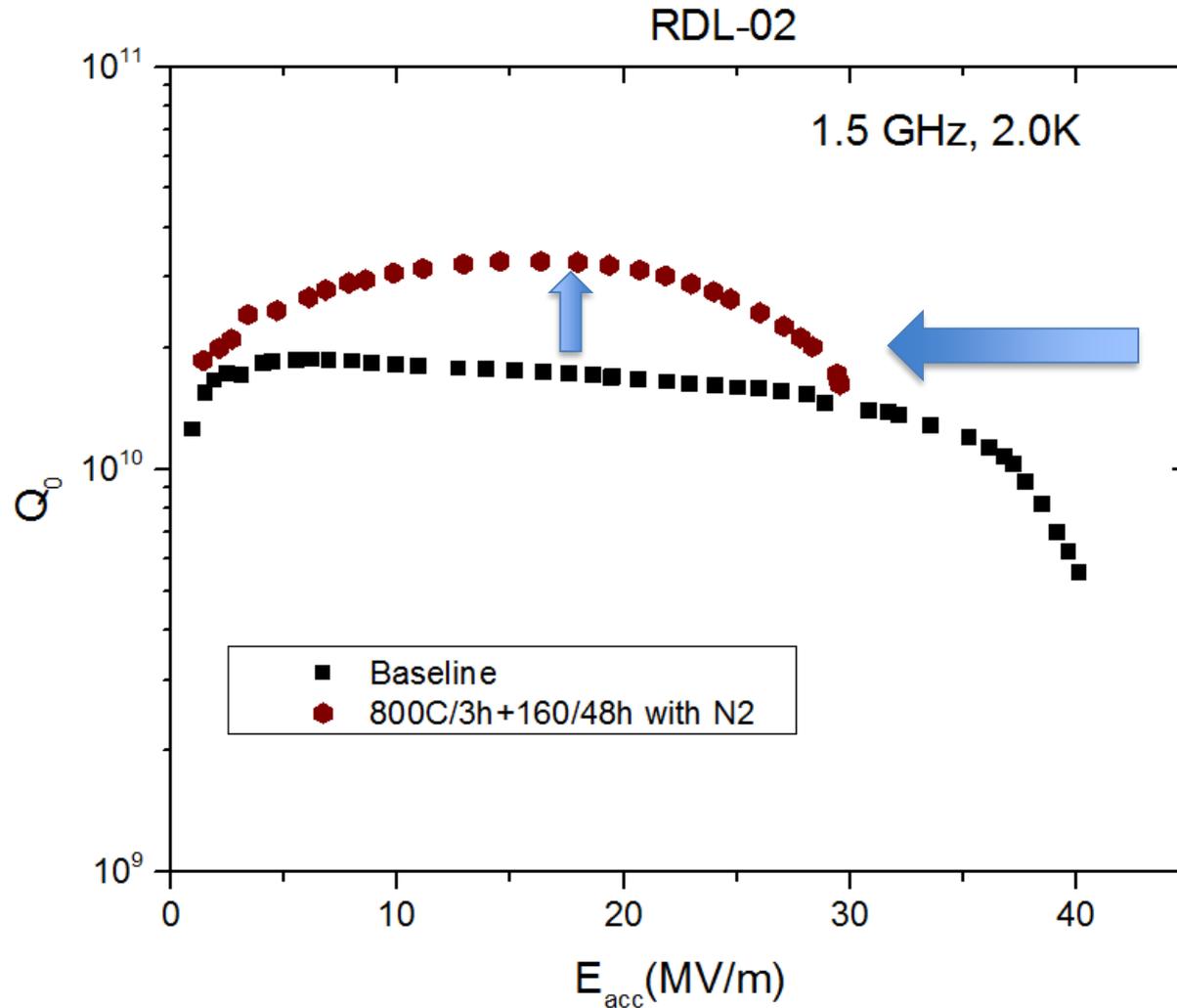
RECENT WORK AT JLAB



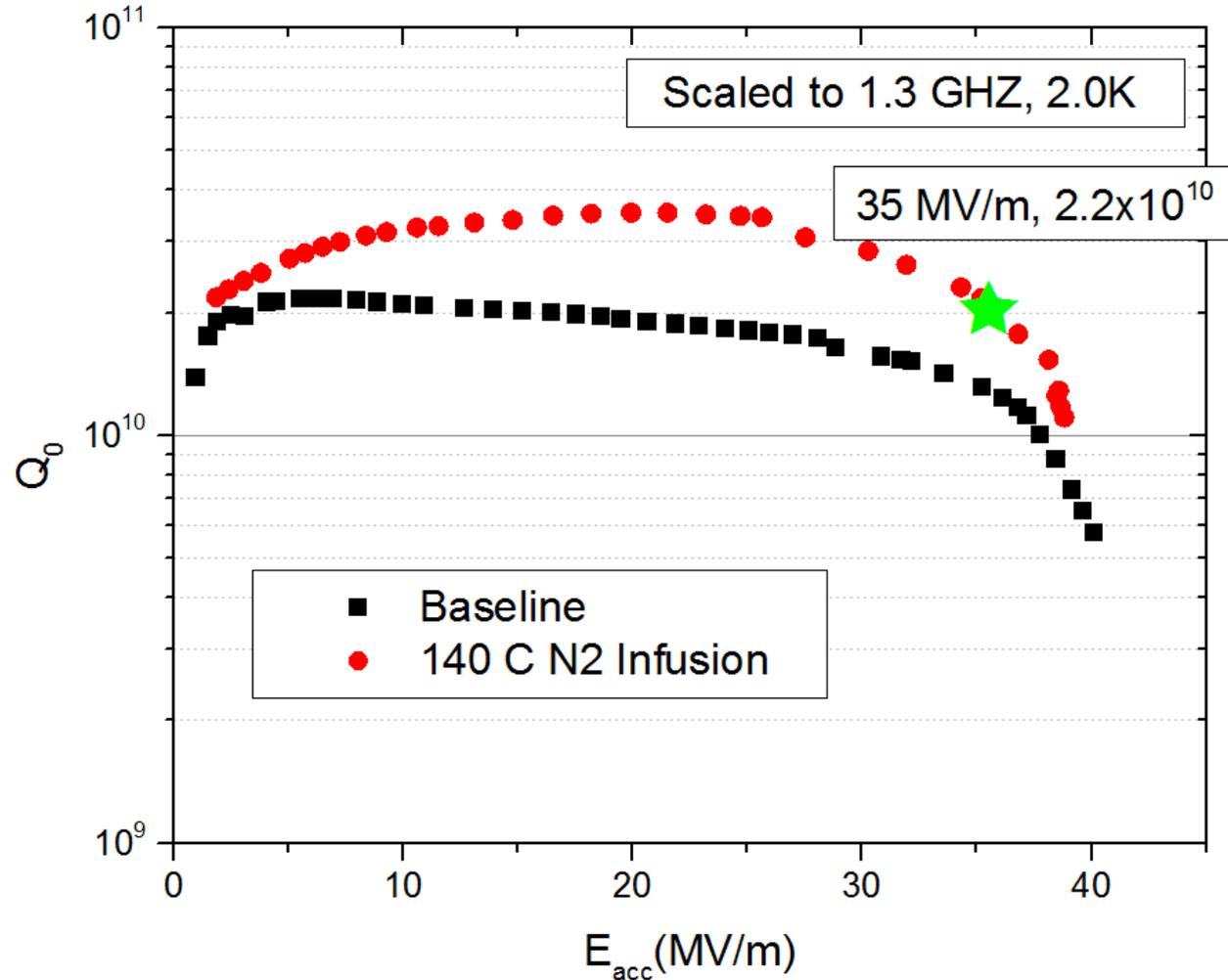
