Status report of the SRF Q_0 improvement program

Ganapati Rao Myneni

Accelerator Division, Jefferson Lab

&

Materials Science and Engineering and Engineering Physics, University of Virginia

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Co-PI's

Gigi Ciovati and John Wallace

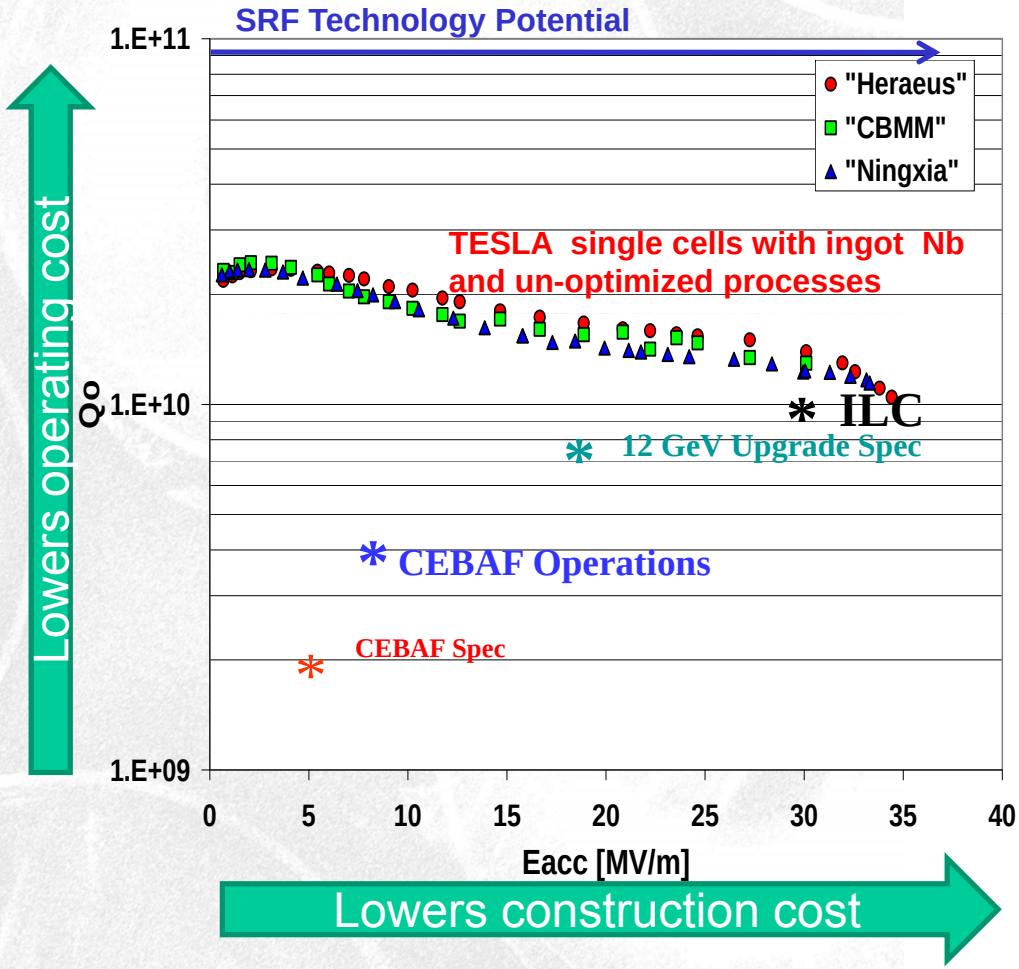
Overview

- Introduction
- Goals of the program
  - Scientific understanding (pursued with collaborators- Universities, Industry and Research Labs) of surface included hydrogen effect on Nb cavity quality factor
  - Technology development (central point of focus)
    - Surface conductivity , micro-magnetic measurement and spectroscopic tools
    - Clean UHV furnace with rf induction heating
- Current status and results
- Future plans
- Summary

Introduction

- DOE NP spearheaded building the first ever largest continuous wave superconducting radio frequency (SRF) linacs in the world at JLab
- All the future CW accelerators (`25 MV/m) require higher Q_0's – energy sustainability and ops. cost savings
- A factor of 3 improvement in the quality factor of the SRF Nb cavities can be expected to reduce the cost of cryogenic refrigerators considerably and reduce the power consumption by a factor of 3 – the primary goal of the program

Niobium cavity – performance (CW)



In nearly 40 years E_{acc} improved by a factor of 5, now DOE NP and JLab working to improve Q_0 by a factor of ~3

Goals of the Program

1. Scientific Understanding

Q_0, hydrogen & cavity performance

- Q-disease in the cavities is an example of a gross manifestation of hydrogen effect similar to gross air leak in high vacuum systems
- As we are looking to improve the cavity performance (Q) further we need to understand the effects of proton in niobium and take steps to minimize the solid-solution of protons, similar to eliminating smaller air leaks in UHV systems
- Hydrogen is difficult to measure quantitatively at the concentration levels that we have to in materials in general and greatly in niobium
- Like vacuum leak standards, we need to develop Nb-hydrogen standards

Hydrogen absorption with BCP and EP

- Very high equilibrium hydrogen activities (fugacity) have been estimated when Nb metal is in contact with water or BCP solution
- Hydrogen is readily absorbed into Nb when the protective oxide layer is removed
- Lower H fugacity's are obtained due to an anodic polarization of Nb during EP and hence lower hydrogen absorption

R.E. Ricker, G. R. Myneni, J. Res. Natl. Inst. Stand. Technol. 115, 353-371 (2010)

