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Investigation of the trapped helium and hydrogen ions in plasma facing materials for LHD using thermal desorption spectrometer and alternating glow discharge cleanings

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Abstract

Preliminary experiment to evaluate, analyze, and reduce the gas accumulation of materials used in LHD as plasma facing components has been carried out using a test devices ACT and a thermal desorption spectrometer. As the test materials, stainless steel (SUS316L) and iso-graphite (IG-430U) are selected and installed inside the vacuum vessel of ACT as linings, which are near the same kinds as the first wall material and armor tile material of the divertor plate used in LHD, respectively. Each material is exposed to alternating glow discharge plasma with He and H_2 gasses. Qualitative measurement using a quadruple mass filter indicates that the He gas amount released from the stainless steel wall during H_2 glow discharge cleaning is several times as much as that released from the graphite wall, which is an unexpected result. This result does not contradict that of the thermal desorption spectrometer measurement for small samples exposed to He glow discharge plasma for 7 h.

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Keywords: Plasma facing material; Divertor; LHD; Graphite; Recycling; Helium ion trapping

1. Introduction

The reduction of the gas accumulation and release of plasma facing material (PFC) caused by high density plasma irradiation is a very important issue for plasma confinement experiments because a large amount of gas released from PFC seriously disturbs the density and impurity controls, and moreover the high gas inventory is undesirable for safety. To relax such phenomena of the PFC, surface modification, degassing by baking, and use of high Z material are generally applied. Quantitative evaluation and analysis of the mechanism for gas accumulation and gas release of PFC have been well performed with pure samples and a monochromatic high energy of several keV [1–3]. However, it is not easy to explain with such pure results the peculiar behavior of gas accumulation and release of PFC caused by GDC or plasma discharge experiment in the large helical device (LHD) [4,5], which has been observed since the third operation cycles. That is a real plasma/wall interaction which must be solved. An investigation using dirty samples and a complex plasma may be required to solve such a phenomena. Therefore, analysis of the mechanism, qualitative evaluation, and relaxation of the phenomena on PFC (the first wall and divertor plate [6]) in LHD have been investigated in ACT [7,8], and TDS [9,10] using materials similar to that used in LHD as PFCs. The results obtained recently are described in this paper.

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2. Experimental device for GDC

Using an alternating glow discharge cleaning (GDC) method, to evaluate the gas accumulation and release of PFC used in LHD, a test facility ACT with a 100 kW electron gun, pumping system, gas analyzing system, gas filling system, power supply for glow discharge, data acquisition system was used as shown in Fig. 1, which is usually used as a high heat test stand to evaluate the thermal performance of brazed type or mechanical type divertor plates. As materials to be evaluated, stainless steel of SUS316L and iso-graphite of IG-430U are used, which are used as the first wall materials of the vacuum vessel and the armor tile of the mechanically joined divertor in LHD, respectively. Each material is installed inside the vacuum vessel of ACT with a volume of 0.4 m^3 and a inner surface area of 3 m^2. The ratio of the surface areas for the two materials versus the surface area of the inner vacuum vessel are about 0.9 and 0.75, respectively. As an anode electrode for GDC, a graphite plate of 20×10 cm is used, and a stainless steel or graphite lining is used as a cathode electrode. A quadruple mass filter (QMA) capable of measuring $M/e = 1$–60 is used in a differential pumping system to analyze the gas released from the wall materials to be evaluated. An orifice with a conductance of 0.033 l/s is located between the differential pumping system and vacuum vessel of ACT. The signals for two wall temperatures, absolute pressure, and mass spectrum of released gas are recorded by the data acquisition system called NMTD. A 650 V current-controlled power supply and series resistor are used to trigger the glow plasma and stably maintain the GDC. For comparison, main parameters related to GDC in the vacuum vessel of ACT and LHD are listed in Table 1.

3. Experiment for gas accumulation and release using an alternating GDC

An evaluation test consists of three GDCs with H_2, He, and H_2, which are carried out in series. Each GDC

