Evaluation of H^- behavior using a spectrally selective imaging method in hydrogen negative ion source

K. Ikeda, H. Nakano, K. Tsumori, M. Kisaki, K. Nagaoka, M. Osakabe, Y. Takeiri, and O. Kaneko

National Institute for Fusion Science, 322-6 Oroshi Toki Gifu, 509-5292, Japan

A hydrogen negative ion (H^-) source is a most important component of high-energy neutral beam injector (NBI) for fusion development. We have used three NBIs with large arc discharge sources for high power heating ($\sim$ 16 MW) in the Large Helical Device (LHD) at the National Institute for Fusion Science (NIFS) [1]. In this source, negative hydrogen ions are produced on a cesium (Cs) covered plasma grid (PG) surface, and they are extracted as a beam from the PG apertures as shown in Figure 1. So, the behavior of these ions near the PG surface called the extraction region is an important factor of the high-power and homogeneous beam generation.

We have developed a spectrally selective imaging system to investigate the behavior of H^- ions in the extraction region [2, 3]. The imaging system consists of a quartz lens, an optical filter, a glass-fiber image conduit for high voltage insulation, and a 16-bit monochromatic CCD detector. This system has been installed in the 1/3 scaled H^- source in the NBI development testbed in NIFS, as shown in Figure 1. The center of the line of sight set parallel to the PG surface with the distance of 11 mm. The viewing angle covers 30 mm from the PG surface, and the three row of the PG apertures can be observed on the image. We also installed a cavity ring-down spectroscopy (CRDS) [4] and an electrostatic probe [5] in the extraction region to measure an absolute value of H^- density (n_{H^-}) and electron behavior, respectively.

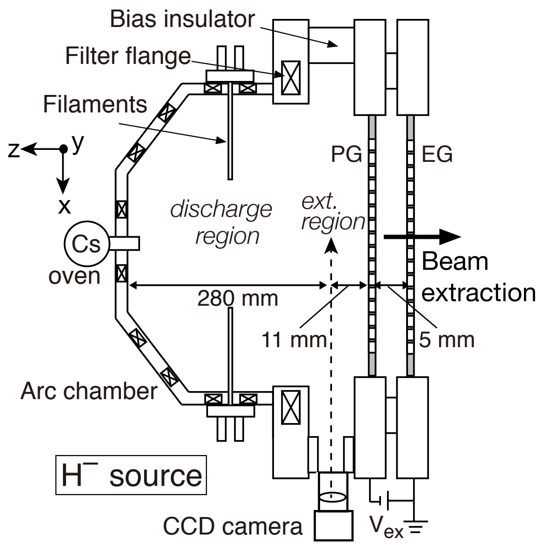

Figure 1: *Schematic drawing of the hydrogen negative ion source with an imaging diagnostic.*

Figure 2(a) shows the shot histories of the electron saturation current (I_{es}) measured by the electrostatic probe and the n_{H^-} the hydrogen discharge with Cs conditioning in the H^- source. A discharge power, hydrogen gas pressure, and bias voltage were set constant of 50 kW, 0.2 Pa, and 2 V, respectively at the beginning of the conditioning. We introduced Cs vapor continuously into the arc chamber from two Cs ovens with the temperature of 185°C installed on the back plate of the source. The interval time of each discharge was two minutes and the duration of the arc discharge was 10 sec. We applied the extraction voltage during 1 s between PG and extraction grid (EG) at the end of arc discharge. Both signals did not change for 30 min after opening Cs ovens; this delay time is likely due to the condition of the inlet tube. The n_{H^-} was increased to 1.5 $\times 10^{17}/m^3$ from 3 $\times 10^{16}/m^3$ as proceeding of surface condition. At the same time, the signal intensity of I_{es} decreased to 10%. This suggests that the contribution of electrons was reduced in the extraction region due to the increasing of H^- ions caused by surface production. We have also confirmed that the ionic plasma condition contained H^- and H^+ ions after sufficient Cs conditioning in the same source [5].

Figure 2(b) shows the shot histories of the spectrum intensity of hydrogen Balmer-α line (H_α), Balmer-β line (H_β), and neutral Cs line with the wavelength of 656 nm, 486 nm, and 852 nm, respectively. The Cs signals started to increase at the same timing of the n_{H^-} increase, but it continuously build up during Cs conditioning. H_α signals also increased after Cs feeding; this shot history is similar to the history of n_{H^-}. This similarity is caused by the increasing of the excited hydrogen population due to the mutual neutralization process between H^+ and H^- ions, which is the important charge exchange reaction in the negative ion source. In the case of pure volume discharge without Cs, the main excitation process of H_α line is the dissociative recombination between H_2^+ and electrons in the low electron temperature under 3 eV. When the negative ion density increases instead of electrons after the Cs conditioning, the excited hydrogen population due to the mutual neutralization process becomes much larger than that due to the dissociative recombination becaus both cross-sections are of the same order[6]. On the other hand, the H_β signal which slightly decreased during the conditioning did not strongly depend on n_{H^-}. This result is also consistent with the cross-section for H_β emissions [6].

