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Abstract

The effect of wall material on volume H^- production in a magnetically-filtered multicusp source has been investigated. Under the same discharge conditions, Al and Cu generally produce the highest H^- ion current. It is shown that secondary electrons emitted from wall surfaces can account for the difference in H^- yield.

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H^- or D^- ions are required to generate efficient neutral beams with energies in excess of 150 keV.¹ A magnetically-filtered multicusp source is capable of producing high-quality volume-generated H^- beams with sufficient current density ($\sim 40 \text{ mA/cm}^2$) to be useful for both neutral beam heating of fusion plasmas and accelerator applications.² Attempts have been made to further improve the arc efficiency of this source in order to provide the capability of long pulse or dc operation.³ The effect of wall material and wall temperature on the H^- ion density has been studied by Graham in a high pressure, diffusion-type plasma.⁴ No significant difference in negative ion densities has been observed for Pyrex, stainless steel, copper or molybdenum. In this paper, we investigate the extracted H^- beam with different metallic liners installed in the magnetically-filtered multicusp source. Experimental results show that the H^- output can be enhanced by proper selection of the chamber wall material when the source is operated with a low pressure hydrogen discharge.

Figure 1 shows a schematic diagram of the apparatus. The source chamber (15 cm diam by 24 cm long) was fabricated from an oxygen-free copper pipe and was surrounded externally by 8 columns of samarium-cobalt magnets to form a longitudinal linecusp configuration for primary electron and plasma confinement.⁵ The magnet columns on the chamber wall were connected at the end copper flange by three additional rows of magnets. A samarium-cobalt magnet filter⁶ was installed in the source chamber. This filter was located very close to the plasma electrode of the extractor because in a recent experiment, we observed that there was a sizable increase in extractable H^- current if the extractor was placed very near the filter.³

To study the effect of wall materials on the H^- ion yield, thin (0.13 mm thick) cylindrical metal liners were installed on the chamber wall as

shown in Fig. 1. These liners were cleaned in an ultrasonic alcohol bath before installation. To ensure good thermal and electrical contact with the source chamber, two stainless-steel rings were used to force the liner to lay flush against the vessel wall. In this arrangement, the ratio of the liner area to that of the uncovered copper end flange was about 6:1.

The open end of the source chamber is enclosed by a two-electrode ion acceleration system. The first, or plasma electrode contained a small ($0.1 \times 1.0 \text{ cm}^2$) extraction slot and this electrode was biased at a potential equal to, or more positive than the anode in order to optimize the H^- ion output.⁶ A turbo-molecular pump was used to evacuate the system down to a pressure of about 4×10^{-7} Torr. A steady-state hydrogen plasma was produced by primary electrons emitted from two 0.05-cm-diam tungsten filaments. The entire chamber wall, together with the filter rods, served as the anode for the discharge. During the experiment, the pressure inside the source was maintained at $\sim 1.5 \times 10^{-3}$ Torr.

Plasma parameters were obtained by a planar Langmuir probe located near the center of the source chamber. A compact magnetic-deflection mass spectrometer,⁷ located just outside the extractor was used for relative measurement of the extracted H^- ions as well as for the analysis of the positive ion species. A discharge power of 90 V, 1A was employed throughout the experiment to generate a modest hydrogen plasma density of about $4 \times 10^{10} \text{ cm}^{-3}$.

Figure 2 shows the magnitude of the H^- output signal when seven different metal liners are compared under the same plasma conditions. The results show that aluminum and copper generate the highest H^- yield while stainless steel produces the lowest. The H^- output of other metal liners such as Mo, Ta, W and Au fall between those of Al and stainless steel.

It was also found that there was essentially no change in the magnitude of the H^- signal when the copper source chamber was operated with or without an extra copper liner. This observation indicates that either there is no large difference in the surface temperature between the copper chamber wall and the copper liner or the liner surface temperature has no appreciable effect on the H^- output. In order to understand the large difference in H^- yield (a factor of 2) between the copper and stainless steel liners, the negative-ion mass spectra, the positive hydrogen ion species distributions and the Langmuir probe traces for these two materials were compared.

Figure 3 shows the mass spectrum of the extracted negative ion beam for the copper and stainless steel liners. Apart from the fact that the H^- output is different, no other negative ions (with mass number greater than 1 but smaller than 70) were detected in either case. The absence of C^- , O^- or OH^- ions demonstrates that the H^- observed is not formed on the source wall⁸ or generated in the plasma volume from molecules such as H_2O or CH_4 . However, there is a noticeable difference in the floating potential V_f as indicated by the probe characteristics shown in Fig. 4. The fact that V_f is more negative, and the electron temperature T_e is slightly higher, indicate that more "hot" electrons are present in the plasma when the source is operated with the stainless steel liner.⁹ If these extra "hot" electrons originate at the liner, they must be produced by secondary electron emission from energetic primary electron bombardment on the anode cusp line.¹⁰ Measurements by Kollath show that the secondary electron emission coefficient δ for 90 eV primary electrons is typically higher for stainless steel ($\delta \approx 1$) than for Al, Mo, W, Ta and Au.¹¹ In the case of Al, δ becomes even smaller as the surface is coated with an oxide layer which increases the work-function.¹²

Secondary electrons are emitted with a peak energy of a few eV,¹¹ and since the potential of the plasma is about 3 V more positive than the wall, this group of electrons will have a final energy of approximately 8 eV when they enter the plasma. In fact, the indication of more "hot" electrons when a stainless steel liner is used, is also indirectly confirmed by the positive hydrogen ion spectrum shown in Fig. 5. Since H^+ can be formed from H_3^+ by relatively hot electrons,¹³ the percentage of H^+ would be expected to be slightly higher (and H_3^+ lower) when stainless steel is compared with copper.

The effect of secondary electrons on H^- production was previously investigated in a separate experiment.¹⁴ In that experiment, it was found that the addition of electrons with energies ≈ 8 eV to a background hydrogen plasma could reduce the H^- yield substantially. Thus, we can conclude that the differences observed in the H^- yield between various metal liners is dependent on the amount of secondary electrons emitted. This in turn depends on the energy and the number of primary electrons impinging on the wall surfaces. In order to optimize the H^- output, it is essential to choose the proper wall material (such as Cu or Al) when the multicusp ion source is operated with a low pressure discharge.

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Figure Captions

- Fig. 1 Schematic diagram of the multicusp ion source equipped with a magnetic filter and a metal liner.
- Fig. 2 the relative yield of H^- ions when the source is operated with different metal liners.
- Fig. 3 The mass spectrum of the extracted negative ion beam when the source is operated with a stainless steel and a copper liner. The electron peaks are not displayed in the figure.
- Fig. 4 Langmuir probe characteristics obtained near the center of the chamber when the source is operated with a stainless steel and a copper liner.
- Fig. 5 Spectrometer output signal showing the distribution of positive hydrogen ion species when the source is operated with a stainless steel and a copper liner.

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Fig. 1

Fig. 2

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Fig. 3

Fig. 4

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Fig. 5

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