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Particle Balance Analysis on Carbon Sheet Pump Applied to the GAMMA10 Tandem Mirror Plasmas

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Abstract

Carbon Sheet Pump (CSP) is expected as a tool for reduction of hydrogen recycling. In this paper, particle balance in the CSP is described. The pumping efficiencies estimated from the time evolution of hydrogen pressures during plasma discharges and those estimated from the thermal desorption experiments have no remarkable difference between the cases of 30°C and 200°C within experimental errors. In cases that CSP is used in actual plasma conditions, we established a method which reduces adsorbed gases on the CSP surface with sustaining a sufficient pumping efficiency by continuously heating CSP.

Keywords:

carbon sheet pump, hydrogen recycling, plasma-wall interaction

1. Introduction

Reduction of hydrogen recycling is one of the important subjects for improvement of the plasma performance. In devices aiming for steady state operation like ITER and LHD, efficient methods for reduction of hydrogen recycling with long life time are needed. Carbon Sheet Pump (CSP) [1] is a hydrogen pump, which has long life time (~5000 sec in GAMMA 10 tandem mirror [2]) and can be regenerated by heating up to about 800°C. Almost all fast neutrals whose energy are above 1 keV are trapped in carbon materials [3,4]. From ref. [5], the total amount of particles trapped at saturation is 7×10^{21} D/m^2 in the case that the particle energy is 5 keV. The life time of CSP is calculated to be about 5000 sec in the case of GAMMA10 plasmas. If CSP is saturated by hydrogen isotopes, almost all trapped particles can be desorbed by heating it up to about 800°C. Carbon material which is the main component of CSP is widely used as the first wall, and it is investigated in detail from the viewpoint of plasma-material interactions (*e.g.* [6]). Pumping capacity of CSP has the upper limit. If the technique which regenerates CSP in the period of plasma discharges is established [7,8], it can be expected as a powerful method for the reduction of hydrogen recycling in steady state operations. Therefore, CSP has great ability to reduce hydrogen recycling in long pulse and steady state operation. However, it is necessary to study particle balance using pulse plasmas for the extrapolation to longer operations than present experiments.

Recently the pumping effect of CSP on the actual plasma device was confirmed [9]. However, the experiments results suggest that the carbon sheet not only traps fast neutrals but also adsorbs the gases such as hydrogen and water molecules to a certain extent under the actual plasma devices. In this paper, operating method of CSP in the GAMMA 10 device is

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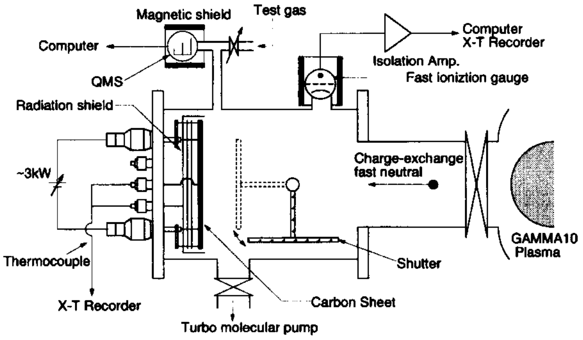

Fig. 1 Schematic view of the CSP test module.

investigated and particle balance in CSP is described in terms of reduction of adsorbed gases which is a problem in actual devices.

2. Experimental Apparatus

The CSP test module for pumping characteristics evaluation is located in the central region of GAMMA 10. Figure 1 shows the schematic view of the CSP test module. CSP is made of a two-dimensional C/C sheet of 0.15 cm thickness with a diameter of 17 cm. CSP is heated by direct joule heating (~90 V, ~30 A) up to about 800°C. In front of the CSP, a rotational shutter which intercepts the incident charge-exchange fast neutrals is mounted and the pumping effect is examined by using the shutter (CSP-on and CSP-off) shot by shot. It was confirmed that the difference of conductance between CSP-on and CSP-off is negligible. Total pressure in the test module is measured by a fast ionization gauge. Impurity gases are measured during plasma discharges and in thermal desorption experiments with quadrupole mass spectrometer (QMS) installed in the test module. Magnetic shields are installed for the fast ionization gauge and the QMS.

