Impact of Target Temperature on Hydrogen Recycling in Divertor Simulation Plasma of GAMMA 10/PDX Tandem Mirror

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Abstract. In GAMMA 10/PDX, a temperature-controlled V-shaped target has been utilized to study an effect of target temperature on hydrogen recycling. The V-shaped tungsten target in the divertor simulation experimental module (D-module) is heated up to 573 K and it is exposed to the end loss plasma. It is found that the H_α intensity and the electron density of the plasma in front of the target are positively correlated with the target temperature, indicating that the recycling is enhanced due to increase in the target temperature. Moreover, additional hydrogen gas is injected into the D-module with the temperature-controlled target. As the amount of hydrogen gas injection increased, enhancement of hydrogen recycling by high temperature target becomes smaller.

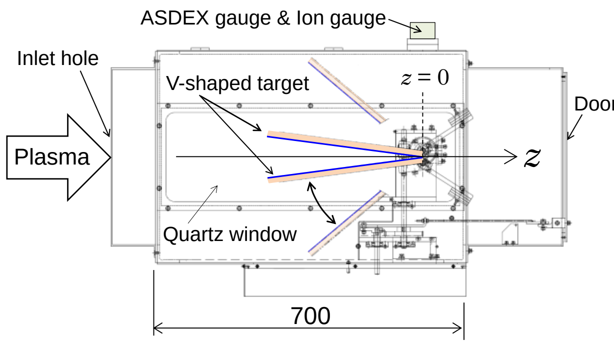
INTRODUCTION

Hydrogen recycling is one of the most important issues for stable plasma operation as well as improvement of confinement [1,2]. For example, density control was lost due to global wall saturation, which means a recycling coefficient exceeds unity, in long duration discharges in the superconducting tokamak TRIAM-1M [3,4]. Increase in the wall temperature plays a crucial role on the wall saturation.

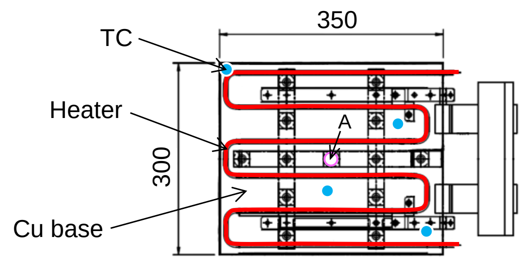
In the tandem mirror GAMMA 10/PDX, a new project has been promoted to study boundary plasma and plasma surface interaction (PSI) [5-8]. The divertor simulation experimental module (D-module) has been installed in the end region of the mirror device and it is exposed to the end loss plasma to make best use of a linear plasma device with plasma confinement. The features of GAMMA 10/PDX for the boundary plasma and PSI studies are the following: (1) high ion temperature of the end loss plasma (i.e. a few hundreds eV), (2) high magnetic field (0.15 ~ 1.5 T), (3) large plasma size (0.1 ~ 0.3 m), (4) low background pressure in the vacuum vessel and (5) high controllability of the plasma exposure since plasma heating systems of ECH, ICH and NBI are equipped. In almost all linear plasma devises for boundary plasma and PSI studies, plasma is generated by DC discharge or RF discharge without plasma confinement, and therefore ion temperature is rather low. The ion energy can be increased by target biasing but the energy becomes monotonic. In GAMMA 10/PDX, on the other hand, a main plasma is confined and thereby ion energy of the plasma is high and distributed as well as electron. It is reported that the ion energy distribution function of the end loss plasma consists of two Maxwellian distributions [9]. A distributed ion energy is suitable to study PSI phenomena such as hydrogen recycling from the viewpoint of divertor simulation for torus plasma. Besides, behavior of neutral atoms in the recycling process can clearly be observed due to the low background pressure in the vacuum vessel. In this paper, impact of target temperature on the hydrogen recycling is discussed.

