PLASMA PROCESSING R&D OF THE 1.3 GHz SINGLE-CELL SRF CAVITY AT IMP*

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Abstract

The China-Accelerator Driven Sub-critical System (C-ADS) injector II has already commissioned with a CW 1 mA and a pulsed 10 mA proton beam. The beam energy achieved 10 MeV. The superconducting linac (SCL) is routinely operating at 4.7 MV/m average accelerating gradient in the low-beta cryomodules. Field emission and surface contaminants of the SCL limit the gradient increase in the beam commissioning. Hence, in order to increase the SCL accelerating gradient, reduce field emission and remove surface pollutants, in-situ plasma processing R&D in a 1.3 GHz single-cell SRF cavity has being studied. In this paper, the current effort of plasma processing R&D in a 1.3 GHz single-cell SRF cavity will be presented in details and the future plan will be also reported.

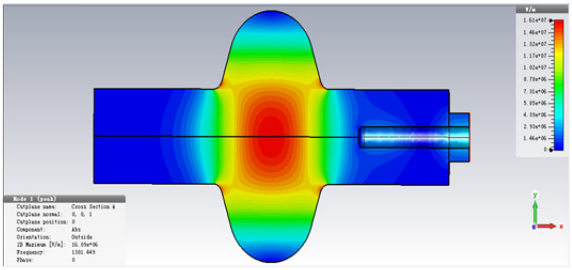
INTRODUCTION

It is significant that the performance of superconducting radio-frequency (SRF) cavities is gradually improved at present. Field emission is a prominent issue that limits the accelerating gradients of SRF cavities, and the surface contaminants (hydrocarbon) also restrict the performance of SRF cavities [1, 2]. However, it has been confirmed that plasma processing can improve the performance and increase the accelerating gradients of SRF cavities in operation [1]. Plasma processing is largely different from electrochemical polishing (EP) and buffered chemical polishing (BCP). The EP and BCP are very necessary for cleaning internal surface of SRF cavities to use concentrated acids that is not safe and contaminate the environment, while plasma processing cleans internal surface of SRF cavities with complicated chemical reactions and ion bombardments. In the plasma processing, ion bombardments via inert gas RF discharge or microwave discharge can be used to etch the surface, and chemical reactions via a small amount of oxidized gas in discharge can be used to oxidize the contaminants.

Recent work at Institute of Modern Physics (IMP), Chinese Academy of Sciences has explored plasma processing based on a 1.3 GHz single-cell SRF cavity. In this paper, we will present electromagnetic field design, show the experimental set-up, discuss the preliminary results and conclude with a future plan.

ELECTROMAGNETIC FIELD DESIGN

The primary aims of plasma processing are to reduce field emission and eliminate the surface contaminants (hydrocarbon) in SRF cavities. We choose the Argon as the discharge gas and the Oxygen as the reaction gas, and the critical issue is to design the electromagnetic (EM) field so that it can produce the plasma. A plasma discharge is an ionization of a gas induced by a strong RF/microwave electromagnetic field, resulting in the breakdown of electrical insulation. This eventually produces a swarm of charged particles (electrons/ions), leading to a high current [3]. The plasma only concentrates in the E-field region but not in B-field region [4]. A uniform distribution of E-field is a key value to obtain well-proportioned plasma. As a consequence, using the CST MWS [5] to analyze the cavity EM field from an approved coupler design, we discover that E-field have a uniform longitudinal distribution in the cell, shown in Fig. 1.



Mode 1 (peak)
Cutplane name: Cross Section A
Cutplane normal: 0, 0, 1
Cutplane position: 0
Component: Abs
Orientation: Outside
2D Maximum [V/m]: 16.09e+06
Frequency: 1301.449
Phase: 0

Figure 1: The E-field distribution in a 1.3 GHz single-cell SRF cavity.

On the other hand, the coupler transfers the RF power into the cavity and the plasma absorbs the RF power, therefore, the antenna structure of coupler has to be well designed. We adopt a straight antenna, and its design drawing is shown in Fig. 2. The antenna material is copper or titanium. The fundamental mode of the 1.3 GHz single-cell cavity is TM010 that is stimulated by the antenna.

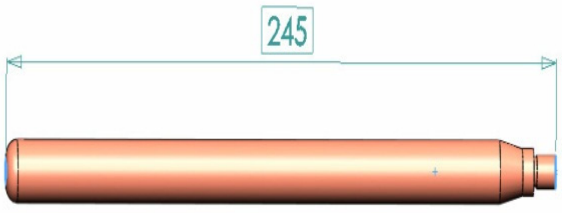


Figure 2: A schematic drawing of the straight antenna.

What's more, we calculate the external Q and it versus antenna length is plotted in Fig. 3. Unload Q of the cavity is approximate 8400 measured by a Vector Network Ana-

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lyzer in normal temperature. For one thing, the cavity wall will consume energy; for another, the plasma also will consume RF power and the quality factor of the plasma can not be measured or calculated precisely by far. Thus, in order to get the minimum reflection power， the value of the external Q was selected 7500 with a coupling factor of 1.12 when the antenna length is about 90 mm.

