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Experimental Study of Membrane Pump for Plasma Devices

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Abstract

Recycling control is a key to improve fusion plasma performance. The membrane pump has potential advantages for hydrogen pumping in fusion devices. However, there are unsolved issues for using membrane pump in LHD (Large Helical Device). The first issue is characteristics of the membrane pump under high incident hydrogen atom flux. The second issue is relationship between the surface condition and the pumping efficiency. Impurities from plasma may change the surface condition of the membrane. In order to solve these issues, a membrane pump system was fabricated and installed in a linear plasma device at NIFS (National Institute for Fusion Science). The membrane pump was successfully operated.

Keywords:

recycling control, hydrogen, membrane pump, superpermeation, atomizer, divertor

1. Introduction

To evacuate recycled hydrogen neutral particles is a key for enhancing plasma performance in magnetic fusion devices. Superpermeable membrane pump is a candidate for hydrogen pump of LHD[1,2], which is under construction at NIFS. Some kinds of metals exhibit a special phenomenon, called "superpermeation" [3,4]. The superpermeation is explained as follows. A potential barrier is set up on a metal surface, originating from a non metallic impurity layer. Superthermal hydrogen atoms are able to pass the barrier. The absorbed hydrogen atoms can reach the opposite side of the metal membrane by diffusion, if the probability of desorption at the inlet side is small. If the probability of desorption at the outlet surface is larger than that of inlet surface (*e.g.* the barrier of outlet surface is lower than that of the inlet surface) the hydrogen particles will be mostly released from the outlet surface as thermal H_2 molecules. Only hydrogen atoms can pass through the superpermeable membrane. Consequently, hydrogen particles which pass through the superpermeable membrane are automatically compressed at the outlet side of the membrane. The permeation probability can be as high as close to unity.

The advantages of the membrane pump are 1) high efficient hydrogen pumping, 2) no saturation of the pumping, 3) no moving part (it can be operated even under high magnetic field.), 4) no cold part. Such advantages are important especially when applied to fusion devices. However, experimental studies have been carried out mostly under ultra high vacuum condition by using an atomizer, which is usually incandescent metal wire[5]. In this study, we studied its pumping

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effect in a plasma device.

2. Experimental

2.1. Apparatus

The Superpermeable Membrane Pump System (MPS) was fabricated to investigate its pumping properties under the conditions similar to those of the divertor[6]. MPS includes a cylindrical superpermeable niobium membrane with a thickness of 0.1 mm, a diameter of 12 cm, and a length of 30 cm (a surface area of 10^3 cm^2) and a hydrogen atomizer consisting a set of incandescent tantalum wires, which dissociate hydrogen molecules into atoms.

The MPS is installed in TPD, which is a linear plasma device at NIFS. TPD produces a plasma with an electron temperature of ≤ 10 eV and density of an order of 10^{13} cm^3. The base pressure of TPD is an order of 10^{-7} Torr and the main impurity is H_2O. TPD has twenty coils and its magnetic field is about 0.3 T.

The whole structure of the apparatus is shown in Fig. 1. Plasma particles are produced at the plasma source region, flow into the experimental region, and hit the target. Using the target, as a probe, ion saturation current and floating potential are measured. The diameter of the plasma is about 3.5 cm. Hydrogen or helium gas is introduced at the plasma source region and experimental region.

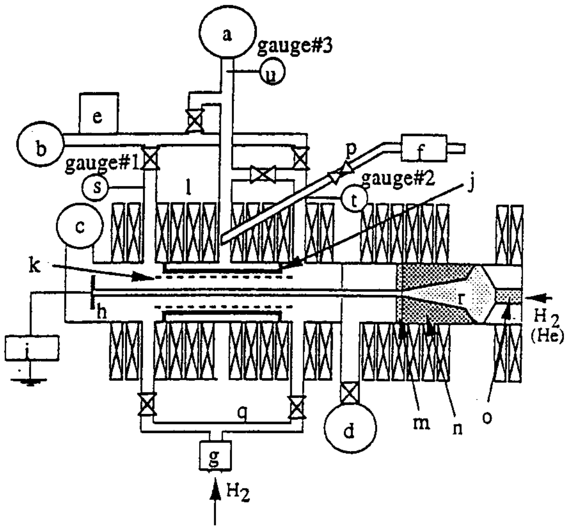

Fig. 1 The apparatus for the membrane pump experiment a: turbo molecular pump, b: ion pump, c: turbo molecular pump, d: turbo molecular pump, e: quadrupole mass spectrometer, f: mass flow controller, g: mass flow controller, h: target, i: power supply, j: membrane, k: atomizer, l: coil, m: anode, n: floating electrode, o: cathode, p: gas inlet for calibration, q: gas inlet, r: plasma, s: ionization gauge, t: ionization gauge, u: ionization gauge.

MPS was installed at the experimental region, and the periphery components were connected to MPS as depicted in Fig.1. Pressures are measured by three ionization gauges (#1, #2, #3). Two regions are separated by the membrane. If there is no permeation, the pressures of inlet side and outlet side are independent. However, when permeation begins, the pressure of the outlet side starts to increase. During the permeation experiment, the permeation flux was estimated using the pressure value of the ion gauge #3, which corresponds to a flow rate through the membrane. (The relation between the pressure value and the flow rate was experimentally obtained in advance).

