Axial Profile of Balmer-Alpha Emission near a Tungsten Target in the Compact PWI Simulator APSEDAS

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The axial profile of Balmer-alpha emission near a tungsten target has been measured in the compact plasma wall interaction (PWI) simulator Advanced PWI Simulation Experimental Device and Analysis System (APSEDAS). Axial H_α emission decreases toward the target at two levels, a steep gradient within 10 mm of the target and a shallow gradient more than 10 mm away. The structure of the H_α profile within 40 mm of the target is the same even though the electron density changes by one order of magnitude and the neutral pressure changes by a factor of three. On the other hand, the H_α profile more than 40 mm from the target gradually increases with increasing hydrogen filling pressure, although it does not change with the density in the case of constant filling pressure.

Keywords: CCD camera, tungsten, H_α emission, edge plasma, neutral hydrogen

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Hydrogen recycling is an important issue for plasma particle control and plasma confinement [1, 2]. Recycling has been studied through the measurement of Balmer-alpha emission, I_{H_α}, which is caused by the excitation of hydrogen atom and molecule [3–6]. I_{H_α} changes not only with plasma parameters such as plasma density and temperature but also with wall conditions such as species of the target material and target temperature, because hydrogen neutrals near the target originate from backscattering on the target and desorption from the target as well as the gas feed. Because the energy and excitation state of hydrogen neutrals depend on the generating process, the spatial structure of I_{H_α} proportional to the hydrogen neutrals is expected to change along with the wall conditions as well as the plasma parameters. The effect of the wall conditions and plasma parameters on the spatial profile of I_{H_α} near the target material is important for understanding hydrogen recycling.

The spatial profile of I_{H_α} near a target material has been measured to study hydrogen recycling in the compact PWI simulator APSEDAS. The plasma is produced with a helical antenna by RF waves (13.56 MHz). This type of device can produce a high-density plasma [7,8]. Both plasma density and neutral pressure are changed separately. In addition, the target temperature can be changed by modification of target cooling. In this paper, I_{H_α} near a tungsten target was examined over a wide range of plasma densities and hydrogen filling pressures.

Figure 1 shows a schematic view of APSEDAS. The z-axis and r-axis are defined as vertical and horizontal coordinates, respectively. The position of $z = 0$ mm corresponds to the target surface. Tungsten on a water-cooled stage was irradiated by hydrogen plasma. In this experiment, the RF supply was pulsed at 10 Hz with a 20% duty cycle. The magnetic field was 0.025 T. The base pressure reached about 2.0×10^{-7} Torr. During plasma discharges, the gas pressure was set at a range of 10-50 mTorr by changing the hydrogen gas supply. The spatial profile of I_{H_α} was measured using a CCD camera with a frame rate of 1 kHz as a maximum, and the dynamic range of image data was 8 bits. The frame size was 228×164. The camera viewed the cylindrical plasma near the tungsten target through a Pyrex window. An interference filter with a half width of 20 nm in the wavelength range of 640-660 nm was attached in front of an objective lens with a focal length of

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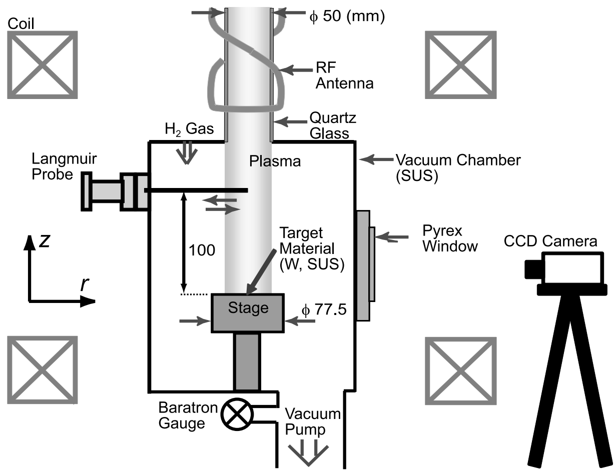

Fig. 1 Schematic view of experimental setup.

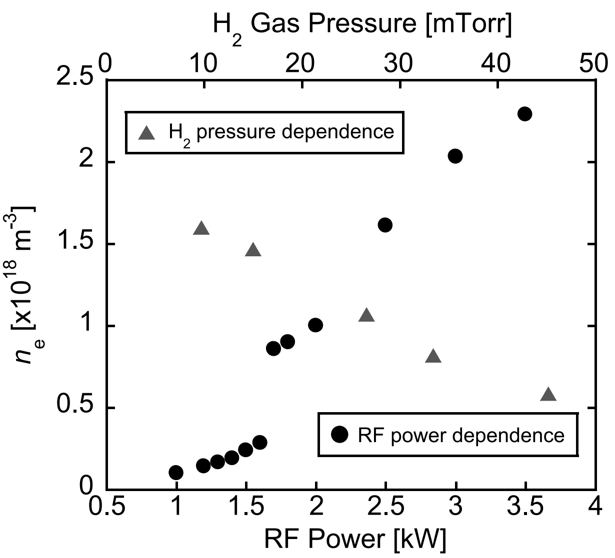

Fig. 2 Electron density as a function of RF power and hydrogen filling pressure.

2.8 mm and F number of 2.2, and only H_α light (656.3 nm) was observed. The electron density and temperature were measured using a Langmuir probe located 100 mm above the target.

