2015

Experiment and Results on Plasma Etching of SRF Cavities

J. Upadhyay
Old Dominion University

Do Im
Old Dominion University

J. Peshl
Old Dominion University

S. Popovic
Old Dominion University, spopovic@odu.edu

L. Vuskovic
Old Dominion University, lvuskovi@odu.edu

See next page for additional authors

Repository Citation

Upadhyay, J.; Im, Do; Peshl, J.; Popovic, S.; Vuskovic, L.; Valente-Feliciano, A. -M.; and Phillips, L., "Experiment and Results on Plasma Etching of SRF Cavities" (2015). *Physics Faculty Publications*. 277.
https://digitalcommons.odu.edu/physics_fac_pubs/277

Original Publication Citation

Upadhyay, J., Im, D., Peshl, J., Vuskovic, L., Popovic, S., Valente, A.-M., & Phillips, H. L. (2015). Experiment and Results on Plasma Etching of SRF cavities. In *Proceedings of the 6th International Particle Accelerator Conference*, Richmond, VA, May 3-8, 2015 (pp. 3581-3583). http://accelconf.web.cern.ch/AccelConf/IPAC2015/papers/wepwi040.pdf

Authors
J. Upadhyay, Do Im, J. Peshl, S. Popovic, L. Vuskovic, A. -M. Valente-Feliciano, and L. Phillips

EXPERIMENT AND RESULTS ON PLASMA ETCHING OF SRF CAVITIES

J. Upadhyay, Do Im, J. Peshl, S. Popović, and L. Vušković
Department of Physics, Center for Accelerator Science, Old Dominion University, Norfolk, VA 23529, USA
A.-M. Valente-Feliciano and L. Phillips
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

Abstract

The inner surfaces of SRF cavities are currently chemically treated (etched or electro polished) to achieve the state of the art RF performance. We designed an apparatus and developed a method for plasma etching of the inner surface for SRF cavities. The process parameters (pressure, power, gas concentration, diameter and shape of the inner electrode, temperature and positive dc bias at inner electrode) are optimized for cylindrical geometry. To study the etching of the inner surface of the varied diameter cylindrical structure, a stainless steel pill box cavity has been made. The niobium samples placed inside this cavity has been studied for etch affects purposes. The inner electrode has been moved and plasma response to the movement of the powered electrode has been seen. Plasma characterization is done with the help of optical emission spectroscopy.

INTRODUCTION

Currently used technologies for superconductive radio-frequency (SRF) cavities processing are buffered chemical polishing or electro polishing. These technologies are based on the use of hydrogen fluoride (HF) in liquid acid baths [1], which poses major environmental and personal safety concern. Plasma etching would be a much more controllable, less expensive and more environment-friendly processing technology. It would also provide the unique opportunity to tailor the niobium surfaces for better superconducting rf properties.

We have been developing the plasma etching technology for SRF cavity in multiple stages. In the first stage, we demonstrated plasma etching of a flat coupon of niobium (Nb) in a microwave plasma of 2.45 GHz frequency inside a quartz tube with a gas mixture of 97% argon and 3% chlorine [2]. The effects of plasma etching on niobium surface on flat coupon samples were studied [3]. In the second stage, to demonstrate plasma etching on the inner surface of three dimensional structures, we designed a cylindrical cavity with diameter equal to the beam tube of single cell SRF cavity of 1497 MHz and length 15 cm. Ring shaped Nb samples were placed on the inner surface of this cylindrical cavity for etch rate measurements. Coaxial-type plasma was generated with the help of different diameter inner electrode and rf (13.56 MHz) power with a gas mixture of 85% argon and 15% chlorine. To overcome the asymmetry in ion energy bombarding the outer electrode wall and the inner electrode wall of this coaxial plasma, an external dc power supply is added. The etching of the samples placed on the outer wall was not possible without the help of the positive bias provided by an external dc power supply.

The dependence of the pressure, rf power, diameter of the inner electrode and chlorine concentration on the etch rate was measured [4]. The etch rate mechanism of Nb in the rf plasma of Ar/Cl_2 was determined by varying temperature, positive dc bias and gas conditions [5]. The variation of etch rate non-uniformity on two ring samples placed along gas flow direction on the process parameters were studied [5]. In this stage, the idea to change the inner electrode geometry for less asymmetric plasma production was implemented and a corrugated structured electrode was developed. The second stage addressed the problem of etching a cylindrical structure but an SRF cavity is a variable diameter cylindrical structure. In a third stage, we designed a steel pill box cavity with similar dimension as a single cell SRF cavity of 1497 MHz. The pill box cavity is filled with ring type and disk type Nb samples on the inner surface. The purpose of this stage is to study the etch rate behaviour of Nb on all the available surfaces of varied diameter cylindrical structure. In the fourth and final stage, single cell SRF cavities would be plasma etched and rf tested at cold temperatures.