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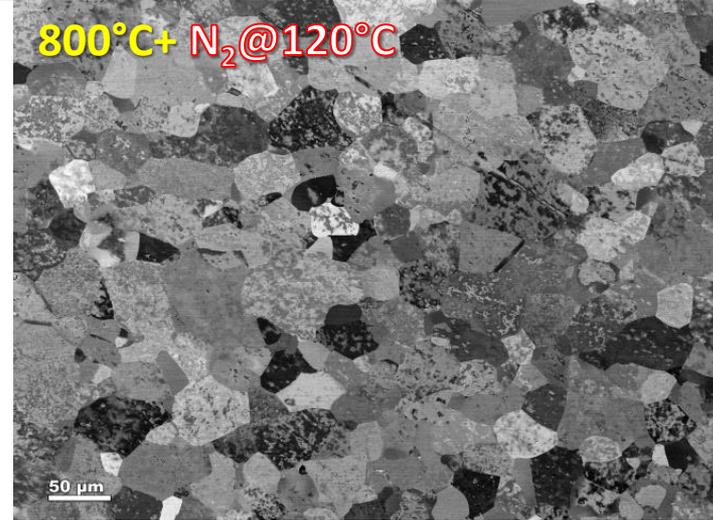
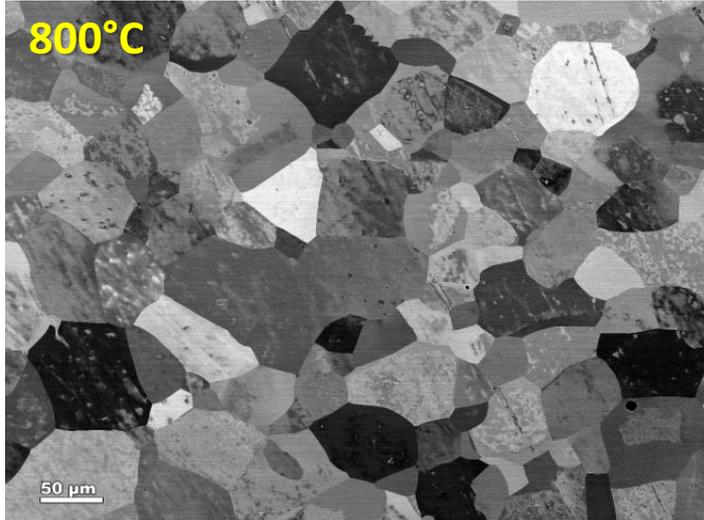


