RESEARCH ARTICLE | SEPTEMBER 21 2018

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AIP Conf. Proc. 2011, 050030 (2018)
https://doi.org/10.1063/1.5053328

Improvements to a 13.56 MHz RF Powered H^- Ion Source

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Abstract. D-Pace's 13.56 MHz RF powered H^- ion source, a hybrid design between the TRIUMF licensed filament powered volume-cusp ion source[1] and the University of Jyväskylä licensed RF ion source[2], has been shown to be less efficient than the filament powered ion source, even though both sources use the same body and extraction system[3]. The difference is thought to be due to RF power losses to the outside of the ion source, to the lack of plasma confinement on the back plate of the ion source, and to the absence of a sputtered tantalum coating on the plasma chamber walls. We believe that the lack of confinement on the back plate also causes the RF window to heat, with a maximum temperature measured at 450 °C at 3.5 kW of RF power. In this paper, we are investigating the use of a solenoid and permanent magnets behind the antenna and the back plate of the ion source to create a magnetic field that confines the plasma by preventing the electrons from striking the RF window. Furthermore, we present the effect of sputtering a tantalum coating in the plasma chamber of the ion source on the production of H^- ions in the RF powered source. Our results show an increase in H^- beam current at higher RF powers with a fresh coat of tantalum, and a subsequent decrease in beam current over time.

INTRODUCTION

RF ion sources with external antennas present a promising alternative to filament-powered ion sources. Filament sources have the potential to offer very low maintenance and long ion source lifetime since they have no consumable parts. The RF ion source used for this study uses the body of the TRIUMF licensed filament powered ion source[1] combined with the RF window, RF amplifier, antenna and impedance matching network of the University of Jyväskylä RADIS ion source[2]. Earlier results have shown that the H^- beam current-to-power efficiency of the RF ion source is lower than the filament powered version[3]. We believe the difference comes from the absence of a tantalum coating on the plasma chamber walls, the lack of confinement from the back plate of the RF powered ion source and RF power losses to the outside of the ion source. This study focuses on improvements to our RF ion source to better our understanding of the two technologies.

To further investigate the effect of the tantalum coating on the production and extraction of H^- ions in our ion sources, a tantalum coating was sputtered on the plasma chamber walls by running the filament ion source with tantalum filaments. The RF window was then replaced on the ion source and the performance was compared to a source without any Ta coating. In addition, the confinement of the plasma on the back of the RF ion source was studied by (i) adding a solenoid and by (ii) adding permanent magnets behind the RF window. Both methods were simulated and tested experimentally.

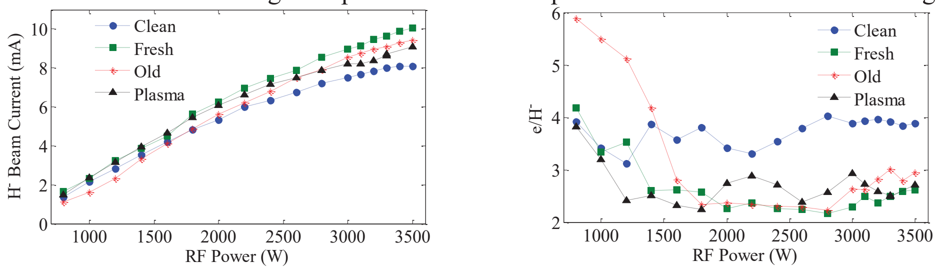
EFFECTS OF TANTALUM COATING

The experiments were carried out at D-Pace's ion source test facility (ISTF) (see ref. 4 for more details). The beam current is measured by a Faraday cup located 480 mm from the ion source's first electrode (plasma electrode)[3]. The co-extracted electrons are dumped onto the second electrode by a magnetic dipole, so the current on the second electrode approximates the co-extracted electron current. The TRIUMF-licensed ion source's plasma chamber walls

Proceedings of the 17th International Conference on Ion Sources
AIP Conf. Proc. 2011, 050030-1–050030-3; https://doi.org/10.1063/1.5053328
Published by AIP Publishing. 978-0-7354-1727-4/$30.00

are made of copper and a thin coating of tantalum is formed by sputtering from four half-circle tantalum filaments. The source was operated with an arc current of 20 A, the tantalum filaments biased at −120 V relative to the source body, the bias voltage set at 30 kV, and the H_2 gas flow set at 15 sccm, (which corresponds to a source pressure of about 1.6 Pa). The plasma chamber walls were cleaned before starting the ion source, and the ion source was operated for two hours to fully coat the inner plasma chamber surface. During this time, we saw the H^- beam current increase from 6.5 mA to 8.6 mA. The system was then vented, and the filament back plate was replaced by the RF window. During this replacement procedure, the system was exposed to atmosphere for a total time of about 15 minutes.

The performance of the RF powered ion source with the Ta coating was studied by running the ion source with 15 sccm of H_2 flow at a bias voltage of 30 kV and at RF powers ranging from 800 W to 3.5 kW. The experiment was also repeated with the Ta coating re-applied using the same procedure and then removed from every surface except the plasma electrode. Finally, the performance of the source over time was investigated by operating the source continuously for 10 hours at 2.5 kW. Figure 1 presents the source performance for the different configurations.



(a) (b)

FIGURE 1. (a) Beam current and (b) electron to H^- ratio with various Ta coating. 'Clean' denotes a plasma chamber with no Ta, 'Fresh' corresponds to a coating that was used for less than an hour, 'Old' is the coating after operating for 10 hours at 2.5 kW and 'Plasma' represents only the plasma electrode coated. The bias voltage was set at 30 kV and the gas flow was set at 15 sccm.

