Heat treatment and passivation of SRF Nb cavities

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Objective

❖ Standard fabrication and chemical treatment procedures for SRF Nb cavities result in high concentration of interstitial impurities at the metal/oxide interface and lattice defects

Contribute to enhanced RF losses by:

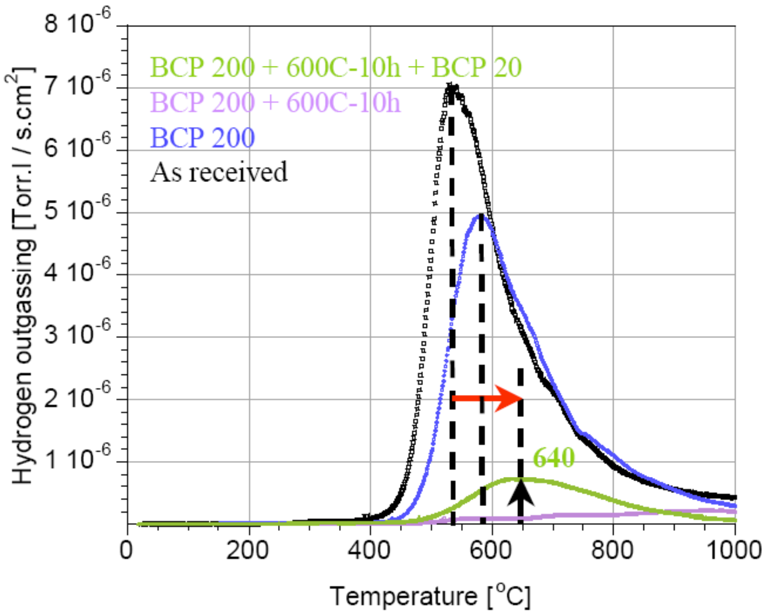
- vortex pinning
- vortex penetration at reduced surface barrier

❖ We'd like to develop a "simple" process to obtain a "better" RF surface based on:

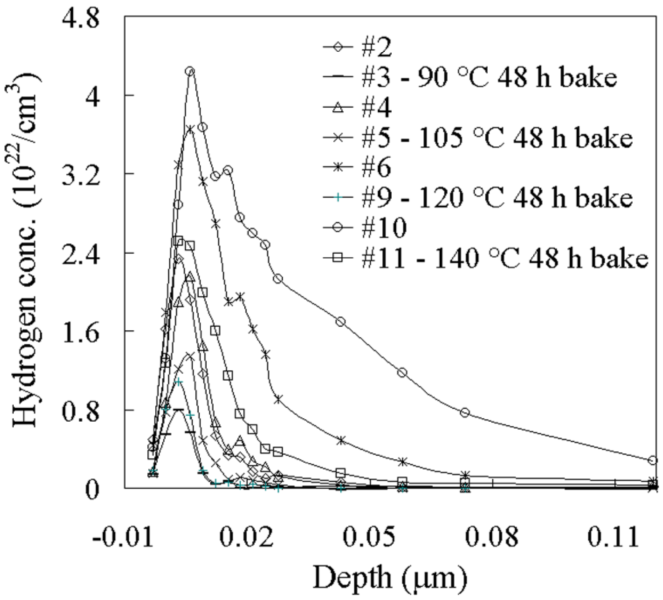
- High-temperature UHV heat treatment
- Surface passivation with thin nitride layer

Few words about Hydrogen

- Bulk hydrogen vs. surface hydrogen:



P. Chiggiato, G. Chuste, I. Wervers, A.-M. Valente, JLab Technical Note, TN-09-056 (2009).

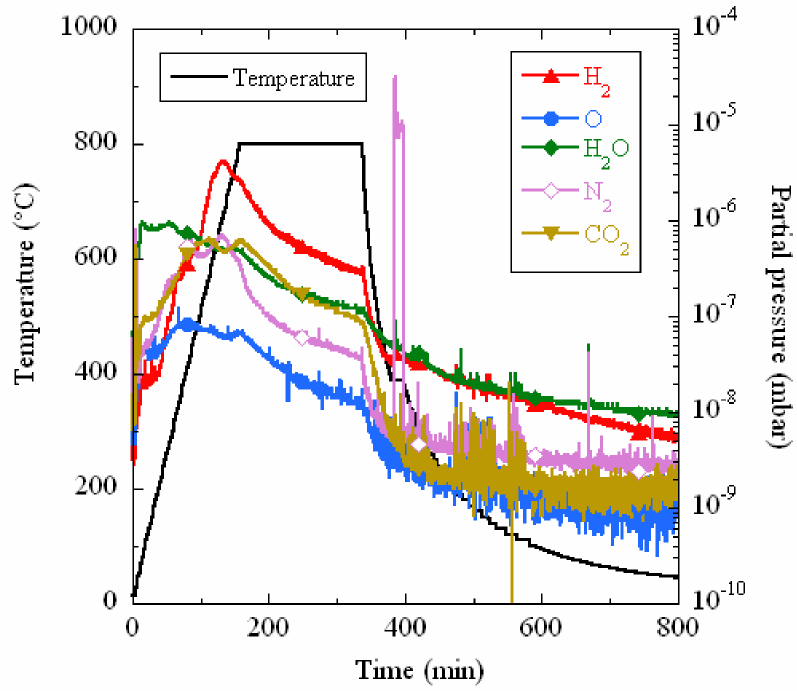


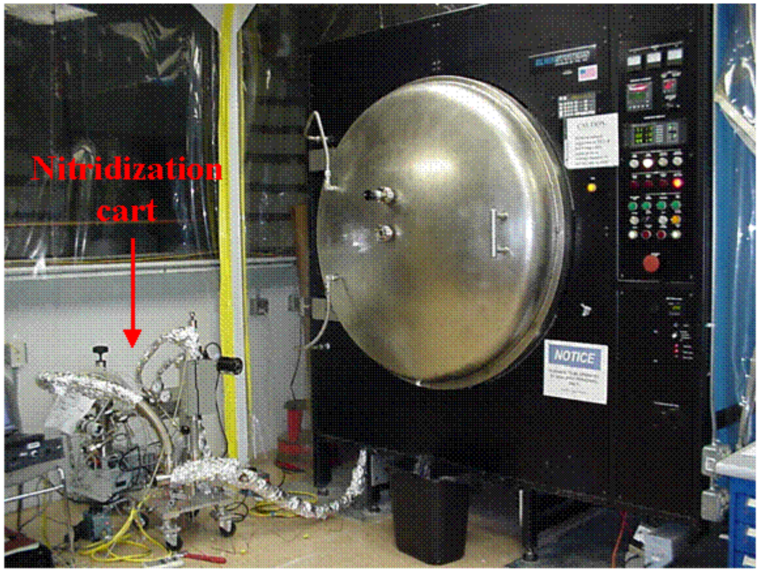
G. Ciovati, J. Appl. Phys. ***96****, 1591 (2004)*

To what extent is hydrogen involved in causing enhanced RF losses?

Heat treatment procedure

- UHV Heat treatment at 800 °C/3h
- Rapid cooling to 400 °C, admit ~ 5×10^{-6} Torr N_2 for 15 min
- Cool to 120 °C and hold for 12 h (optional)
- No chemical etching afterwards!!! Just degreasing and HPR





Cavity test results

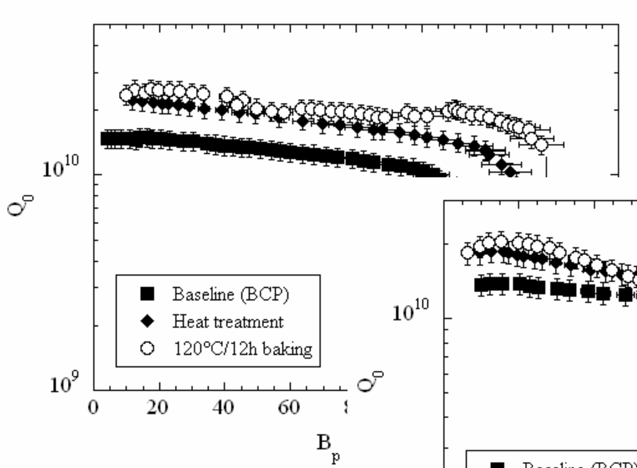
- Several single-cell cavities (1.3 GHz and 1.5 GHz) from:
  - Large-grain Nb (Ningxia and Tokyo-Denkai), BCP
  - "Rolled" single-crystal (Heraeus), BCP
  - Fine-grain (Wah Chang), EP

Summary of results:

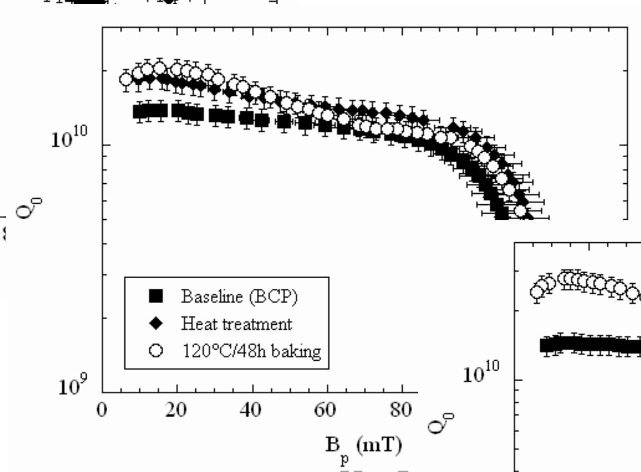
- No nitride layer was formed
- Q_0(2K, 100mT) improved, on average, by about 45% (± 25%) over the baseline test after 800°C/3h + 120°C/12h heat treatment
- All tests were limited by quench at $B_{p,avg}$ = 135 ± 24 mT*
- Q-drop at high field improved significantly only by adding 120°C step*

*Except for "rolled" single-crystal cavity, limited by Q-drop

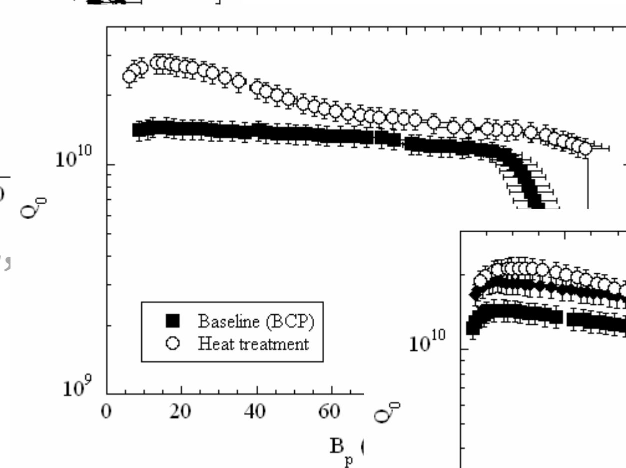
Some $Q_0(B_p)$ data plots



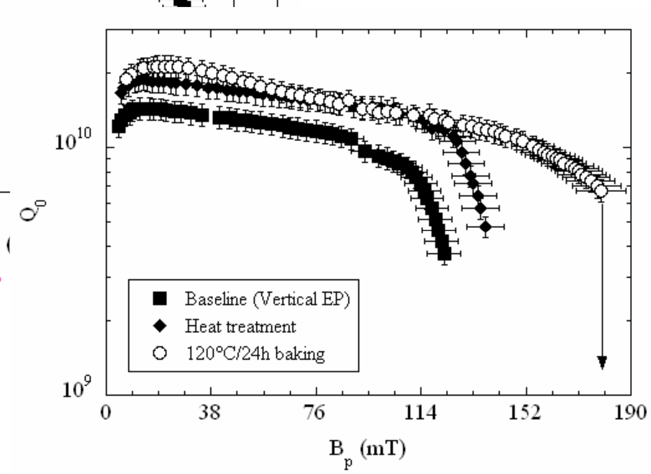
Ningxia LG



Heraeus “rolled’



Tokyo-Denkai



Wah Chang FG

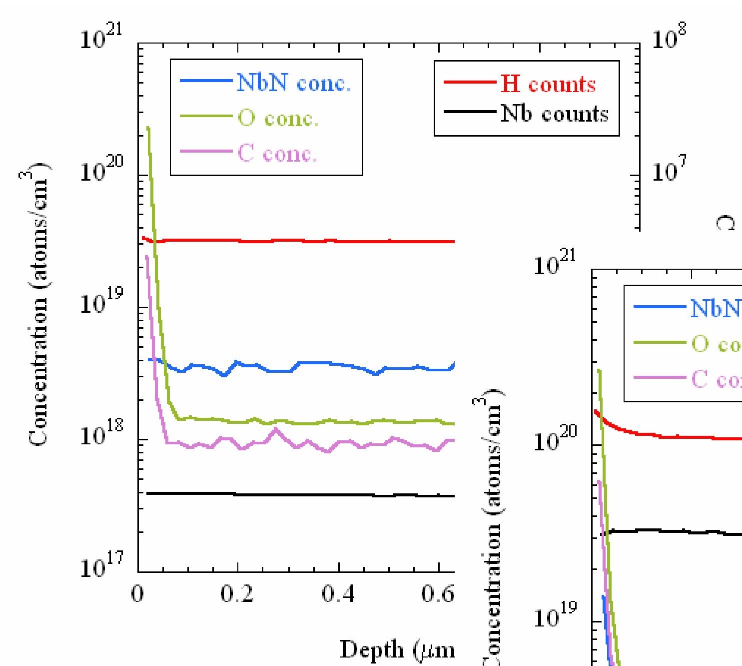
SIMS samples analysis

- Several Nb samples have been heat treated with the cavities and depth profiling of impurities (C, N, O, H) was done by SIMS