Figure 2 shows the electron density as a function of RF power and hydrogen filling pressure. In the case of an RF power scan, the hydrogen filling pressure was constant at 20 mTorr. The electron density increased with the RF power. A density jump occurred around $P_{rf} \sim 1.6$ kW, and the electron density increased by a factor of three. The electron temperature was 14 eV below $P_{rf} \sim 1.2$ kW and decreased in the range of $P_{rf} \sim 1.2$-1.6 kW. It was constant at 8 eV after the density jump. As shown in Fig. 2, the electron density decreased with the filling pressure. In the filling pressure scan, the RF power was 2.5 kW. The electron temperature also decreased from 12 eV to 8 eV.

Image data of I_{H_α} measured by the CCD camera were

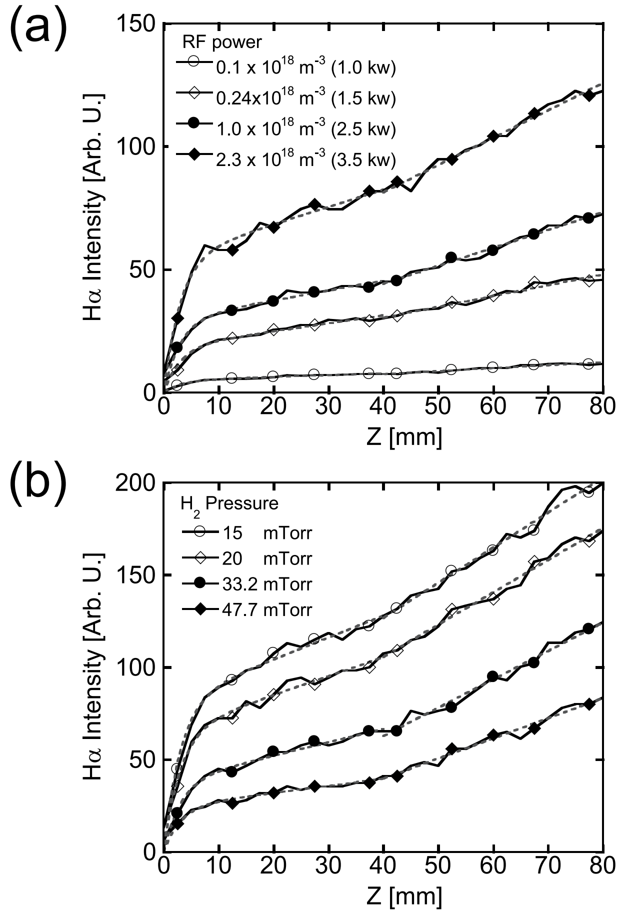

Fig. 3 Dependence of axial I_{H_α} on RF power (a) and hydrogen filling pressure (b). Solid lines are the experimental data. Dotted lines show exponential distributions fitted within 20 mm from the tungsten target by Eqs. (2) and (3).

extracted in z direction, as shown in Fig. 3. Here I_{H_α} at $r = 10$ mm was used to avoid light reflected from the back wall. I_{H_α} is found to change along with the electron density and hydrogen filling pressure, because I_{H_α} can be written by the following equation [9]:

$$I_{H_\alpha} \propto n_e(n_i R_0 + n_H R_1 + n_{H2} R_2), \tag{1}$$

where n_e, n_i, n_H, and n_{H2} correspond to the electron density, ion density, and atomic and molecular hydrogen density, respectively. R_0, R_1, and R_2 are defined as population coefficients. The I_{H_α} profiles are also found to decrease toward the tungsten target at two levels. One is a steep gradient within 10 mm of the tungsten surface, and the other is a shallow gradient more than 10 mm away. The steep gradient of the I_{H_α} profile has been measured in other devices [5, 6], but the shallow gradient was measured here for the first time. The axial profiles of I_{H_α} were fitted well with the following equations, as shown in the dotted lines of Fig. 3:

$$I_{H_\alpha}(z) = k(1 - \exp(z/\lambda)) + az + b \quad [0 < z < 40 \text{ mm}], \tag{2}$$

$$I_{H_\alpha}(z) = cz + d \ \ [z > 40 \text{ mm}], \quad (3)$$

where k, $a - d$, and λ are constant values. λ was evaluated at 3 mm. This implies that I_{H_α} near the tungsten target had almost the same structure as that shown, even though the electron density changed by one order of magnitude and the neutral pressure changed by a factor of three. The steep gradient of I_{H_α} toward the target may reflect the plasma density profile. In practice, the steep gradient of the density toward the target was measured in Ref. [10], and the density profile was consistent with the profile derived from the continuity equation and momentum equations, considering the pressure gradient, electric field, and collisions between ions and neutral particles. The axial profiles of I_{H_α} within 40 mm of the target have the same structure (i.e., the same λ). On the other hand, when the axial profile of I_{H_α} was normalized at $z = 20$ mm, c in Eq. 3 gradually increased with increasing hydrogen filling pressure, although c was almost constant in the case of the RF power scan. The gradient c was found to change from 0.018 at 15 mTorr to 0.034 at 47.7 mTorr. The above dependence on the hydrogen filling pressure may be caused by the increase in the hydrogen neutrals supplied by the gas feed compared with those due to backscattering on the tungsten or desorption from the tungsten target. In the next step, neutral transport simulation will be executed to quantitatively examine the spatial distribution of the hydrogen neutrals accompanying each process in detail.

I_{H_α} was found to decrease toward the tungsten target at two levels, a steep gradient within 10 mm of the target and a shallow gradient more than 10 mm away. I_{H_α} structures within 40 mm of the target were the same even though the electron density changed by one order of magnitude and the neutral pressure changed by a factor of three. The gradient more than 40 mm from the target increased with increasing hydrogen pressure by a factor of three, although the gradient was almost constant in the case of the electron density scan.

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