3. Experimental Results

3.1 Pumping effect of CSP during plasma discharges

It is reported that a high temperature of carbon material reduces the total amount of trapped particles. We investigated the pumping effect of CSP with an operational temperature of 200°C. Figure 2 shows time evolutions of total pressures in the test module (P_{CSP}) and GAMMA 10 (P_{CC}). Though there was no difference between the total pressure in the case of CSP-on and that of CSP-off in GAMMA 10, the pressure difference occurred in the test module. This pressure difference is considered to be caused by CSP trapped fast neutrals.

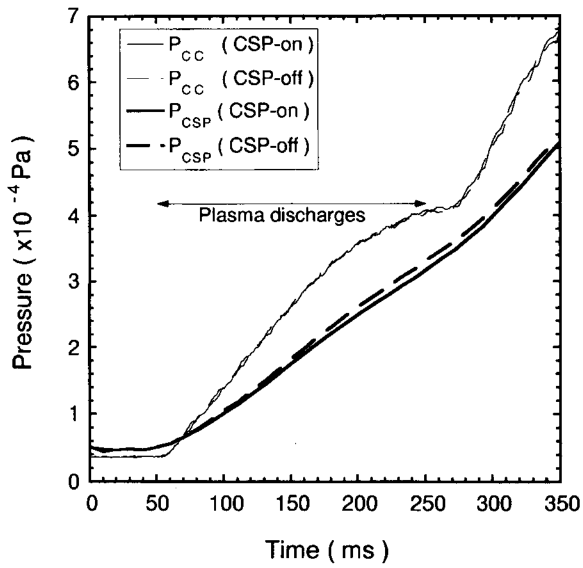

Fig. 2 Time evolution of total pressure in the test module and GAMMA 10 during plasma discharges for the cases of CSP-on and CSP-off.

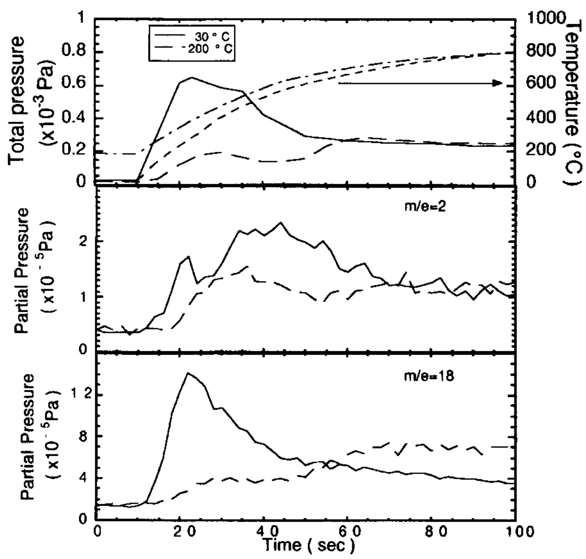

Fig. 3 Time evolution of total pressure and that of partial pressure in the thermal desorption experiments with operational temperatures of 30°C and 200°C for two days (~120 shots).

This result indicates pumping effect of CSP at operational temperature of 200°C.

3.2 Results of continuously heated CSP

Figure 3 shows the results of thermal desorption experiments after exposure of CSP to charge exchange fast neutrals (CSP-on) with the operational temperature

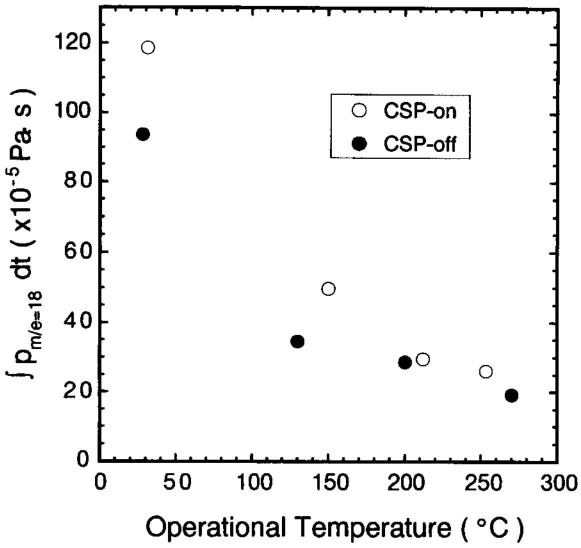

Fig. 4 Time integration of partial pressure of m/e=18 as a function of operational temperature.

