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H- PRODUCTION FROM DIFFERENT METALLIC CONVERTER SURFACES*

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ABSTRACT

The relative yield of H⁻ ions generated from various metallic surfaces (such as Mo, Ti, V, Nb, Pt, Pd, Rh, Cu, Ta, Al, Au and stainless steel) are compared in a multicusp source with and without the presence of cesium. Result of the investigation shows that one can optimize the H⁻ yield and formation process by choosing the proper converter material for a given range of source operating conditions.

INTRODUCTION

For heating plasmas and for current drive in some fusion reactors high energy neutral beams will be required.¹ The high neutralization efficiency of H⁻ or D⁻ makes them favorable to form neutral atoms with energies in excess of 160 keV.² It has been shown that H⁻ ions can be generated by surface conversion processes³ and a self-extraction negative ion source based on this principle has already been operated successfully to generate a steady-state H⁻ ion beam current greater than 1 A.⁴

In this experiment, we compare the negative ion yield generated by different converter materials in the pure hydrogen and cesium modes of operation. It is shown that H⁻ ions can be formed by both desorption and reflection processes even in the absence of cesium in the hydrogen discharge. The fraction of H⁻ ions formed by the desorption process can be high. We find that the number of H⁻ ions generated by this process is closely related to the amount of OH⁻ ions present in the self-extracted beam. When cesium is added to the discharge, the H⁻ yield can vary from one converter material to the other. Under optimum conditions, the majority of these H⁻ ions are formed by the desorption process.

EXPERIMENTAL SETUP

A schematic diagram of the experimental arrangement is shown in Fig. 1. The device is a cylindrical multicusp ion source (20 cm diam by 18 cm long) with the open end enclosed by a stainless-steel plate. The chamber is surrounded externally by 10 columns of samarium-cobalt magnets ($B_{\max} \approx 3.6$ kG) to form a linecusp configuration for primary electron and plasma confinement.⁵ A steady-state hydrogen plasma is produced by primary electrons emitted from two 0.05-cm-diam tungsten filaments which are biased at -70 V with respect to the anode (chamber wall). In normal operation, the source pressure is adjusted to 1.5×10^{-3} Torr. If needed, metallic cesium is introduced into the discharge through a molybdenum tube connected to a cesium oven.

Fig. 1 Schematic diagram of the multicusp negative-ion source.

In order to investigate the negative ions produced by different converter materials, a rotatable water-cooled copper disk with four different materials brazed on the four quadrants was employed. Negative ions formed at the converter surface will accelerate across the sheath, pass through the plasma and the exit aperture on the stainless steel plate, and then enter into a magnetic-deflection mass spectrometer. With this arrangement, only one type of converter material at a time is seen by the viewing system formed by the exit aperture and the entrance slit of the mass spectrometer (Fig. 1). The yield of H^- ions for each metal can be compared under identical conditions of gas pressure, discharge power, cesium environment, and converter potential. For negative ions with the same mass-to-charge ratio, the mass spectrometer also acts as an energy analyzer.

EXPERIMENTAL RESULTS

(a) Pure hydrogen mode operation

The source was first operated without cesium and with a discharge current of 4 A. Langmuir probe measurements indicate that the plasma density is approximately 10^{10} cm^{-3} . The electron temperature is about 1 eV and the plasma potential is ~ 1.5 V positive with respect to the anode.

Figure 2 shows the energy spectra of the H^- ions produced by Rh, Pt, Pd and Mo. Two distinct groups of H^- ions can be easily identified. The energy of one group is approximately equal to the sheath potential ($\sim E$), indicating that the ions leave the converter surface with very small energy. These H^- ions are desorbed (or sputtered) from the converter surface by bombardment with energetic hydrogen ions.⁶ In this process, the average energy gained by the H^- ions is usually small (~ 5 eV), and their final energy

Fig. 2 Energy spectrum of the H^- ions produced on Rh, Pt, Pd and Mo at a converter voltage of 600 V.

should be approximately equal to the sheath potential.

The second group of H^- ions has a higher energy and they are produced by reflection (or back-scattering) of hydrogen ions from the converter.⁷ All positive hydrogen ions (H^+ , H_2^+ , H_3^+) acquire the same amount of energy E as they cross the sheath. However, the molecular ions H_2^+ and H_3^+ are fragmented to form atomic particles with energy $E/2$ and $E/3$ respectively. If H^- ions are converted from the three groups of backscattered atomic hydrogen particles, their average energy at the detector should be close to the limiting values of $2E$, $1.5E$ and $1.33E$. Because of

this species effect, three superimposed peaks should appear in the energy spectrum of the H^- ions formed by the reflection process. In this experiment, the species distribution $H^+ : H_2^+ : H_3^+ = 4 : 35 : 61$. Therefore only the peaks resulting from H_3^+ and H_2^+ ion reflection are visible in the energy spectra shown in Fig. 2.

