SUPERCONDUCTING RF PERFORMANCE OF CORNELL 500MHz N-DOPED B-CELL SRF CAVITY*

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Abstract

The Cornell SRF group is working on rebuilding a 500MHz B-cell cryomodule (CRYO-2 BB1-5) as a spared cryomodule for operation of the CESR ring. To minimize BCS surface resistance, achieve a high quality-factor (Q_0), and increase maximum fields, we prepared the cavity's surface with electropolishing and performed a 2/6 N_2-doping. In this work, we report 4.2K and 2K cavity test results with detailed surface resistance analysis, showing improved performance, including significant higher fields.

INTRODUCTION

The CESR storage ring at Cornell University is now used as an X-ray source for a state-of-the-art X-ray facility, and includes four 500MHz B-cell cryomodules. During CESR operation, the cavity of the cryomodule CRYO-2 BB1-5 was damaged and the cavity cell had to be replaced. The cavity was originally built in 1999 [1]. The rebuild of this cavity and cryomodule now offered the opportunity to prepare the repaired cavity with cutting-edge SRF treatments to achieve higher RF performance. N_2-doping, which introduces a low level of impurity into the cavity surface to shorten the mean free path (MFP) and lower BCS resistance, had been shown in practice as an effective way to increase the quality-factor (Q_0) of a SRF cavity [2, 3]. Therefore, N_2-doping was selected for this project.

CAVITY TREATMENTS

The new cavity cell was fabricated by Research Instruments (RI) with the high-pure Nb (RRR=300) provided by Cornell University. After receiving the cavity back from RI, it was buffered chemical polished (BCP) for 32µm, followed by ~100µm electropolishing (EP) on both cavity body and waveguide. In total, the bulk surface removal was ~140µm, which is sufficient to remove surface contamination from the fabrication. Pictures from the BCP and EP of the cavity are shown in Fig. 1 and Fig. 2 respectively.

The cavity then received a 3 hour, 800ºC vacuum bake to degas H_2. Right after the vacuum bake, 2/6 N_2-doping [4] was performed in the furnace, in which the cavity was doped under ~30 mTorr N_2 atmosphere for 2 minutes, then annealed under vacuum for 6 minutes, and then cooldown to room temperature. When the N_2-doping was completed, 5µm surface removal by EP was carried out.

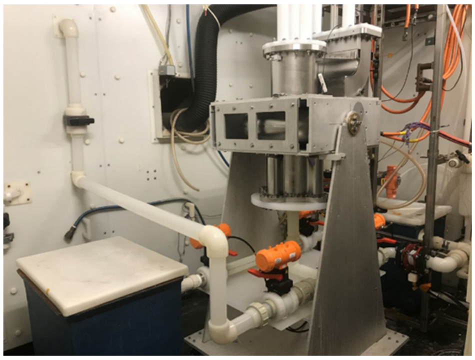

Figure 1: Photograph of Cornell B-cell BCP.

Figure 2: Photograph of the EP of the Cornell B-cell cavity.

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Figure 3: Photograph of the Cornell TM-furnace with the B-cell placed inside.

Before the cryogenic RF test, the B-cell cavity was high-pressure-water-rinsed (HPR) in a class 10 cleanroom on both cavity body and waveguide, as is shown in Fig. 4 left and right respectively.

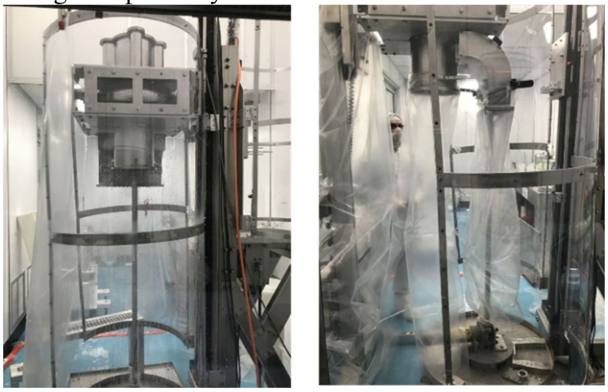

Figure 4: The HPR of the cavity body (left photograph) and waveguide (right photograph).