RECENT WORK AT JLAB

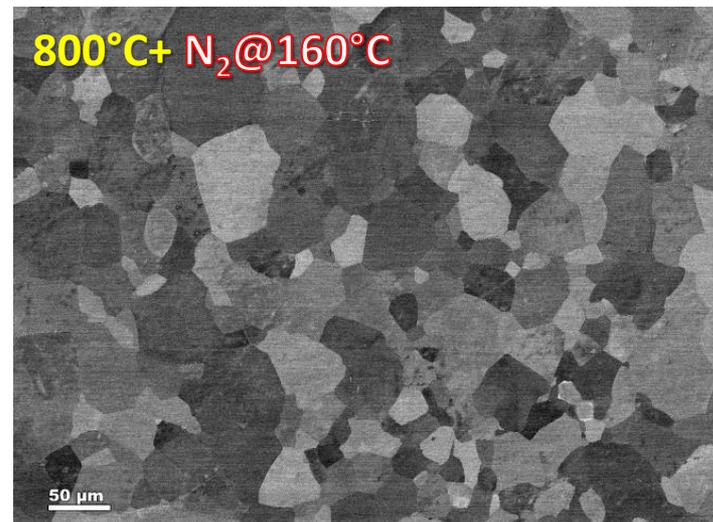
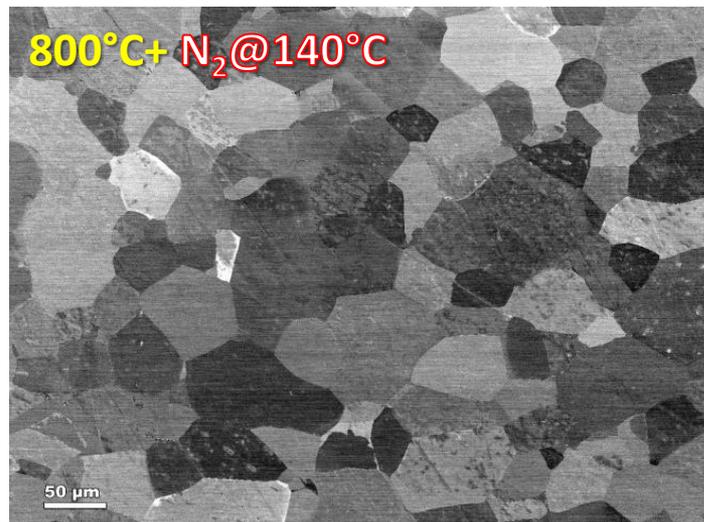


Work in Large grain cavities as well as process control are in progress.

