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NEGATIVE ION FORMATION DUE TO HYDROGEN PLASMA
SURFACE INTERACTION

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Abstract

Negative ions can be produced by a desorption process when energetic positive hydrogen ions impinge on the surface of reactor walls. The relative yield of different negative ions generated from various surface materials (such as Mo, Pt, Pd, Rh, Cu, Ta, Au, C, TiC and stainless-steel) have been compared in a multicusp plasma source. The negative ions generated are self-extracted from the source, and are identified by a mass spectrometer. The total negative ion current is measured by a Faraday cup.

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Introduction

The plasma contained by various magnetic confinement devices usually assumes a potential that differs from the walls of the reactor. In the case of the tokamak, this plasma potential is believed to be positive by several hundred volts. This potential is then effective at causing the limiter and the reactor walls to be bombarded by positive ions from the plasma. Depending on the magnitude of this potential, various amount of sputtered neutral particles and negative ions will be produced. The result of this plasma-surface interaction is credited for supplying impurities to the reactor plasma. In deed, it has been demonstrated by Oren et al. that positive plasma potentials are always accompanied by sputtering and rapid recycling in Macrotor.¹ Thus, control of the plasma edge potential will influence the overall impurity evolution and transport in a tokamak.

In this paper, we study the negative ions generated by the bombardment of various wall materials by hydrogen ions with energies of several hundred eV. A mass spectrometer shows that a variety of negative ions are produced at the target surface, and that the proportion of these ions, as well as the total negative ion current generated, can vary from one material to another. Thus, one can minimize the heavy impurity negative ion yield by choosing the proper wall and limiter material. It is also found that H^- ions are formed by both desorption and reflection processes. The number of H^- ions produced by the desorption process is closely related to the amount of OH^- ions present in the self-extracted beam.

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 to form a linecusp configuration for primary electron and plasma confinement. 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 $\sim 1.5 \times 10^{-3}$ Torr.

In order to investigate the negative ions produced by different materials, a rotatable water-cooled copper disk with four different materials brazed onto the four quadrants was employed. By biasing the disk negative with respect to the plasma, positive ions are accelerated across the sheath to strike the disk surface. Negative ions that are formed at the target surface will then be accelerated back through the sheath by the same potential. They pass through the plasma, the exit aperture on the stainless-steel plate, and then enter a magnetic-deflection mass spectrometer. With this arrangement, only one type of target material at a time is seen by the viewing system formed by the exit aperture and the entrance slit of the mass spectrometer. The yield of negative ions for each material tested can be compared under identical conditions of gas pressure, discharge power, and target potential. For negative ions with the same mass-to-charge ratio, the mass spectrometer also acts as an energy analyzer.

Experimental Results

(a) Negative ion spectrum from different materials

When the source was operated with a discharge current of 4 A, Langmuir probe measurements indicated a hydrogen plasma density of approximately 10^{10}

cm^{-3} . The electron temperature was about 1 eV and the plasma potential approximately 1.5 V positive with respect to the anode.

Figures 2(a)-(c) illustrate the mass spectra of the negative ions produced from Rh, Pt, Pd, Mo, Ta, Cu, stainless-steel and Au targets with a bias voltage between -200 to -300 volts. It can be seen that H^- ions are present in all these spectra, and the formation processes of these ions will be discussed in the next section. The other negative ions that are detected by the spectrometer include O^- , OH^- , O_2^- and CO_2^- . The composition of these higher mass ions varies from one metal to the other. For example, O_2^- is the principal negative ion produced on Rh, Pt, Pd, Cu and Au targets. But O^- and OH^- are the main negative ion components in the mass spectra of Ta, while Mo and stainless-steel targets generate approximately equal amount of O^- , OH^- and O_2^- . In all cases, no negative ions with mass greater than 60 have been detected by the spectrometer.

Since the spectra of these ions were obtained under almost identical source operating condition, the difference in negative ion yield can be attributed to the chemical composition of individual target surface. Thus, some metals (e.g. Ta) absorb mainly OH molecules (and perhaps atomic oxygen) on the surface, while others (such as Cu and Au) retain mainly the diatomic oxygen molecule O_2 . Under positive hydrogen ion impact, some of these atomic or molecular "impurities" will form negative ions as they are desorbed (or sputtered) from the target surface.