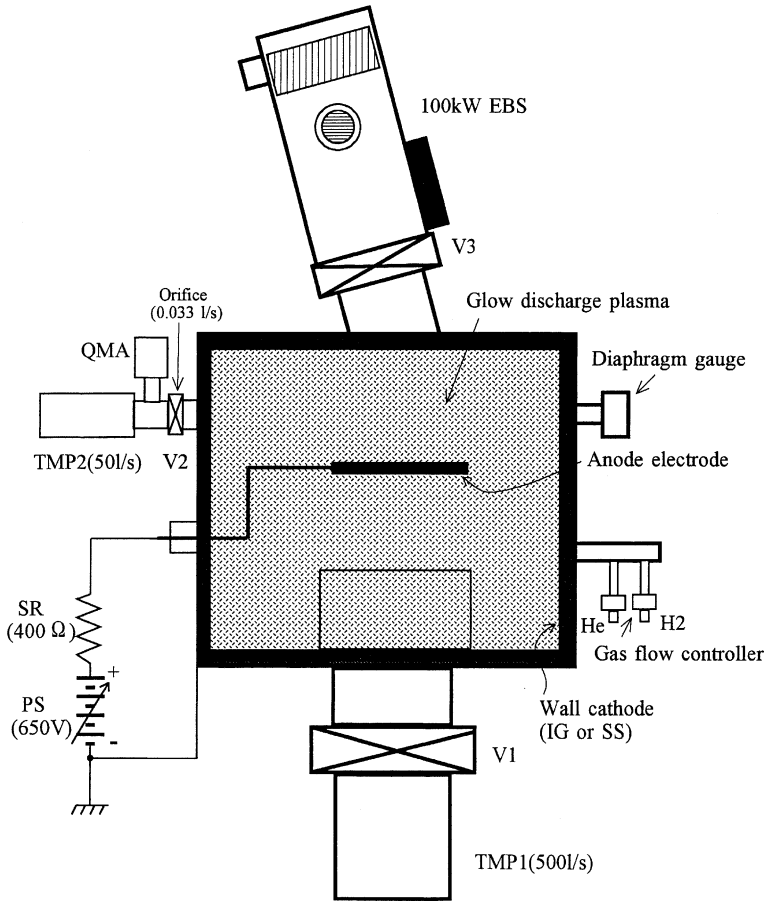

Fig. 1. Experimental setup to evaluate the gas accumulation and release of PFC.

Table 1
Comparison of the parameters of ACT and LHD for the vacuum vessel and GDC

Item	ACT	LHD
Volume of vacuum vessel (V)	0.4 m^3	210 m^3
Inner area of vacuum vessel (S)	3 m^2	1000 m^2
Kind of graphite	IG-430U	IG-430U
Total surface area of graphite (Sg)	2.25 m^2	34 m^2
$100 \times Sg/S$	72.50%	3.40%
Kind of stainless steel material	SUS316LL	SUS316L
Total surface area of stainless steel (Ss)	2.7 m^2	1000 m^2
Vacuum pump system during GDC	TMP	TMP
Initial filling pressure (mTorr)	15 mTorr	7.5 mTorr
Discharge current (A) during GDC	0.3 A	2×11 A
Discharge current density	0.1 A/m^2	0.022 A/m^2
Discharge terminal voltage	~450 V	~200 V
Holding time of GDC	60 min	170–500 min

sequence has a gas filling time of 10 min, 1 h glow discharge time, rest time of 10 min and pumping time of 10 min. Each initial gas filling pressure is adjusted to 15 mTorr by a gas flow controller. The discharge current is 0.3 A, which corresponds to a current density of 0.1 A/m^2. During GDC, the wall temperature increased gradually with time from the room temperature to about 30 °C. Figs. 2 and 3 show the responses of hydrogen and helium mass ion currents during alternating GDC with He and H_2 gasses for a stainless steel (SUS316L) wall and a graphite (IG-430U) wall, respectively. From the figures, during H_2 GDC, the maximum changes in H_2 ion current are 7.0×10^{-9} and 1.3×10^{-8} A for a stainless steel wall and a graphite wall, respectively. Against that, the maximum changes in H_2 ion current are 3.3×10^{-10} and 1.1×10^{-10} A for stainless steel wall and graphite wall, respectively. These mean that the hydrogen accumulation of the graphite wall is about two times larger than that of the stainless steel. On the other hand, it means that the helium accumulation of the stainless steel wall is three times larger than that of graphite wall.

4. The effect of wall temperature on PFC

To evaluate the effect of wall temperature on the gas accumulation and release of the stainless steel and graphite walls, the responses of helium and hydrogen ion peak currents were measured with QMF during alternative GDC with H_2 and He gasses under a high wall temperature (~80 °C). In the case of a stainless steel wall, there is no large change in gas accumulation and release for both He and H_2 gasses even by increasing the wall temperature up to about 80 °C. However, in the case of a graphite wall, the hydrogen accumulation into the wall reduces to half and helium release reduces to 1/3. As a result, at a high wall temperature (~80 °C), helium release from the graphite wall reduces to 1/6 compared with that from stainless steel under the same high wall temperature.