NIST/JLab

High temperature annealing removes gross hydrogen

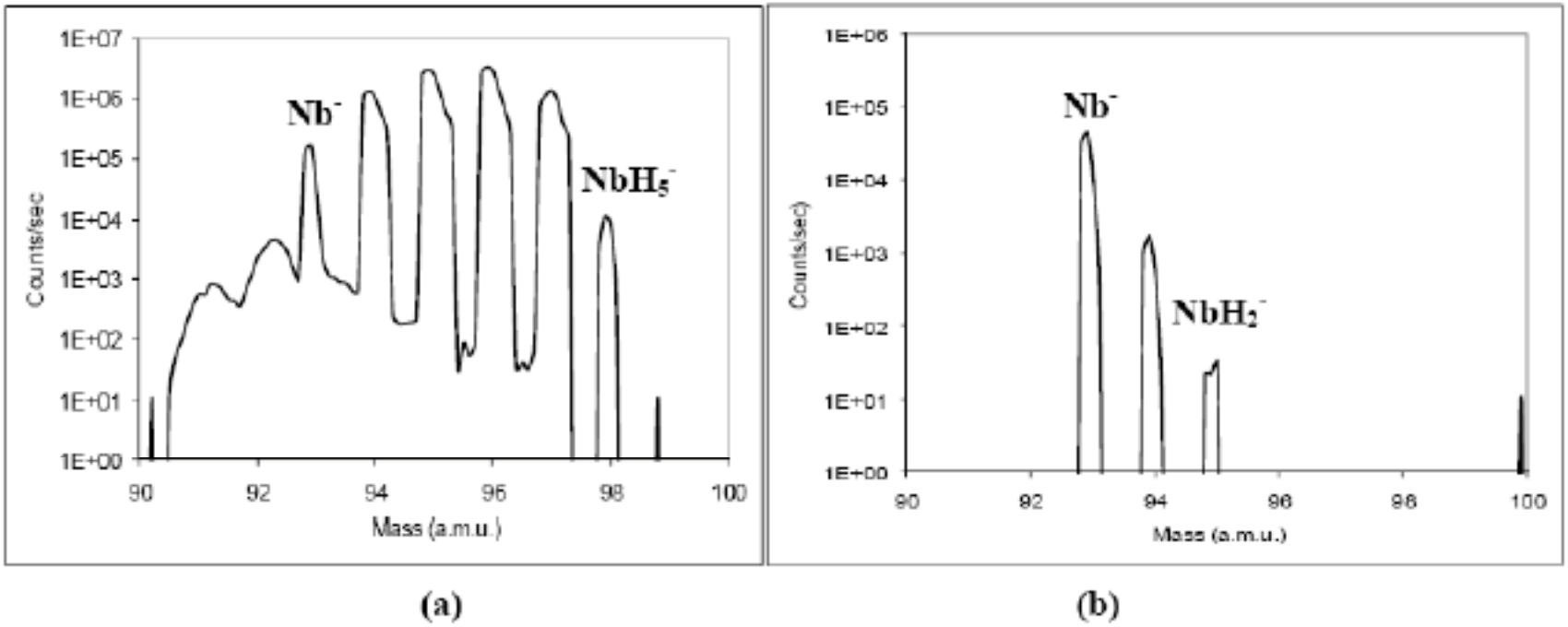


FIGURE 1. SIMS mass spectra showing difference in H between (a) non-heat treated and (b) heat treated sample.

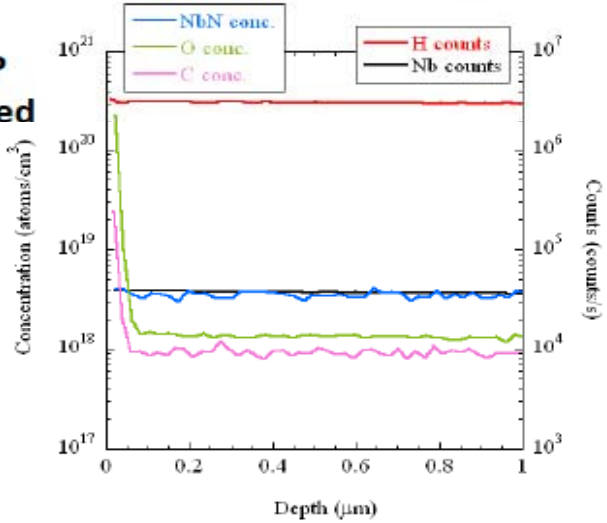
NbH (Beta Phase) very much in existence after anneals

Heat treatment to remove hydrogen

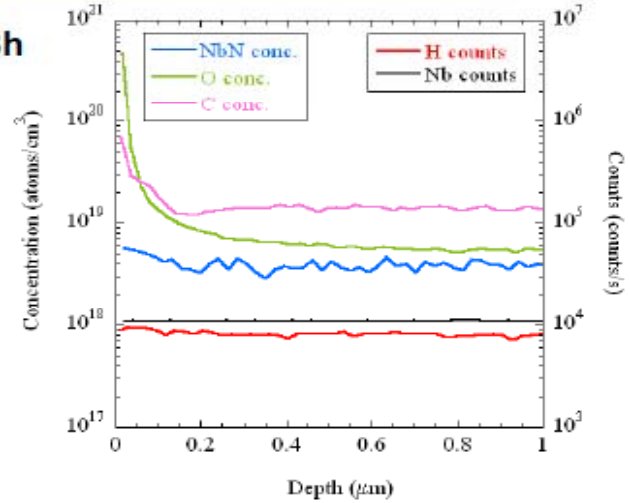
- 800°C/3h, pressure ~ 10^{-6} mbar
- **No chemical etching afterwards!**
- Nb samples were treated with the cavities and depth profiling of the impurities was done at NCSU