CAVITY TEST RESULTS AND ANALYSIS

Test Results

The cavity's 4.2K performance is shown in Fig. 5, in which the cavity Q_0 was ~3×10^9 at low fields and ~1×10^9 at 10MV/m, two times higher as the specification (5×10^9). The Q_0 result is close to the N_2-doping result of the BNL B-cell cavity which was also treated and tested at Cornell [5]. The accelerating gradient (E_{acc}) of the Cornell B-cell reached 11MV/m at 4.2K limited by the RF power, and not quench.

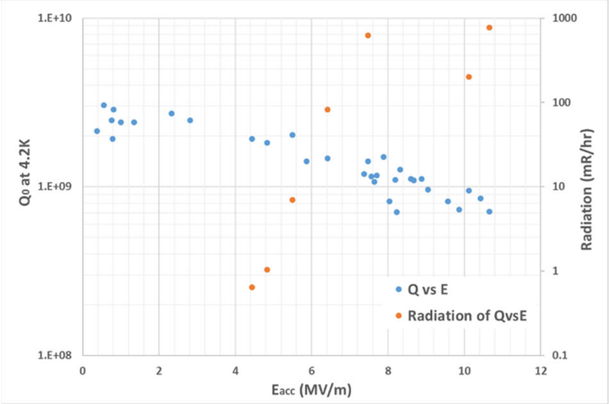

Figure 5: Q_0 versus E_{acc} curve of the Cornell B-cell tested at temperature 4.2K.

In the 2K measurement, the cavity gradient achieved above 20MV/m, a field record for the Cornell B-cell cavity. Again, the measurement was limited by the RF power and not quench. The Q_0 versus E_{acc} curve is flat as is shown in Fig. 6: at low field the Q_0 reached ~1.1×10^{10}; and it was about ~1×10^{10} at 10MV/m; the mild Q-slope above 10MV/m was due to field emission.

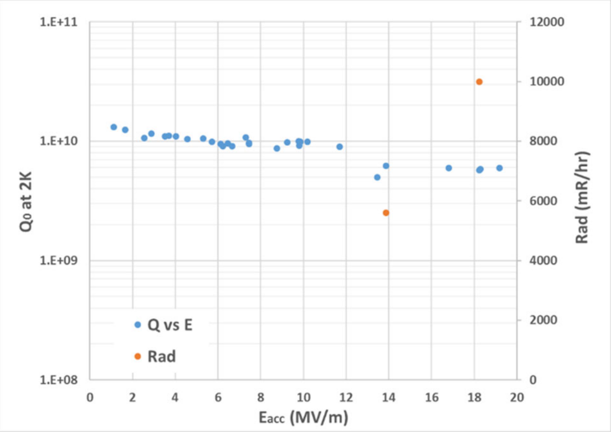

Figure 6: Q_0 versus E_{acc} curve of the Cornell B-cell tested at temperature 2K.

Analysis

The RF measurements between 2K and 4.2K gave us a precious opportunity for detailed analysis of the performance of this cavity for the first time. The surface resistance was calculated from the Q_0 using the RF parameters of the B-cell cavity listed in Table 1.

Table 1: RF Parameters of the B-cell SRF Cavity

Items	Values
G (Ω)	270
R/Q (Ω)	88
E_{pk}/E_{acc}	2.5
B_{pk}/E_{acc} (mT/MV/m)	5.2

