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OPTIMISATION OF D⁻ ION PRODUCTION IN A MULTICUSP ION SOURCE

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Abstract

D-Pace's multicusp ion source achieves high beam currents for negative hydrogen ions in both the TRIUMF-licensed filament-powered ion source (~18 mA) and the University of Jyväskylä-licensed RF-powered ion source (~8 mA) [1]. It is well known that ion sources producing negative deuterium ions achieve lower beam currents compared to similar negative hydrogen ion sources and indeed we have found that negative deuterium ion beam currents in our sources are typically 1/3 that of negative hydrogen beam currents. The reasons behind this are not completely understood, but factors such as the magnetic field strength and the electron temperature are believed to play a major role and offer the potential for significant optimisation. In this paper, we look into the issues surrounding swapping of deuterium for hydrogen in our ion source by studying the properties of plasmas and extracted currents with different magnetic field strengths and gas flows.

INTRODUCTION

The ion source used for this study is a D-Pace filament based multicusp ion source licensed from TRIUMF [2], which produces negative ions based on volume production and uses low-pressure discharge plasmas of H_2 and D_2. This ion source is optimised for the production of H^- ions and has achieved 18 mA of beam current at a beam energy of 30 keV [1]. But the ion source has achieved only 6 mA of beam current for D^- ions under the same operating conditions. The reactions producing D^- ions are believed to be the same as those producing H^- ions [3]. To accomplish a current density for D^- ions comparable to H^- ions in the ion source, it is important to study the plasma characteristics of deuterium and compare it with hydrogen.

A Langmuir probe is used for studying the parameters of hydrogen and deuterium plasmas. The parameters for deuterium plasmas under different magnetic dipole filter field strengths are studied and compared with hydrogen plasmas. The effect of varying magnetic fields and gas flows on the total current extracted from the ion source for deuterium is also presented.

ION SOURCE AND MAGNETIC FIELD

The schematic of the ion source used is presented in Fig.1a). Filaments are made up of four half circles of tantalum. The plasma is confined by 10 rows of Sm_2Co_{17} magnets and another 4 rows of magnets on the back plate which hold the filaments. This is a three electrode extraction system consisting of the plasma electrode, the extraction electrode and the ground electrode. The co-extracted electrons are dumped on the extraction electrode. The current measured on the extraction electrode approximates the co-extracted electron current.

The ion source is biased at negative potential compared to the ground electrode for the extraction of negative ions. The source is biased at 5 kV in the current study.

a)

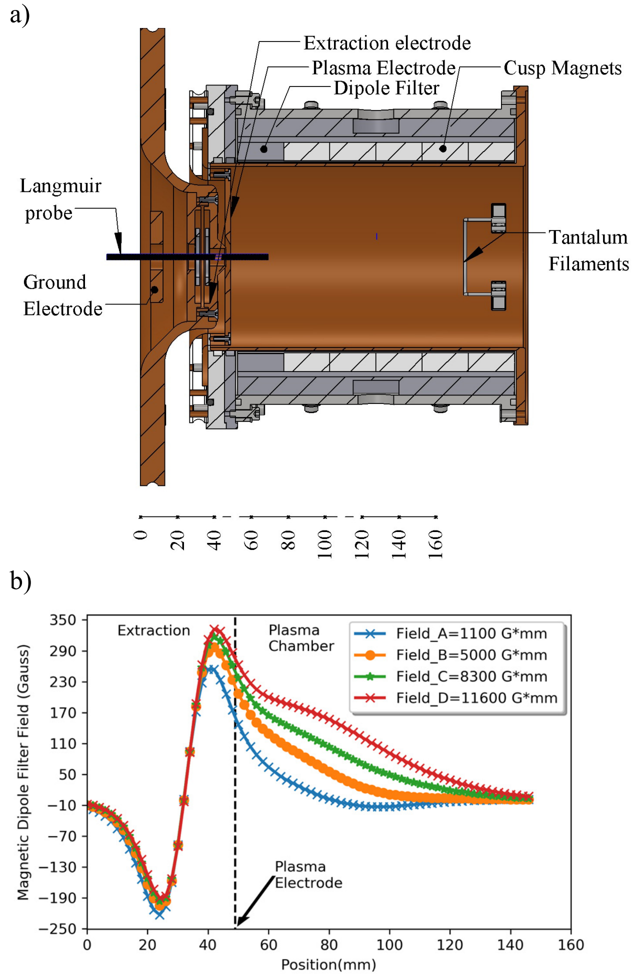

Figure 1: a) Schematic of the filament based multicusp ion source. b) Different magnetic dipole filter fields used for this study. The magnitude of field indicated is the integrated field over length in the plasma chamber.