~ 2 orders of magnitude lower hydrogen content after HT

BCP treated

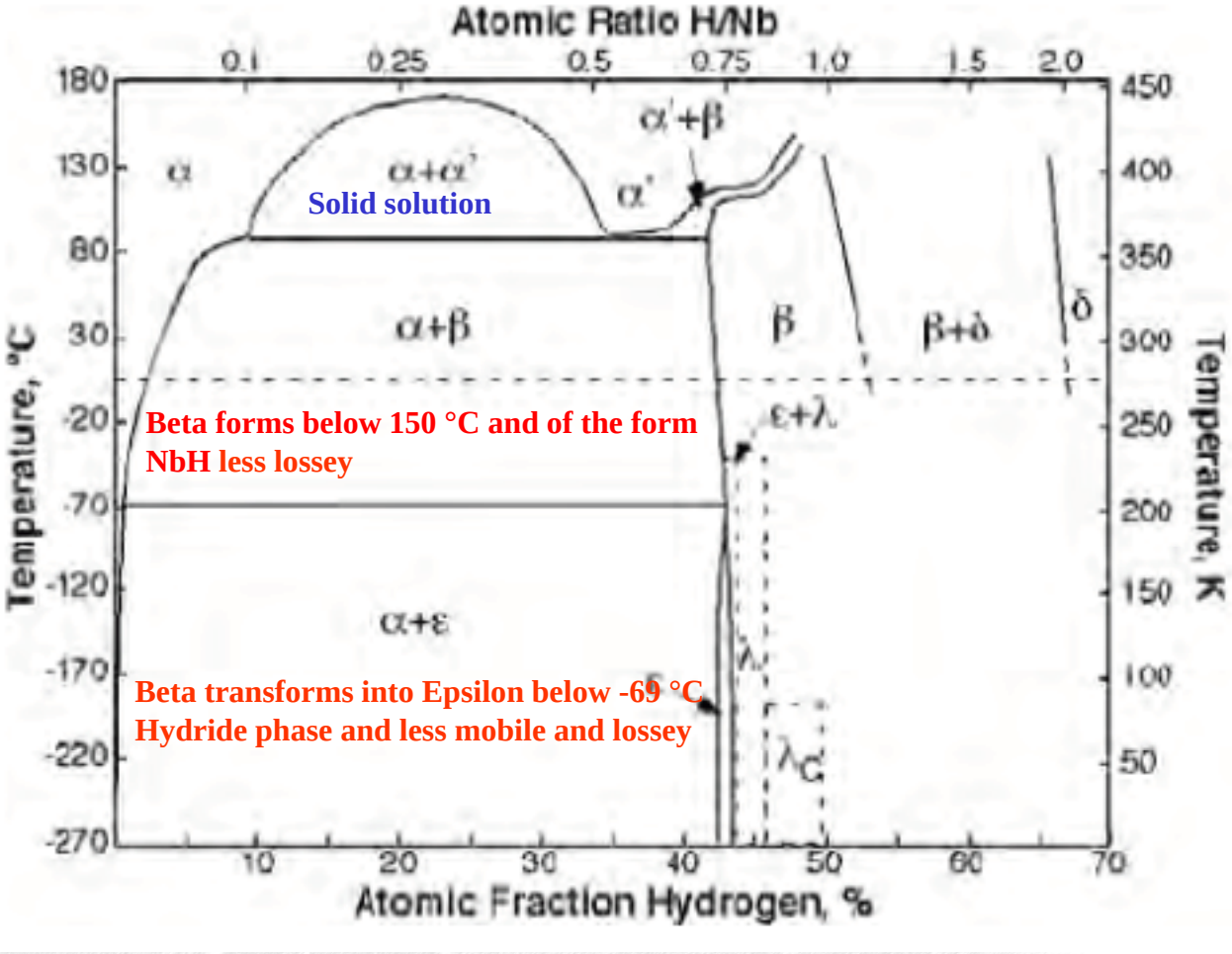


800C/3h

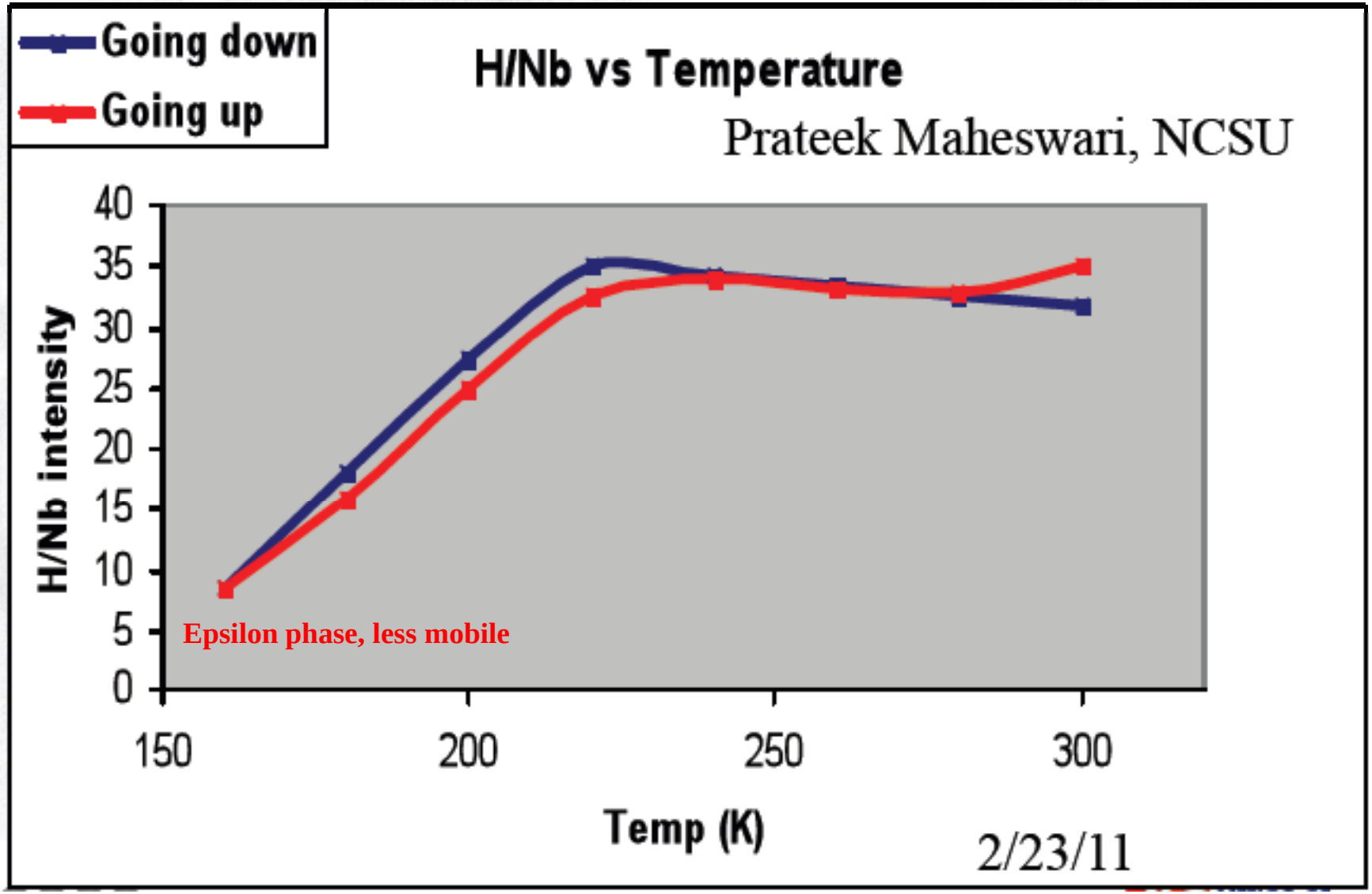


Currently used furnaces contaminate the cavity surfaces, chemical re-etching reintroduces H