SAMPLE COUPONS STUDY



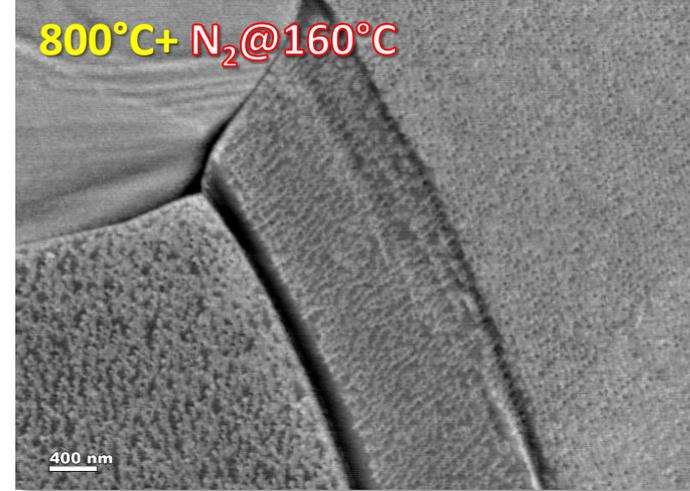
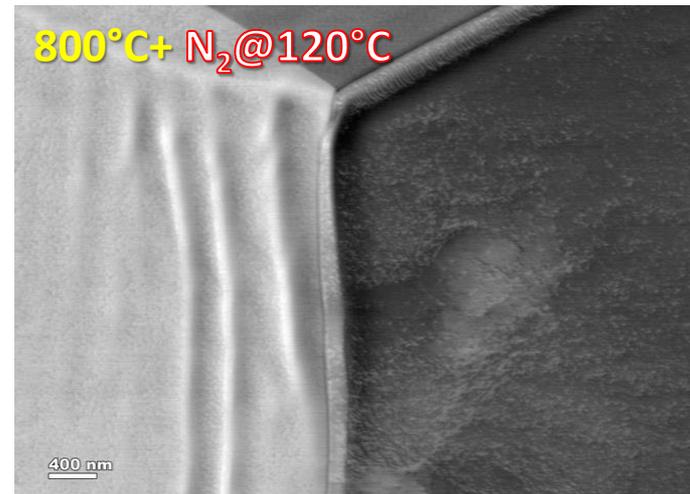
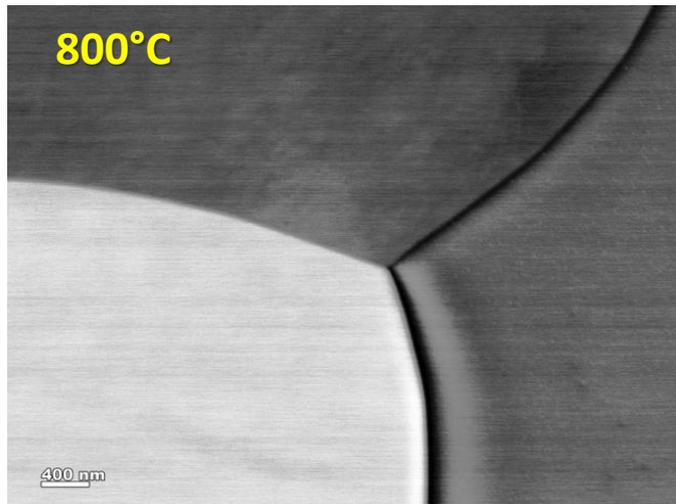
FSU/ASC