5. TDS measurement

To evaluate helium gas release and accumulation of materials in another way, TDS measurement of samples

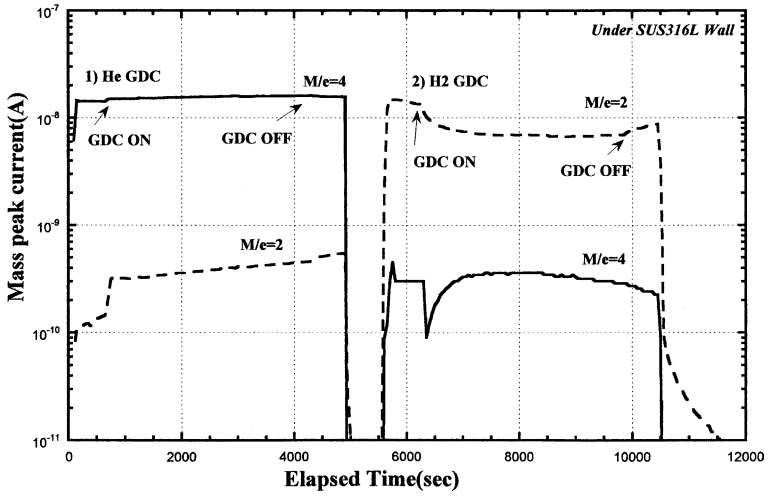

Fig. 2. Responses of hydrogen and helium ion currents during alternating GDC for a stainless steel wall (SUS316L).

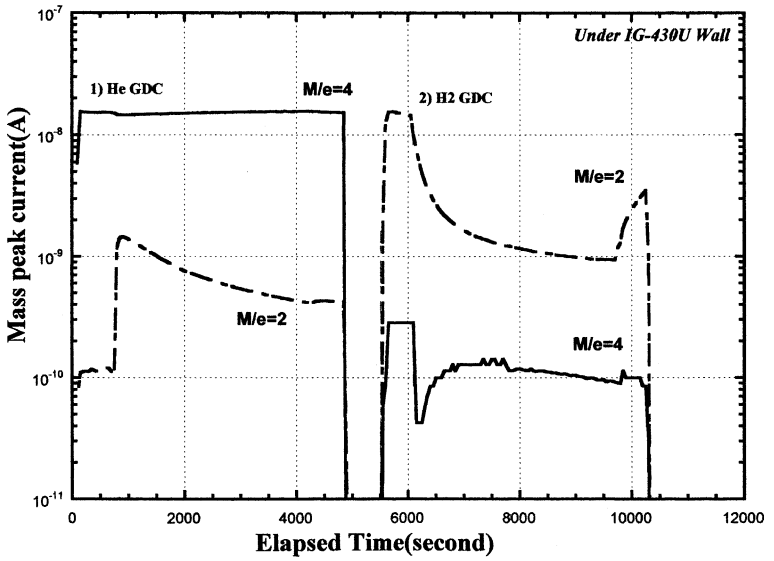

Fig. 3. Responses of hydrogen and helium ion currents during alternating GDC for a graphite wall (IG-430U).

exposed to helium GDC has been carried out. As the sample, tungsten (W), tantalum (Ta), molybdenum (Mo), stainless steel (SS), and graphite (IG) are selected and alternately arranged in a matrix on a copper holder to obtain uniform ion flux for same kinds of sample as shown in Fig. 4. The size of the sample is 10 mm wide, 50 mm long, and 0.1–1 mm depth. The number and total surface area of each sample is 10 and 50 cm^2, respectively. Preceding the installation of the samples into ACT, washing using acetone and an ultrasonic washer was performed. After that, the copper holder with the samples was located about 25 cm apart from an anode electrode and exposed to helium GDC for 7 h. The helium initial pressure and glow discharge current were 15 mTorr and 0.3 A, respectively. TDS measurement were carried out by heating up to 1000–1400 °C each of the 10

