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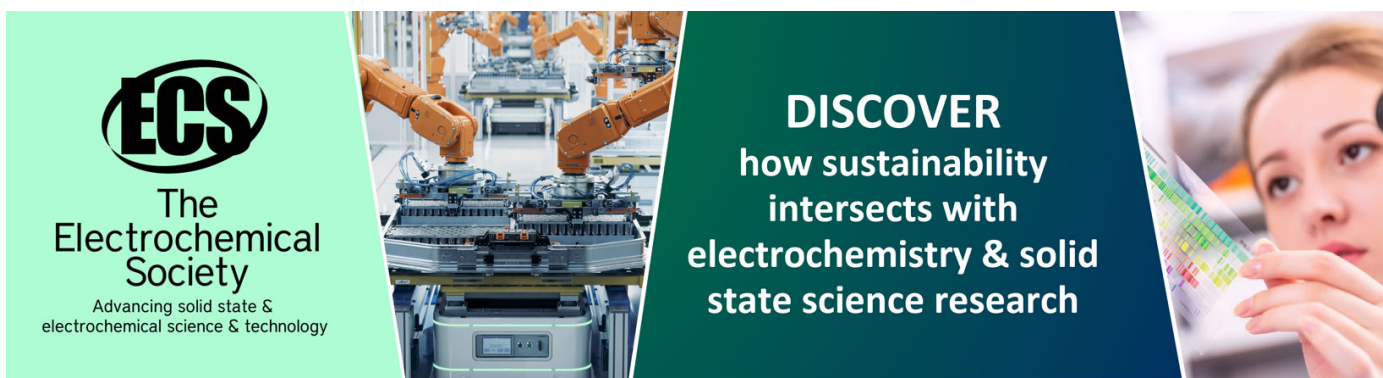
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Investigation of plasma chamber erosion in an RF ion source

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Abstract. Filament driven plasma sources are widely used to produce ion beams, but they require frequent maintenance due to the limited filament lifetime. External radio-frequency (RF) coupled ion source offers a filament-free plasma and hence better maintenance. However, one of the issues encountered during the development of a planar external RF-powered ion source at D-Pace was the erosion of its copper plasma chamber and subsequent formation of copper deposits on the Aluminum Nitride (AlN) RF window. The copper deposits on the RF window deteriorate the power coupling between the external antenna and the plasma. This paper investigates the erosion of the plasma chamber and describes some of the methods used to control the deposition of copper on the RF window.

1. INTRODUCTION

D-Pace is developing a 13.56 MHz RF ion source capable of producing negative ion beams (H^- , D^-) of energy around 25 keV [1]. The cross-section view of the RF ion source is shown in Fig. 1. The ion source is a hybrid design between the TRIUMF-licensed filament ion source [2] and the RADIS ion source licensed from the University of Jyväskylä [3]. The RF ion source uses a 3-turn planar spiral external RF antenna for sustaining an Inductively Coupled Plasma (ICP) inside the copper plasma chamber. The RF antenna is powered by a 5kW RF power supply, through an L-network impedance matching circuit. The RF power is coupled between the antenna and the plasma through an Aluminum Nitride (AlN) RF window. The beam extraction system consists of the plasma electrode, the extraction electrode and the ground electrode. The beam current is measured using a water-cooled Faraday cup at about 480 mm from the plasma electrode.

This new RF ion source is expected to have lower maintenance compared to D-Pace's TRIUMF-licensed filament ion source due to the filament-free operation. Currently, D-Pace's TRIUMF-licensed filament ion source has a filament replacement period of about 500 hrs at 10 mA H^- beam output [4]. We expect the new RF ion source maintenance to extend to once per year or two years with downtime related only to the RF window replacement. However, it has been found that the plasma-facing surface of the RF window gets coated with copper during the regular operation of the ion source, as shown in Fig. 1. These metal deposits decrease the power coupling from the spiral antenna to the plasma and deteriorate the beam current extraction from the ion source. For example, the H^- beam current decreases by more than 50% in about 20 minutes of operation at about 800 W of RF power and 10 sccm H_2 gas flow. It is evident from the experiments that Cu is getting eroded from the plasma chamber during the operation and subsequently getting deposited on the AlN RF window. A known method of reducing the Cu erosion