MOVING INNER ELECTRODE IN CYLINDRICAL CAVITY EXPERIMENT

It was found that the ring sample placed further from the gas entry point has substantially lower etching than the sample placed closer to the gas entry point. The depletion of active radicals (positive ions, excited neutrals, negative ions) along the gas flow direction due to consumption by Nb during the etching process is a critical challenge to uniform etching of a long cylindrical tube. Segment-wise plasma production can be a viable alternative to overcome this problem. The movement of the inner electrode in a coaxial plasma, where the inner electrode is rf powered and positively dc biased is applied to produce the plasma in the segmented fashion. To achieve this, inner electrode is attached to thin flexible cylindrical bellows. The compression in the bellows allows the movement of the inner electrode in the vacuum while the plasma is on. The gas flow is in the opposite direction of the rf power flow direction.

The moving electrode with cylindrical cavity is shown in Fig. 1. We produced the plasma in the cylindrical cavity and moved the electrode and found that the movement of the inner electrode does not affect the plasma or etching behaviour.

Figure 1: Cylindrical cavity with moving inner electrode for processing experiments.

To understand the plasma etching behaviour in a varied diameter cylindrical structure, we designed the pill box cavity by joining three cylindrical structures. The varied diameter cylinder is challenging due to two reasons. First, the discharge is asymmetric. Second, the consumption of the radicals is variable along the gas flow direction. This problem may be overcome by moving the electrode.The asymmetry in the plasma sheath voltage arises due to the surface area difference between inner and outer electrode, which varies along the cavity profile (as beam tube diameter is approximately half of the cell diameter). To avoid this complication, the inner electrode was chosen to be 9 cm in length, which is closer to the cell length.

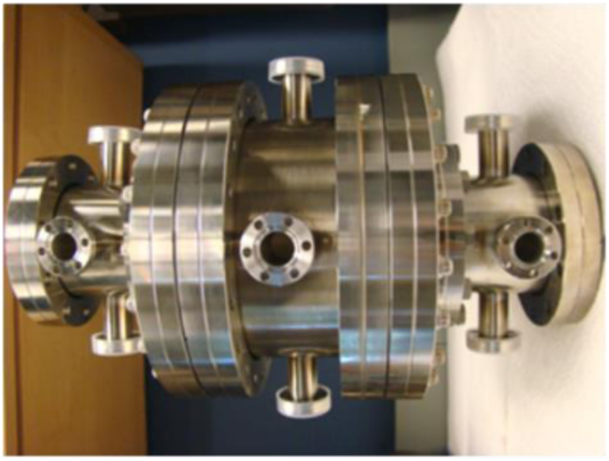

Figure 2: Cylindrical pill box cavity with varied diameter electrode.

The variable diameter cylindrical pill box cavity is shown in Fig. 2. The smaller cylindrical cavity is of 10 cm length and 7 cm diameter, which mimics the beam tube of the single cell cavity, while the middle cylindrical cavity is of 15 cm diameter and 10 cm length, which is close to cell geometry. Each cavity has four mini conflate flanges welded to it for diagnostic and sample holding purposes. This cavity is filled with different diameter Nb samples as shown in the Fig. 3.

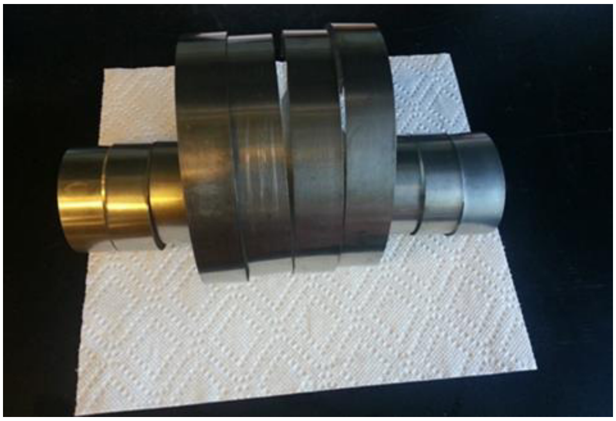

Figure 3: Different diameter Nb samples to be placed in the pill box cavity.