of 30°C and 200°C. In each case experimental duration is fixed for two days (~120 shots). As shown in figure 3 (a), the total pressure in the case of 200°C is lower than that of 30°C until ~40 seconds after the start of heating CSP. Main component of desorbed gas is confirmed to be water at low temperature of thermal desorption experiment (below ~400°C). The partial pressure of m/e = 18 (water molecule) is considerably reduced in the early period of thermal desorption experiment (≤ 40 seconds, figure 3 (c)). It is considered that released gas comes from CSP, since the temperature of the wall surrounding CSP does not increase so much in the early period. Therefore this partial pressure difference between two experiments is mainly ascribed to decrease of water molecule adsorbed on the CSP.

Figure 3 also shows that both the total and partial pressure in the case of 200°C are higher than those of 30°C after 40 seconds from the start of heating CSP. As to m/e = 18, it is unlikely that further water molecules are desorbed from CSP, because the temperature of CSP is over 600°C after ~40 seconds. Though the inner wall temperature of vacuum vessel is not measured, it is supposed that the wall temperature in the 200°C experiment is higher than that in the case of 30°C. Thus the increase of total and partial pressure after ~40 seconds is probably caused by released gas from the wall of vacuum vessel.

Figure 4 shows the relation between operational temperature of CSP and the time integration of partial pressure of m/e = 18. The time integrated partial pressure of m/e = 18 decreases with increase of operational temperature of CSP below 200°C. However, the values are hard to decrease above 200°C. The above results indicate that a very high operational temperature is not required because the increased temperature of carbon material reduced the total amount of trapped particles.

4. Discussion

4.1 Pumping efficiency of CSP during plasma discharges

Time evolution of total pressure during discharges in the case with CSP-on is explained by the following pressure-balance equations :

$$V_{CSP} \frac{d P^{on}_{CSP}}{dt} = C(P_{CC} - P^{on}_{CSP}) - S_{eff} P^{on}_{CSP} + AS(1-\xi)\Gamma_{CX}, \quad (1)$$

while in the case of CSP-off :

$$V_{CSP} \frac{d P^{off}_{CSP}}{dt} = C(P_{CC} - P^{off}_{CSP}) - S_{eff} P^{on}_{CSP} + AS\Gamma_{CX}, \quad (2)$$

where V_{CSP} is the volume of the test module, P^{on}_{CSP} and P^{off}_{CSP} the total pressure in the test module in the cases of CSP-on and CSP-off, C a conductance between the test module and GAMMA 10, S the area of CSP, A the coefficient relating particles/sec to Pa·m^3/sec, S_{eff} the effective pumping speed of the turbo molecular pump installed on the test module, Γ_{CX} the fast neutral flux and ξ the pumping efficiency which is defined as the number of trapped particles divided by that of incident ones. We assumed that the time evolution of P_{CC} is equal for cases of CSP-on and CSP-off. The number of trapped particles are obtained by using eq. (1) and (2) as follows

$$AS\xi \int_{t_0}^{t_d} \Gamma_{CX} dt = V_{CSP}(P^{off}_{CSP} - P^{on}_{CSP})\big|_{t=t_d} + (S_{eff}+C)\int_{t_0}^{t_d}(P^{off}_{CSP} - P^{on}_{CSP})dt, \quad (3)$$

where t_0 is the starting time of plasma, t_d is the termination time of plasma. The number of trapped particles by CSP is estimated from the time evolution of the total pressure by use of eq. (3). The number of incident particles is estimated from plasma parameter such as diamagnetism, line density measured with microwave interferometer, and neutral atomic density was estimated by use of the results calculated by DEGAS [10,11]. Radial density distribution and ion temperature profile

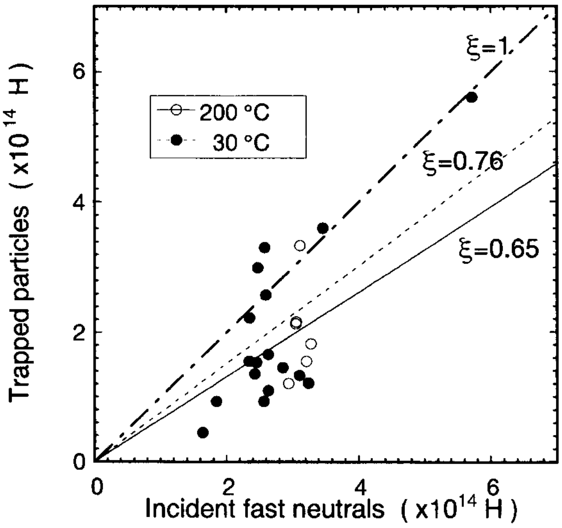

Fig. 5 Correlation between the number of incident particles and that of trapped ones during plasma discharges.

