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Q DISEASE: INSIGHTS FROM 350 MHZ SPOKE CAVITIES TESTS AND ERD ANALYSES OF HYDROGEN IN NIOBIUM*

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Abstract

While degassing hydrogen at an elevated temperature (>600 °C) can reduce the chance of Q degradation (Q disease), eliminating this process would significantly reduce the cost and time of producing cavities. Past published data elsewhere have shown significant Q disease at relatively low frequencies such as the 130 MHz quarter-wave resonator at JAERI despite general observation of insignificant effect on low-frequency cavities. We have tested our 350 MHz spoke cavities and found that these cavities do not show any Q disease after up to 24 hours of holding at 100 K, but show the disease with longer holding time, although the extent of the degradation was different between the two cavities. Elastic Recoil Detection Analyses (ERDA) data on the hydrogen content and the depth profile in niobium used for the fabrication of our spoke cavities will also be shown with various surface treatments. Finally, insights from these studies into what is the best way to treat cavity to avoid high-temperature degassing will be drawn.

INTRODUCTION

At LANL, no cavities fabricated for the APT and AAA projects have been baked at >150 °C, although baking at >600 °C has been routinely performed at many labs in order to degas hydrogen and avoid Q disease.

Baking at a high temperature with good vacuum is a costly and time-consuming process in addition to a reduction of yield strength. Therefore, it would be beneficial if there is a way to avoid this and ensure that the same high performance can be achieved.

350-MHZ SPOKE CAVITY TESTS

We have tested the Q disease using our two spoke cavities. The details of the tests and results are written in Ref. [1, 2]. The results are summarized as follows.

- With our spoke cavities, the Q disease does not occur after up to 24 hours of holding at 100 K before cooling down.
- The Q disease occurs with longer holding time at 100 K and the additional surface resistance (R_s) increases linearly with the holding time. (See Figs. 1 and 2).
- The R_s versus temperature plot (Fig. 3) shows a kink at 2.18 K with the cavity suffering from Q disease, suggesting an existence of a superconductor with T_c at this temperature.

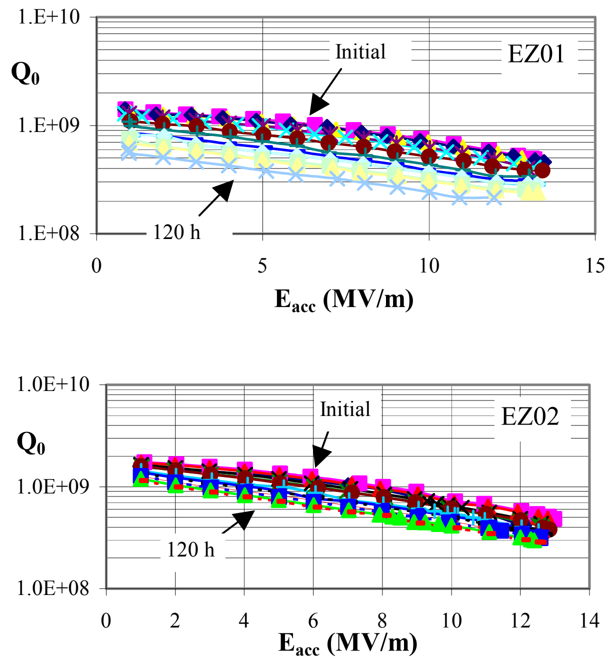

Figure 1: A collection of Q_0-E_{acc} curves of our 350-MHz spoke cavities EZ01 (top) and EZ02 (bottom) measured at 4 K after every 12 hours of holding the cavity at 100 K up to 120 hours.

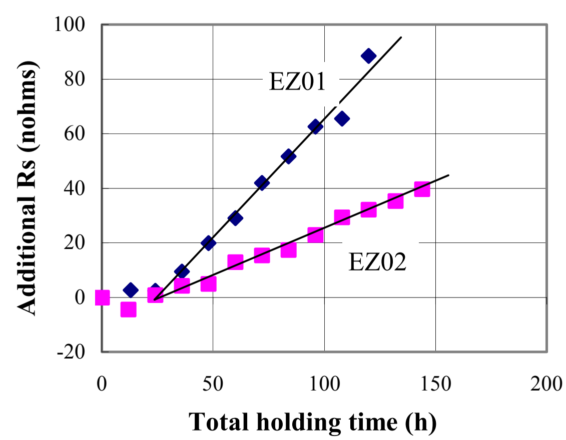

Figure 2: Additional surface resistance due to Q disease as a function of accumulated holding time at 100 K. The data was taken at E_{acc}=4 MV/m.