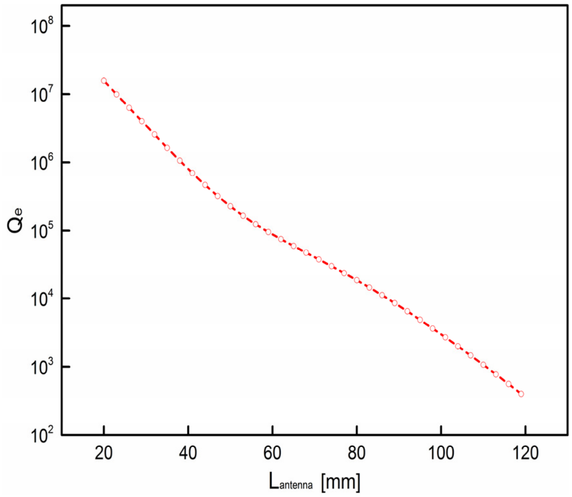

Figure 3: The external Q versus the antenna length in the cavity.

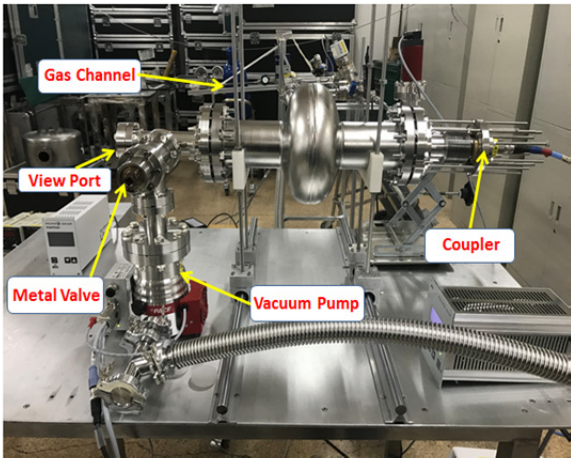

Figure 4: The plasma processing experimental set-up with a 1.3 GHz single-cell SRF cavity.

THE EXPERIMENTAL SET-UP

The details of the experimental set-up is shown in Fig. 4. The cavity is powered by a RF power source (1.3 GHz, 300 W). The RF power is coupled by a transmission line and a feedthrough (coupler). The gas flows into the cavity through a port on a tuning coupler which closes the end-flange of the beam pipe. A vacuum port is connected on the other end-flange through a three-channel pipe with a mechanical pump and a turbo molecular pump. The gas pressure and gas flow are monitored by two vacuum gauges and three flow meters connected to the whole gas circuit. The forward power and reflection power are measured via a power meter connected to directional couplers. In addition，a view-port is installed on a three-channel pipe near the end-flange.

THE PRELIMINARY RESULTS

In the initial experimental process, discharge gas is Argon. The ionization energy of Argon is 15.76 eV which is smaller than the ionization energy of Neon (21.56 eV) and Helium (24.59 eV). Consequently, it is probable that Argon is prone to be ignited in experiment. In order to ignite Argon plasma, TM010 mode is excited in the 1.3 GHz single-cell cavity with a coupling factor of 1.12. Under the circumstances, we discover that the plasma can be ignited with the minimum pressure of 6 Pa. In addition, when the RF power and gas pressure are altered, we observe that the plasma colors have been varied from red to grey, shown in Fig. 5. It is likely that various colors of the plasma represent different plasma energy.

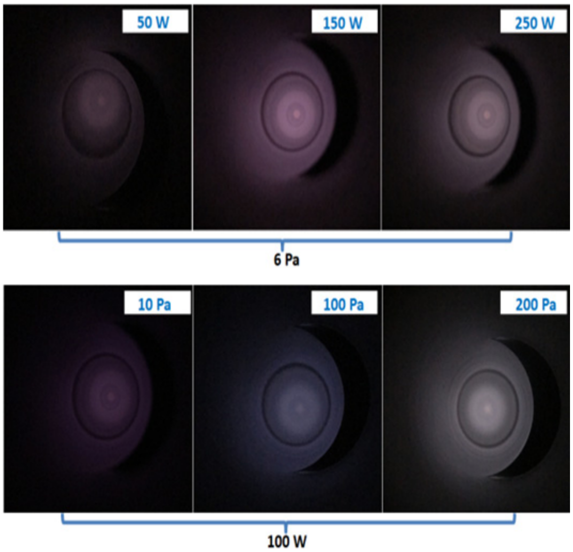

Figure 5: The Argon plasma drawings with different RF power and pressure.

CONCLUSION AND FUTURE PLAN

The plasma processing system of a 1.3 GHz single-cell SRF cavity has been designed preliminarily at room temperature. We show that radio-frequency Argon plasma is generated in the cavity with different RF power and gas pressure. And, we discover that in the case of the TM010 mode and 1.12 coupling factor, the plasma can be ignited with the minimum pressure of 6 Pa and the plasma colors are changed from red to grey with varying RF power and gas pressure.

The future research will be focused on optimizing, altering the electromagnetic field mode and mixing Oxygen into Argon. Optical emission spectroscopy and Langmuir probe will be used to measure the plasma properties.

ACKNOWLEDGEMENT

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