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RF TEST RESULT OF A BNL N-DOPED 500 MHz B-CELL CAVITY AT CORNELL*

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Abstract

Cornell's SRF group has collaborated with Brookhaven National Laboratory (BNL) on one 500 MHz CESR type SRF "B-cell" cavity (BNL B-cell) for the National Synchrotron Light Source II. Cornell has been responsible for RF surface preparation, vertical testing, and short cavity string assembly. As a state-of-the-art surface preparation protocol, Cornell selected "Nitrogen doping" for the BNL B-cell. N-doping has been well demonstrated and established to push the cavity quality factor (Q_0) higher in 1.3 GHz SRF cavities at many laboratories. Cornell calculated that N-doping could also be beneficial on a 500 MHz SRF cavity, with a potential to increase its Q_0 by a factor of two compared with the traditional chemical polishing based surface preparation protocol. Here we report on the detailed surface preparation and vertical test result of the BNL B-cell.

INTRODUCTION

Recent high-Q progresses on 1.3 GHz Nb SRF cavities has resulted in deeper understanding of the surface resistance (R_s) of niobium cavities [1, 2]. R_s is usually divided into the BCS resistance (R_{BCS}) part and the temperature independent residual resistance (R_{res}) part. For the R_{BCS} part, A. Gurevich has developed a theoretical model to describe the observed RF field dependence of the BCS surface resistance R_{BCS} [3]. Cornell has further expanded this model to include the dependence of the "anti=Q-slope" on the electron mean free path (MFP) of the Nb cavity surface [4]. For the R_{res} part, recent R&Ds suggest that RF losses by trapped magnetic flux, $B_{trapped}$, in the cavity wall is the major contributor to R_{res}. Various RF test results on 1.3 GHz cavities prepared with different surface preparations and cooled down in a range of ambient magnetic fields have been analyzed. These studies give a model of the MFP dependent sensitivity $R_{res,B}$ /$B_{trapped}$, which quantifies the increase in residual resistance $R_{res,B}$ induced by trapped magnetic flux as function of MFP [5]. These models can now be used to predict the residual and BCS resistances of a 500 MHz cavity as function of the MFP and accelerating field. Since surface preparation can be adjusted to control the MFP, these models allow to predict and compare the resulting cavity quality factor Q_0 for various surface preparations. These state-of-the-art studies on SRF high-Q cavities suggest use of a light nitrogen doping as the most promising surface preparation recipe on the BNL 500 MHz cavity to achieve the highest Q_0 in the required conditions [6]. As an encouraging result, FNAL recently applied a light N-dope on a 650 MHz cavity and achieved higher Q than with EP + 120C bake, as we predicted [7]. In this paper, we report on the progresses of this project with detailed cavity test results.

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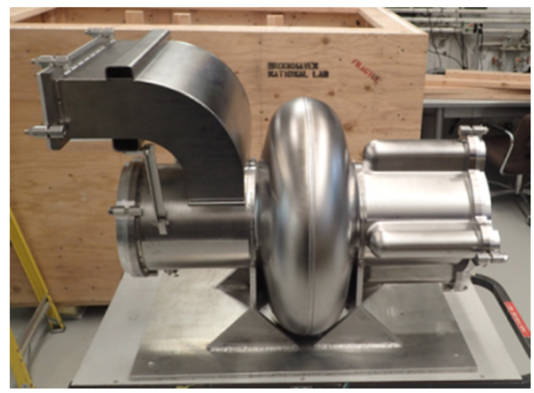

Figure 1: Image of the BNL B-cell cavity.

500MHz B-CELL TYPE CAVITY

RF Parameters

RF parameters of 500MHz B-cell cavity (see Fig. 1) are summarized in Table 1.

