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Hydrogen gas and plasma driven permeation in counter directions through the first wall of a DEMO reactor

実証炉第１壁用低放射化合金の水素気体・プラズマによる双方向透過挙動
① フェライト系低放射化合金のプラズマ照射透過挙動

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The first wall backed by a breeding blanket structure of a DEMO reactor can be subject to hydrogen permeation in two counter directions because on the one side it is exposed to hydrogen isotope plasmas in the edge region but is in contact with tritium dissociated from the breeding coolant. As the first stage of the investigation of bi-directional hydrogen permeation, a reduced activation ferritic steel alloy (F82H), a candidate first wall material, is subject to hydrogen plasma-driven permeation in a laboratory-scale linear plasma device: VEHICLE-1 at ion bombarding energies up to 100eV, and at temperatures up to 500°C. Resultant permeation behavior has been analyzed using the DIFFUSE code.

1. Introduction

In recent DEMO reactor studies such as FFHR [1], the breeding material serves as a coolant as well in the blanket structure. The first wall is then defined as the plasma-facing surface of these blankets. For efficient tritium recovery and heat exchange, the breeding blanket is required to operate at rather high temperatures. However, it is also true that to reduce thermal stress, the first wall thickness is limited to a certain level, which is often less than 1cm.

Under these conditions, the first wall can be subject to bi-directional hydrogen permeation by two separate mechanisms because on the one side it is exposed to the edge and on the other side it is under the pressure of dissociated tritium as high as ~10 Torr [2]. One predicts that bi-directional hydrogen permeation will occur simultaneously but in a yet-to-be explored manner. If plasma-driven permeation dominates, deuterium flowing into the blanket will hinder the recovery of tritium and will probably necessitate isotope separation as well. On the other hand, if the opposite is true, gas-driven permeation will result in an increase in first wall recycling such that R>1, which can lead to confinement instabilities.

In the present work, as the first stage of the investigation of complex bi-directional hydrogen transport phenomena, plasma-driven permeation through a reduced ferritic steel alloy has been studied, using a laboratory-scale, well-diagnosed steady-state linear plasma device.

2. Experimental

Used in this work is a steady-state linearly magnetized device: VEHICLE-1[3] with a 1kW ECR plasma source. A schematic diagram of this device is shown in Fig. 1(a). Typically, the plasma density is of the order of 10^{10}1/cm^3 and the electron temperature is around 3eV. The hydrogen flux is of the order of 10^{16}1/cm^2/s, typical of the first wall environment, and the ion bombarding energy can be controlled by DC-biasing between the target and the test chamber up to a few 100V.

VEHICLE-1 is equipped with a variety of diagnostics important for plasma-wall interactions research, including a Langmuir probe, total pressure gauge, partial pressure gauge, visible spectrometer, and an IR pyrometer, all set aiming at the target region.

In the test chamber of VEHICLE-1, a plasma-driven permeation setup is installed and it is illustrated in Fig. 1(b). Permeation targets are made of reduced activation ferritic steel: F82H and also SUS316 stainless steel as the reference, both in the form of circular disk with the diameter of 70mm. The central circular portion of these targets with the diameter of 30mm is machined down to 0.5-1mm to allow hydrogen permeation.

In all the permeation experiments, as will be shown, the plasma column diameter is set at around 70mm by a donut limiter and the axial magnetic field. This means that the effect of 2D diffusion in parallel to the surface is negligible unlike other "pencil beam" experiments.

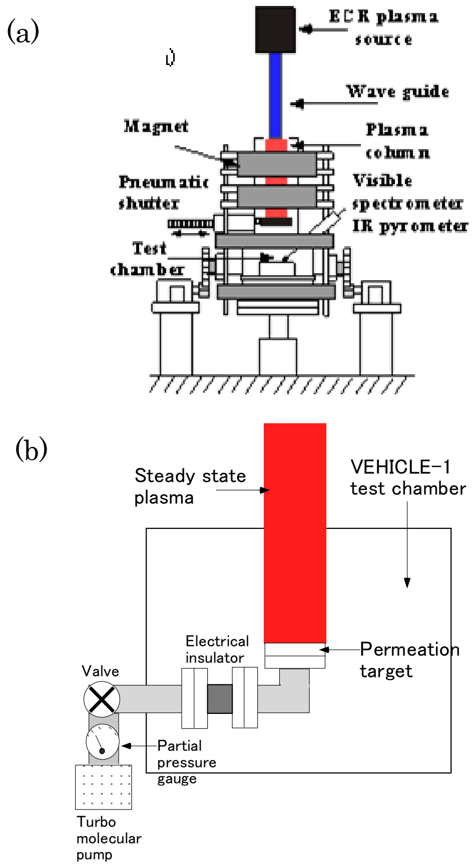

Fig. 1 (a) The VEHICLE-1 device [3]; and (b) the current plasma-driven permeation setup.

3. Results and discussion

Shown in Fig. 2 is a photo of an F82H target bombarded with hydrogen plasma. Notice that the target is attached with a thermocouple in the plasma-facing surface. At the same time, the surface temperature is monitored by an IR pyrometer. As can be seen, the plasma diameter is set about the same as the target diameter whereas permeation occurs only in the central portion shown by the dotted circle.

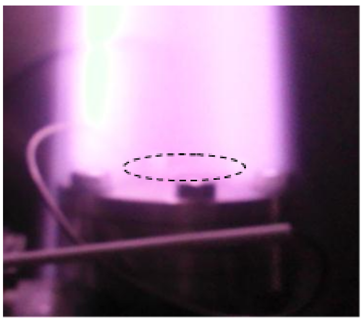

Fig. 2 Hydrogen permeation experiments in VEHICLE-1. The dotted circle area with a diameter of 30mm is the thinned permeation area.

A typical permeation break-through curve, taken from an F82H target, is shown in Fig. 3. In this particular case, the ECR power is set at 500W, the plasma bombarding flux is about 3 x 10^{16}1/cm^2/s and no DC bias is applied. However, because of the heat flux associated with plasma bombardment, the target temperature increases gradually, reaching a steady state of about 200^{o}C. Notice that the steady state is attained after about 25min, indicative of rather rapid diffusion of hydrogen in F82H, as expected from the database[5]. The steady state permeation flux evaluated from downstream partial pressure gauge measurements is about 6 x 10^{13} H-atoms/cm^2/s, which has been found to agree with the DIFFUSE code [3] calculation executed under similar conditions to those used for experiments.

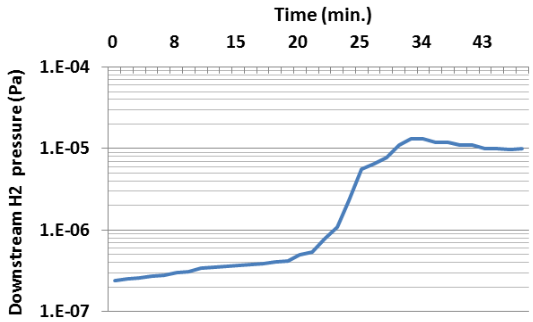

Fig. 3. A permeation breakthrough curve for F82H.

3. Summary and future plans

A new plasma-driven permeation setup has been installed in VEHICLE-1. Preliminary data on a reduced activation ferritic steel alloy have been taken successfully.

Future plans up until the plasma 2011conference include;

1. A comparison between the permeation behavior through SUS316 stainless steel and F82H will be made.
2. The effect of DC-biasing will be investigated.
3. Permeation behavior at higher plasma bombardment fluxes will also be investigated.
4. More detailed data analysis by the DIFFUSE code will be done;

References

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