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

SAMPLE COUPONS STUDY

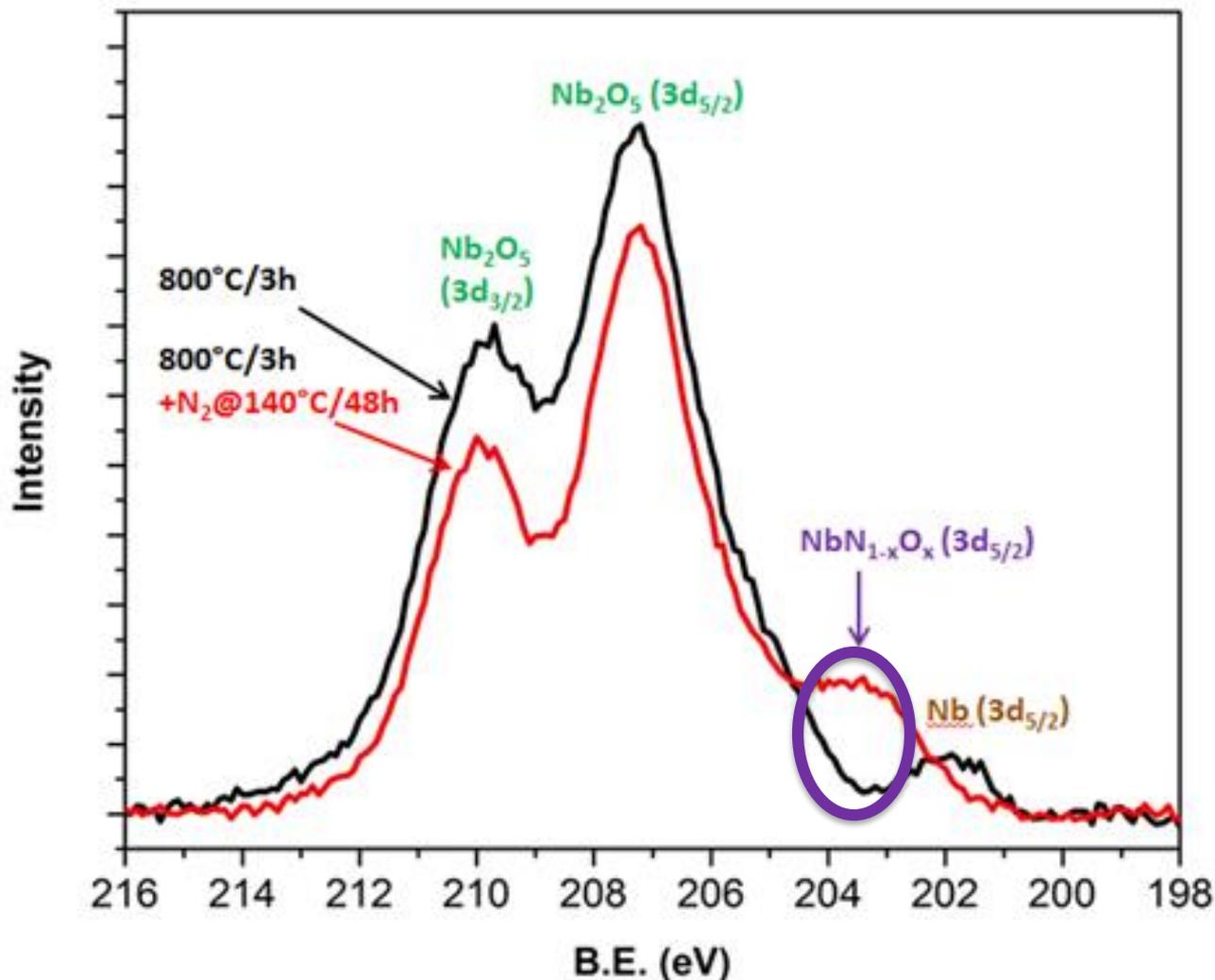
FSU/ASC



Granular surface morphology on low temperature N doped samples

