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THE DESTRUCTIVE EFFECTS TO THE RF COUPLER BY THE PLASMA DISCHARGE*

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Abstract

The low temperature RF plasma was proved an effective method to clean the niobium surface and relieve the field emission effect for the SRF cavities. In the case of half-wave resonators, these cavities were usually powered via the fundamental coupler with the electric coupling. Thus, coupler antennas were fixed in the intense electric field region, and this region was where the plasma routinely ignited. Therefore, the ceramic window of coupler taken the risk of breakdown under the sputtering of ions and heating loads that may be caused by the plasma drift and diffusion from the electric field region. In this paper, the plasma ignition for surface cleaning on the HWR cavity and its coupler was investigated, and the power transmission, temperature raising and vacuum degradation were tested to characterize the adverse impacts on the ceramic window. Finally, the solution was proposed to figure these issues.

INTRODUCTION

The online technique of plasma cleaning was already developed to relive the field emission effect for the multi-cell elliptical cavities on SNS facility [1-2]. In addition, the plasma cleaning was also proved an effective mothed for the HWR in previously study [3]. However, there were some issues need to be solve for HWRs to utilize the plasma technique online with safety and reliable. In the mechanism research of in-situ plasma cleaning for HWR cavity, a special variable coupler was temporally used in order to reduce the mismatch between the Q_{ext} of antenna and the Q_0 of cavity at room temperature. Thus, the online plasma ignition and control on the HWRs needs to be verified by the fundamental power coupler with the same Q_{ext}. A HWR015 cavity and a dual ceramic window coupler were configured for the online plasma ignition experiment. The Q_0 was 5.4×10^3 at room temperature, and the Q_{ext} was 5.4×10^5 to match loading of the 10 mA of CW proton beam for CiADS project.

The argon was selected as ignition gas and frequency of the fundamental mode of cavity was used, which were same recipes with previous mechanism study [3]. The threshold value of peak electric field of the inner surface was about 15-150 kV/m for the argon ignition with gas the pressure range of 0.5 to 1.2 Pa that in the previous study with coupling strength of 0.9 and its corresponding RF power forward was 20-150 Watters. However, the coupling factor for operation online was only 0.039. Thereby, the threshold forward power could be increased in this online condition to establish the enough electric field strength for argon plasma ignition and its power value would be 0.5-3.75 kW.

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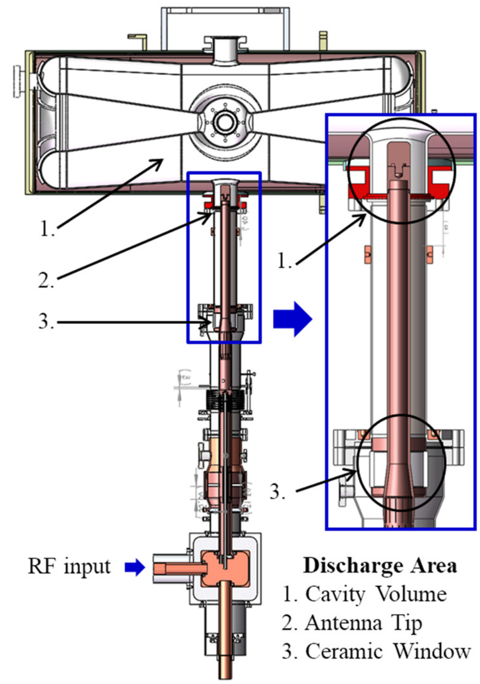

Figure 1: HWR015 assembled with coupler for plasma online ignition.

DESTRUCTIVE EFFECTS TO COUPLER

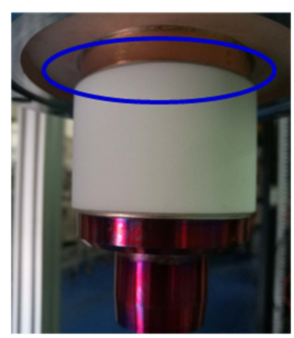

Figure 2: Vacuum leakage of cold ceramic window caused by argon plasma.

