# FASTEST ELECTROPOLISHING TECHNIQUE ON NIOBIUM FOR PARTICLE ACCELERATORS*

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*Abstract*

As niobium (Nb) based superconducting radio frequency (SRF) technology is maturing, more and more particle accelerators go superconducting. One of the most important challenges that SRF community is facing is how to reduce the production cost and increase throughput of Nb SRF cavities. R&D in this field has demonstrated that the inner surface smoothness of a Nb cavity is one of the key issues in this regard. Nb SRF cavities with a smoother surface finish tend to have fewer field emission limited RF tests and a better chance to reach a high accelerating gradient. Previous experiments have demonstrated that buffered electropolishing (BEP) could produce the smoothest surface finish ever reported in the literature. In this paper, it is showed that under suitable experimental conditions, Nb removal rate can reach as high as 10 μm/min. The mechanism responsible for high Nb removal rate during BEP treatments as well as the implications of BEP technique for cost savings in the fabrication of Nb SRF cavities will be discussed.

## INTRODUCTION

More and more particle accelerators have selected niobium (Nb) based supercoducting radio frequency (SRF) technology as one of the important components of their systems. This popularity can be, at least partially, attributed to the steady progress made in the field of SRF in the past couple of decades, especially on the surface treatments of Nb SRF cavities. After the first systematic study [1] of electropolishing (EP), researchers in the SRF community have gradually realized that Nb cavities after EP treatments have a better chance to reach a high accelerating gradient as compared with those treated by buffered chemical polishing (BCP). The only difference between EP and BCP that has been found so far is that EP treated Nb surfaces are generally much smoother. Therefore, by now we can safely say that a smoother surface finish on the inner surfaces of Nb SRF cavities is highly desirable from the viewpoint of RF performance. This desirability can be further understood from the following two angles: 1) Smoother surfaces can reduce the degradation effect from local magnetic enhancements [2]. 2) Smoother surfaces can allow the surface cleaning to be done relatively easily. Therefore, SRF cavities with a smoother surface finish will have less chance to suffer from field emission. At this moment, it is unclear about how smooth the inner surface of a Nb SRF cavity is enough in order to reproducibly reach good RF performance with an accelerating gradient higher than 35 MV/m and a $Q_o$ at around $10^{10}$. However, one thing is very clear is that there is still much room to improve the current Nb SRF cavity fabrication process since the RF test data of the nine-cell cavities for international linear collider worldwide still scatter a lot. Many cavities cannot surpass the required gradient of 35 MV/m [3].

Buffered electropolishing (BEP) is a proved Nb surface treatment technique that can produce a much smoother surface finish on Nb than EP [4-6]. In this paper, it is shown that under a suitable condition, the polishing rate of BEP on Nb can be as high as 10 μm/min. The Nb surfaces produced under such a high polishing rate from surface areas close to iris and equator inside a demountable cavity are measured by a metallographic optical microscope (MOM) and profilometer for getting their topographic information. Possible mechanism responsible for the extremely high polishing rate as well as the implications of BEP technique for cost savings in the fabrication of Nb SRF cavities is discussed.

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## EXPERIMENTAL

BEP treatments on Nb were carried out employing a simple yet versatile vertical single cell polishing system that was built at JLab [7]. A unique demountable cavity was mounted to the vertical system for the BEP treatments. The polishing was done at a electrolyte flow

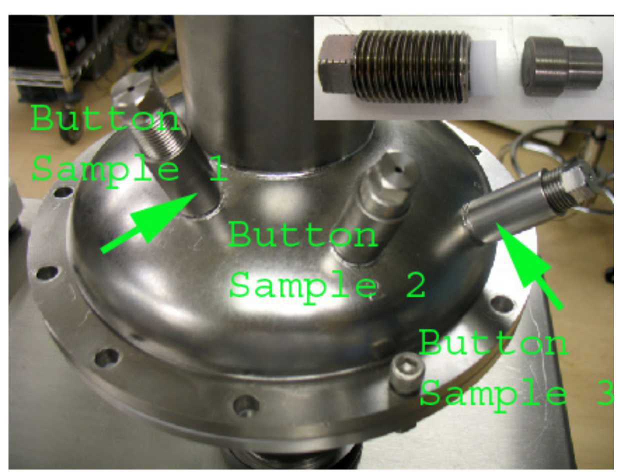



Figure 1: Photo of the demountable cavity fabricated at JLab. The arrows indicate the three button samples. The insert on the upper right corner shows the button sample assembly.

rate of ~ 1 L/min and 30 °C. To obtain a precise determination of Nb polishing rate, Nb button samples were weighed before being installed to the demountable cavity and co-processed with the cavity and then weighed again afterwards. Fig.1 shows the demountable cavity and the button samples.