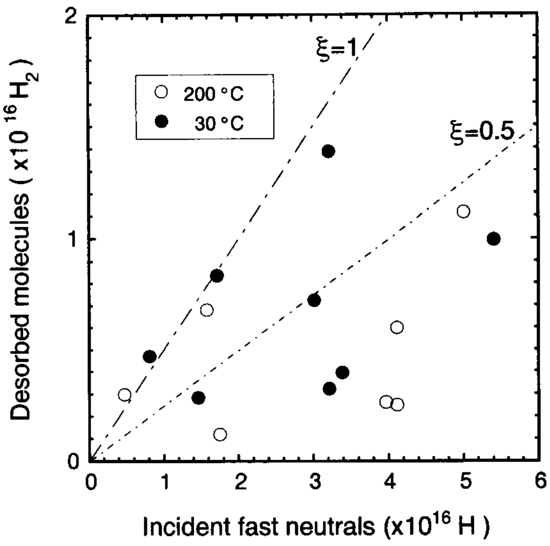

Fig. 6 The number of desorbed particles as a function of incident fast neutrals.

are assumed to be Gaussian which have typical FWHM obtained from experimental data.

As shown in figure 5, the number of trapped particles increases with that of incident ones. Although the data are scattered to some extent, the pumping efficiencies ξ of CSP are estimated to be 0.76 and 0.65 for the cases of 30°C and 200°C, respectively. Data of incident fast neutrals are almost in the range of 2~3 × 10^{14} (H), because many experiments are carried out under the similar parameters. The above results also indicates that the reduction of pumping efficiencies are small in the application to actual devices. There are no remarkable difference between two operational temperatures within the experimental error.

4.2 Pumping efficiency estimated from thermal desorption experiments

Here, the pumping efficiency is discussed based on the thermal desorption experiments after exposure of CSP to fast neutrals. In the analysis of the thermal desorption experiments, a model which consists of CSP, the vacuum chamber and pumping system is assumed. A time evolution of a total pressure is explained as follows:

$$V_{CSP}\frac{dP_{TDS}^{on}}{dt}=Q_{on}-S_{eff}P_{TDS}^{on},$$
$$V_{CSP}\frac{dP_{TDS}^{off}}{dt}=Q_{off}-S_{eff}P_{TDS}^{off}, \qquad (4)$$

where Q is the amount of desorbed gases from CSP. P_{TDS}^{on} and P_{TDS}^{off} are the total pressure in cases of CSP-on and CSP-off, respectively. Since there is finite background gases in the thermal desorption experiments in case of CSP-off, the number of trapped particles is estimated by subtracting the number of desorbed particles of CSP-off case from that of CSP-on. Figure 6 shows the correlation between the number of incident particles and that of trapped ones estimated from the thermal desorption experiments. Thermal desorption experiments were carried out after exposure for 0.5 ~ 4 days (30 ~ 250 shots). The data also scatter due to the considerable amount of background signal, and the pumping efficiencies ξ of CSP are estimated to be 1 ~ 0.2 for the cases of 30°C and 200°C. These values roughly agree with the pumping efficiencies estimated in sec. 4.1.

5. Summary

The particle balance in CSP for reduction of hydrogen recycling in long-pulse was investigated. CSP is continuously heated in order to reduce adsorbed gases. The results are summarized as follows :

1. The adsorbed water on the CSP surface decreases with the increase of operational temperature of CSP.
2. The pumping efficiencies estimated from the time evolution of hydrogen pressures during plasma discharges and those estimated from the thermal desorption experiments have no remarkable difference between the cases of 30°C and 200°C within experimental errors.

In cases that CSP is used in actual plasma conditions, we established a method which reduces adsorbed gases on the CSP surface with sustaining a sufficient pumping efficiency by continuously heating CSP. This contributes to the reduction of hydrogen recycling for long pulse, and steady state operation in GAMMA 10.

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