Table 1: RF Parameters of the 500 MHz B-cell Cavity

Item	Parameter
Γ (Geometrical factor)	270 Ω
R/Q	88 Ω
E_{pk}/E_{acc}	2.5
H_{pk}/E_{acc}	5.2 mT/MV/m

Surface Preparation

The "light nitrogen doping" process and conditions protocol Cornell applied on the BNL B-cell is summarized as follows:

- Bulk Buffered Chemical Polishing, 100 μm removal
- Vertical Electro-Polishing , 50 μm removal
- 800C light nitrogen doping in vacuum furnace
  - 3hrs in vacuum at 800 ºC
  - 2 min. in ~20 mTorr N_2 at 800 ºC (Fig. 3)
  - 6 min. in vacuum at 800 ºC
- Light Vertical Electro-Polishing, 5μm removal

Each chemistry was followed by ultra-sonic cleaning (USC) and high-pressure DI water rinsing (HPR). Figure

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2 shows images from the surface preparations of the BNL B-cell at Cornell.

Figure 2: The 500MHz cavity on the BCP stand (top left), on the HPR stand in the clean room (top middle), on the VEP stand (top right), in the vacuum furnace (bottom left), and on the vertical test stand (bottom middle).

Figure 3 shows the partial pressure of nitrogen during the doping.

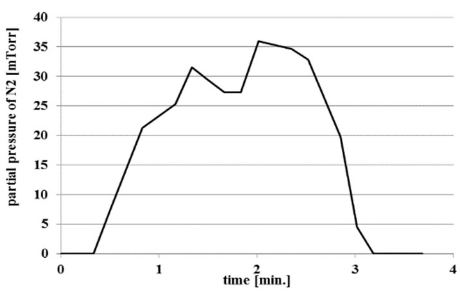

Figure 3: Partial pressure of Nitrogen during the N-doping of the cavity.

RF TEST RESULTS OF NITROGEN DOPED 500 MHz B-CELL CAVITY

Instrumentation and Cooldown to 4 K

Three temperature sensors and one fluxgate were mounted on the cavity to monitor those profiles during the cool down of the cavity (Fig. 4).

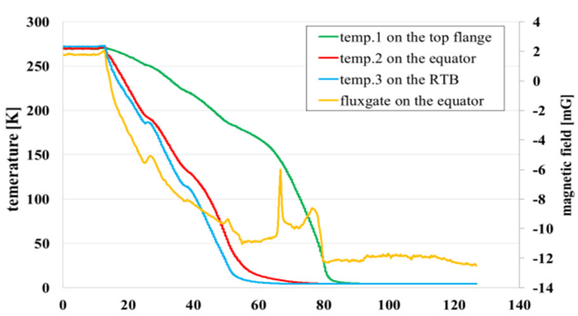

Figure 4: Cavity cooldown profiles.

The fluxgate was perpendicular to the equator. The end of helium transfer tube was located next to the waveguide and reached to almost the bottom of the vertical test dewar.

RF Test Result at 4.2 K

The cavity was cooled down to 4.2 K and RF test was performed. The resonance frequency during the vertical test at 4.2 K was 499.372 MHz. Along with the first RF power rise into the cavity from a low to high field, RF processing was performed. Radiation monitoring was also performed during the test with the radiation detector located inside the RF shielding block (~50 inch above the cavity top flange). When the cavity field (E_{acc}) reached ~12 MV/m, we were almost at the limit of the available RF power for the vertical test (~200 W). RF processing was continued at that gradient for a while; the radiation level decreased from 200 mR/h to 100 mR/h during the processing, without change in the gradient. The final 4.2 K Q_0 vs E_{acc} plot measured is shown in Fig. 5. The cavity reached a maximum E_{acc} of 12 MV/m with Q_0 of $1.4x10^9$ at 4.2 K. The cavity showed no quench limitation, but the field was limited by the available RF power for the vertical test. During the measurement, the whole cavity was covered with liquid helium.