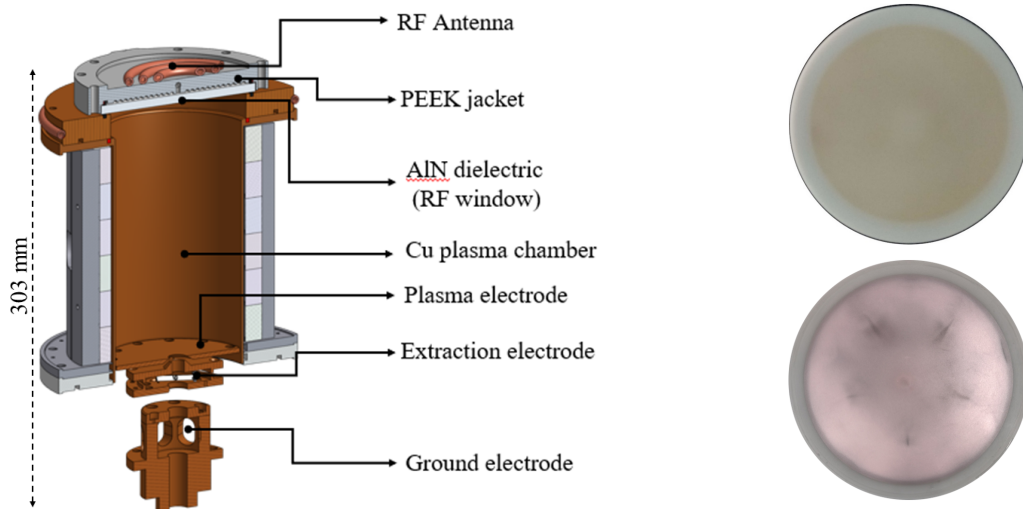


Figure 1: (L) Cross section view of D-Pace's RF ion source design with Cu plasma chamber of size 98.4 X 160 mm, and (R) Picture of plasma-facing surface of the AlN RF window cleaned (top) and after (bottom) experiments using 10 sccm H_2 gas flow.

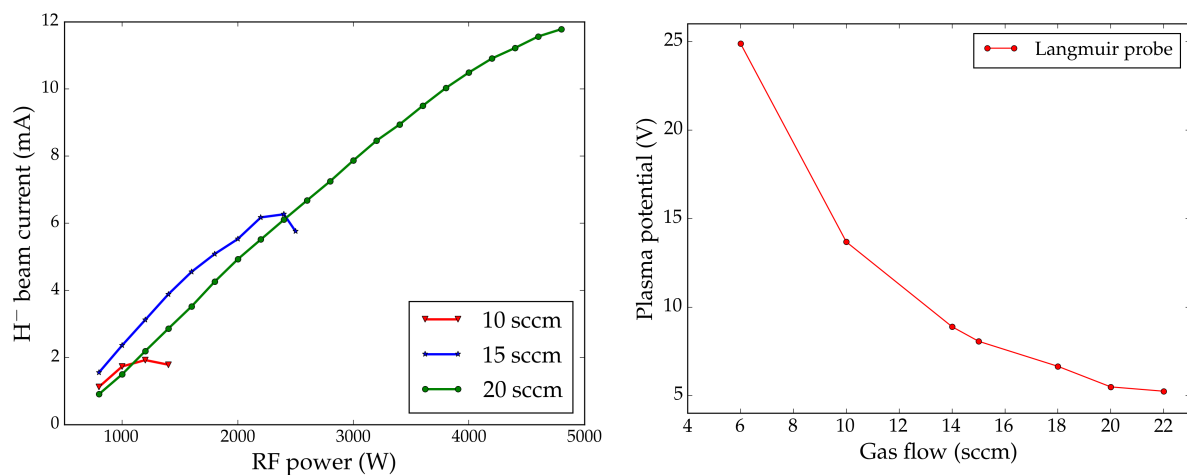


Figure 2: (L) H^- beam currents measured at the Faraday cup for different RF power and gas flows, and (R) Plasma potential response of the RF ion source at different gas flows. The study was done using an RF compensated Tungsten Langmuir probe inserted into the plasma through the plasma electrode aperture. The tip of the probe was at 12 mm axially from the plasma electrode

is the application of a Molybdenum coating to the plasma facing surfaces [5]. However, initial tests performed using a Mo liner on the chamber also showed sputtered deposition on the window. Different trials were performed to control the deposition of copper on the RF window in an H_2 plasma and some of the methods investigated are explained in this paper.