It has been demonstrated [8] that cathode shape can affect the polishing results significantly for BEP. Therefore, a wheel cathode as showed in Fig.2 was employed in this study. Button samples 1 and 3 were weighed before and after the treatment to get a precise determination of the removal rates at the two locations.

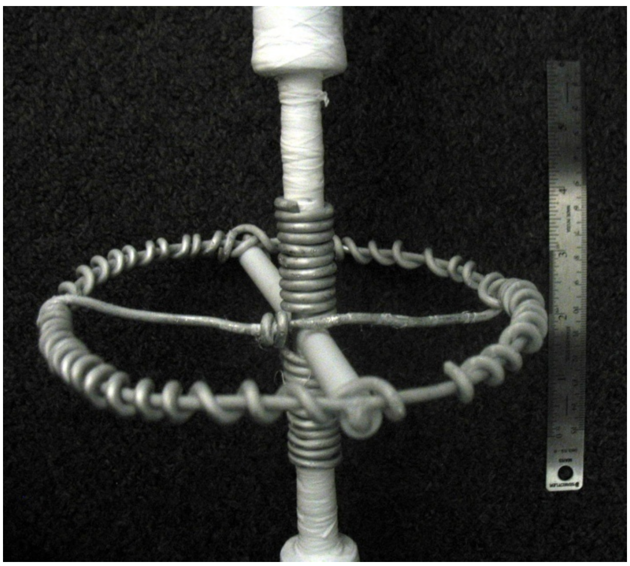


Figure 2: Cathode used in this study.

MOM measurements were done using a Carl Zeiss system as described in Ref.9.

Profilometer measurements were carried out via the commercial system P15 made by KLA-Tencor. The vertical repeatability of this system can be as high as 0.75nm. Typical scanning area was 200X200 $\mu m^2$. This would allow the scans to cover several grains of the sample under study so that meaningful topographic information about the surface could be extracted. The reason for this is that the average grain size of our Nb samples is 50µm. Scanning below or at such a length scale could not capture the general features of the Nb surfaces, since only one grain could be covered by the scans or sometimes scans were done only inside one grain.

## RESULTS AND DISCUSSION

The surface of the demountable cavity after the BEP treatment is shown in Fig.3. Due to the strong cathode shape dependence, some irregularities caused by the aluminium wire wrapped on the aluminium cathode ring could be clearly seen. The polishing rates determined from button samples 1 and 3 (referred later as But3) were 10.1 µm/min and 9.7 µm/min respectively. Interestingly, the lower half cell did not show effect from the irregularity on cathode ring. This result is consistent with

Figure 3: Photos of the demountable cavity after BEP treatment. Left is the upper cell. Right is the lower cell (see text for more details).

I-V curves measured recently on the button samples of the lower half cell as reported in Ref.10.

It is important to stress here that the Nb removal rate of the cavity may not be as high as those of the button samples. In this experiment, the high polishing rates of the button samples were caused by the fact the temperatures of the button samples were considerably higher than 30 °C since the Teflon jackets of the button samples were not removed after the I-V measurements were done on the button samples. Therefore the heat generated during polishing could not be removed immediately, leading to a higher temperature on the button samples. We estimated that the temperature of the button samples was about 45 °C.

This experiment was repeated with a smaller cathode shape similar to Fig.2. Polishing rates of 9.2 µm/min and 5.7 µm/min were obtained from the button samples 1 and 3 respectively. The lower polishing rate for the button sample 3 was due to the fact that the diameter of the wheel cathode was only 8.5 cm in this case.

Fig.4 shows a typical MOM photo of But3 that shows the smoothest surface finish. The surface appears to be smooth and shinny similar to what shown on the left photo of Fig.3, implying therefore the removal rate of the demountable cavity should not be significantly less than 9.7 µm/min. Some grain boundaries can still be seen since the process has not be completely optimized yet.

To quantitatively assess the surface morphology of

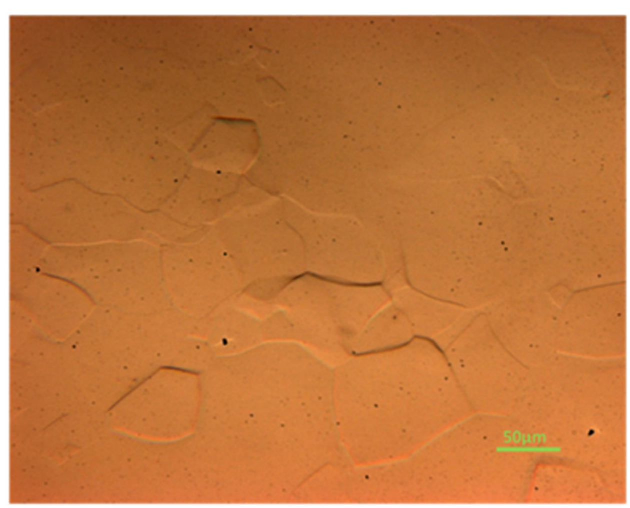



Figure 4: Typical MOM photo of the button sample that shows a Nb removal rate of 9.7 µm/min.