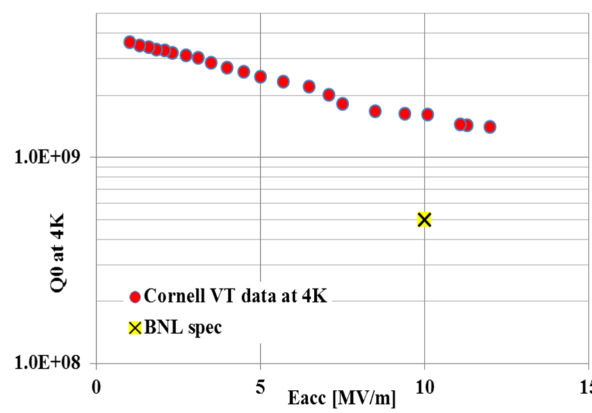

Figure 5: Cornell's vertical test result of the 500 MHz BNL B-cell cavity at 4.2 K (red) and BNL's specification value (yellow).

Discussion

The achieved Q_0 of $1.4x10^9$ at E_{acc} of 12 MV/m with the BNL B-cell operated at 4.2 K is a record Q_0 for a Cornell-style B-cell style cavity at that gradient and temperature. S. Bauer from RI reported Q_0 performance of cavities produced and prepared at RI (tested at Cornell) during EPAC04, which were about $(1.0\pm0.2)\ x10^9$ at 10 MV/m at 4 K [8]. The BNL B-cell prepared and tested at Cornell achieved a significantly higher Q_0 ($1.6x10^9$ at E_{acc} of 10MV/m; see also Table 2), approximately 50% higher than the typical RI cavity Q_0 at that gradient. Cornell therefore demonstrated the benefits of electropolishing and N-doping on a 500 MHz cavity successfully. For a further discussion and analysis of the contributions of the BCS resistance (R_{BCS}) and of the residual resistance (R_{res})

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of the N-doped BNL B-cell cavity, Q_0 measurements in different temperatures would have been needed.

Table 2: Comparison of Q_0 at 4 K

500MHz B-cell	BNL spec.	N-doped by Cornell	Non-doped by RI [7]
Q_0 at 10 MV/m, 4 K	$0.5x10^9$	$1.6x10^9$	$(1.0\pm0.2)x10^9$

A magnetic field measurement was performed during the cool down (Fig. 4). The fluxgate on the cavity equator, which was perpendicular to the cavity equator, showed 1.7 mG at room temperature and increased to ~12 mG during the cool down. The high-Q control of N-doped cavities has been investigated a lot in the 1.3 GHz cavities to maximizing flux expulsion, minimizing flux trapping, or minimizing the induced flux from the thermal current during the cool down. The measured ambient magnetic field of 12 mG on BNL cavity implies that we could also explore magnetic field control during the cool down and that there could be room to increase the Q_0 of the BNL B-cell cavity further by reducing the ambient magnetic field during cool down. But, this would require another significant R&D effort on a 500 MHz cavity including a parametric study of N-doping on a 500 MHz cavity, which is beyond the scope of this project.

SHORT STRING ASSEMBLY

After completing the RF test, the cavity was disassembled, cleaned, and had HPR again prior to the cavity string assembly. Figure 6 shows the B-cell in the support yoke with the fluted beam tube on the top and the helium end plate on the bottom.

Figure 6: BNL B-cell cavity on the A-frame for the short string assembly.

SUMMARY

Cornell successfully completed RF surface preparation and vertical testing of the BNL B-cell type cavity. The cavity performance significantly surpassed the BNL specification values and achieved the record Q_0 of $1.4x10^9$ at E_{acc} of 12 MV at 4.2 K. Cornell thereby demonstrated the benefit of N-doping on a 500 MHz cavity for the first time. Additional R&D on Q_0 vs E_{acc} at different temperatures would be desirable in the future to better understand the field dependence of the BCS resistance and the residual resistance for a N-doped 500 MHz cavity.

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