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Fuel hydrogen retention of tungsten and the reduction by inert gas glow discharges

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ABSTRACT

Polycrystalline tungsten was exposed to deuterium glow discharge followed by He, Ne or Ar glow discharge. The amount of retained deuterium in the tungsten was measured using residual gas analysis. The amount of desorbed deuterium during the inert gas glow discharge was also measured. The amount of retained deuterium was 2–3 times larger compared with a case of stainless steel. The ratios of desorbed amount of deuterium by He, Ne and Ar glow discharges were 4.6, 3.1 and 2.9%, respectively. These values were one order of magnitude smaller compared with the case of stainless steel. The inert gas glow discharge is not suitable to reduce the fuel hydrogen retention for tungsten walls. However, the wall baking with a temperature higher than 700 K is suitable to reduce the fuel hydrogen retention. It is also shown that the use of deuterium glow discharge is effective to reduce the in-vessel tritium inventory in fusion reactors through the hydrogen isotope exchange.

1. Introduction

Control of fuel hydrogen retention is quite important both for reductions of in-vessel tritium inventory and hydrogen recycling in fusion reactors. The in-vessel tritium inventory and the fuel hydrogen recycling affect safety issues of fusion reactors and the confinement of fusion plasmas, respectively. Tungsten [1] is regarded as a candidate for the plasma facing material of fusion reactors, so that the fuel hydrogen retention and the tritium inventoryof tungsten have to be investigated. The performance of the control method on the fuel hydrogen retention such as inert gas glow discharge has to be clarified. In this study, gas retention of polycrystalline tungsten is measured by a residual gas analysis (RGA) in a glow discharge apparatus [2–6] with liner walls of polycrystalline tungsten. The liner wall is taken cathode, so that the ion species is implanted into the tungsten. First, the deuterium retention is measured by using D_2 glow discharge. The hydrogen retention is also measured by using H_2 glow discharge to find the effect of hydrogen isotopes on the retention. The deuterium glow discharge followed by the inert gas (He, Ne or Ar) glow discharge is conducted to measure the amount of desorbed deuterium during the inert gas glow discharge [3–6]. The effect of the inert gas glow discharge on the reduction of deuterium retention is investigated. Similar experiments were previously conducted for the case of stainless steel (SS) wall [2]. The present results are compared with the case of SS. The experiment on the hydrogen isotope exchange is also conducted. From this experiment, the exchange ratio of tritium by deuterium during the deuterium glow discharge is evaluated. The small tungsten sample irradiated by the deuterium glow discharge is prepared. The desorption spectrum of deuterium is obtained by using a thermal desorption spectroscopy (TDS). The wall temperature required to reduce the fuel hydrogen retention as well as the tritium retention is obtained.

2. Experiments

In the glow discharge apparatus shown in Fig. 1, the discharge pressure and the discharge time were taken 8 Pa and 2 h, respectively, for every type of the discharge. The anode voltage was in the range from 300 to 400 V. The anode is made by copper and the chamber made by SS is grounded (cathode). Inside of the chamber wall is fully covered by sheets of polycrystalline tungsten with a purity of 99.9% (Nilaco). The average grain size is approximately 100 nm. The ion fluence is obtained by measuring the ion current from the chamber to the earth. The ultimate pressure of the vacuum chamber is 10^{-6} Pa. Numerous gas such as H_2, D_2, He, Ne or Ar is driven to the chamber with a constant flow rate through a mass flow controller (MFC). The gas retention is obtained by a residual

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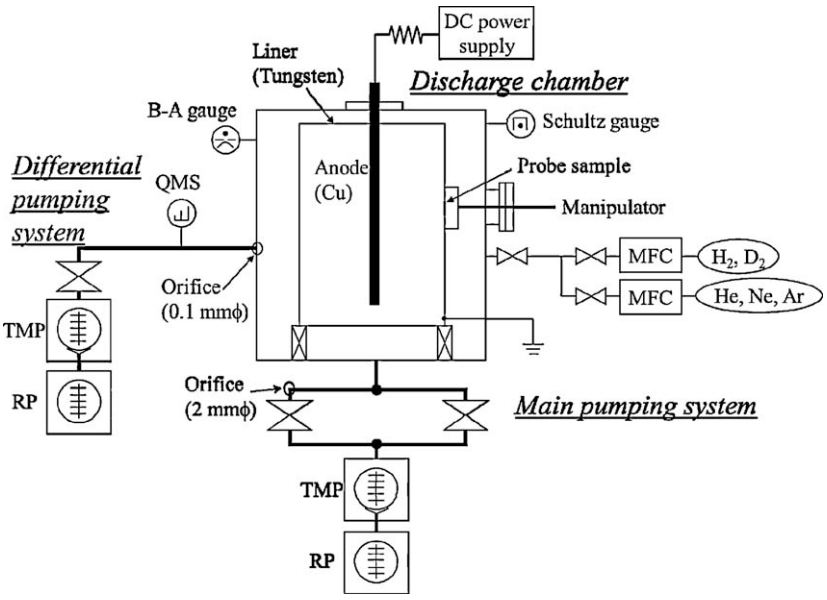