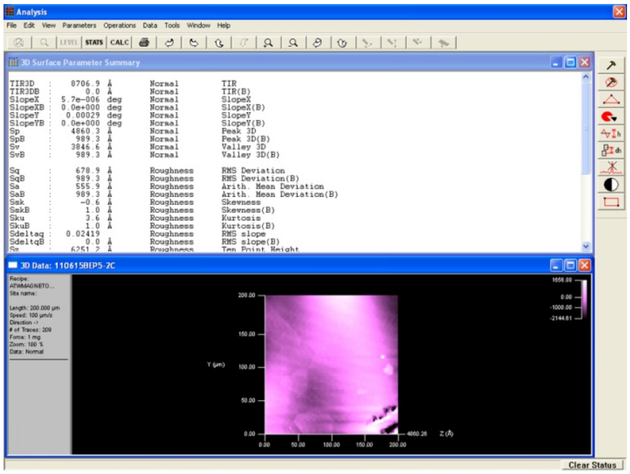
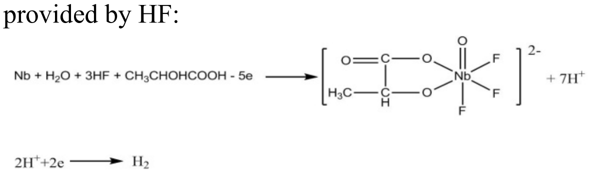


Figure 5: Profilometer image of the button sample that shows a Nb removal rate of 9.7 μm/min. As shown in the upper part, the RMS of the surface is 67.9 nm.

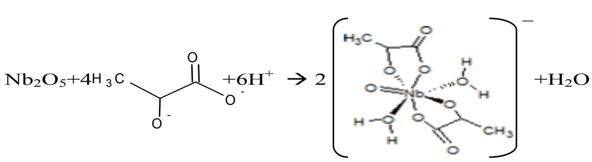
But3, profilometer measurements were performed. A typical result is shown in Fig.5. Root mean square (RMS) of the surface is 68 nm. This is much smoother than the typical RMS of 251 nm [11] of EP treated Nb surfaces.

This extremely high polishing rate of 10 μm/min as compared with EP of 0.3 μm/min must come from the use of an organic acid (lactic acid) and a slight increase in HF concentration in BEP electrolyte. It has been suggested [12,13] that lactic acid can participate in the removal of Nb in the following ways in addition to the removal provided by HF:



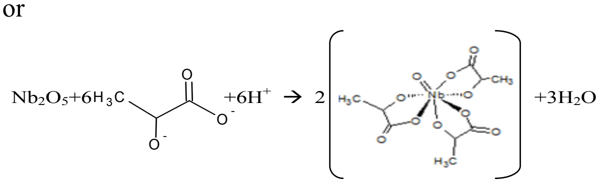
1)

or



2)

or



3)

This needs to be verified experimentally.

Another possible reason for the high polishing rate is that the visicosity of lactic acid is higher than that of sulfuric acid. It was noticed [4] that higher viscosity of the BEP electrolyte can increase the throwing power on the treated surfaces during polishing, leading to a higher polishing rate. At 20 $^oC$, the viscosity of latic acid is 53.5 cP [14] as compared with 26.7 cP of sulfuric acid [15]. To check how significant the difference it is in viscocity

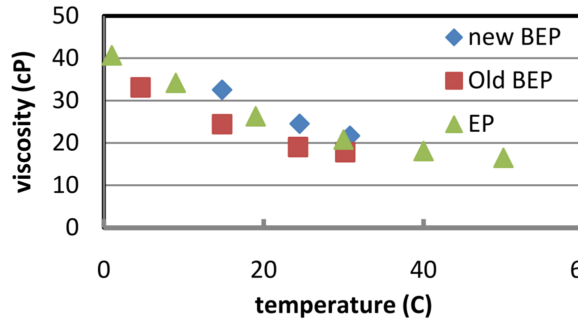



Figure 6: Viscosity measured as a function of temperature for old and new BEP and EP electrolytes.

between the electrolytes of BEP and EP, experiments are done and the results are shown in Fig.6.

High Nb removal rate is highly desirable due to the following reasons: 1) It is well known that during Nb cavity fabrication, a surface damage layer of 150 μm has to be removed. Using BEP will reduce this treatment time by 33. 2) High removal rate can reduce the contact time between SRF cavities and the nasty electrolyte, leading to a less chance for the cavities to get containimated and a smoother surface finish.

To summarize up, it is demonstrated that the polishing rate of BEP can be as high as 10 μm/min while the resulted surface is still much smoother than that of EP.

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