The disk type sample is used to cover the side wall of this cavity and see the effect of the plasma on the Nb placed there. The widths of the samples are 2.5 cm and only three samples are placed in each cavity to make sure a place is open for the optical window. The pill box cavity filled with ring type and disk type Nb samples with short electrode is shown in Fig. 4.

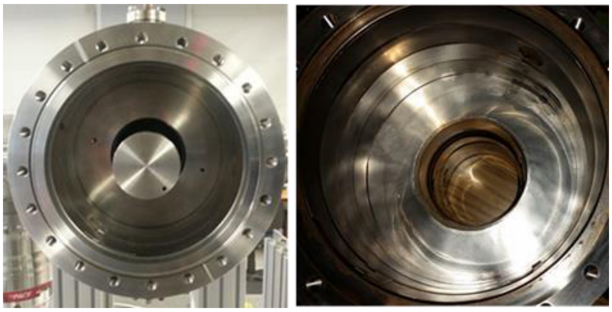

Figure 4: Niobium samples and electrode in the pill box cavity.

The concept of pill box cavity filled with Nb samples and a short electrode attached with linear translator provides an opportunity for segmented plasma production and to see the effects on the Nb placed on multiple surface. Due to complex shape of the SRF cavity it is harder to do any plasma based surface modifications uniformly on all the available surfaces. The segment wise plasma production/confinement with varied conditions optimum for that segment might be the solution. The plasma produced in the pill box cavity is shown in in Fig. 5.

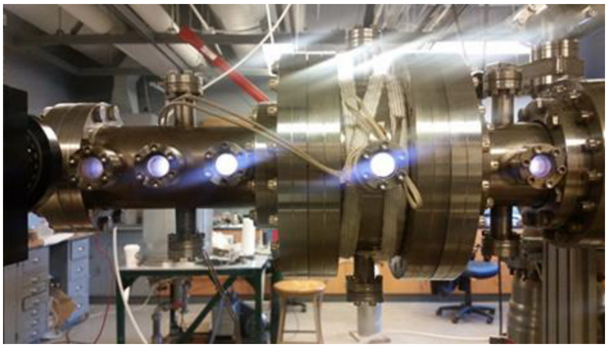

Figure 5: Pill box cavity with plasma.

The middle section of the pill box cavity is heated with the help of a heating tape to raise the temperature to compensate the decrease in etch rate due to higher asymmetry of that plasma, which is the consequence of this section's larger diameter. A closer look at Fig. 5 shows us that the plasma in third and fourth window from left shows much more intensity than the other windows as the inner electrode was positioned at that section, approximately.

CONCLUSION

Complex technological challenges facing the development of plasma based modification of inner surfaces of any three dimensional structure, the SRF cavity in particular, has been addressed in a systematic manner. The etch rate variation for niobium on different process parameters is established. The concept of varied diameter cylindrical cavities with holes for diagnostic and sample holding purposes has been chosen as a model for a single cell SRF cavity. The concept of inner electrode motion for segmented plasma production to overcome the multiple asymmetry and etch rate non-uniformity, has been applied. The next step would be to optimize the procedure, plasma etch actual single cell SRF cavity and apply the RF performance test.

AKNOWLEDGMENT

This work is supported by the Office of High Energy Physics, Office of Science, Department of Energy under Grant No. DE-SC0007879. Thomas Jefferson National Accelerator Facility, Accelerator Division supports J. Upadhyay through a fellowship.

REFERENCES

[1] P. Kneisel, Nucl. Instrum. Methods **557**, 250 (2006).

[2] M. Rašković, J. Upadhyay, L. Vušković, S. Popović, A.- M. Valente-Feliciano, and L. Phillips, J. Vac. Sci. Technol. A **29**, 301 (2009).

[3] M. Rašković, J. Upadhyay, L. Vušković, S. Popović, A.-M. Valente-Feliciano, and L. Phillips, Phys. Rev. ST. Accel. Beams **13**, 112001 (2010).

[4] J. Upadhyay, D. Im, S. Popović, A.-M. Valente-Feliciano, L. Phillips, and L Vusković, Phys. Rev. ST Accel. Beams **17** 122001 (2014).

[5] J. Upadhyay, D. Im, S. Popović, A.-M. Valente-Feliciano, L. Phillips, and L Vusković, J. Appl. Phys. **117**, 113301 (2015).