The inside space of HWR015 and coupler was classified into three areas, which were the cavity volume, antenna tip area and the cold ceramic window region, as shown in the Figure 1. The plasma ignition in the cavity volume was required for cleaning but in the coupler region would be avoid protecting the ceramic window from breakdown. However, the experiment revealed that the argon plasma was primarily ignited at the cold ceramic window and the antenna tip region during increasing the forward power slowly. Moreover, the cavity volume was hardly contained

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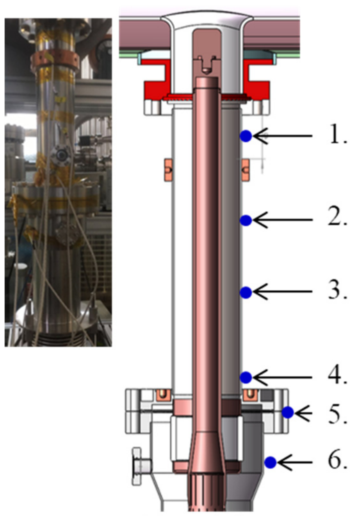
with plasma by changing the gas pressure and increasing forward power. Finally, the warm window part was disassembled to expose the cold window for vacuum checking. The checking results indicated that cold ceramic window was breakdown with vacuum leakage rate of 1.5×10^{-4} mbar•L/s at the interface of welding between ceramic and copper that caused by the frequently argon plasma discharge, the leakage position was shown in the Figure 2.

Impact on RF Transmission



Position of thermocouples

Figure 3: Schematic diagram of thermocouples on the coupler.

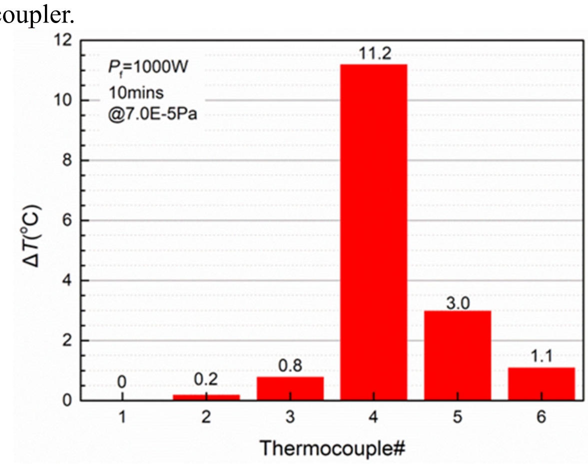


Figure 4: Temperature variation of coupler surface after the argon plasma discharge.

The surface temperature of the coupler out conductor was measured to evaluate the performance degradation of coupler induce by the argon plasma discharge. The position of thermocouples was shown in the Figure 3. The test under the condition of 1 kW forward power to cavity, the background vacuum was about 7×10^{-5} to 9×10^{-5} Pa, and operation time was 10 mins. The temperature was rarely increased with maximum about 0.2 K before the argon plasma discharge. However, the variation of temperature increasing was reached maximum value of 11.2 K at where the cold ceramic window region after the argon plasma discharges experiment, as shown in the Figure 4. This result illustrated that the characteristics of ceramic surfaces was modified to some extents.

Copper Sputtering During the Plasma Cleaning

The visual inspection was conducted for the cold ceramic window and inner HWR cavity surface, as shown in the Figure 5. The ceramic window was seriously covered with the metal material that might be copper, which sputtered by the plasma. Thus, the metal material on the window caused the additional RF power deposition that result in temperature increasing and wielding interface breaking. In the antenna tips region, the copper was eroded, and then coated on the coupling tube surface of HWR015. The foreign contamination of copper coating might induce the adverse impact for cavity because it was non-superconductivity material.

