PLASMA TREATMENT OF NIOBIUM SRF CAVITY SURFACES*

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Abstract

Plasma based surface modification provides an excellent opportunity to eliminate non- superconductive pollutants in the penetration depth region of the SRF cavity surface and to remove mechanically damaged surface layer improving surface roughness. We have demonstrated on flat samples that plasma etching in Ar / Cl_2 of bulk Nb is a viable alternative surface preparation technique to BCP and EP methods, with comparable etching rates. The geometry of SRF cavities made of bulk Nb defines the use of asymmetric RF discharge configuration for plasma etching. In a specially designed single cell cavity with sample holders, discharge parameters are combined with etched surface diagnostics to obtain optimum combination of etching rates, roughness and homogeneity in a variety of discharge types, conditions, and sequences. The optimized experimental conditions will ultimately be applied to single cell SRF cavities.

INTRODUCTION

To improve the RF performance of the SRF niobium cavities, the cavity surface must be prepared by a process that improve surface roughness, remove impurities and create less sharp grain boundaries. Currently used technologies are buffered chemical polishing or electro polishing. These technologies are based on the use of hydrogen fluoride in liquid acid bath, which poses major environmental safety concern. HF-free plasma-based ("dry") technologies are a viable alternative to wet acid technologies as they are much more controllable, less expensive and more environment-friendly. We have seen that plasma etching technology has replaced the wet etching process in semiconductor industry.

FLAT SAMPLE EXPERIMENT

To understand the plasma etching of bulk Nb we designed a microwave based barrel type reactor for flat sample etching. Scheme of the experimental setup is shown in the Fig. 1. The etching gas mixture contained 0.3 to 3% chlorine diluted in Argon. Gas pressure in the reactor was maintained at 0.1 to 1 Torr using a rotary and turbo pump combination. The disk-shaped Niobium sample was placed in the middle of a cylindrical microwave cavity supporting TE01 mode. Therefore dominant component of the electric field was perpendicular to the sample surface. This arrangement supported the anisotropic feature of the radical dynamics in the vicinity of the surface. A systematic study of the effect of variation of microwave power density and gas pressure on the etching rate and surface roughness of disk shape Nb sample has been carried out. Extensive optical emission spectroscopy measurements were used to study actual mechanism of the etching and chemical kinetics of Nb transport out of the cavity. Gas temperature in the reactors supports volatile effluents from as much as eight different chemical reactions on the surface involving Nb and its oxides. Although $NbCl_5$ is found to be the dominant effluent, other Nb chlorides and oxychlorides are present in the Nb transport kinetics.

While the results with flat samples were very encouraging, with etching rates up to 1.7 μm/min and surface roughness down to below 100 nm, the two parameters could not be achieved with the same treatment. Results are indicative of competitive character of the surface smoothness and etching rate. In every case, however, the surface roughness of plasma etched sample is equal or better than the chemically etched samples [1, 2].

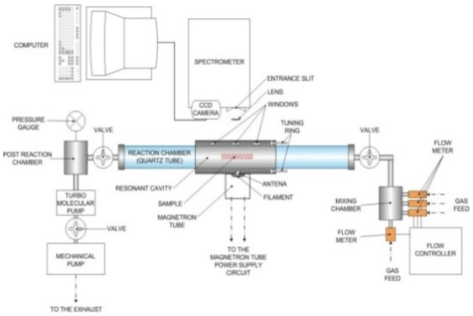

Figure1: Experimental setup for flat sample experiment [1].

SINGLE CELL EXPERIMENT

In order to test the RF performance, plasma processing has to be applied to a single cell cavity. Cavity shape is defined by the resonant low-loss requirement for generating the accelerating gradients. This design does not favor the electric configuration on the surface that is optimal for plasma etching. Therefore, the generic etching configurations are capacitive coupled radio frequency or a coaxial microwave discharge. In the first approach, the radio-frequency discharge seems to be the natural choice.

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To do the plasma etching of a single cell cavity a bell jar system has been built, the whole bell jar would be under vacuum with the help of a turbo molecular pump backed by a rotary pump. The schematic diagram of the system has been shown in Fig. 2. The plasma is produced with the in-house built AC power supply.

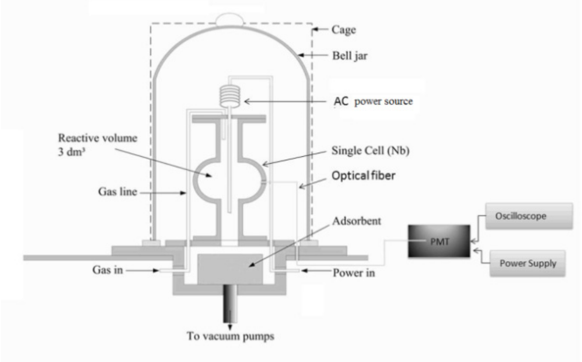

Figure 2: Schematic diagram of single cell cavity experiment

For the single cell cavity plasma etching experiment we adopted a single cell cavity with 20 sample holder holes symmetrically placed on cavity ellipsoid. These holes can be used for the sample etching experiment (where samples are placed on the actual geometry of the single cell cavity) as well as the diagnostic port for the plasma parameters measurement. The image of the cavity is shown in Fig. 3.

Figure 3: Specially designed single cell cavity.

To measure the plasma properties an electro –optical probe (a combination of Langmuir and optical fiber) would be used. 1 mm optical fiber is used with the help of feedthrough for spectroscopy measurement of the plasma inside the cavity. The optical fiber arrangement is shown in Fig. 4.

Figure 4: Bell jar system for single cell cavity with multiple optical fiber diagnostic setup

To partially overcome the asymmetric discharge which arise due to cavity geometry, a specially designed electrode for the single cell cavity is being used which is shown in Fig. 5.

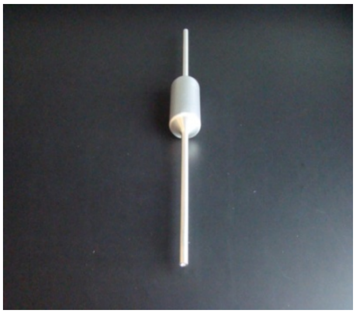

Figure 5: Specially designed electrode for single cell cavity.

The plasma parameter variation between driven and grounded electrode are much smoother with this new electrode. The electron temperature variation across the diameter at the equator is shown in Fig 6.

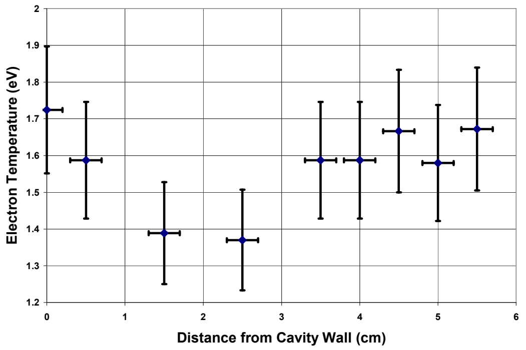

Figure 6: Electron temperature variation across the diameter of the cavity

CONCLUSION

In order to develop the plasma etching technology for the surface processing of superconducting radio frequency cavity we have completed the first step which was to prove the bulk removal of niobium and the surface smoothness of the sample. We have partially overcome the problem of non uniform plasma with the help of our new electrode. We are in the process of optimizing the plasma parameters for the etching of the sample placed on actual geometry of the cavity.

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