EXPERIMENTAL SET UP

The D-module is installed in the west end region of GAMMA 10/PDX. It consists of a rectangular box (0.5 m square and 0.7 m in length) with an inlet aperture at the front panel and a V-shaped target inside the box as shown in Fig. 1(a). Tungsten target plates with the thickness of 0.2 mm are attached on the V-shaped base made of Cu. The target size is 0.3 m in width and 0.35 m in length. The length between the front edge of the target and the inlet of the D-module is about 0.3 m. The open-angle of the V-shaped target can remotely be changed from 15 degrees to 80 degrees. In this study, the open-angle was 45 degrees. A door is attached on the backside of the D-module. The open-angle of the door can also remotely be changed. Usually, the door is fully closed. Sheath electric heaters and thermocouples are attached on the backside of the Cu base to control the target temperature (T_{target}) up to 573 K as shown in Fig. 1(b). Besides, additional hydrogen gas can be supplied from near the inlet of the D-module. The neutral pressure is measured with an ASDEX gauge and an ion gauge which are installed at the top of the D-module. The D-module can be moved up and down. In the case of a divertor simulation experiment, it is moved up and set on the axis of the plasma.



(a)



(b)

FIGURE 1. Schematic views of (a) the D-module and (b) backside of the target base.

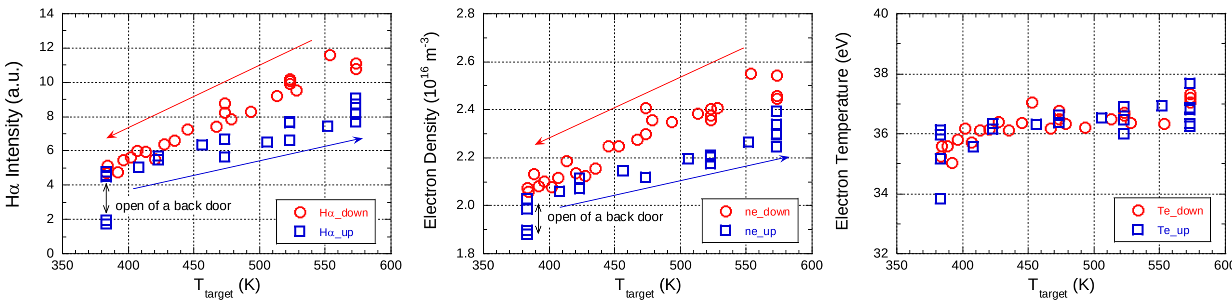
For plasma characterization, thirteen Langmuir probes have been installed on the upper target plate and two probes have been installed at the upper stream from the front edge of the V-shaped target. Emission from plasma in front of the V-shaped target is measured by a spectroscopy. The measurement position is located 150 mm upstream from the corner of the V-shaped target. Two dimensional image of the H_α line intensity ($I_{H\alpha}$) is also measured by a fast camera with an interference filter (656 nm ± 10 nm).

EXPERIMENTAL RESULTS AND DISCUSSION

The effect of wall temperature on hydrogen recycling is one of the most important issues for particle balance study. We have investigated this effect using the temperature-controlled V-shaped target. The main plasma was produced and maintained by ion cyclotron range of frequency (ICRF) heating and the plasma duration was 200 ms. The V-shaped target in the D-module was exposed to the end loss plasma. Figure 2 shows $I_{H\alpha}$, electron density (n_e) and electron temperature (T_e) in front of the target as a function of T_{target}. In this experiment, the target was heated to 573 K at the beginning to reduce an effect of outgassing from the target. The pressure in the D-module was 1.9 x 10^{-5} Pa at 573 K without plasma and it is low enough to ignore the outgassing effect. The target temperature was decreased from 573 K to 383 K (temperature down phase) and then increased again up to 573 K (temperature up phase) shot by shot. Both $I_{H\alpha}$ and n_e increased and decreased almost linearly with T_{target}. On the other hand, T_e was almost constant against change in T_{target}.

The increase in $I_{H\alpha}$ occurred in the whole region of the plasma in the D-module and the increase at the upper stream was larger than that at the downstream as shown in Fig, 3. Note that images of Fig. 3 were obtained in a different experiment with Fig.2 but the experimental condition was similar to that of Fig. 2. It is found that $I_{H\alpha}$ and n_e in the temperature up phase were lower than those in the down phase at each T_{target}. This would be caused by change in a condition of the target surface due to the plasma exposure such as a wall conditioning. The difference of $I_{H\alpha}$ at 573 K and 383 K is about twice. That of n_e is about 20 %. The change rate of $I_{H\alpha}$ is larger than n_e, indicating that hydrogen neutral atom density must be increased with T_{target} and hydrogen recycling on the target would be enhanced with increase in T_{target}.