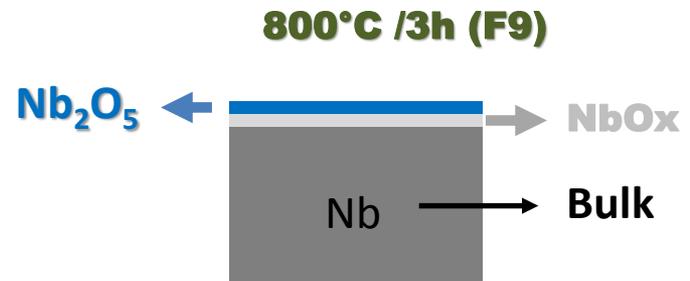
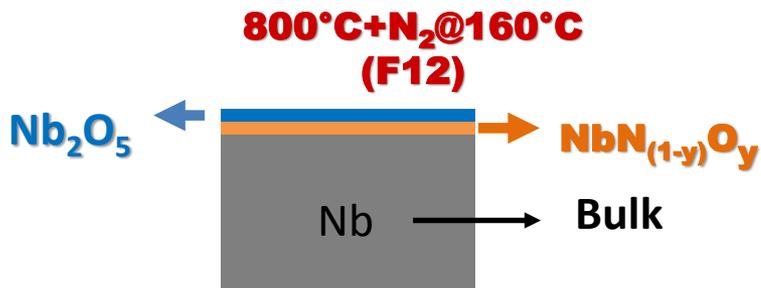
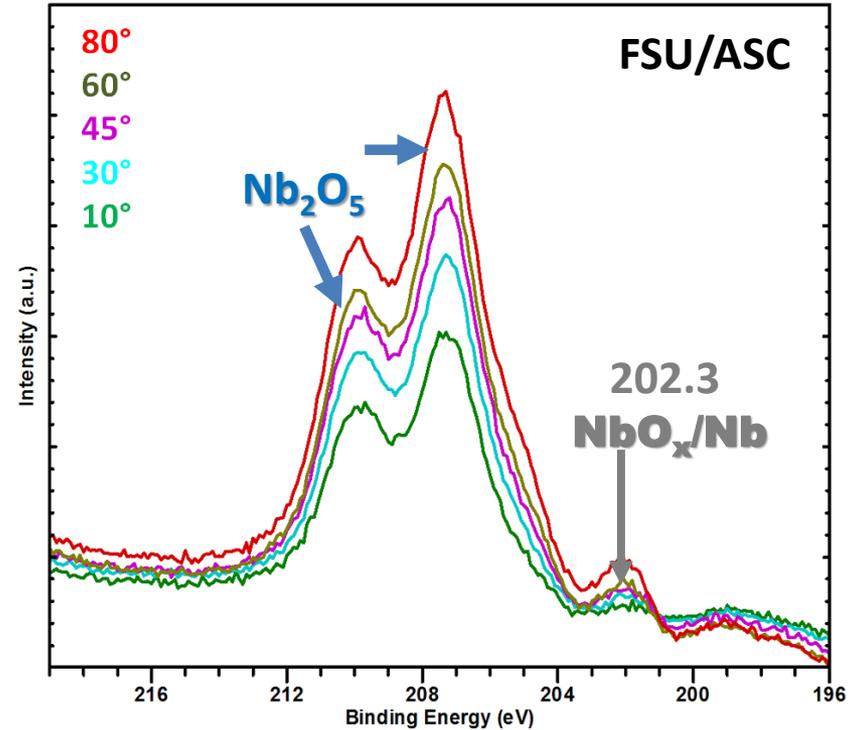
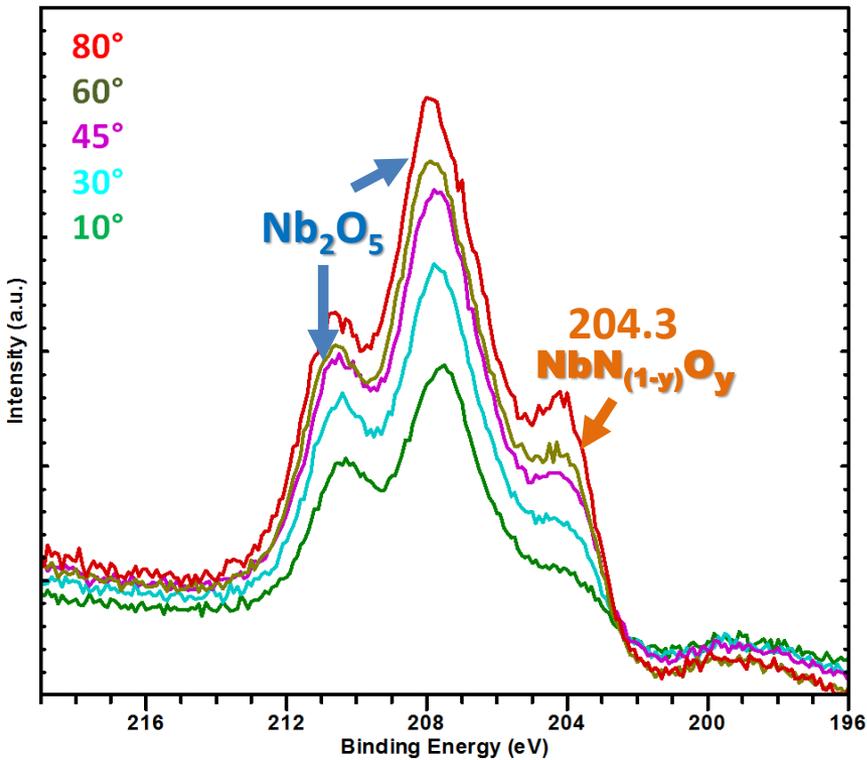
SAMPLE COUPONS STUDY (XPS)