This ion source is optimized for beam energies between 25 keV and 30 keV. But the detection of neutrons while producing deuterium ion beams with beam energies above 10 keV restricted the current study to a maximum beam energy of 5 keV considering the safety of operations. The

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beam currents, measured with a Faraday cup located at 510 mm from the plasma electrode, for 5 keV beam energy is shown in Fig. 2. Increasing the arc current beyond 6 A resulted in a more divergent beam and beam loss due to low electric field between the extraction electrode and the ground electrode. As shown in Fig. 2, the lower beam current of D^- ions compared to H^- current is evident at 5 keV beam energy.

The plasma electrode current was higher for D^- ions compared to H^- ions at the same conditions. This indicates that there is a higher density of electrons in deuterium plasma compared to hydrogen plasma. Altering the electron density and temperature can be one of the solutions for achieving higher beam current. This can be achieved using a magnetic dipole filter of a different strength than normally used for hydrogen plasma. This is achieved by changing the Sm_2Co_{17} magnet arrangement at the dipole filter. Axial magnetic field distribution in the ion source for different dipole filter fields used for this study is shown in Fig. 1 b).

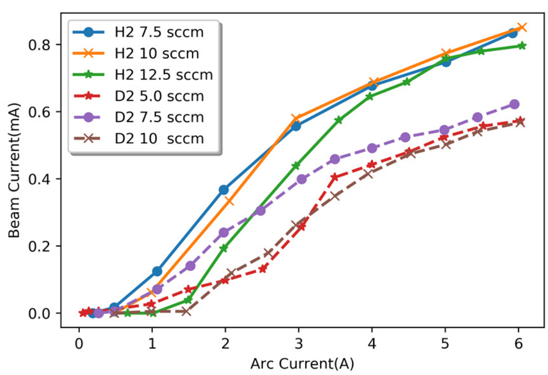

Figure 2: H^- and D^- ion beam currents at a beam energy of 5.0 keV, for different gas flows, at 120 V of arc voltage.

PLASMA STUDY

A Langmuir probe with a tantalum tip length of 5 mm and a diameter of 1.6 mm was inserted into the plasma through the extraction side of the ion source as shown in Fig. 1a). The Langmuir probe tip was located at 20.5 mm from the plasma electrode. The plasma potential was found by finding the inflection point of the current-voltage characteristics. An exponential fit of the current-voltage characteristics was used to find the electron temperature and the electron density [4]. The measurements were taken at a constant arc current of 5.0 A and voltage of 120.0 V. Measurements were made at different gas flows and magnetic fields and compared to hydrogen. The results of the calculations are plotted in Fig 3.

As evident from the results, the plasma potential of deuterium is higher than hydrogen. Electron density and temperature are also higher for deuterium compared to hydrogen. This explains the higher co-extracted electron currents for deuterium beams. The effect of increasing the strength of the magnetic dipole filter on the plasma parameters of deuterium is shown in Fig. 3. Increasing the magnetic field results in a reduction of the electron temperature and the electron density of deuterium plasma, except in the case of the weakest field, Field_A. Field_A also gives rise to comparatively high density of electrons and electron temperature.

a)

