§18. Development of Optical Emission Spectroscopy for Measuring H⁻ and D⁻ Densities in Divertor Plasmas

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Control of diverter plasmas is a critical issue in fusion research. Recently, much attention has been given to neutralization processes of positive ions by recombination with electrons and negative ions. Efficient neutralization in the diverter region reduces thermal flux toward diverter plates. In the present work, we propose a simple method for diagnostics of negative ions in diverter plasmas. Since the present method employs passive optical emission spectroscopy, it has good accessibility to fusion devices having a limited number of observation ports.

The principle of the method is based on mutual neutralization reaction between positive and negative ions,

$$H^+ + H^- \rightarrow H + H^*. \quad (1)$$

Excited hydrogen atoms are produced by this reaction, and the excited state decays with optical emissions. If we detect the optical emission from H^* produced by this reaction, we can monitor negative ions in plasmas. This method has been demonstrated in an oxygen plasma successfully.[1)]

The development is composed of five parts: 1) production of high-density H_2 and D_2 plasmas, 2) measurement of positive ion composition, 3) measurement of negative ion density, 4) measurement of optical emission intensity due to reaction (1), and 5) comparison of the optical emission intensity with the product between H^+ (D^+) and H^- (D^-) densities. If the variation of the optical emission intensity due to reaction (1) is similar to that of the product between H^+ (D^+) and H^- (D^-) densities, it confirm the usefulness of the present method for the diagnostics of negative ions. In this year, we have carried out the items 1)–3) successfully.

High-density H_2 and D_2 plasmas were produced by helicon-wave discharges in a small plasma device having a magnetic field of 1 kG. By using a specialized spiral antenna, high electron density of 1×10^{12} cm^{-3} was obtained under a low gas pressure of 10–15 mTorr and an rf power (13.56 MHz) of 2.4 kW.

The composition of positive ions was measured by time-of-flight mass spectrometry. Positive ions in plasmas were sampled into a laboratory-made time-of-flight mass spectrometer, which had a flight length of 1.2 m and an acceleration voltage of 0.8–1.5 kV. The mass of ion was determined from the flight time of the ion beam. Figure 1 shows the composition of D^+, D_2^+, and D_3^+ observed in D_2 plasmas as a function of the rf power. The gas pressure was 10 mTorr. The fractional abundance of

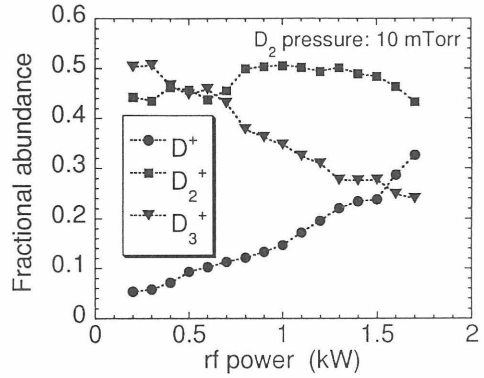

Fig. 1. Fractional abundance of positive ions observed in D_2 plasmas at a gas pressure of 10 mTorr.

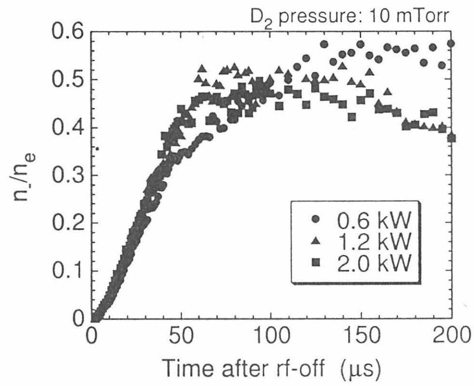

Fig. 2. Ratio of negative ion to electron densities observed in afterglow of D_2 plasmas at a gas pressure of 10 mTorr.

D_3^+ decreased monotonically with the rf power, while the fractional abundance of D^+ increased with the rf power.

Negative ion density was measured by probe-assisted laser photodetachment. Pulsed laser radiation at a wavelength of 680 nm was launched into plasmas. The fluence of the laser pulse was 130 mJ/cm^2. Electrons released from negative ions were collected by a Langmuir probe, and the negative ion density was evaluated from the pulsed increase in the electron saturation current. It was shown by time-of-flight mass spectrometry that negative ions were completely occupied by D^-. Figure 2 shows temporal variation of the ratio of negative ion to electron densities in the afterglow of D_2 plasmas at a gas pressure of 10 mTorr. The ratio of negative ion to electron densities increased in the afterglow, and had a saturation level of ~ 0.5. We recently succeeded in the detection of H_α (D_α) emission due to reaction (1) in the afterglow. The temporal variation of the H_α (D_α) emission intensity will be compared with that of the product between the H^+ (D^+) and H^- (D^-) densities.

Reference

1) T. Ishikawa, D. Hayashi, K. Sasaki, and K. Kadota, Appl. Phys. Lett. **72**, 2391 (1998).