H⁻, D⁻, C₂⁻: A COMPARISON OF RF AND FILAMENT POWERED VOLUME-CUSP ION SOURCES

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Abstract

Today's industrial ion source applications often require high beam currents with long source lifetime and low maintenance. Filament powered ion sources produce high beam currents but are limited by the short lifetime (~5000 mA·h) of the filament, while RF ion sources with external antennas do not require such maintenance. By changing the filament back plate of our TRIUMF licensed ion source [1] to the ceramic window, planar coil antenna and 13.56 MHz RF amplifier of our University of Jyväskylä [2] licensed ion source, we are able to directly compare the effect of the two technologies for powering sources on negative ion production in volume-cusp ion sources for the case of H⁻, D⁻ and C₂⁻ using our ion source test facility [3].

INTRODUCTION

The RF ion source used for this study is a hybrid design between the TRIUMF licensed filament-based ion source [1] and RADIS ion source licensed from the University of Jyväskylä [2]. The body and extraction of the ion source are from the TRIUMF source, while the back plate was replaced by an aluminium nitride (AlN) window. A planar coil, 3 turn, copper antenna is used to couple the 13.56 MHz RF power into the plasma chamber. An L-network impedance matching circuit composed of two variable capacitors is used. A schematic of both ion sources is presented in Fig. 1.
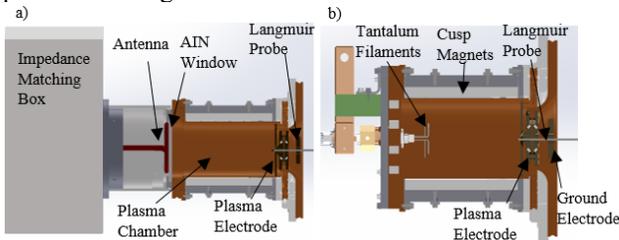
Figure 1: Schematic of a) the RF ion source and b) the filament ion source.

Four half-circle tantalum filaments are used in the filament-powered source. The plasma is confined by 10 rows of Sm_2Co_{17} magnets, with 4 rows on the back plate of the filament ion source. The co-extracted electrons are dumped onto the second electrode of our three electrode extraction system, thus the current on the electrode approximates the co-extracted electron current. Beam diagnostic equipment is described in [4], and includes an Allison-type emittance scanner, a pneumatic Faraday cup and a mass spectrometer system.

The performance of the new RF ion source as compared with the filament powered source will be presented

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for H⁻, D⁻ and C₂⁻. The plasma properties have also been investigated in both sources.

H⁻/D⁻

The production of H⁻ beams was investigated by injecting 99.999% purity H_2 gas in the sources. More than 8 mA of CW H⁻ beam has been extracted from the RF source, and near to 18 mA from the filament source into a Faraday cup located 368 mm from the plasma electrode of the ion source. Figure 2 presents H⁻ beam current as a function of the RF power and arc power at various gas flows. The pressure inside the ion source is not measured. However, the vacuum system was simulated using Molflow+ [5] and the pressure in the source was found to increase linearly from about 0.8 Pa to 2.5 Pa when the H_2 flow is varied from 5 sccm to 30 sccm.
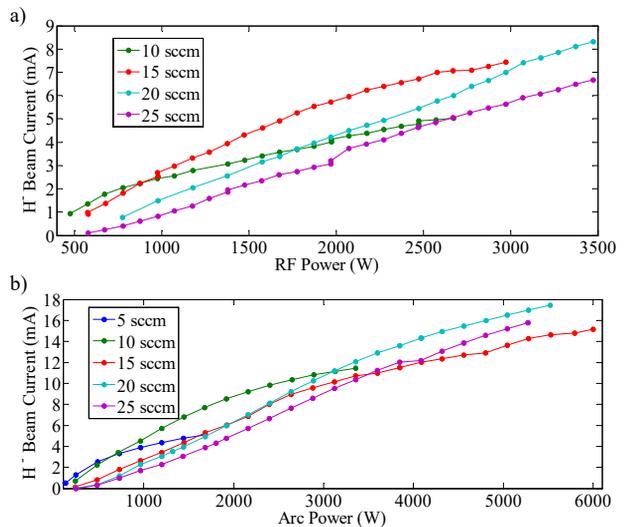
Figure 2: H⁻ beam current as a function of power for a) the RF source and b) the filament source at various gas flows. An arc voltage of 120 V was used in the filament source. The beam energy was set at 30 keV for both sources.