In this experiment, the back door was opened for two shots at T_{target} = 383 K and then it was closed. The change in $I_{H\alpha}$ and n_e is indicated by arrows in Fig. 2. The Hα intensity decreased by ~60 % and n_e decreased only by ~10 % due to escape of hydrogen neutrals through the opening of the back door. It is found that the change rate of $I_{H\alpha}$ is larger than that of n_e as well as the result of high target temperature. Note that the plasma density in the D-module is sustained by not only ionization of neutral hydrogen atoms in the D-module but also inflow of plasma from the upstream side. So, the change in n_e became smaller than that of $I_{H\alpha}$ in the both cases of high temperature target and open of the back door.



(a) (b) (c)

FIGURE 2. (a) Hα intensity that was measured by the spectroscopy, (b) electron density and (c) electron temperature as a function of the target temperature. The open circle and open square represent the temperature down phase and the temperature up phase, respectively. The measurement position of the density and temperature was at almost center of the target (position A in Fig. 1).

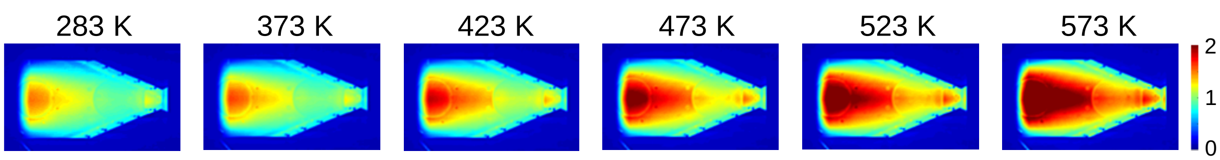
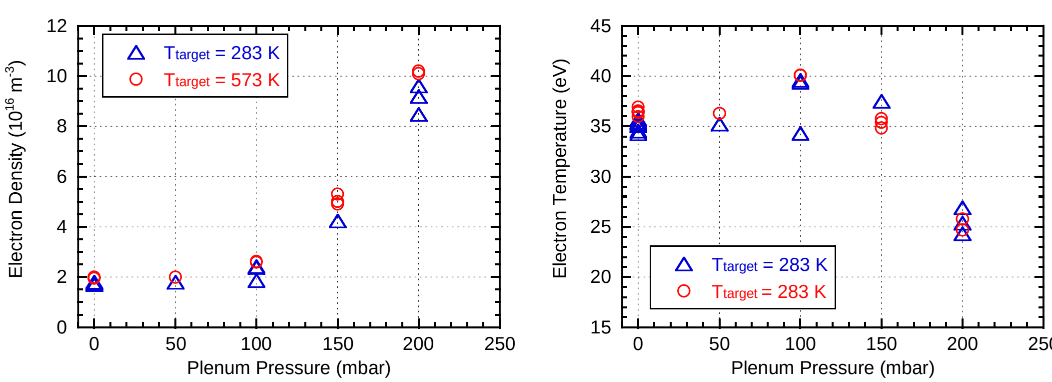


FIGURE 3. Comparison of two dimensional images of the Hα intensity in front of the V-shaped target in the D-module. The target temperature is shown above each image. The color bar of each image is the same, which is indicated at the right hand side.



(a) (b)

FIGURE 4. (a) Electron density, (b) electron temperature as a function of the plenum pressure. The measurement position of the density and temperature was at almost center of the target (position A in Fig. 1).

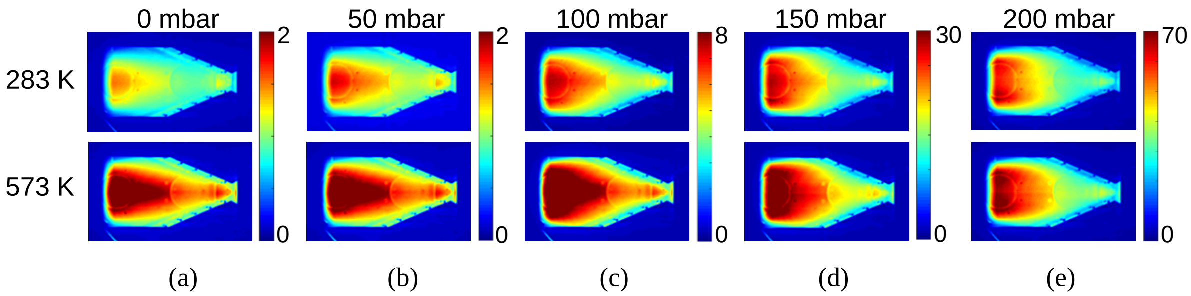


FIGURE 5. (a)-(e) Comparison of two dimensional images of H_α intensity in front of the V-shaped target in the D-module at each gas injection. The target temperature of the upper figures is 283 K and that of the lower figures is 573 K.

