PLASMA TREATMENT OF SINGLE-CELL NIOBIUM SRF CAVITIES

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Abstract

In our previous work, 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. Here we report on the progress in experimental design for plasma processing of a single cell SRF cavity. The experiments are centered on two discharge types - asymmetric RF and low mode microwave cavity discharge. We report on the experimental design of the setup with a specially designed single cell cavity with sample holders, and discuss the diagnostics of plasma and samples. We provide preliminary results on the RF discharge in the single cell that is to be the main part of the optimized experiment.

INTRODUCTION

It has been confirmed with flat samples in a barrel type microwave plasma reactor that plasma etching is a viable alternative to BCP and EP techniques [1, 2]. The schematic of the experimental setup is described in detail in Ref [1]. The etching gas mixture contained 0.3 to 3% chlorine diluted in Argon. The gas pressure in the reactor was maintained at 0.1 to 1 Torr using a rotary and turbo pump combination. The disk-shaped Nb sample was placed in the middle of a cylindrical microwave cavity. 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 the actual mechanism of the etching and chemical kinetics of Nb transport out of the cavity (to be published). The 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.

The results with flat samples were very encouraging, with etching rates up to 1.7 μm/min and surface roughness comparable to wet processing. The results were indicative of the competitive character of the surface smoothness and etching rate [2].

While, during the development of plasma processing of bulk Nb cavities, the adequate etching rates have never been in doubt [3], further experiments were dictated by the characteristics of plasma source power supplies. This is especially the case in the single cell etching apparatus. Currently we are utilizing sources that operate at two fixed frequencies or in a narrow frequency range - ”low” frequency, operating around 100 MHz, and ”high” frequency, operating at 2.45 GHz. In the classification of plasma sources the ”low” frequency source signifies a capacitively coupled radio-frequency (RF) discharge [4]. Under the term ”high” frequency source we are confined to a barrel type microwave cavity discharge reactor. In this configuration the single cell cavity is out of resonance. The SRF cavity geometry is optimized to almost exclusively generate axial gradient at about 1.5 GHz. However, for etching purposes, a slight radial gradient in the wall boundary layer (sheath) is needed to insure the transport of etching radicals to the wall [2].

This sheath gradient is readily provided in the RF discharge configuration with a shaped driven electrode placed along the axis of the cell. The electrode shape insures constant gradient in the wall sheath at all latitudes from iris to equator. Due to the limited diameter of the iris, the inter-electrode distance varies with latitude, the driven electrode being substantially narrower. This leads to the inequality of sheath gradients and to the configuration usually called the ”asymmetric” discharge [4]. The correction of the asymmetric discharge is possible with the use of two or more sources operating at different frequencies [5], what we will consider in the future. Presently, the walls are processed with minimum etching rate as opposed to minimum uniformity. The approach is currently being tested on an array of samples in a specially designed single cell cavity.

The microwave discharge can operate with or without the central driven electrode. The main problems of the resonant cavity approach (absent central electrode) are (a) the mismatch of the source and resonant frequencies leading to the generation of higher modes and possible cusps in the plasma wall sheath, and (b) the longitudinal attenuation of the travelling wave due to reflection and absorption in the plasma. The coaxial electrode approach leads to the impedance mismatch along the cell due to the limitations in the driven electrode shapes.

Thus the disparate problems with ”high” and ”low” frequency dictate parallel work with the single cell cavity. Both systems are being tested on the experimental perforated single cell cavity and then transferred to the single cell for RF performance tests.

In this paper, we report on the current status of the work on the plasma processing of the single cell. After a brief description of the experimental cell, we show the schemes of the RF power circuit and diagnostics, discuss the results of the RF plasma diagnostics, and conclude with the description of the work plan in the immediate future.

SINGLE CELL EXPERIMENT AND DIAGNOSTICS

For the single cell cavity plasma etching experiment we adopted a single cell cavity with 20 sample holders symmetrically placed on the cavity ellipsoid. These holders can be used for the sample etching experiment (where samples are placed on the actual geometry of the single cell cavity) as well as diagnostic ports, for the plasma parameters measurement. These elements can be seen in the image of the cavity shown in Fig. 1.

The diagnostic tools include fiber optical probes for optical emission spectroscopy and discharge tomography, a time and space resolved image spectrometry equipped with a gated ICCD detector to study the local kinetics of the RF discharge, and an RF compensated Langmuir probe for local ion density measurements.

Figure 1: Specially designed perforated single cell cavity with optical fiber diagnostic tools.

The scheme of the ”low” frequency RF power supply is given in Fig. 2. The supply is capable of varying the output power from 10 to 500 W, but the plasma presents a highly nonlinear circuit element and adjustment of the matching network is necessary after each power increment of 20-50 W. The connection to the plasma applicator is still being developed and the study of global properties of the asymmetric RF discharge is ongoing.

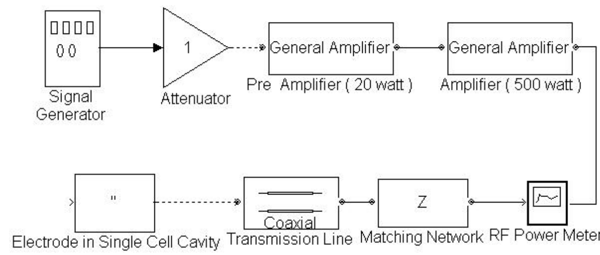

Figure 2: Scheme of the RF power supply.

Figure 3: Complete system including RF power supply, vacuum system, bell jar assembly and diagnostic units.

Figure 4 presents the variation of the argon spectral line intensity at a port location as a function of the RF power applied to the plasma.

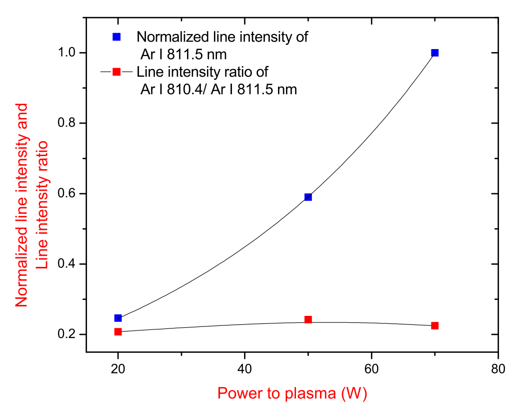

Figure 4: Power dependence of Ar level populations in RF plasma.

It consists of two data series. The first data series is the normalized (to the 70W value) population of a low energy 4p level, corresponding to the spectral line at 811.5 nm. It increases exponentially with power. The second data series is the ratio of population of a high energy 4p level, corresponding to the spectral line at 810 nm, and the population of low energy level. This ratio is close to saturation at higher power, suggesting that the populations are approaching equilibrium distribution. This is a favourable plasma condition for sheath stability.

CONCLUDING REMARKS

We present a progress report on the development of plasma processing of Nb SRF cavities. The present goals are to determine the most efficient discharge type between the "low" and "high" frequency systems assembled out of the existing RF and MW components. For each system type the goal is to define optimum operating conditions based on the criteria of minimum tolerable etching rate and minimum surface roughness. The optimum conditions are investigated with plasma diagnostics and Nb samples. The final tests will be performed on standard single cell cavities to be RF tested at cryogenic temperature.

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