We limited the RF power to 3.5 kW since the AlN window temperature got hotter than the thermal shock limit. By comparing the H⁻ beam current to power efficiency, we see that the RF ion source produces ~2.4 mA/kW of RF power while the filament ion source has an efficiency of ~3.5 mA/kW. The RF source was less efficient because of RF power loss to the outside of the ion source since the antenna is not internal, a poorer confinement of the plasma due to the lack of cusp fields on AlN window, and the absence of a thin tantalum coating on the inner plasma chamber walls. It was found that lower e/H⁻ ratios could be achieved with the RF powered ion source. The lowest

value achieved was 1.99 with an RF power of 2100 W and a gas flow of 15 sccm. The lowest e/H$^-$ ratio achieved with the filament ion source was 2.93 with an arc current of 18.8 A, an arc voltage of 120 V and a gas flow of 13 sccm. An average normalized 4-RMS emittance was 0.60 mm·mrad for the RF powered source and 0.70 mm·mrad for the filament powered source for H$^-$ beam.

Deuterium gas at a purity of 99.999% was used in both the RF and filament powered ion sources. Figure 3 presents the performance of both sources with D$^-$.
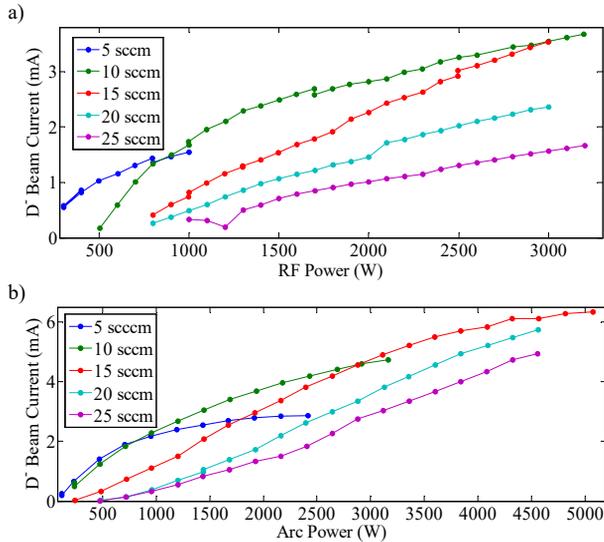
Figure 3: D$^-$ beam current as a function of power for a) the RF ion source and b) the filament ion sources for various gas flows. An arc voltage of 120 V was used for the filament source. The beam energy was set at 30 keV for both sources.

The efficiency of the RF source is about 1.13 mA/kW of RF power while the filament ion source has an efficiency of about 1.6 mA/kW for the case of D$^-$.

An important difference observed with deuterium compared to hydrogen is that the e/D$^-$ ratios were significantly higher than the e/H$^-$ ratios. The RF ion source still gave lower ratios than the filament ion source. The lowest value achieved was 4.14 with an RF power of 1200 W and a gas flow of 15 sccm. The lowest e/D$^-$ ratio achieved with the filament ion source was 5.98 with an arc current of 12 A, an arc voltage of 120 V and a gas flow of 12 sccm. The normalized 4-RMS emittance was higher with the RF ion source as compared to the filament powered source at 0.9 mm·mrad compared to 0.75 mm·mrad for the case of D$^-$.

PLASMA STUDY

A Langmuir probe consisting of a 10 mm tantalum tip was used to measure the plasma potential, the electron temperature and the electron density for both the RF and the filament-powered ion sources. A passive filter as described by Wendt [6] was used with the RF ion source. The probe was inserted through the extraction aperture of the ion source, on the central axis with the probe tip 30

mm into the plasma region from the upstream surface of the plasma electrode.

For the RF ion source, the plasma potential was found to be between 4 V and 10 V depending on the gas flow and the RF power, compared to between 2 V and 3.5 V for the filament ion source, depending on the arc current, the arc voltage and the gas flow. This is consistent with the higher bias that is needed on the plasma electrode of the ion source in the RF ion source to maximize the extracted H$^-$ current and minimize the co-extracted electron current [7]. Biasing the plasma electrode of the ion source at the plasma potential has the effect of eliminating the potential barrier created by the positive plasma potential, and it helps deplete the extraction region of electrons. Figure 4 shows the H$^-$ beam current and the co-extracted electron current as a function of the bias on the plasma electrode for the RF ion source, and the RF ion source.
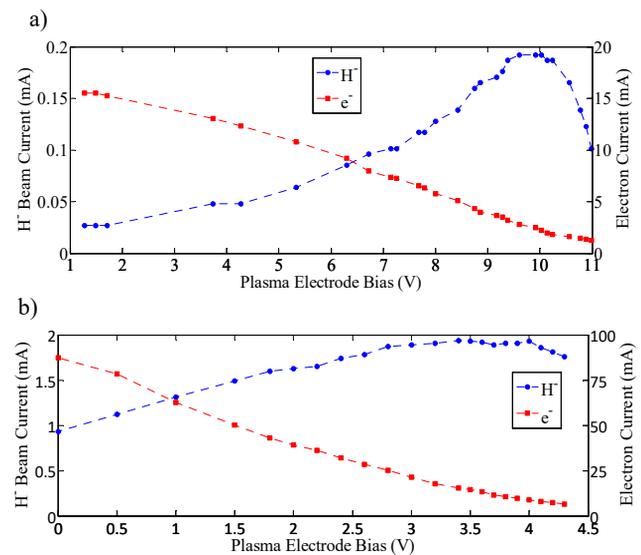
Figure 4: H$^-$ beam current and co-extracted electron current as a function of the bias on the plasma electrode for a) the RF ion source (the RF power was set at 576 W and the gas flow was set at 22 sccm), and b) the filament ion source (the arc current was set at 120 V and 4 A with the gas flow set at 10 sccm).