2. EXPERIMENTS AND DISCUSSIONS

2.1. Effect of gas flows

H^- beam extraction experiments were performed at different gas flows and the results are shown in Fig. 2(L). As can be seen, the beam extraction improves with increase in gas flows and this is due to

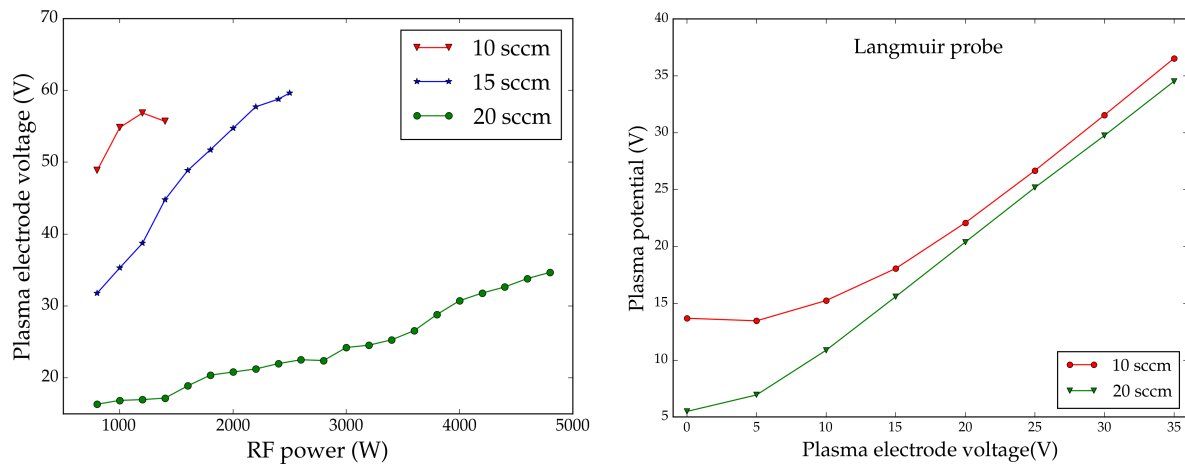


Figure 3: (L) The corresponding plasma electrode voltages used in the beam current-gas flow experiments in Fig. 2, and (R) Langmuir probe measurement of the plasma potential values in the RF ion source at different plasma electrode voltages and gas flows.

a lower rate of Cu deposition on the RF window at higher gas flows. At 20 sccm of gas flow (≈ 18 mTorr in the plasma chamber), close to 12 mA of H^- is measured at the Faraday cup and no decrease in beam current was noticed during the operation of the ion source. However, at lower gas flows the Cu deposition occurs faster and beam current decrease is observed. In general, the plasma potential decreases as the gas flow increases as shown in the Langmuir probe [6] measurements of Fig. 2(R). The copper plasma chamber erosion can be mostly due to the bombardment of ions on the chamber walls. The ions accelerated through the plasma sheath potential can cause the erosion if they acquire energy more than the sputter threshold of the copper chamber. The ion energy at the walls and hence the erosion can be reduced by decreasing the plasma potential using higher gas flows.

2.2. Effect of reduction in plasma electrode surface area

Fig. 3(L) shows the corresponding values of the plasma electrode voltages used in the experiments described in Fig. 2(L). The magnitude of the plasma electrode voltages are tuned such that maximum H^- beam current is measured at the Faraday cup. It can be seen that the optimum plasma electrode voltages are in the range of 20 V - 60 V during the experiments with different gas flows. The optimum plasma electrode voltages are expected to be comparable to the plasma potential values during the maximum beam current extraction [7]. However it can be seen from Fig. 3(L) that the optimum plasma electrode voltages are much higher than the plasma potential values expected from Fig. 2(L).