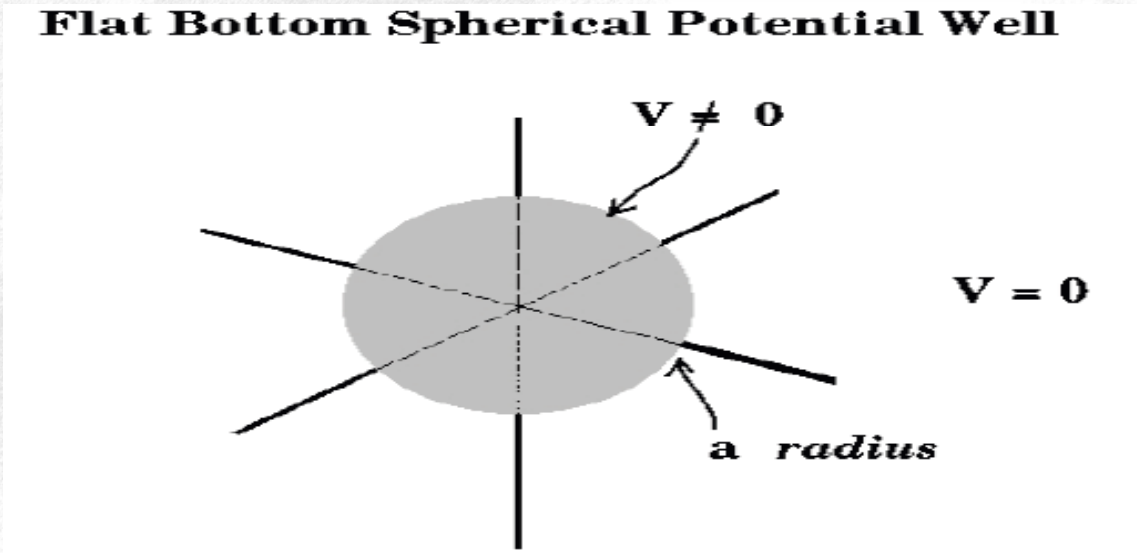
Niobium – hydrogen phase diagram



Hydrogen phase change



Atomic model of proton in niobium

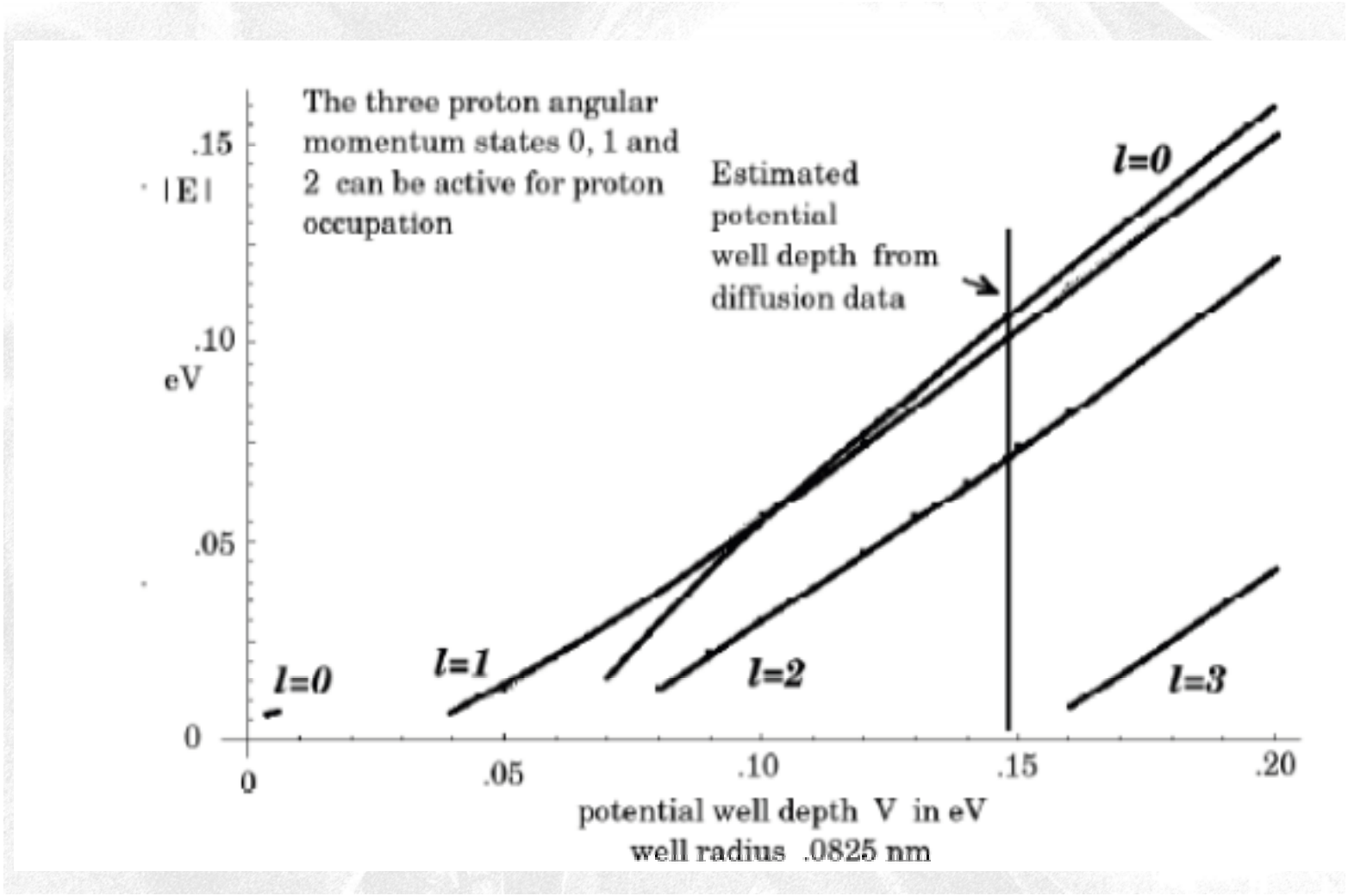


- **The proton at an interstitial site is represented by a wave function in a spherical potential well of radius a and depth V**

- **The proton's bound states will strongly interact with one another leading to more complex electronic properties**

- **Formation of a "proton band structure" within the metal will also affect mechanical and superconducting properties**

Ionization energies – potential well depth



Summary of the scientific understanding

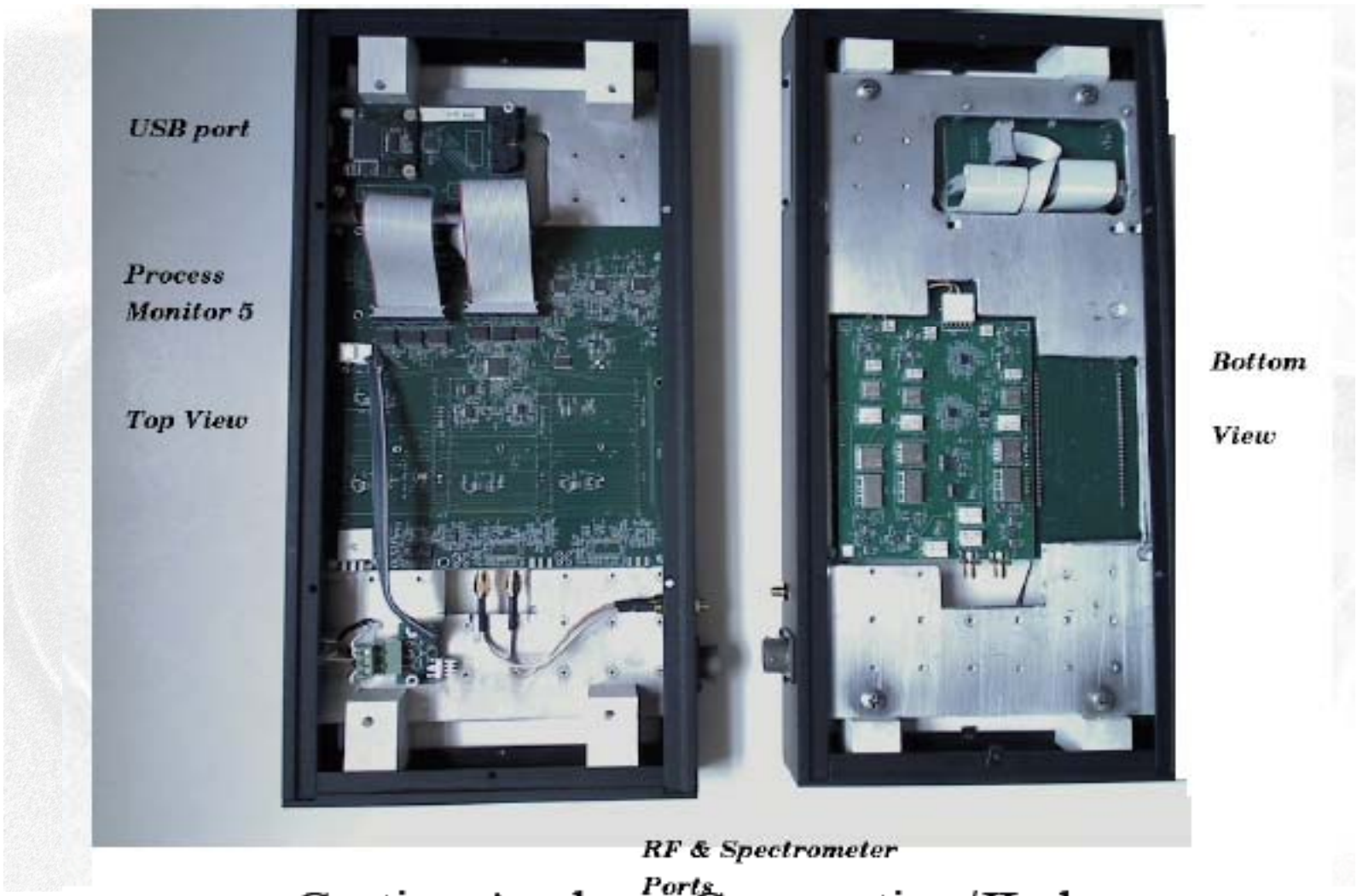
- **A new quantum mechanical model of proton has been introduced, this allowed calculation of the activation energies for diffusion of hydrogen in metals verifying the experimental data**