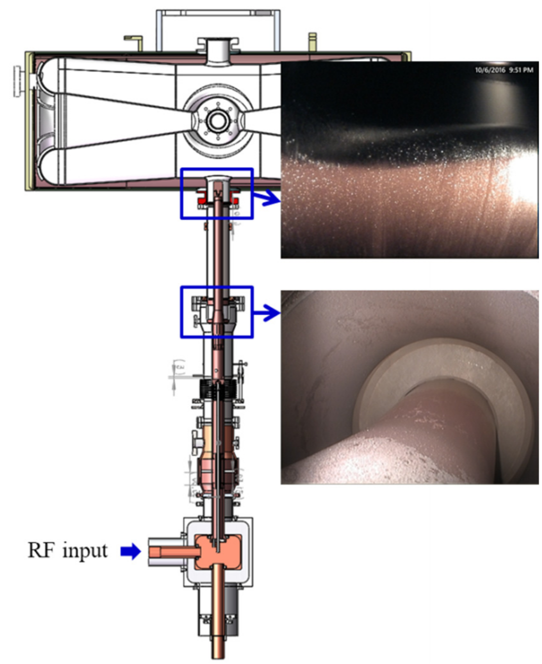


Figure 5: Visual inspection by optical camera.

SOLUTION AND NEXT WORK

Dependence of Discharge Region on the Ignition Gas

Table 1: Plasma Discharge Region with He/Ne/Ar Gas

Discharge Areas	Helium	Neon	Argon
Cavity Volume	Yes	Yes	Hardly
Antenna Tip	Yes	Yes	Yes
Ceramic Window	No	Yes	Yes

Instead of argon, the neon was selected for plasma cleaning of the multi-cell elliptical cavity to avoid the discharge in the fundamental coupler at Oak Ridge Lab. The ionization energy for neon was higher than argon, thus the threshold electric field for plasma ignition on coupler would be

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increased that avoid the priority discharge on coupler than cavity. Thus, the argon, neon and helium were employed for HWR plasma discharge, as shown in the Table 1. Our experiment indicated that the plasma discharge at ceramic window can be avoided by using of helium gas, but the plasma in the antenna tip region was not removed and the issue of copper erosion needs further consideration.

Avoid Sputtering by Turning Plasma Parameters

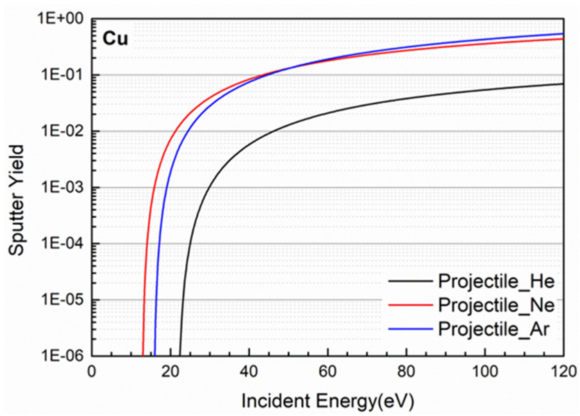

Figure 6: Sputter yield of copper by He/Ne/Ar ions as the function of incident energy.

The erosion of material induced by the sputtering progress in the plasma was mainly depend on energy of ions reached on the surface and the ion species of projectile. For the certain kind of target material and ions, the sputter interaction would not occur when incident energy belows to the threshold value. A partial empirical formula was widely used to evaluate the sputter yield rate, which proposed by Noriaki Matsunali et al [4]. From this formula, the sputter yield rate of copper was calculated as the function of incident energy with bombardment of He/Ne/Ar, as shown in the Figure 6. The helium ions with highest threshold incident energy of 22 eV for sputter progress, thus turning the plasma parameters to reduce the kinetic energy of helium ions below 22 eV, the copper contamination in the HWR cavity can be avoid. In the plasma physics, there is a bias voltage region called electric sheath between the plasma region and the surface of the cavity, and this bias voltage accelerated the ions to bombard the surface of the cavity. The bias voltage is determined by the electron temperature, as follows:

$$V_{\text{sheath}} = -\frac{T_e}{2} \cdot \ln\left(\frac{M_i}{2\pi \cdot m_e}\right) - \frac{T_e}{2} \qquad \text{(Eq. 1)}$$

From the (Eq. 1), turning the electron temperature was ideal method to solve sputter effect of copper in the plasma cleaning treatment, and the characterization and turning of helium plasma will be conducted in our next work.

CONCLUSION

The realization of plasma cleaning online for HWR cavity was limited by the distructive effects to the coupler. Plasma ignition with the helium gas was proper chioce for protecting coupler window from destruction. And the characteristic of helium plasma needs for more detail study to eliminate the risk of copper coating on the HWR cavity.

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