Langmuir probe measurements were again performed to understand the reason behind the high value of the optimum plasma electrode voltages. Fig. 3(R) shows the plasma potential values obtained at different plasma electrode voltages. It can be seen that the plasma potential increases as the potential applied on the plasma electrode is increased. The plasma electrode voltages shown in Fig. 3(L) can thus result in high energy ion bombardment at the chamber wall. In order to verify the interaction between the plasma electrode voltage and Cu erosion, a 1 hour experiment was conducted with 0 V on the plasma electrode and a high 55 V on the plasma electrode (no beam extraction), at 10 sccm gas flow. It was found that there were no copper deposits seen on the RF window for the 0 V plasma electrode voltage experiment, and the usual copper deposits were present in the experiment using 55V of plasma electrode voltage. This confirms that the magnitude of the voltage on the plasma electrode affects the erosion through its influence on the plasma potential.

Studies [8, 9] have shown that a biased electrode in a plasma can cause a growth in the plasma potential due to the formation of an ion sheath in front of the electrode. One of the ways of forming

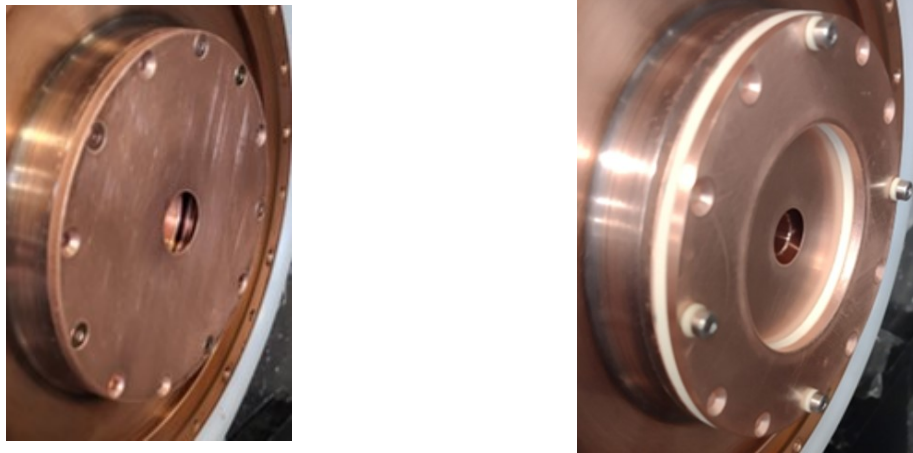


Figure 4: (L) Original plasma electrode picture, and (R) Modified plasma electrode with AlN plate (white) and copper plate added on top of the original plasma electrode.

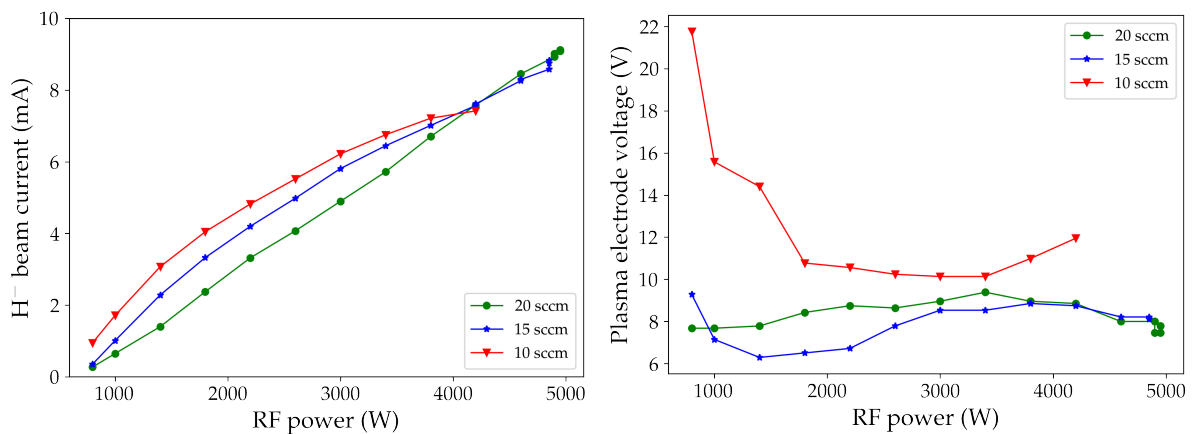


Figure 5: (L) H^- beam currents, and (R) optimum plasma electrode voltages obtained in the modified plasma electrode experiments at different gas flows and RF power values. The extraction electrode voltages are in the range of 1.5 to 3.5 kV for beam extraction.