There is a clear maximum in H$^-$ for both sources, although the maximum is found at a higher potential for the RF ion source, and the co-extracted electron current decreases as the bias on the plasma electrode is increased.

The electron density and the electron temperature were also measured as a function of the input power and the gas flow. The electron temperature was found by fitting the I-V curve of the probe to an exponential, while the electron density was found by measuring the probe current when the probe was biased at the plasma potential [8]. Results are presented in Fig. 5. The error bars correspond to the 95% confidence interval when fitting for T$_e$ and assuming a 5% error when measuring the current at the plasma potential.
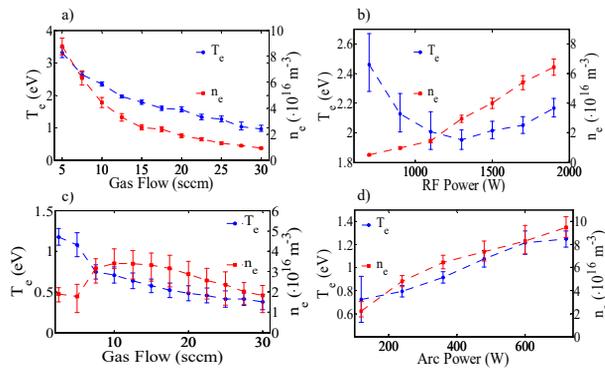
Figure 5: Electron density and temperature as a function of a) the gas flow, b) the RF power for the RF ion source, and c) the gas flow and d) the arc power for the filament ion source. The RF power was set at 1000 W for a), the gas flow was set at 15 sccm for b), the arc was set at 120 V and 1 A for c) and the arc voltage was set at 120 V and the gas flow was set at 10 sccm for d).

The electron temperature decreases when the gas flow is increased in both sources, while the electron density decreases in the RF source but remains relatively constant in the filament ion source. The difference might be due to increased shielding of the RF fields by the neutrals close to the plasma electrode, where the measurements were taken. The RF power and arc power have little effect on the electron temperature, but increase the electron density almost linearly. The increase in electron density could be explained by a greater ionization rate at higher powers, while the electron temperature stays relatively stable because measurements were taken in the "cold" plasma region, where a dipole magnetic field filters out the fast electrons. The electron density in the filament ion source was found to be significantly higher than the RF ion source by a factor of about 10 at comparable power levels, while the electron temperature was slightly lower. Similar results have been found for another H^- ion source [9].

ACETYLENE/C_2^-

Acetylene was used in both ion sources in an effort to extract negative carbon ion beams. The four main species extracted from the ion source are H^-, C_2^-, C_2H^- and $C_2H_2^-$ with both the filament and the RF powered ion sources. Up to 0.35 mA of C_2^- was extracted with the RF ion source, compared to 0.09 mA of C_2^- with the filament ion source. It was found that the $C_2H_2^-$ component was considerably lower with the RF ion source at around 8-13% compared to 15-23% with the filament ion source. It is thought that the $C_2H_2^-$ ions are produced from surface reactions with the chamber walls since volume processes, such as dissociative electron attachment and dipolar dissociation, require the dissociation of the acetylene molecule. The tantalum coating on the filament ion source walls may increase the surface production of $C_2H_2^-$ in this ion source in competition to our desired C_2^- ions.

CONCLUSION

The back plate of our TRIUMF licensed filament powered ion source has been replaced by a ceramic window, planar antenna and 13.56 MHz RF amplifier, licensed from the University of Jyväskylä, to allow for direct comparison of RF powered and filament powered technologies. The maximum beam currents are presented in Table 1.

Table 1: Maximum Beam Currents

Ion Source	H^- (mA)	D^- (mA)	C_2^- (mA)
RF	8.3	3.6	0.35
Filament	17.4	6.3	0.09

We believe the tantalum coating created by the filaments enhances the production of H^- and D^- in the filament ion source. However, it's a detriment for the case of C_2^- since it contributes to a higher fraction of $C_2H_2^-$ rather than C_2^-.

ACKNOWLEDGMENTS

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