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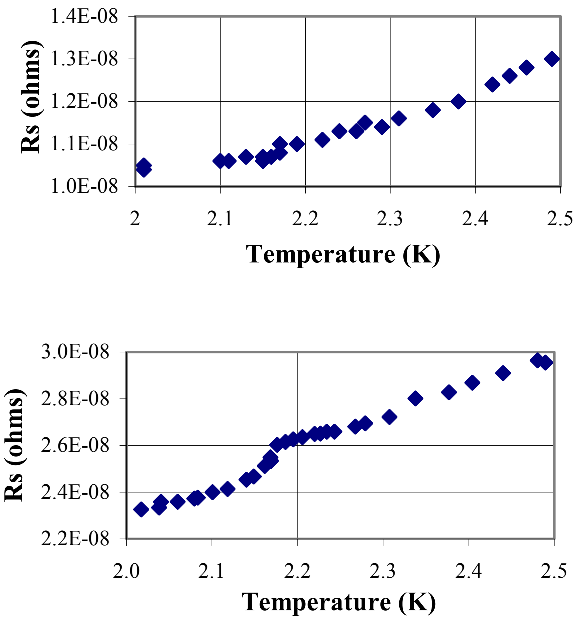

Figure 3: Surface resistance R_s as a function of temperature of the initial (top) and Q-degraded cavity EZ02 (bottom).

HYDROGEN CONTENT IN NB

We measured the content of hydrogen (H) and depth profile in the niobium samples taken from the same lot RRR~250 sheet used for the fabrication of our spoke cavities. We used a non-destructive method using 2-MeV helium ion beams and detect the number of recoiled hydrogen atoms or so-called Elastic Recoil Detection Analysis (ERDA).

Usual output of this analysis is a plot of normalized yield versus channel, which are related to the content and depth, respectively. The following figures show approximate H content versus depth plots analyzed using simulation software XRump [3].

Samples #3 and #4 were measured without any treatment or cleaning as a reference (designated as "virgin"). Also, all the following measurements were carried out on the same day (July 9, 2003) to avoid the effect of the difference of machine conditions, etc.

Since RF surface losses occur within 100 nm, the amount of H in this region is very important to understand the Q disease.

Effect of Buffered Chemical Polishing (BCP)

Figure 4 shows the effect of BCP (HNO_3:HF:H_3PO_4= 1:1:2) with different polishing depths. The data of the BCPed samples were not so different from the virgin samples. In a preliminary test conducted on March 26, 2003, the 193-micron polished sample showed an increase of H content by 57 % compared to the 155-micron polished sample [2], but there was no such difference in this test. Since we neglected the calibration of the yield count in the preliminary test, it might have affected the result.

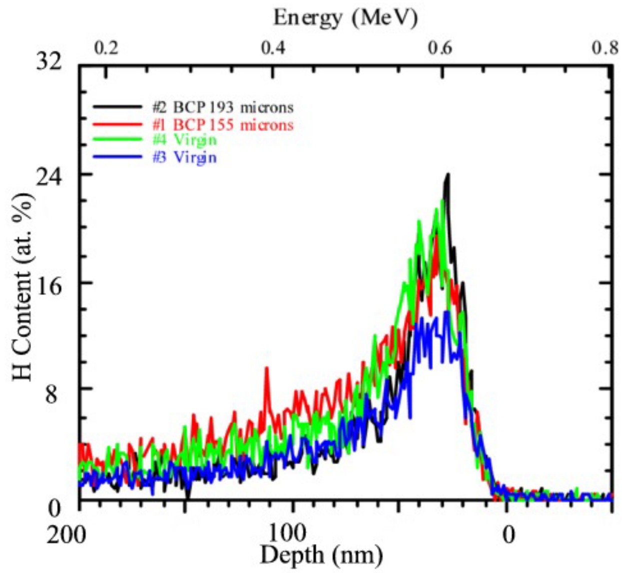

Figure 4: Depth profile of hydrogen for the non-treated (virgin) samples and those after BCP of 155 and 193 microns.

Effect of baking at 1000 ℃

Figure 5 shows the data of the two samples baked at 1000 °C for 3 hours at a pressure of 2.5E-5 Torr (at start) and 7.3E-6 Torr (at end). Baked samples show a significant reduction of H that is consistent with other published data [4, 5].

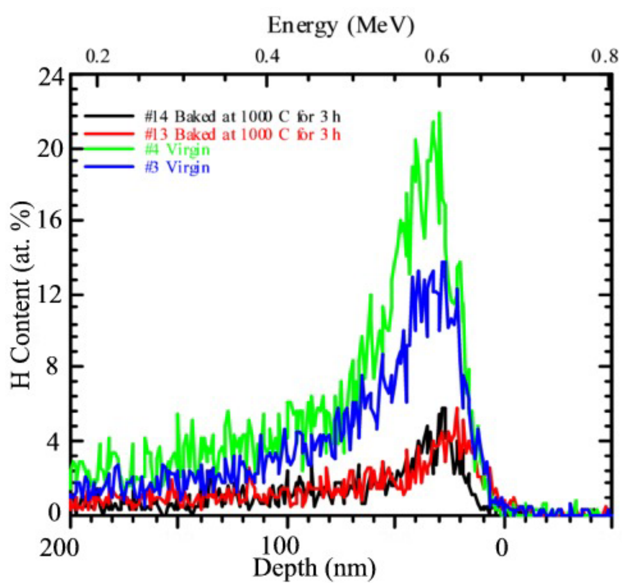

Figure 5: Depth profile of the hydrogen for the non-treated (virgin) samples and those baked at 1000 °C for 3 hours.