FSU/ASC



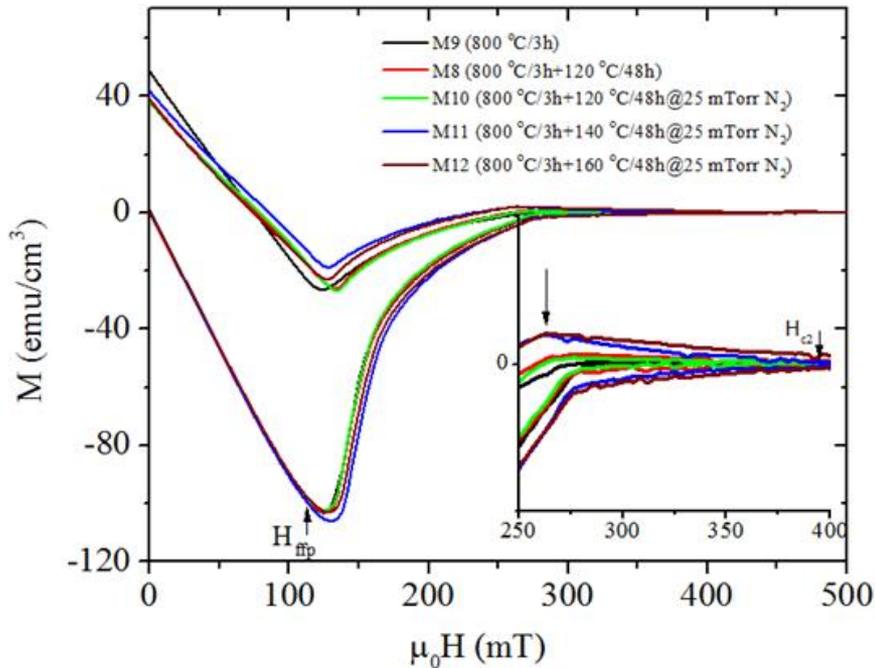
Preliminary XPS Result: Presence of a NbNO peak in low temperature N doped sample