Fig. 1. Glow discharge apparatus.

gas analysis (RGA). Before the start of the glow discharge, the gas is supplied with a constant flow rate. Just after the glow discharge turns on, the ion species is implanted into the tungsten, so that the gas pressure drops. The gas pressure then recovers to the previous value after the ion implantation saturates. The change of the partial pressure is monitored by a quadruple mass spectrometer (QMS). The amount of the decreased gas pressure corresponds to the amount of retained gas.

In the glow discharge apparatus, a sample holder is placed at the center of the chamber as shown in Fig. 1. The sample holder is also grounded. Small tungsten samples are placed on the holder. After the glow discharge, these samples are extracted from the chamber. Thermal desorption spectroscopy (TDS) is conducted in order to look the gas desorption behavior. The depth profile of the atomic composition is also analyzed by using Auger electron spectroscopy (AES). The surface morphology is observed both by atomic force microscopy (AFM) and scanning electron spectroscopy (SEM).

3. Results

The hydrogen glow discharge was conducted as shown in Fig. 2. The implantation saturated approximately within 60 min.

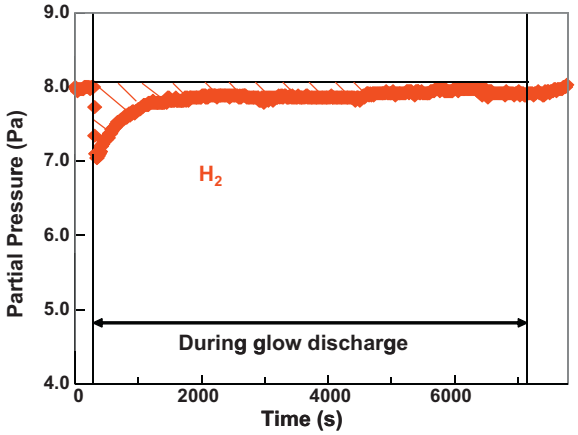

Fig. 2. Change of H_2 partial pressure during H_2 glow discharge.

The amount of retained hydrogen was determined as follows. The partial pressure drop δp was integrated with the time t to obtain $\int \delta p dt$ [Pa s]. The amount retained at the wall surface δQ was obtained as $\delta Q = \int \delta p dt / S$ [Pa m^3], where S [m^3/s] is the pumping speed. The amount of retained hydrogen was 5–6 $\times$ 10^{16} H/cm^2. The deuterium glow discharge was similarly conducted as shown in Fig. 3. The partial pressure of D_2 dropped but the partial pressures of HD and H_2 increased. The implanted D and the background H in W produce HD and H_2. The net reduced amount of deuterium gas pressure corresponds to the amount of retained deuterium, the deuterium retention. This value was ~5.0 $\times$ 10^{16} H/cm^2, which is very close to the amount of retained hydrogen. We repeated the measurements for both the hydrogen retention and the deuterium retention. The significant difference between hydrogen and deuterium retentions was not found. Thus, the tritium retention is regarded as the same as the hydrogen or deuterium retention. This result was same in the case of SS. However, the amount of retained deuterium or hydrogen in tungsten was 2–3 times larger than that in SS. This reason is explained later.

The tungsten wall was exposed to the H_2 glow discharge until the hydrogen retention saturated. After that, the deuterium glow discharge was conducted to replace the hydrogen into the deuterium. The result was similar with Fig. 3. Namely, the desorption of H in forms of HD and H_2 occurred due to the isotope exchange between H and D. The ratio of exchanged H by D was ~60% in the

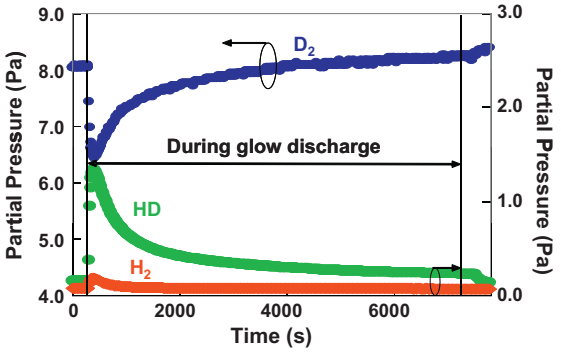

Fig. 3. Changes of D_2, HD and H_2 partial pressures during D_2 glow discharge.