Figure 2(d) shows the negative ion spectrum obtained from hydrogen ions impinging on a TiC target at 400 eV. It can be seen that H^- , C^- , O^- , OH^- , O_2^- , and CO_2^- ions are formed as with the other metal targets, however, two additional large peaks with mass 38 and mass 60 are also present. The latter can be recognized as TiC^- ions. Since TiC is often used for coating chamber wall and limiters in tokamaks, the formation of

TiC^- ions may provide a source of heavy mass impurity when they are accelerated into the reactor plasma. For a graphite target, the mass spectrum is similar to that of TiC except for the absence of the TiC^- peak.

(b) H^- ion formation processes

The energy spectra of the H^- ions produced by Rh, Pt, Pd and Mo are illustrated in Fig. 3(a). Two distinct groups of H^- ions can be easily identified. The energy of one group is approximately equal to the disk bias potential ($\sim E$), indicating that the ions leave the target surfaces with low energy. These H^- ions are desorbed (or sputtered) from the converter surface by bombardment with energetic hydrogen ions.² In this process, the average energy given to the H^- ions is usually small, and their final energy should be essentially equal to the sheath potential.

The second group of H^- ions has a higher energy and they are produced by reflection (or backscattering) of hydrogen ions from the target surfaces.³ All positive hydrogen ions (H^+ , H_2^+ , H_3^+) acquire the same 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. In this experiment, the species distribution $\text{H}^+ : \text{H}_2^+ : \text{H}_3^+ = 4 : 35 : 61$. Therefore, only those peaks resulting from H_3^+ and H_2^+ ion reflection are visible in the energy spectra shown in Fig. 3(a).

Figure 3(a) also shows that the desorbed H^- ion peak is much higher for Mo than from Rh, Pt and Pd. By comparing the mass spectrum of negative ions generated on these metals (Fig. 2(a)), one finds that O^- and OH^- ions are

also higher for Mo than the other three metals. This result seems to suggest that hydrogen atoms are adsorbed on the Mo target surface preferentially in the form of OH. With ion impact, both the atomic ions H^- and O^- and the molecular ion OH^- are desorbed from the target surface. For a gold target, Fig. 2(c) shows that O^- and OH^- peaks are not visible in the mass spectrum, and correspondingly the H^- ion energy spectrum (Fig. 3(b)) shows the complete absence of desorbed H^- ions.

(c) Total negative ion current

In order to measure the efficiency of generating negative ions by positive ion impact, a spherical converter (5.5 cm diam) made of either stainless-steel, Mo or graphite was installed in a multicusp negative ion source.⁴ In this geometry (Fig. 4), negative ions are self-extracted from the source while plasma ions and electrons are efficiently confined by the cusp fields. The total negative ion current output was measured by a large gridded Faraday cup located outside the source exit aperture. A permanent magnet mass separator installed behind the cup was used to monitor the percentage of high mass impurity negative ions in the beam.⁵

When the discharge is operated with hydrogen, the total negative ion current (I^-) normally increases with the converter bias voltage V_C . For a stainless-steel converter, Fig. 4(a) shows that I^- increased from ~ 1 mA at $V_C = -100$ V to approximately 4 mA at $V_C = -400$ V while the ion current to the converter was maintained at 1 A. Thus, 0.4% of the impinging positive ions can be converted into negative ions. The mass spectrometer has two collectors, one measures only H^- and the other receives all higher mass negative ions. By switching from one collector to the other, as shown in Fig. 4(b), the output signal indicates that the high mass negative ions comprise $\sim 75\%$ of the beam, regardless of converter bias voltage.

Conclusion

The results of this experiment indicate that a large and generally unrecognized amount of impurity negative ions can be generated if the total interaction surface area, impinging positive ion current and the sheath potentials are high. In some cases, these negative ions may have an even higher probability of entering the reactor core plasma than neutral particles. In order to reduce plasma contamination, one should also choose the proper wall material to minimize the formation of high mass negative ions.

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Figure Captions

- Fig. 1 Schematic diagram of the multicusp negative-ion source.
- Fig. 2 The mass spectrum of the negative ions produced on Rh, Pt, Pd, Mo, Ta, Cu, S.S., Au and TiC surfaces at a target bias voltage between 200 to 400 V.
- Fig. 3 Energy spectrum of the H^- ions produced on Rh, Pt, Pd, Mo and Au targets.
- Fig. 4 (a) The total Faraday cup current and,
(b) The H^- and impurity ion cup currents for a stainless-steel converter with a constant $I_C = 1A$.

Fig. 1

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Fig. 2

XBL 8311-12286A

Fig. 3

MSL 803-80385

Fig. 4

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