2.2 Results

The superpermeation under high incident flux condition has been studied using incandescent tantalum wires. Figure 2 shows pressures of inlet and outlet side of the membrane. Before atomization, the pressure of the inlet side was higher than the pressure of the outlet side. When atomization started, the pressure of the inlet side decreased and the pressure of the outlet side increased, and finally the pressure of the outlet side become higher than the pressure of the inlet side. This is a clear evidence of an active pumping. Using incandescent wires, a high incident flux was produced and finally a permeation flux as high as 3×10^{17} H/cm^{2}s was achieved.

Then the superpermeation of hydrogen atoms which are produced by plasma was studied. Figure 3 shows the pressure of the outlet side when the plasma discharge current is changed. The plasma discharge current is almost proportional to the density of the plasma.

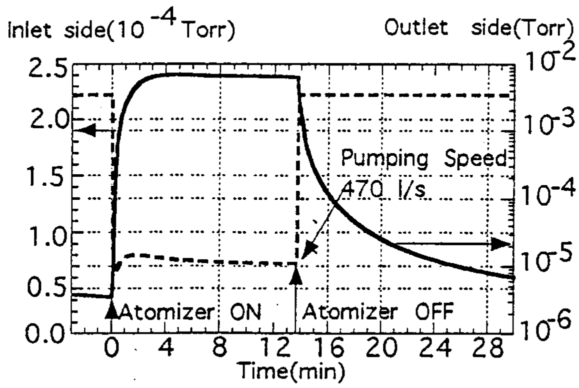

Fig. 2 Temporal behavior of the inlet and outlet pressures when hydrogen atom flux on the membrane is turned on and off.

So, this result shows that the permeation flux increases with increasing plasma density. This is a clear evidence that MPS pumps the hydrogen atoms which are produced by the plasma. Permeation of hydrogen was measured under a variety of conditions.

3. Discussion

The TPD produced a plasma with an electron temperature of < 10 eV. In this case, hydrogen atoms are produced mainly by Franck-Condon dissociation process. The production rate of the hydrogen atoms by plasma can be written as follows.

$$Q = F(T_e) n_e n_{H_2} \quad (1)$$

where F is a function of electron temperature, n_{H_2} is the hydrogen molecule density of the inlet side and n_e is the electron density. Thus, production rates of hydrogen atoms can be estimated by measuring hydrogen gas pressure, electron density, and electron temperature.

Unfortunately it is not easy to estimate the shadowing effect of atomizer support and atomizer themselves. (Only a small fraction of hydrogen atoms generated by plasma hits the membrane directly, *i.e.* without striking the surrounding components.) Consequently, it is not easy to estimate the incident hydrogen atom flux, although the production rate of the hydrogen can be estimated. However the shadowing effect is constant. So the permeation rate should be proportional to the production rate of the hydrogen atoms by the plasma.

Figure 4 shows the relationship between the estimated hydrogen production rate and the observed permeation rate. The permeation rate is proportional to the production rate of hydrogen atoms, showing that the permeation probability is constant. This result suggest that the hydrogen atoms which are produced by dissociation process in the plasma passed through the membrane, and the permeation probability was constant.

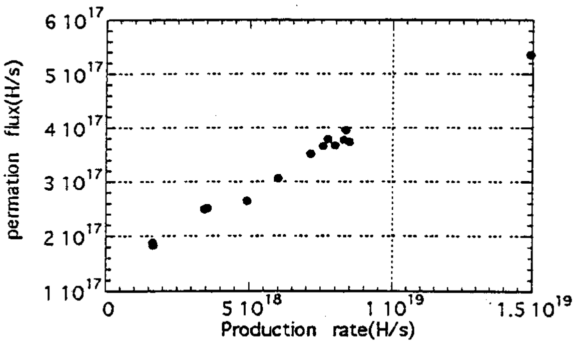

Fig. 4 Relationship between hydrogen atom production rate and permeation rate of hydrogen atoms which were produced by plasma

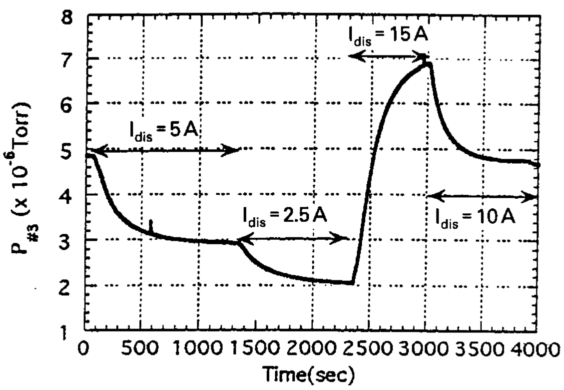

Fig. 3 The pressure value of the ionization gauge #3 (proportional to the permeation rate) increases with the discharge current (I_{dis}) of the H plasma.

4. Summary

The membrane pump in a plasma device successfully pumps out hydrogen atoms. No technical difficulty was found in operating the superpermeable membrane. This study shows that the superpermeable membrane pump is an effective hydrogen pumping system for fusion devices.

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