- **This proton model can be the basis for the further study of the effect of various concentrations of H on the superconducting and mechanical properties of Nb**

Goals of the Program

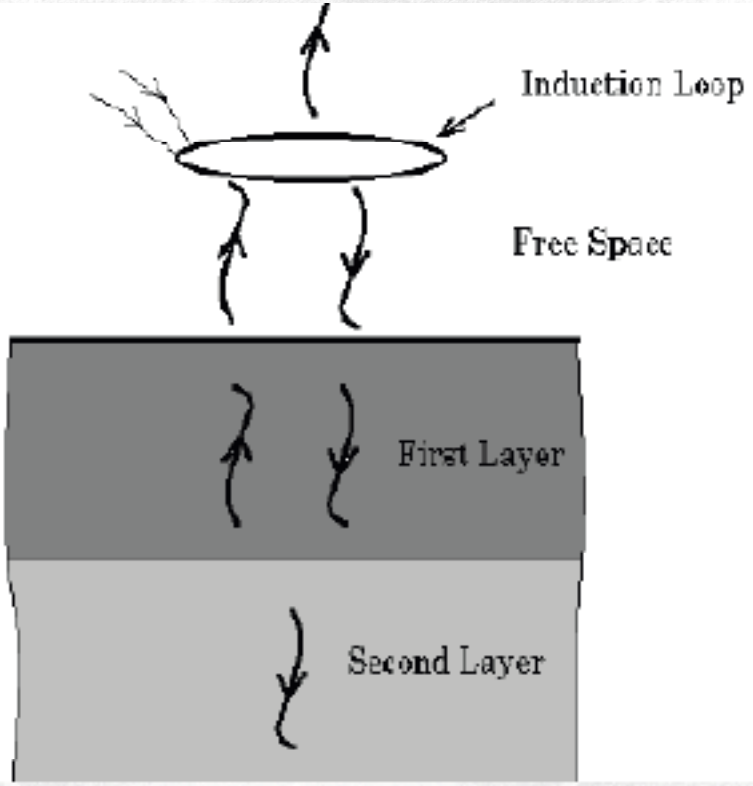
2. Technology Development

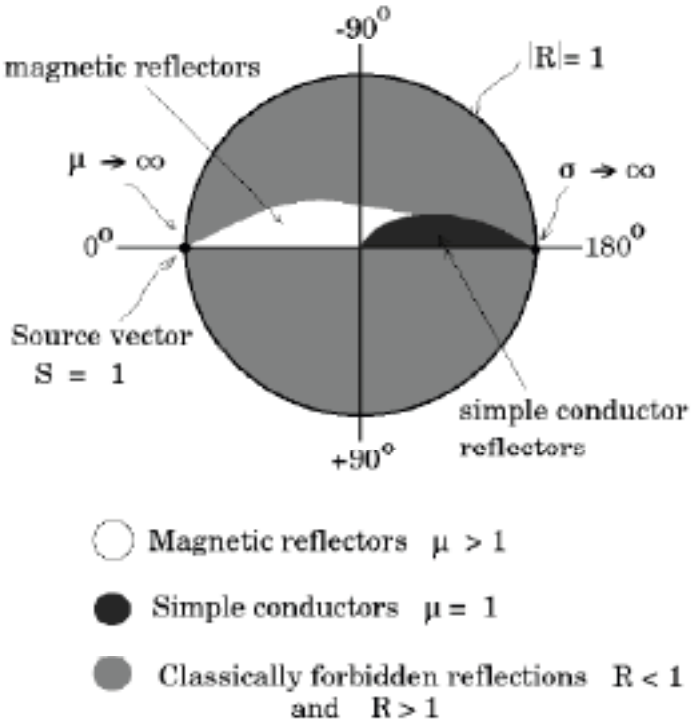
Eddy current (0.1 to 2 GHz) & Optical measurement system