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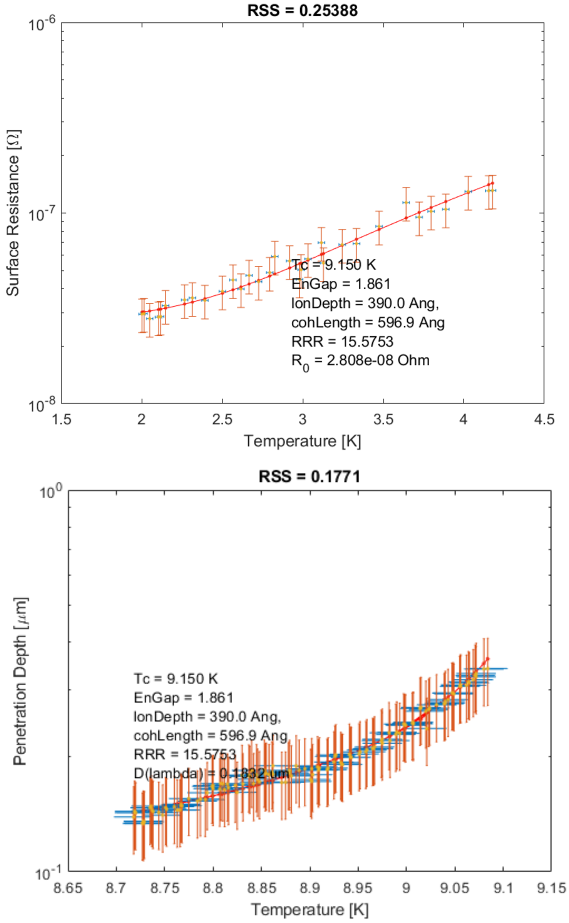

Figure 7: Top plot) Surface resistance versus temperature data for fitting residual resistance R_0 and energy gap; Bottom plot) Penetration depth versus temperature data for extracting RRR and T_c.

Figure 7 shows an example of the surface resistance results as well as fits to extract superconducting parameters at E_{acc} = 5 MV/m. From the surface resistance versus temperature data (Fig. 7 top plot), we obtain the residual resistance R_0 and energy gap (EnGap), while the RRR and T_c can be extracted robustly from the penetration depth versus temperature data (Fig. 7 bottom plot). The RRR value shows that the N_2-doping followed by light EP set the cavity's surface MFP near to the optimum range to minimize BCS resistance. Table 2 shows a comparison of the fitted results with the undoped case (RRR= 200) calculated by the BCS-theory based code SRIMP [6], from which it can be seen that the BCS resistance is reduced about ~50% by the doping.

Table 2: Superconducting parameters of the B-cell SRF cavity extracted from the fitting and compared with the BCS calculation of clean surface case (undoped case).

Parameters	Measurement	BCS calculation of clean surface
R_0 (nΩ)	28	-
R_bcs @ 2K (nΩ)	**~2**	**3.6**
R_bcs @ 4.2K (nΩ)	**~90**	**207**
RRR	**15.6**	**200**
Energy Gap	1.86	1.86
T_c (K)	9.15	9.15

The full surface resistance decomposition results are plotted in Fig. 8, in which we do not observe a BCS resistance decreases with field increase ("anti-Q slope") at 500MHz. This result is consistent with the conclusion in Ref. [7]. The high R_0 was likely caused by flux trapping from the ambient magnetic fields.

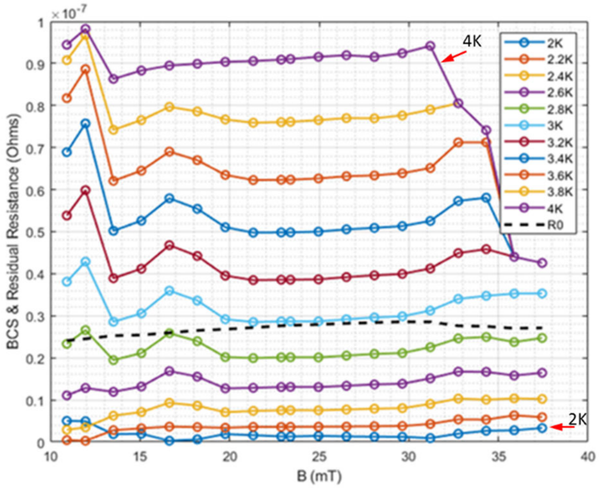

Figure 8: R_{BCS} at various temperatures and R_0 of the Cornell B-cell cavity versus magnetic fields.

CONCLUSION

A 500MHz Cornell B-cell cavity has been successfully treated by 2/6 N_2-doping and electropolishing. Detailed RF testing of the cavity shows significantly improved RF performance of this cavity type for the first time: the cavity gradient achieved above 20MV/m without quench, which is two times above specification; the BCS resistance at 2K and 4K reached ~2 nΩ and ~90 nΩ respectively, which is ~2x lower than that of a clean surface (undoped case).

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