The experiments clearly showed the improvements resulting from the Ta coating (fresh) versus no Ta coating (clean). The difference seen at lower RF power for the 'Old' coating is thought to be due to improper tuning of the impedance matching network, leading to higher power losses in the tuning circuit. We believe that the effect of an adsorbate tantalum coating on the extraction and the production of H^- is two-fold, which agrees with a previous study by Bacal and Wada[5]. Firstly, the coating reduces the emission of H atoms from the plasma electrode, which leads to a reduction in stripping of the H^- ions. The second effect is the increase in the density of vibrationally-excited hydrogen ($H_2(v'')$) by recombinative desorption on the chamber walls, which leads to a higher volume production of H^- ions through dissociative attachment. We observed roughly the same co-extracted electron current with a fully-coated chamber as we did with only the plasma electrode coated. This supports the theory that the Ta adsorbate helps reduce the stripping of the negative ions close to the plasma electrode, where it is thought that most of the ions are produced. The difference in beam current between the two cases could be explained by a higher $H_2(v'')$ population from the larger Ta surface area seen in a fully coated plasma chamber. Finally, we observed a decrease in beam current with the ageing of the Ta adsorbate. This might be due to the erosion of the coating by the sputtering from the plasma particles. We see a slow increase and a saturation in H^- beam current when the filament ion source is started from a clean source, which could indicate a minimum Ta thickness for optimum source performance. Further testing is required to determine if thicker Ta coatings can be used to prevent the gradual beam current reductions, in order to utilize this RF powered ion source for industrial applications.

PLASMA CONFINEMENT

Unlike the filament powered ion source, the back plate of the RF ion source does not have cusp magnets since the space is occupied by the RF window and the antenna. This is thought to be a source of beam loss and contributor to heating of the RF window. To verify this, two different magnetic confinement methods were investigated. The first consists of placing a solenoid behind the back plate, around the RF antenna (Fig. 2a), and the second is to mount Sm_2Co_{17} magnets on either side of the antenna to create a permanent dipole field which protrudes into the plasma (Fig. 2c).

The magnetic field created by both methods was simulated with Opera[6], and the software's particle tracking was used to simulate electron flights in the plasma chamber. 20 000 electrons with a temperature of 2 eV were randomly generated in the plasma chamber and tracked freely with only the magnetic field affecting their trajectory. The electrons were tracked until they collided with a wall or travelled a distance of 10 m. It was found that both confinement methods reduce the electron flow to the RF window, and that the solenoid has a deeper influence in the plasma chamber than the permanent magnets.

Both methods were tested experimentally on the RF-powered ion source. Firstly, a solenoid with an ID of 173 mm and an OD of 260 mm, made of 97 turns of 50.8 mm x 0.38 mm (width x thickness) copper strip, was placed 15 mm behind the RF window. Secondly, Sm_2Co_{17} magnets were placed around the top and bottom of the RF antenna shield, forming a dipole field with variable strengths, with the center of the dipole located 10 mm behind the RF window. A maximum strength of 50 G at the center with a full width at half the maximum of about 60 mm was achieved. The results are presented in Fig. 2.

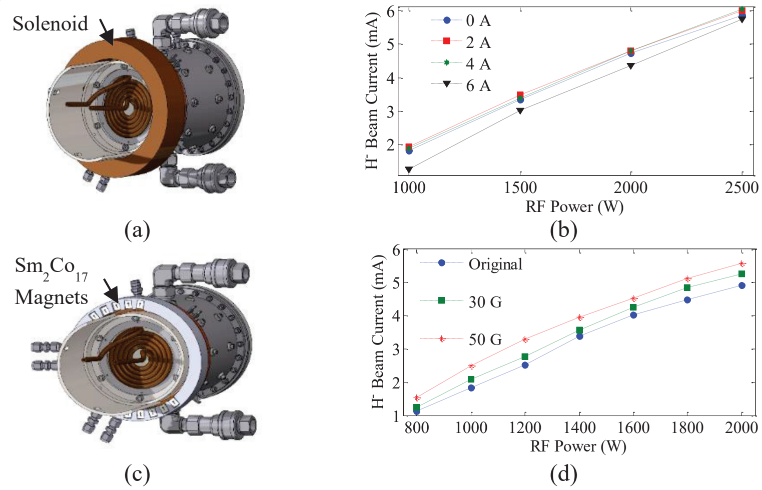


FIGURE 2. Schematic of (a) a solenoid and (c) permanent added to the back of the RF ion source. (b) Performance of the source with an added solenoid and (d) with added Sm_2Co_{17} magnets. The gas flow was set at 15 sccm and the source was biased at 30 kV for all the measurements.

There was a slight increase in beam current at low solenoid currents, but there was a decrease in beam current above 5 A of solenoid current. We believe the solenoid magnetic field is interfering with the RF magnetic field at higher solenoid currents since we observed higher reflected power with increased solenoid current. Adding magnets proved to be an effective method to increase the beam current, with an increase in beam current seen with increased magnetic field strength. Both methods were ineffective in decreasing heating to the RF window.

CONCLUSION

The addition of a thin coating of tantalum has been shown to increase the H^- beam current in the RF powered ion source, with more than 10 mA of H^- at 3.5 kW RF powers with a fresh coat deposited on the chamber walls. The addition of plasma confinement on the back of the plasma chamber was best achieved with Sm_2Co_{17} magnets forming a dipole behind the RF window, with an average increase of 23% in beam current, however, no additional decrease in heating of the RF window could be seen with both confinement methods tested.

ACKNOWLEDGMENTS

The authors are grateful for Canada's SR&ED program, NRC-IRAP, NSERC, BDC and Callaghan Innovation for significant R&D funding. The authors also thank Buckley Systems for the significant investment to build the ISTF.

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