Figure 2 also shows that the desorbed H^- ion peak is much higher for Mo than the other three metals. By comparing the mass spectrum of negative ions generated on these converter materials (Fig. 3), one finds that the peaks corresponding to mass 16 (O^-) and mass 17 (OH^-) are also much higher for Mo than Rh, Pt and Pd. In fact, for a gold converter, Fig. 4 shows that the O^- and OH^- peaks are not visible in the mass spectrum. Correspondingly, the H^- ion energy spectrum in Fig. 5 illustrates the absence of the desorbed H^- ion peak. This result seems to suggest that hydrogen atoms are adsorbed on the converter surface mostly in the form of OH. Under ion impact, both the atomic ions, H^- and O^- , and the molecular ion OH^- can be desorbed (or sputtered) from the converter.

The degree of forming the OH bond (and therefore the desorbed H^- ion yield) differs from one converter material to the other. Indeed, the mass spectra in Figs. 3, 4, 6 and 7 suggests that the OH bond is more likely to form on Mo, Al, Ta, and S.S. (stainless steel) surfaces. Notice that both Cu and Au produce mainly O_2^- ions, but this molecular ion forms only a very small fraction of the negative ion spectrum of the Ta and Al converters.

Figure 7 shows that the desorbed H^- ion peak is the highest when Al is used as the converter. In fact, the mass spectrum for

Al shows the desorbed H^- ion peak is even larger than the O^- and OH^- peaks. The reason for this high desorbed H^- ion yield is not yet understood, but it is known that oxide layers always exist on Al surfaces. As a result more hydrogen atoms may adsorb on the Al surface than other converter materials.

Fig. 3 The mass spectra of the negative ions produced on Rh, Pt, Pd and Mo at a converter bias voltage of 200 V.

Fig. 4 The mass spectra of the negative ions produced on Mo and Au at a converter bias voltage of 300 V.

Fig. 5 The energy spectra of the H^- ions produced on Mo and Au at a converter voltage of 300 V.

Fig. 6 The mass spectra of the negative ions produced on Mo, Ta, Cu and stainless steel at a converter bias voltage of 200 V.

Fig. 7 The mass spectrum of the negative ions produced on aluminum at a converter bias voltage of 200 V.

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(b) Cesium mode of operation

When cesium is added to the hydrogen discharge, the total H^- ion yield in general is enhanced by more than two orders of magnitude. The impurity negative ions now form only a percent or two of the total self-extracted beam current. Figure 8 shows the energy spectra of the H^- ions generated by Ta, Cu, stainless steel and Mo converters. The amount of H^- ions produced differs from one converter material to the other. But for each of these four metals,

the energy spectrum shows a very narrow peak near the converter potential. As in the case of the pure hydrogen mode, this group of H^- ions are produced by a desorption

Fig. 8 The energy spectra of the H^- ions produced on Ta, Cu, stainless steel and Mo at a converter voltage of 300 V.

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process. With cesium added to the source, it is believed that the hydrogen atoms could adsorb on the converter surfaces in the form of CsH . Due to impact by positive hydrogen and cesium ions, H^- ions are desorbed from the converter surface. With cesium, H^- ion formation is much enhanced due to the lowering of the surface work function.^{8,9} For Cu and stainless steel, the energy spectra in Fig. 8 show that a larger fraction of the H^- ions are produced by reflection of positive hydrogen ions.

When Rh, Pt, Pd, Al and Au are compared with Mo, we again find that Mo produces the highest desorbed H^- ion yield. However, when the source is operated with Ti, V, Nb and Mo converters, the energy spectra in Fig. 9 show that the majority of the H^- ions are formed by desorption and that Ti and V produce more desorbed H^- ions than Mo.

In the operation of the "self-extraction" negative ion source, the desorbed H^- ions are desired as they have a very small transverse energy component and therefore can leave normal to the converter surface. Thus these H^- ions can be better focused geometrically at the exit aperture of the source and then be accelerated to form a high energy beam. For this reason, Ti, V, and Mo

are better candidates to be used as converter materials than the other metals we have tested in this experiment.

Fig. 9 The energy spectra of the H^- ions produced on Ti, V, Nb and Mo at a converter voltage of 300 V.

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