SAMPLE COUPONS STUDY

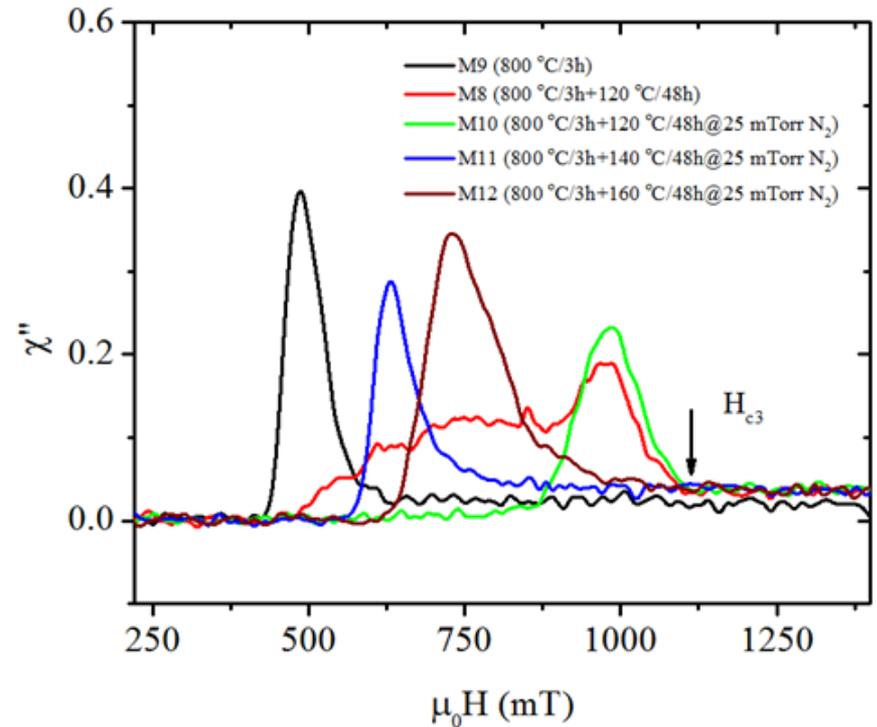


Nb_2O_5 , and $\text{NbN}_{(1-y)}\text{O}_y$ exists within first 10nm in low temperature N infused sample

SAMPLE COUPONS STUDY (MAGNETIC)



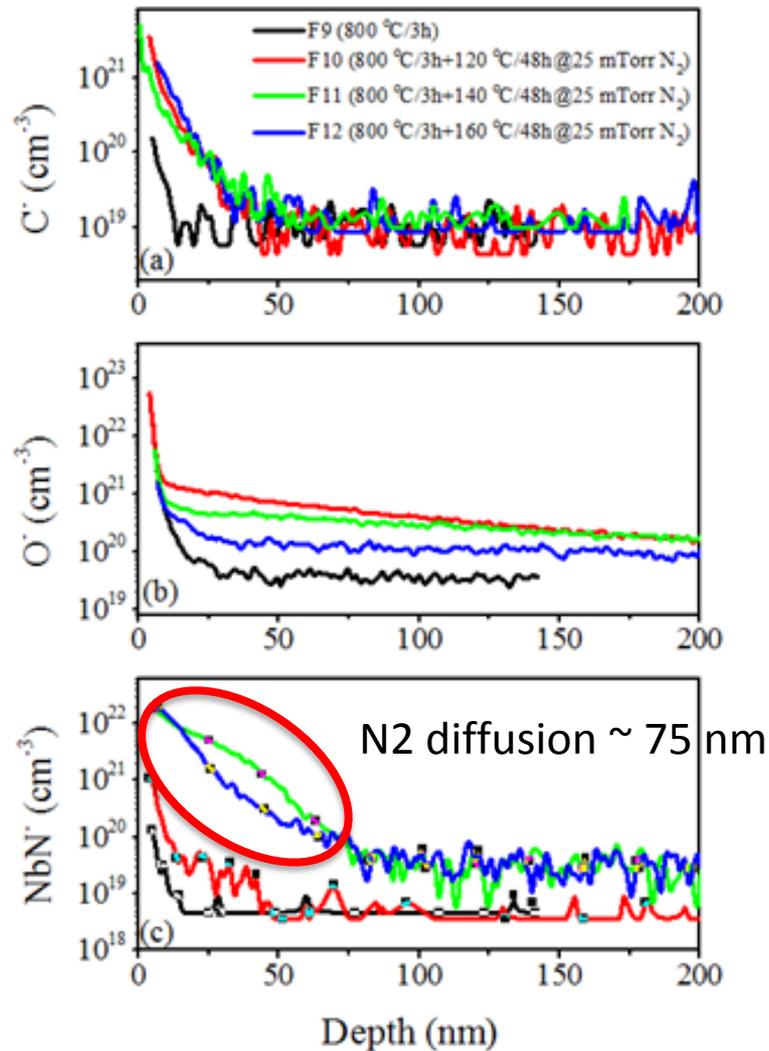
Isothermal DC magnetic hysteresis of samples measured at 4.2 K.



Imaginary part (χ'') dc magnetic field-variation-mode AC susceptibility with different surface treatments measured at 4.3 K.

SAMPLE COUPONS STUDY (SIMS)

SIMS depth profile of
(a) carbon, (b) oxygen
and (c) nitrogen
measured in samples



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 confirm from RF data
 - Different baking temperature in N_2 atmosphere leads to different surface condition.
 - XPS results showed nitrogen infused sample with $NbN_{(1-y)}O_y$ 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. H_{c2} enhancement was observed with heat treatment temperature is higher.
 - Sample study shows higher flux trapping efficiency, similar to conventional nitrogen doping. The flux expulsion/trapping in N-infused cavities are work in progress.