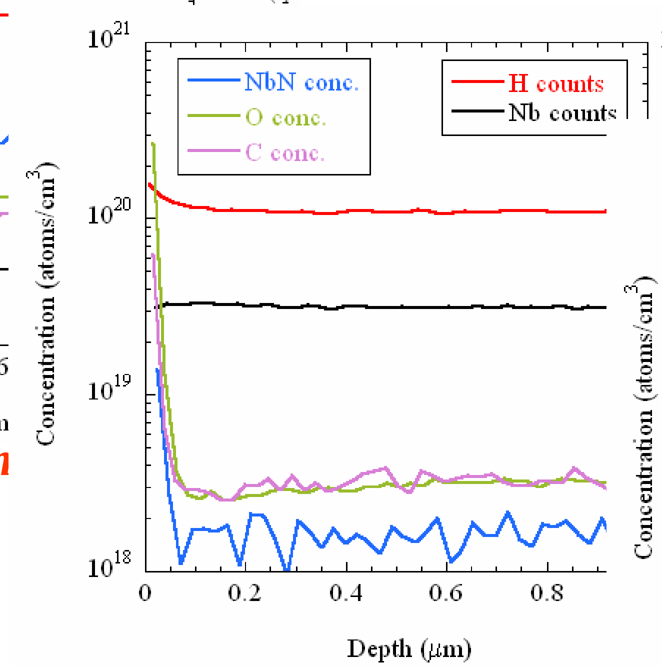
Summary of results:

- No systematic trend of the C, N, O content (< 0.1 at.%) for samples with different treatments was found
- Lowest H content was measured on a LG sample heat treated at 800°C/3h + 120°C/12h
- H content of "control" samples was lower in the sample treated by EP than treated by BCP
- For the same treatment, H content was lower in LG samples than FG samples

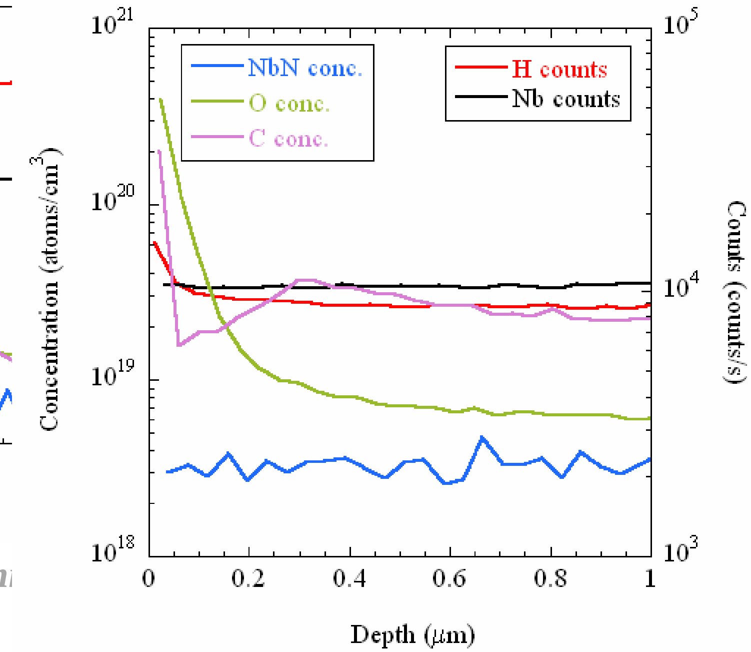
Some SIMS depth profiling data



LG "control" sam



FG, 800°C/3h + 400°C/15mi



LG, 800°C/3h + 120°C/12h

Future work

- Purchase a new UHV furnace for heat-treatment studies of single-cells:
  - Which annealing temperature is the best compromise between reducing lattice defects and H concentration while maintaining an acceptable yield strength?
  - Explore different parameters (time, T, P) and/or processes (reactive magnetron sputtering, ALD) for surface passivation with nitride layer

Conclusions

- Reproducible improvement of the performance of SRF Nb cavities was measured after heat treatment in UHV at 800°C/3h + 120°C/12h, with no chemical treatment afterwards
- SIMS analyses of Nb samples treated with the cavity show some correlation between H content and cavity performance
- Future work to optimize the heat treatment parameters and apply a passivation layer will be done with a dedicated furnace

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