§19. Diagnostics of Negative Hydrogen Ions in Divertor Plasmas by Visible Spectroscopy

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In the LHD project, the control of divertor plasmas is one of important subjects. Mutual neutralization between positive and negative ions may be a useful process in order to suppress ion fluxes on the divertor plates. It is necessary to understand behaviors of negative hydrogen ions in the high-density divertor plasmas. In this report, we describe a simple diagnostic technique of negative hydrogen ions with good accessibility to the divertor plasmas produced in geometrically complicated devices.

The principle of the method is as follows: Excited hydrogen atoms H^* are efficiently produced by mutual neutralization reaction.

$$H^- + H^+ \rightarrow H + H^* \qquad (1)$$

The intensity (I_{em}) of the Balmer line emission from the excited atoms H^* is proportional to the positive ion density (n_+) and negative ion density (n_-) ($I_{em} \propto n_+ \times n_-$). This visible emission can be used for detection of H^- ions and for monitoring the contribution of mutual neutralization to the suppression of the heat flux on the divertor plates.

The high-density hydrogen plasmas were produced by helicon-wave discharge. The vacuum chamber was composed of a glass discharge tube (1.7cm in diameter and 25cm in length), a stainless steel observation chamber (20cm × 20cm × 10cm) and a stainless steel cylindrical chamber (11 cm in diameter and 21 cm in length). A magnetic field along the cylindrical axis of the vacuum chamber was 1kG. The H_2 pressure was varied from 0.8 to 2.7Pa. An rf power up to 2.5kW at 13.56MHz was applied to an m=1 helical antenna wound around the discharge tube. The discharge was operated with a pulsed mode of 5Hz (discharge duration 10ms). The typical electron temperature was 5 eV, and electron densities were in the range of 1×10^{11}-1×10^{12} cm^{-3}.

The absolute electron and negative ion densities were measured using a microwave interferometer and a laser photodetachment technique, respectively. The total positive ion density was evaluated from charge neutrality with the densities of both the negative charge particles. The compositions of negative and positive ion species were measured with a time-of-flight mass spectrometer. The dominant negative ion species was H^-. For positive ions, H_2^+ was main ion species in the discharge phase and H_3^+ became superior in the afterglow phase. The fractional abundance of H^+ did not significantly vary in both the phases. The emission by mutual neutralization reactions between H^- and H_2^+ (H_3^+) can be neglected from the consideration on the energy balance before and after the reactions. The H^- ions were efficiently produced in the afterglow. The H^- density reached a peak about 20 μs after the termination of the rf power, and the peak density increased with the electron density.

The temporal variations of emission intensities of the Balmer lines in the afterglow are shown in Fig. 1. The emission intensities steeply decreased within 10 μs after rf-off and with longer decay times after 10 μs. The emissions just after rf-off were due to electron impact excitation. Those with the longer decay times resulted from mutual neutralization. In the latter emission, the H_α intensity was the strongest and the use of the H_α line is best for diagnostics.

In Fig. 2, the temporal variation of the H_α emission intensity for mutual neutralization in the afterglow is compared with that of the product of the positive and negative ion densities ($n_+ \times n_-$). Since the agreement between both the temporal behaviors is good, it is suggested that the visible spectroscopic technique detecting the H_α emission may be applicable to diagnostics of negative H^- ions.

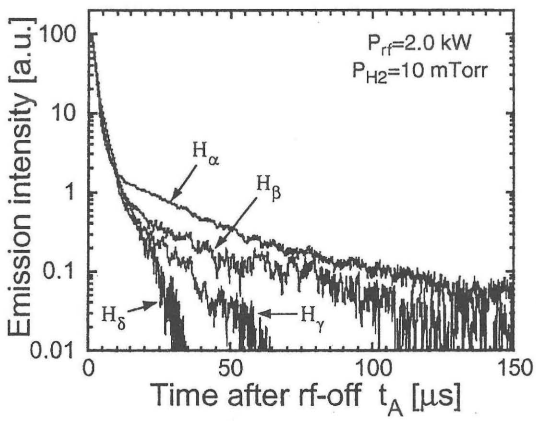

Fig. 1. Temporal variations of Balmer line intensity in the afterglow of the hydrogen plasma.

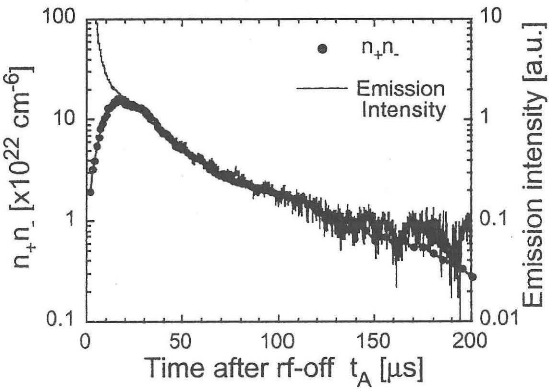

Fig. 2. Comparison between the temporal variation of the product of H^+ and H^- densities ($n_+ \times n_-$) and that of the H_α emission intensity.