Niobium-hydrogen measurement cells

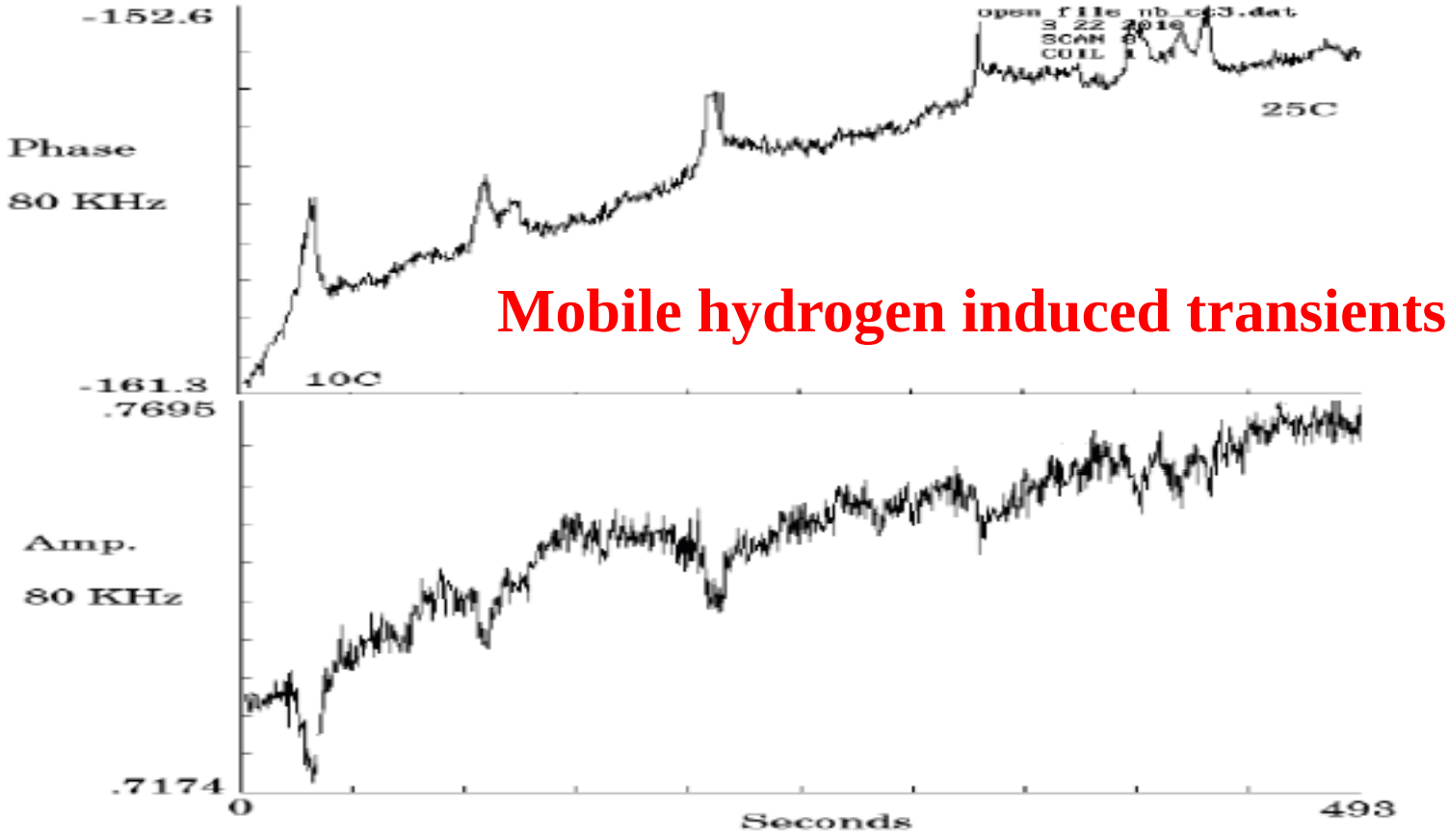
RF reflection measurement principle





Proton in SRF niobium, J. P. Wallace, SSTIN10 AIP CP 1352, 2011

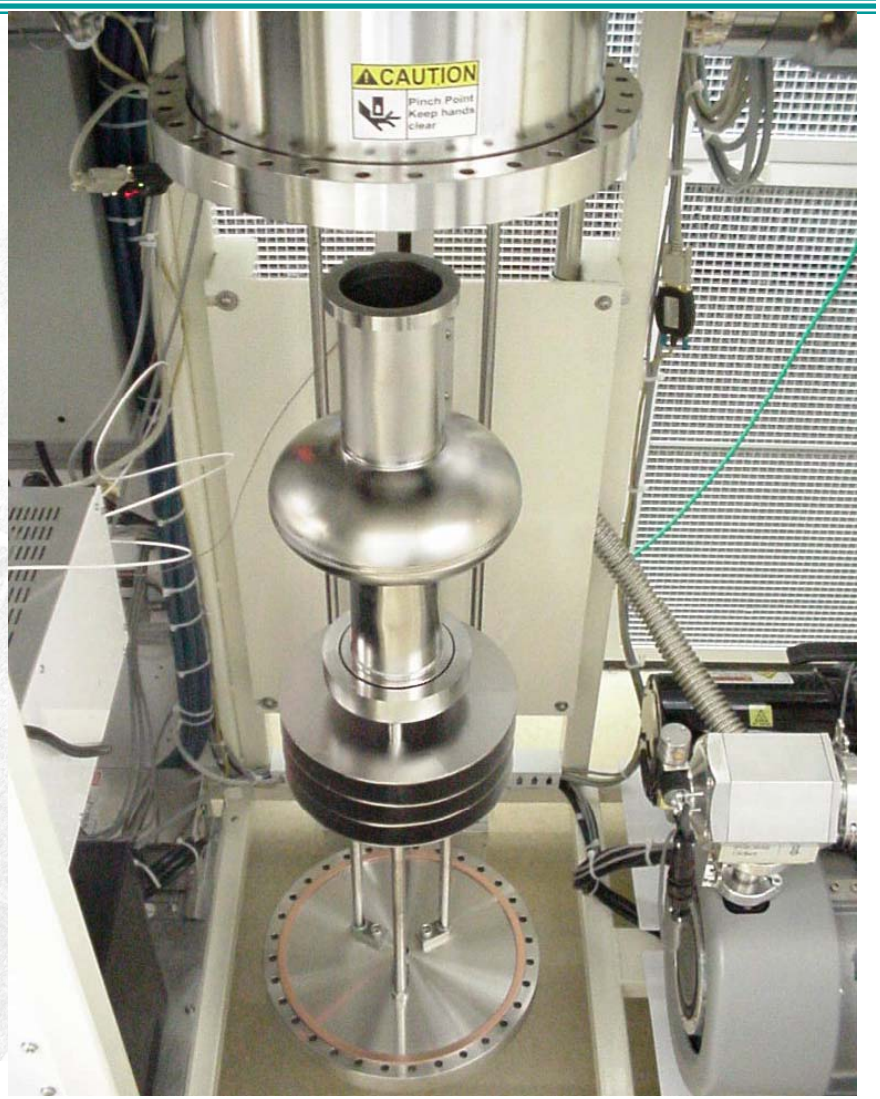
Niobium subsurface magnetic transients



Mobile hydrogen induced transients

FIGURE 31. Fine grain sample of SRF Niobium subject to BCP, showed subsurface magnetic transient on slow warming after being cooled to liquid nitrogen temperatures. These transients almost appear regular but they are not often reproducible on recycling. Changes due to normal electrical conductance increase would be very small effect in these plots.