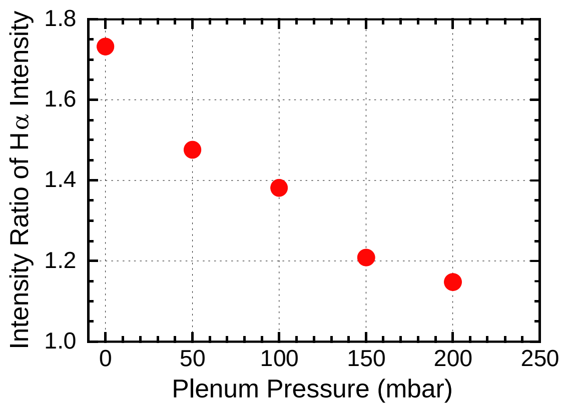


FIGURE 6. Ratio of the H_α intensity of plasma at high target temperature to that at low target temperature as a function of the plenum pressure. The measurement position of the H_α intensity is 300 mm away from the corner of the target along the central axis of the plasma.

The additional hydrogen gas injection was carried out at low target temperature (283 K) and at high target temperature (573 K) to study the effect of the gas injection on recycling at high target temperature. Figure 4 shows n_e and T_e as a function of plenum pressure (i. e. gas pressure in a reservoir tank at the upper stream of a piezoelectric valve). In this time, unfortunately, the gas pressure could not be measured due to a noise problem but the neutral pressure in the D-module should be increased by increase in the plenum pressure. The electron density increased significantly at 150 mbar and 200 mbar. The electron temperature did not change up to 150 mbar and decreased by ~30 % at 200 mbar. The density is a little higher for the high target temperature case than the low temperature case. However, it is not yet convinced that recycling would be enhanced by the high temperature target only from this density change, since the difference was within uncertainty of the measurement and reproducibility.

Figure 5 shows comparison of two dimensional images of $I_{H\alpha}$ in front of the V-shaped target at each amount of gas injection. Note that the color bar of images is different at each gas injection. As the injection gas amount (i.e. the neutral pressure) was increased, $I_{H\alpha}$ increased as a whole but the increase at the upper stream was larger than that at the downstream, which is similar to the result of Fig. 3. Although the effect of high target temperature on n_e was little, that on $I_{H\alpha}$ was significant, suggesting enhancement of hydrogen recycling. The difference between trends of n_e and $I_{H\alpha}$ seems to be attributed to difference in measurement position. A ratio of $I_{H\alpha}$ at high target temperature to that at low target temperature decreased with increase in the gas injection as shown in Fig. 6. It indicates enhancement of hydrogen recycling due to high target temperature decreased with increase in the gas injection, since the ratio is considered to mean the effect of target temperature on the recycling.

SUMMARY

The effect of wall temperature on hydrogen recycling is one of the most important issues for the particle balance study. In GAMMA 10/PDX, this effect has been investigated by using a temperature-controlled target which is installed in the D-module and is exposed to the end loss plasma. The target was heated to 573 K. The H_α intensity and n_e changed almost linearly with T_{target}. The difference of $I_{H\alpha}$ at 573 K and 383 K is about twice. That of n_e is about 20 %. This indicates that recycling was enhanced by increase in T_{target}. The difference in the change rate between $I_{H\alpha}$ and n_e seems to be attributed to that the density in the D-module was sustained mainly by the plasma flow from the upstream side. Moreover, additional hydrogen gas was injected into the D-module with the temperature-controlled target. The effect of high target temperature on $I_{H\alpha}$ was significant although that of n_e was little. As the amount of hydrogen gas injection increased, enhancement of hydrogen recycling by high temperature target becomes smaller.

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