Effect of Electro-Polishing (EP)

Figure 6 shows the data of EPed samples. The EP was carried out at Cornell University in the following conditions. Sample #5: temperature ~ 60 °C and without current oscillation, other samples: temperature 20-35 °C with current oscillation.

Most of the EPed samples showed significantly lower H content compared to virgin samples except #5 (EP 78 microns). The increase in sample #5 is probably attributed to the higher temperature and without current oscillation during the EP.

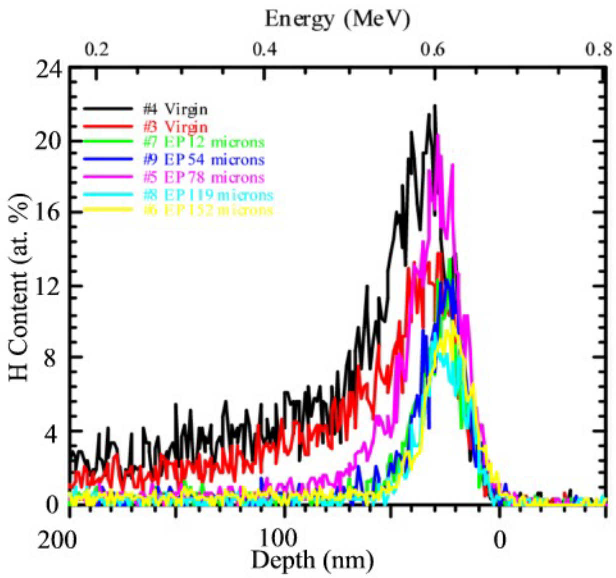

Figure 6: Depth profile of the hydrogen for electropolished (EP) samples as compared to the virgin samples.

Effect of Water

Figure 7 shows the data of the two samples soaked in DI water for 24 hours. They showed the same or higher H content compared to the virgin samples.

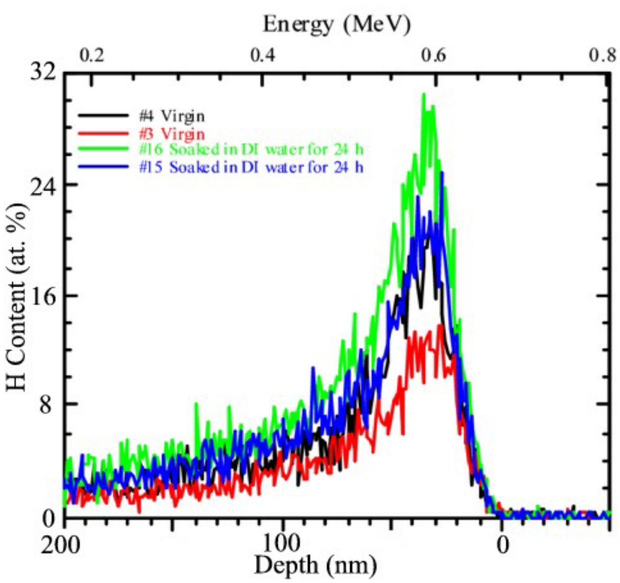

Figure 7: Depth profile of the hydrogen for the samples soaked in DI water for 24 hours as compared to the virgin samples.

Effect of HCl

Figure 8 shows the data of the two samples soaked in 37.5 wt. % HCl for 24 hours then quickly rinsed with DI water. The data were not different from the virgin samples.

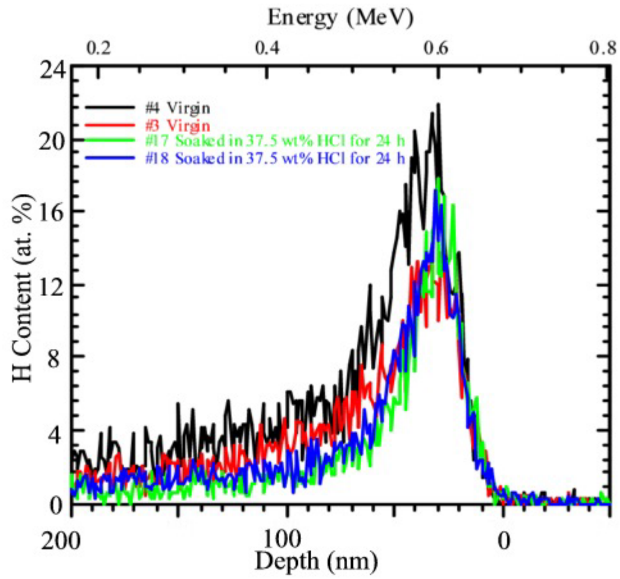

Figure 8: Depth profile of the hydrogen for the samples soaked in 37.5 wt% HCl for 24 hours as compared to the virgin samples.

SUMMARY AND FUTURE PLANS

Neither BCP at LANL nor EP at Cornell increases the H content in the Nb. Exposure to water seems to increase the amount of H. This observation is consistent with the study at KEK [6]. Careful surface treatments avoiding the hydrogen stagnation on the Nb surface and exposure to water seem to be able to keep the H content low.

Our future plan is to find a process to reach the H content as low as that of high-temperature baked samples without baking.

REFERENCES

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