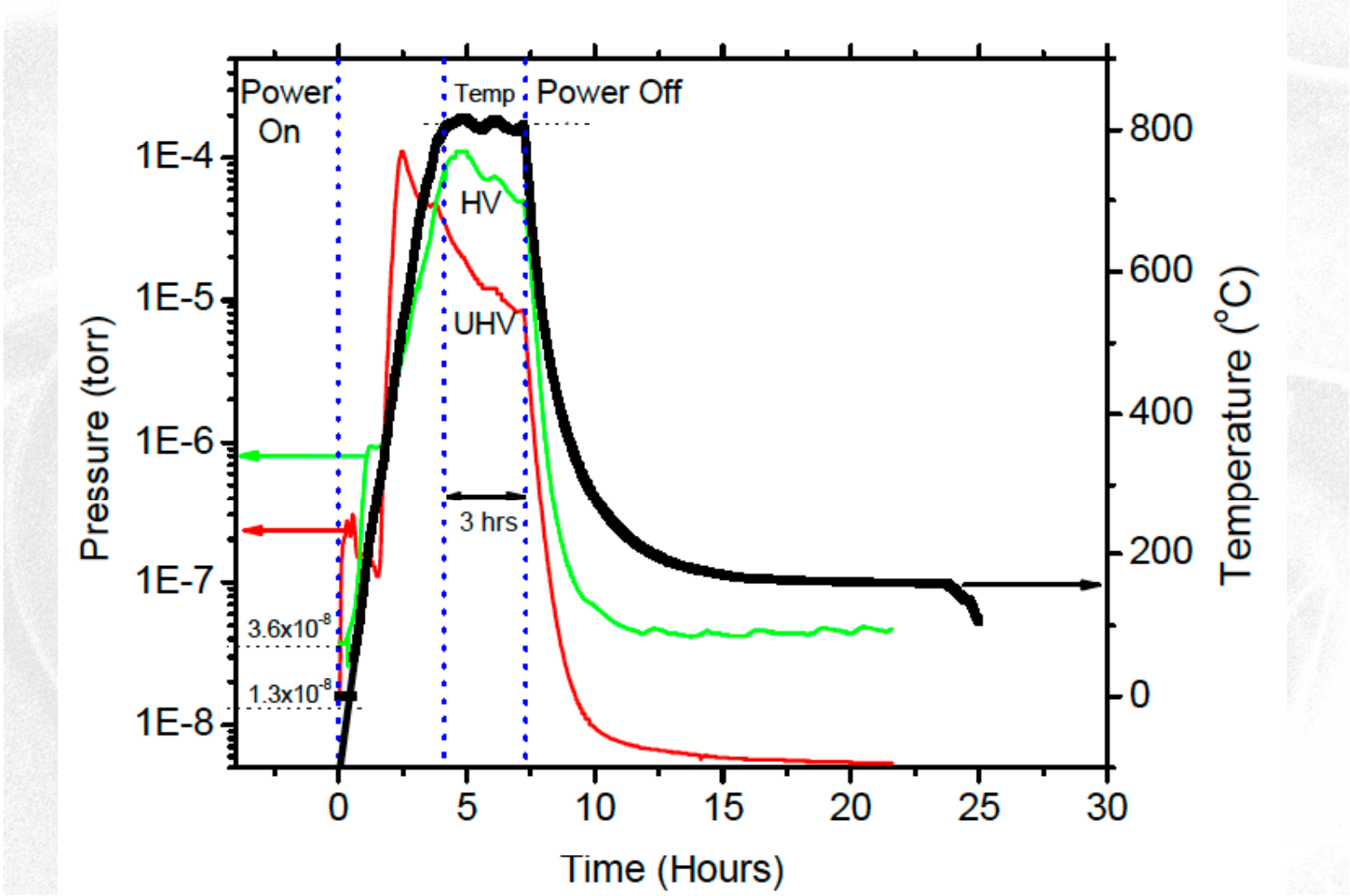
Clean UHV furnace - patents applied for



Cavity material and preparation

- CBMM ingot niobium, RRR ~ 200 (>350), Ta ~ 1350 (<500) wt ppm, inexpensive 50% to 60% less than conventional Nb
- Barrel polishing 73μm, BCP 65μm , a total of 138 μm removal and high pressure UHP water

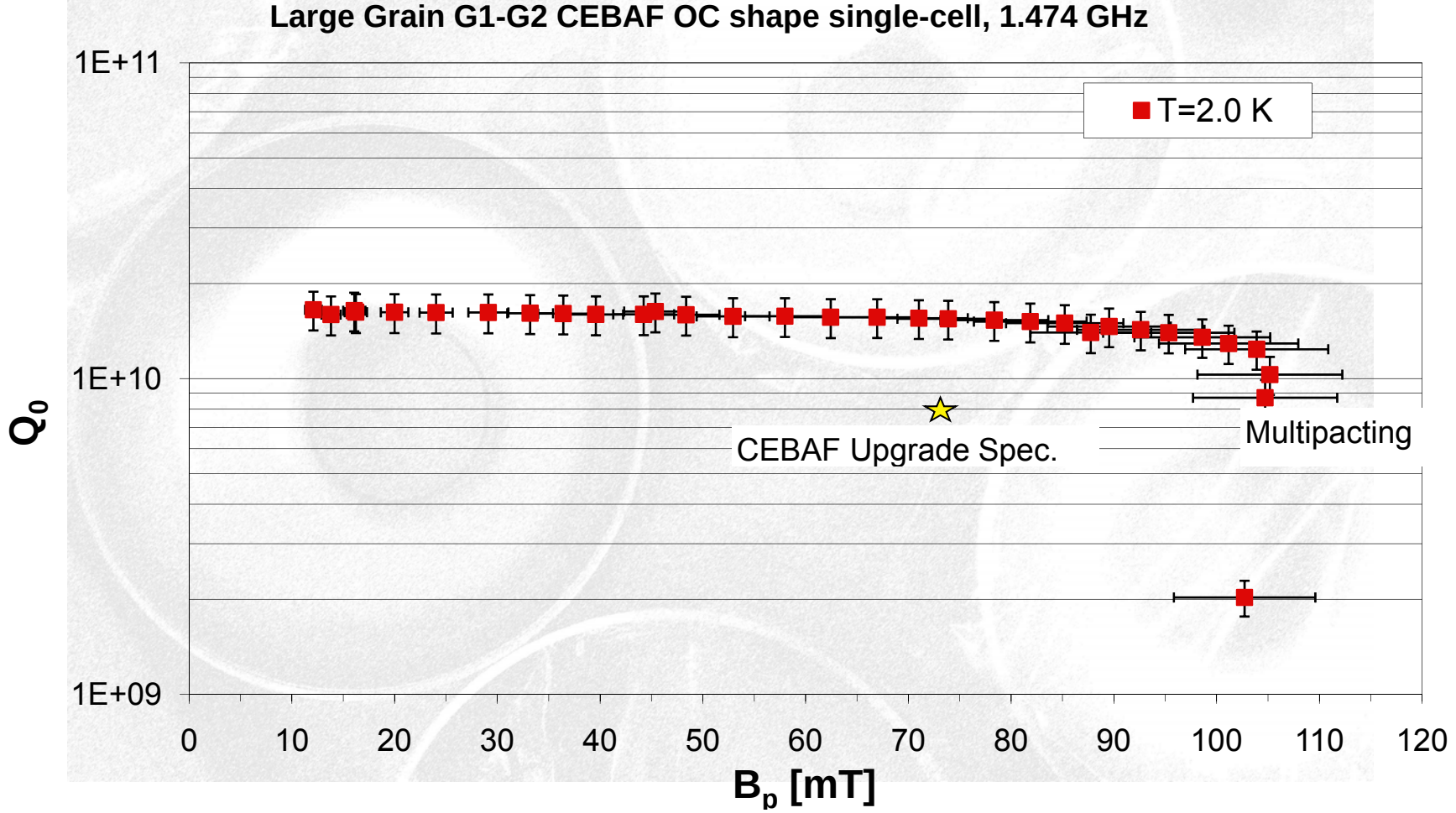
Single cell CEBAF cavity heat treatment



Annealed at 800 °C for 3 hours, held accidentally at160 °C for 7 hours, above 140 °C is known to reduce Q_0