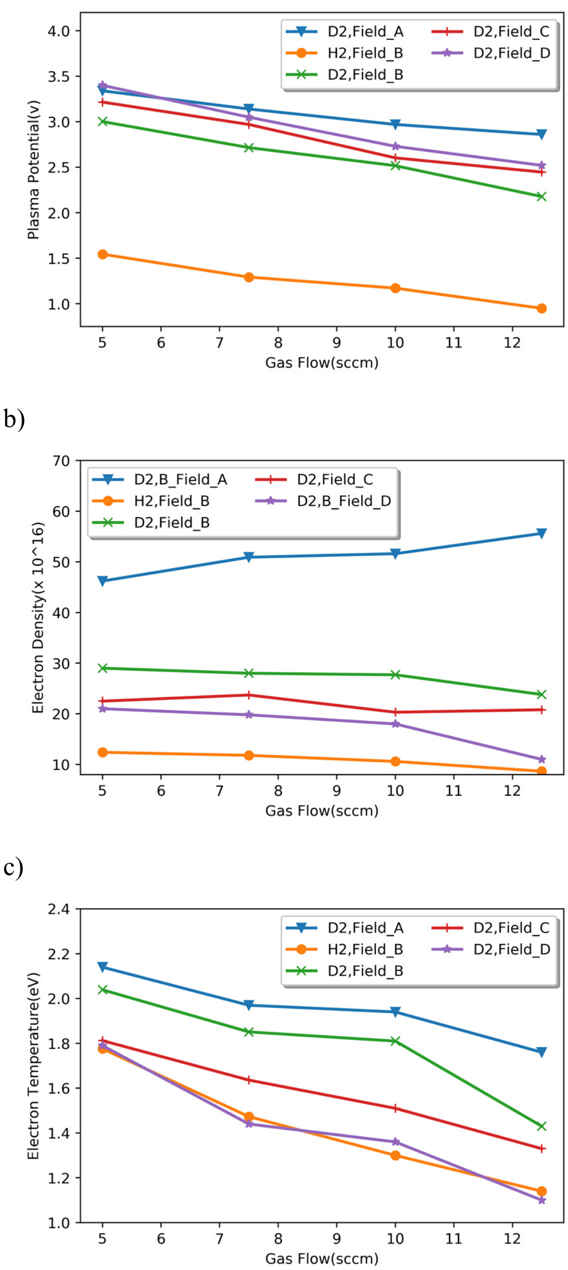

Figure 3: a) Variation of the plasma potential, b) the electron density and c) the electron temperature for various gas flows and magnetic filter fields. The measurements are taken at 5.0 A arc current & 120.0 V arc voltage.

It is also found from the experiments that an increased gas flow leads to reductions in the plasma potential and electron temperature for both hydrogen and deuterium plasmas, for all magnetic filter fields.

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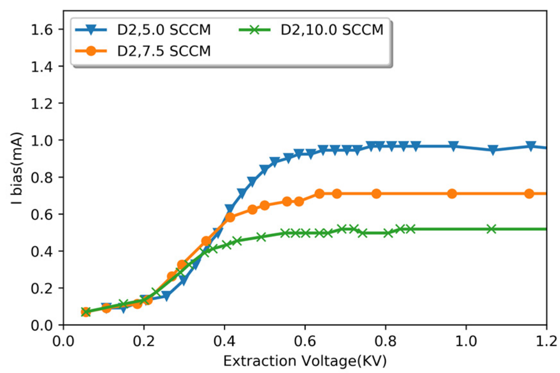
D⁻ BEAM

As mentioned above, it was not possible to operate at higher arc currents as higher extraction voltages were needed for beam formation. This led to high beam divergence due to low electric field between extraction and ground electrodes. Therefore the effect of the magnetic dipole fields on the ion beam extraction was studied by measuring the total ion current extracted from the source, I_{bias}, where I_{bias} is measured on the bias power supply which provides the negative potential for the ion source.

Figure 4a) shows the variation of I_{bias} for different gas flows at a constant arc power. Increasing the gas flow has an adverse effect on the total extracted ion current. This is in agreement with the results in Fig. 3.

a)



b)

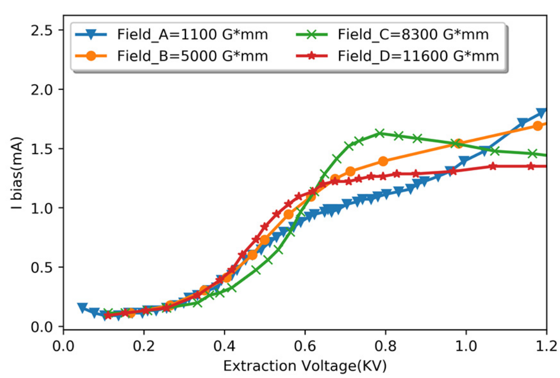


Figure 4: a) Variation of I_{bias} for different gas flows at a constant arc current of 5.0 A for Field_D. b) Variation of I_{bias} for different magnetic dipole strengths at arc current of 6.5 A and arc voltage of 120.0V.

The variation of the I_{bias} for different magnetic dipole strengths is shown in Fig. 4 b). As evident from the graph, I_{bias} is maximum for Field_C. Magnetic fields larger or less than Field_C yield lower extracted ion currents. The plasma current and co-extracted electron current decreases for increasing magnetic dipole filter fields. Even though, the co-extracted electron current decreases while increasing the magnetic field, it can also lead to less ion beam current [5].

CONCLUSION

The current study was performed to increase the D⁻ ion beam extraction in the ion source. Plasma parameters for the deuterium plasma are larger than the hydrogen plasma. Variations in magnetic dipole filter field can change the plasma parameters. Increasing the magnetic dipole filter field helps in reducing the electron temperature and the electron density of the plasma. But, there exists an optimum magnetic dipole filter field for which maximum ion beam is extracted and beyond which the ion current decreases. This also indicates the presence of an optimum electron temperature and density for maximum ion current extraction.

Future plans include measuring the ion beam current at magnetic fields of magnitude close to the optimal field and studying the plasma parameters inside multiple locations in the ion source.

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