an electron sheath instead of an ion sheath is by reducing the surface area of the biased electrode. Fig. 4(L) shows the picture of the original 96 mm diameter plasma electrode with 13 mm aperture for beam extraction. In order to reduce the effective area, an AlN plate (52 mm aperture) and a copper plate (51 mm aperture, shorted to the plasma chamber wall) was added on top of the original plasma electrode. This is shown in Fig. 4(R) and this modification reduces the effective plasma electrode area to 28% of the original design. Experiments were performed using this design and the beam extraction results are shown in Fig. 5. As seen from the results, the modified plasma electrode design showed no decrease in beam currents during the experiments even at low 10 sccm gas flows compared to Fig. 2(L). The optimum plasma electrode voltages have reduced considerably in the modified design compared to the original design in Fig. 3(L). This suggests a decrease in plasma potential with the reduction in the surface area of the biased plasma electrode, as expected from the studies described in [8]. Most importantly, no copper deposits were found on the RF window after the experiments with the modified plasma electrode design in all the cases. Note that the saturation of beam current observed for the 10 sccm gas flow is due to power supply limitation related to the co-extracted electron current.

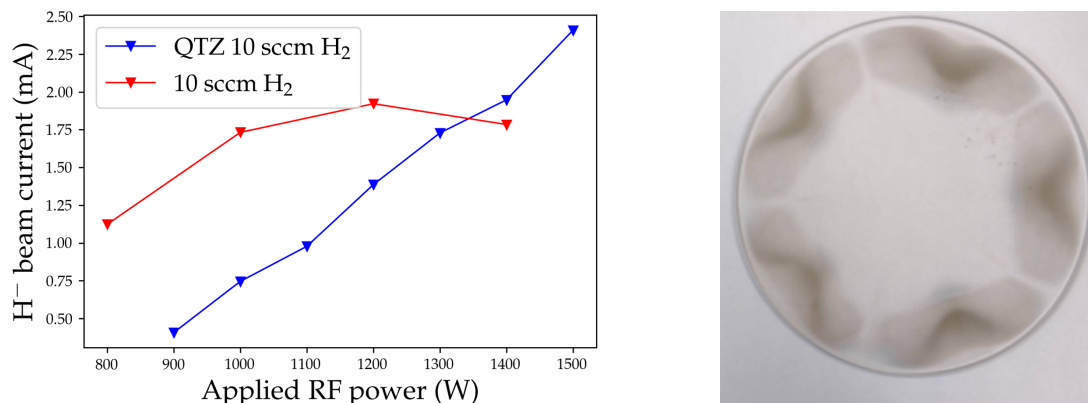


Figure 6: (L) Comparison of beam current extraction with and without additional quartz window (R) Picture of the quartz window after experiment. No copper deposits were found. The pattern seen is believed to be from the plasma interaction.

2.3. Effect of surface temperature of the dielectric window

In the current design, the outer surface of the AlN RF window is cooled with water circulating through the PEEK jacket [1]. In the original design, the window was not water cooled [10] and the rate of copper deposition was observed to be slower comparatively. It is important to understand if the low temperature surface of the plasma facing side of the AlN window promotes the adhesion of copper on the surface. In order to understand the effect of a higher surface temperature, experiments were performed with an added dielectric quartz window placed between the AlN RF window and the plasma. This quartz window is not cooled and hence offers a higher surface temperature to the eroded copper, compared to the AlN RF window. Experimental results indicate that the additional quartz window reduces the copper deposition. No decrease in beam currents were observed in the experiment with the additional quartz window as shown in Fig. 6. Moreover, no copper deposits were found on the quartz after the experiment. Thus a high temperature surface can reduce the copper adhesion to the surface. However, the additional window results in loss of power coupling between the antenna and the plasma, and results in lower beam current extraction compared to the original case.

3. CONCLUSIONS

This paper describes the problem of unstable beam current extraction from D-Pace's developmental RF ion source due to the erosion of the Cu plasma chamber. Some of the methods used to control the deposition of copper on the RF window were outlined in the paper. Operation of the RF ion source at high gas pressures (≥ 18 mtorr) and reduction in the effective plasma electrode area results in the lowering of the plasma potential and thereby reducing the ion energy and erosion at the walls of the plasma chamber. It is also found that a high temperature RF window surface results in the reduction of copper deposits on the RF window. Additional experiments are being planned with the RF ion source to verify the reliability of these methods in the long term operation.

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