Very first test result of low RRR and high Ta CBMM ingot niobium cavity

Furnace commissioned on 8/12/11 **Heat treated on 8/16/2011** **Tested on 8/18/11**



Current status and results

- The program objectives are completed - 97% of budget spent
- Scientific understanding and path to improving the Q_0 are in excellent shape
- Unique surface property measurement instrumentation is developed
- A state of the art UHV furnace for single cell cavity heat treatments is designed, built and commissioned

Expenditure by category

- Large business 2%
- Small Business 60%
- Small women business 28%
- Universities 10%

Work force training

- Three undergraduate summer interns from two local universities (funded by the Q_0 program)
- Three graduate students
  - NCSU
  - ODU (funded by the Q_0 program) and
  - Homi Bhabha National Institute, India
- One post doctoral fellow

Future plans

- **Develop optimum procedures**
  - The furnace, micro-magnetic and spectroscopic tools will be used to develop optimum procedures for high Q_0 single cell Nb SRF cavities and train future scientific, engineering and technology workforce
- **Design, build and commission a large furnace for multi cell cavities**
  - to meet the wide variety of future programs in BES, HEP, NP, DoD, commercial and University compact linacs, FEL's and advanced reactor cycles using thorium as green nuclear fuel
- **We are looking forward to your support in reaching these exciting goals**

Summary

- The SRF cavity Q_0 improvement program is successfully completed
- This program supported several small and women owned businesses and trained future workforce
- The low purity (200 RRR), high tantalum content (~1350 wt ppm), inexpensive (>60%) CBMM ingot niobium single cell cavity with simple process-procedures performed extremely well in the very first test it self which is very unique in the SRF community
- We are planning to design and build a clean UHV furnace for multi cell SRF accelerator structures and looking forward to your support

Publications 2010-2011

1) R. E. Ricker, G. R. Myneni, “Evaluation of the Propensity of Niobium to Absorb Hydrogen During Fabrication of Superconducting Radio Frequency Cavities for Particle Accelerators” J. Res. Natl. Inst. Stand. Technol. 115, 353-371 (2010)

2) G. Ciovati, G. Myneni, F. Stevie, P. Maheshwari, and D. Griffis, "High field Q slope and the baking effect: Review of recent experimental results and new data on Nb heat treatments", Phys. Rev. ST-AB 13, 022002 (2010)

3) X. Zhao, G. Ciovati and T. R. Bieler, "Characterization of etch pits found on a large-grain bulk niobium superconducting radio-frequency resonant cavity", Phys. Rev. ST-AB 13, 124701 (2010)

4) Gianluigi Ciovati, Peter Kneisel and Ganapati R. Myneni, "America’s Overview of Superconducting Science and Technology of Ingot Niobium", Proceedings of the Symposium on the Superconducting Science and Technology of Ingot Niobium", Newport News, Virginia, September 22-24, 2010, edited by G. R. Myneni, G. Ciovati and M. Stuart, AIP Conference Proceedings 1352 (2011), p. 25

5) A. S. Dhavale, G. Ciovati and G. R. Myneni, "Effect of Electropolishing and Low-Temperature Baking on the Superconducting Properties of Large-Grain Niobium", Proceedings of the Symposium on the Superconducting Science and Technology of Ingot Niobium", Newport News, Virginia, September 22-24, 2010, edited by G. R. Myneni, G. Ciovati and M. Stuart, AIP Conference Proceedings 1352 (2011), p. 119

6) S. B. Roy, V. C. Sahni and G. R. Myneni, "Research & Development on Superconducting Niobium Materials via Magnetic Measurements", Proceedings of the Symposium on the Superconducting Science and Technology of Ingot Niobium", Newport News, Virginia, September 22-24, 2010, edited by G. R. Myneni, G. Ciovati and M. Stuart, AIP Conference Proceedings 1352 (2011), p. 56

7) John P. Wallace, Ganapati R. Myneni, Robert pike, “Curvature, hydrogen , Q”, Proceedings of the Symposium on the Superconducting Science and Technology of Ingot Niobium", Newport News, Virginia, September 22-24, 2010, edited by G. R. Myneni, G. Ciovati and M. Stuart, AIP Conference Proceedings 1352 (2011), p. 38

8) G. Ciovati, P. Dhakal, G. R. Myneni, F. Stevie and P. Maheswari, "High-Temperature Heat Treatment Study on a Large-Grain Niobium Cavity", Proceedings of the 15th International Conference on RF Superconductivity, Chicago, Illinois, July 25-29, 2011, paper TUPO051, to be published.

9) Pashupati Dhakal, Gianluigi Ciovati, Peter Kneisel, and Ganapati Rao Myneni, "Superconducting DC and RF Properties of Ingot Niobium", Proceedings of the 15th International Conference on RF Superconductivity, Chicago, Illinois, July 25-29, 2011, paper TUPO057, to be published.

Publications 2010-2011contd.

10) G. Ciovati and G. R. Myneni, "Summary of the Symposium on Ingot Nb and New Results on Fundamental Studies of Large Grain Nb", Proceedings of the 15th International Conference on RF Superconductivity, Chicago, Illinois, July 25-29, 2011, paper TUIOB02, to be published.

11) P. Maheshwari, H. Tian, C. Reece, G. Myneni, F. Stevie. M. Rigsbee, A. Batchelor, D. Griffis, Surface Analysis of Nb Materials for SRF Cavities", Surf. Int. Analysis 43, 151-153 (2011)

12) John Paul Wallace, "Proton in SRF Niobium", Proceedings of the Symposium on the Superconducting Science and Technology of Ingot Niobium", Newport News, Virginia, September 22-24, 2010, edited by G. R. Myneni, G. Ciovati and M. Stuart, AIP Conference Proceedings 1352 (2011), p. 205

13) Ashraf H. Farha, Ali O. Er, Yuksel Ufuktepe, Ganapati Myneni, Hani E. Elsayed-Ali, "Influence of nitrogen background pressure on structure of niobium nitride films grown by pulsed laser deposition", accepted for publication in Surface and Coatings Technology

14) Ashraf Hassan Farha, Ali Oguz Er,, Yuksel Ufuktepe, Ganapati Myneni, and Hani E. Elsayed-Ali, "Effects of substrate temperature on properties of NbN films grown on Nb by pulsed laser deposition" in press

15) John P. Wallace, Michael J. Wallace, "Dark Matter from Light – extending quantum mechanics to Newton's' First Law" 2011 published by Casting Analysis Corp.

16) John P. Wallace, Ganapati R. Myneni, "Zero Momentum Nuclear Processes" in preparation for submission to Nature

17) Proceedings of the Symposium on the Superconducting Science and Technology of Ingot Niobium", Newport News, Virginia, September 22-24, 2010, edited by G. R. Myneni, G. Ciovati and M. Stuart, AIP Conference Proceedings 1352

18) Ganapati Rao Myneni and John Wallace,"Clean UHV Furnace", Patent application submitted to United States Patent Office 2010

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Sindhunil Roy – RRCAT