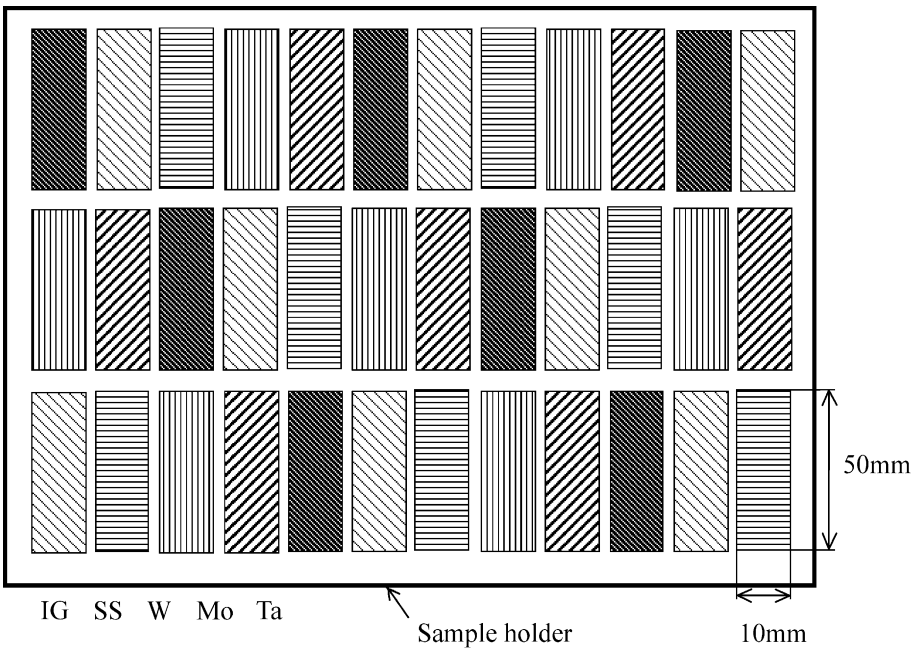

Fig. 4. Arrangement of four different materials in a matrix to make uniform the ion flux density during He GDC.

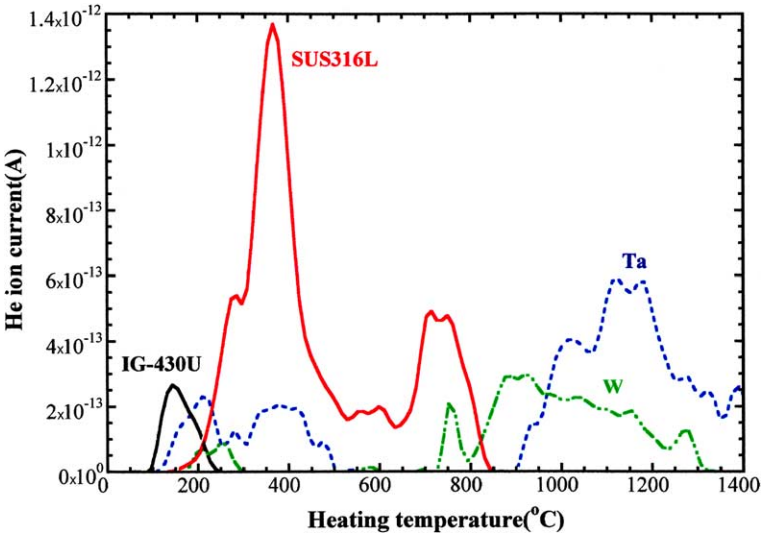

Fig. 5. Thermal desorption spectrum of four samples exposed to He GDC for He gas.

pieces. Fig. 5 shows the thermal desorption spectrum for helium measured with a QMA. As you can see, a helium gas desorption spectrum with two high peaks can be observed for stainless steel samples. However, only very little peaks can be observed for graphite samples. Moreover, there is no peak for molybdenum samples. He released gas amounts obtained by integrating the spectrum are 4.8×10^{-6}, 4.4×10^{-7}, 3.2×10^{-8}, 2.2×10^{-6}, and 4.6×10^{-6} Torr l/cm^2 for SS, IG, Mo, W, and Ta, respectively. This result proves that stainless steel, tungsten and tantalum accumulate and release helium gas much more than molybdenum and graphite samples do.

6. Summary

(a) The amount of helium gas released from stainless steel (SUS-316L) during H_2 GDC after He GDC is about three times larger compared with that from graphite (IG-430U) under RT.
(b) The amount of hydrogen gas accumulated in the stainless steel during H_2 GDC after He GDC is about half compared with that in the graphite under RT.
(c) The amount of helium gas released from the graphite reduces to about 1/3 increasing the graphite wall temperature by about 40 °C although it remains nearly constant for the stainless steel wall.
(d) TDS measurement (RT-1000, 1400 °C) for small samples (IG, SS, Ta, W, Mo) exposed to helium GDC for 7 h showed much helium release from stainless steel, tungsten and tantalum samples, but hardly observed any for graphite and molybdenum samples.

7. Conclusion

The results indicate that stainless steel (SUS316L) accumulates helium gas several times more compared with graphite (IG-430U) by plasma irradiation under helium GDC, which suggests that the helium behavior during plasma confinement experiment in LHD originates from the stainless steel used as the first wall of the vacuum vessel. However, it is difficult to explain quantitatively the helium behavior in LHD with the result because there is a large difference in the plasma parameters between GDC at ACT and the high density plasma experiment at LHD. More efforts to clarify the mechanism for gas accumulation and release of plasma facing components are required using a high density plasma such as that in LHD.

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