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Authors

Leung, K.N.
Kunkel, W.B.

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H^- Formation Process in a Multicusp Ion Source*

K. N. Leung and W. B. Kunkel

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720, U.S.A.

In recent years, H^- ions have found important applications in high energy accelerators and in neutral beam heating of fusion plasmas.¹ There are different techniques for producing the H^- or D^- ions.²⁻⁴ The most attractive scheme is the direct extraction of H^- ions from a hydrogen discharge. This technique requires no cesium and it utilizes the existing large area positive ion source technology. The H^- ions generated by volume processes have lower average energy than those formed by surface conversion or by charge exchange processes. For this reason, intensive research and development of volume H^- sources are now being conducted in various accelerator and fusion laboratories.⁵

In the past, attempts have been made to extract volume produced H^- ion from the plasma of a duoplasmatron, a magnetron, or a Penning-type discharge source. In 1983, a novel method of extracting H^- ions directly from a multicusp source was reported by Leung et al.⁶ From this type of source, H^- beams with current density as high as 250 mA/cm^2 have been produced successfully in a pulse mode operation. In order to further improve the extractable H^- current density, it is essential to understand the production

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process of the H^- ions in these type of negative ion sources. By employing a mixture of xenon and hydrogen gas, it is found that the production of H^- ions in the tandem discharge geometry is consistent with a model of dissociative attachment of low energy electrons to vibrationally excited hydrogen molecules.

Figure 1 shows a schematic diagram of the multicusp generator when it is operated as a H^- ion source. The source chamber (20 cm diam by 24 cm long) is surrounded externally by 10 columns of samarium-cobalt magnets which form a longitudinal line-cusp configuration for primary electron and plasma confinement. The magnet columns are connected at the end flange by four extra rows of similar magnets. The open end of the chamber is enclosed by a two-grid extraction system. A steady state hydrogen plasma is produced by primary electrons emitted from two tungsten filaments and the entire chamber wall served as the anode for the discharge.

In order to enhance the H^- yield, a water-cooled permanent magnet filter⁶ is installed and it divides the entire source chamber into an arc discharge and an extraction region. This filter provides a narrow region of transverse magnetic field ($B_{\max} \approx 70$ G) which is strong enough to prevent the energetic primary electrons from entering the extraction chamber. Excitation and ionization of the gas molecules are performed by the primaries in the discharge region. Both positive and negative ions, together with cold electrons are present in the extraction chamber and they form a plasma with very low electron temperature ($T_e \leq 1$ eV) in the extraction zone. More H^- ions can be generated in the extraction region via processes such as the dissociative attachment of electrons to vibrationally excited H_2 ,^{11,12} or the recombinational attachment of H_2^+ and H_3^+ ions with electrons.^{13,14}

In order to identify which is the dominant H^- production process, the source must be operated with either H_2^+ ions or neutral H_2 in the extraction chamber. The former condition is difficult to achieve but the latter can be accomplished by employing the gas-mixing technique, that is by introducing a gas which has a threshold ionization energy lower than that of H_2 ($E_i = 15.4$ eV). In this experiment, xenon ($E_i = 12.1$ eV) was chosen as the supporting gas because it has a relatively high ionization cross-section ($\sigma_i = 10^{-16} \text{ cm}^2$) even at electron energy as low as 15 eV and it does not react chemically with hydrogen.

Figure 2 shows the distribution of the positive hydrogen ion species for discharge voltage $V_d = 11, 15$ and 40 V. All the three ion species (H^+ , H_2^+ , H_3^+) are present for discharge voltages of 15 and 40 V. For $V_d = 11$ V, no positive hydrogen ion species can be detected. However, the mass spectrometer output in Fig. 3 shows the presence of H^- ions even when V_d is reduced to 11 V. The extracted H^- ions in this case can only be generated from the neutral H_2 and most probably by dissociative attachment of low energy electrons to the vibrationally excited H_2 molecules.

According to Fig. 3, the H^- signal obtained for a discharge power of 11 V, 3 A is approximately one-fourth of that produced by 40 V, 3 A. Langmuir probe measurement also showed that the source plasma density decreased by the same amount as the discharge power was reduced from 40 V, 3 A to 11 V, 3 A. The drop in H^- yield could then be simply due to the reduction of electron density in the source and extraction chamber. Indeed when the discharge power was adjusted to 40 V, 0.75 A, both the electron density and the H^- output signal (Fig. 4) were nearly the same as those obtained for 11V, 3 A discharge, except that the positive hydrogen ion species reappeared again in the spectrum as

illustrated in Fig. 5. The above results demonstrate that positive hydrogen ions do not play an important role in the formation of H^- in modest discharge power. However, in the case of a pure hydrogen discharge, the positive hydrogen ions do provide the space charge necessary to neutralize the H^- in the extraction region.

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XBL 847-2898B

Fig. 1

XBL 873-1205

Fig. 2

(11V, 3A)

(15V, 3A)

(40V, 3A)

XBL 873-1207

Fig. 3

(40V, 0.75A)

(40V, 3A)

XBL 873-1206

Fig. 4

[40V, 0.75 A]

(a)

[40V, 3 A]

(b)

XBL 873-1204

Fig. 5

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