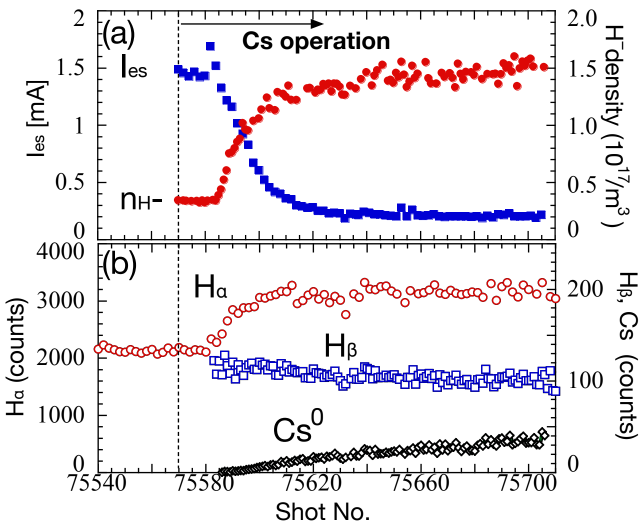

Figure 2: *(a) Shot history of the electron saturation current (closed squares) and H^- density (closed circles) measured by the electrostatic probe and CRDS, respectively. (b) shows the signal counts of H_α (open circles), H_β (open squares), and neutral Cs spectrum (open diamond).*

After sufficient Cs conditioning, we have clearly observed the density reduction on H^- ions during beam extraction. We also found such signal reduction on the H_α intensity in our arc discharge source [3]. A similar reduction has been also observed in the RF discharge source [7], which method will be used on the ITER-NBI. The reduction value of H_α emission (ΔH_α) defined the subtraction of signal intensity acquired before beam extraction from that acquired during beam extraction. Figure 3 shows the subtraction image of H_α emission; here the reduction area is represented in black. We also represent the black lines as the envelop of the components in the source, such as the row for PG apertures, the PG flange, and the magnetic filter flange to understand the positional relation. This ΔH_α image was acquired in the 38 kW constant arc discharge during beam extraction with the 0.2 Pa hydrogen pressure and 0.2 V lower bias voltage condition. We applied -8.1 kV extraction voltage between the PG and EG to extract negative charged particles.

We find the wide reduction area for H_α emission expanded inside the plasma farther than 25 mm from the PG surface, as shown in Figure 3. Strong reductions appeared in the region close to the PG apertures ($z < 10$ mm) due to the reduction of H^- ions caused by the beam extraction. On the other hand, there are few reduction on the PG surface region between the apertures row which is considered to be a production region for n_{H^-} ions. From these results, the H^- ions which are produced at the PG surface release to the extraction region and widely distribute during arc discharge. Then, these ions are considered to enter the meniscus ranges near the PG aperture. We also observed a large H_α reduction in the upper side of the image; this deviation of the distribution is caused by the deviation of the negative ion distribution due to the position of Cs nozzle located at 9 cm above the LOS for the imaging diagnostic. The apertures row at the center of the LOS is the third row from the bottom close to the camber wall. It is believed that the beam distribution in the peripheral region such as the top and the bottom beam has been found to be weak from a colorimetric

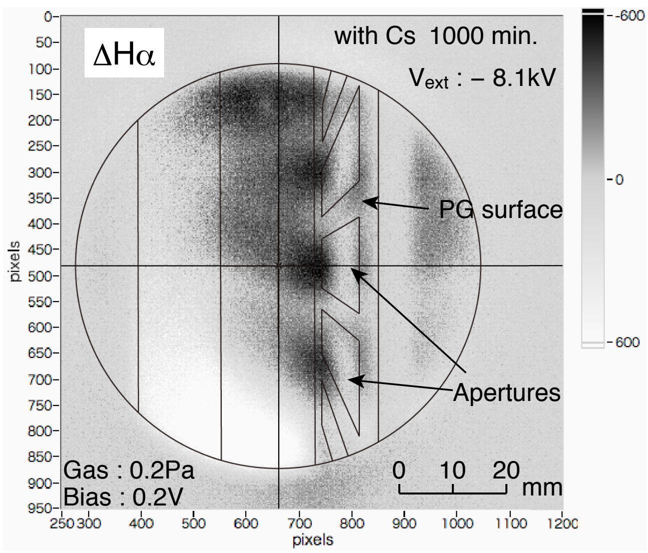

Figure 3: *Reduction distribution image for the H_α emission caused by the beam extraction. Right and left hand side is the PG surface with apertures and the hydrogen discharge area, respectively. The reduction signals are represented in black.*

measurement, and is relevant to the deviation of the reduction distribution for negative ions.

ACKNOWLEDGEMENTS

The authors acknowledge the NBI technical staff for their operational support. This work was supported by JSPS KAKENHI Grant Number 25249134 and the budget for the NIFS No. ULRR702 and No. ULRR009.

References

[1] Y. Takeiri, O. Kaneko, K. Tsumori, Y. Oka, K. Ikeda, M. Osakabe, K. Nagaoka, E. Asano, T. Kondo, M. Sato, and M. Shibuya, Nucl. Fusion, **46**, S199 (2006).

[2] K. Ikeda, H. Nakano, K. Tsumori, M. Kisaki, K. Nagaoka, M. Osakabe, Y. Takeiri, and O. Kaneko, Rev. Sci. Instrum. **85**, 02A724 (2014).

[3] K. Ikeda, H. Nakano, K. Tsumori, M. Kisaki, K. Nagaoka, M. Osakabe, Y. Takeiri, and O. Kaneko, New Journal of Physics, **15**, 103026 (2013).

[4] H. Nakano, K. Tsumori, K. Nagaoka, M. Shibuya, U. Fantz, M. Kisaki, K. Ikeda, M. Osakabe, O. Kaneko, et al., AIP Conf. Proc., **1390**, 359 (2011).

[5] K. Tsumori, H. Nakano, M. Kisaki, K. Ikeda, K. Nagaoka, M. Osakabe, Y. Takeiri, O. Kaneko, et al., Rev. Sci. Instrum. **83**, 02B116 (2012).

[6] U. Fantz and D. Wünderlich, New Journal of Physics, **8**, 301 (2006).

[7] U. Fantz, H. Falter, P. Franzen, D. Wünderlich, M. Berger, A. Lorentz, W. Kraus, P. McNeely, R. Riedl, and E. Speth, Nucl. Fusion, **46**, S297 (2006).