Hydrogen isotope exchange behavior for deposited layers formed in a fusion reactor

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In a fusion reactor, a deposited layer is formed on the plasma-facing wall. Hydrogen isotope exchange in the deposited layer based on SS316 was measured in situ using NRA. The behavior of hydrogen isotope exchange was studied by fitting the rate-limiting step assumption. The experimental results were well reproduced by considering the ER recombination.

1. Introduction

The practical application of nuclear fusion power generation is expected as an alternative to nuclear power generation. A fusion reactor is using hydrogen, which is a safe and abundant resource. In this reactor, various interactions occur between tritium and the plasma facing wall. Since tritium is a radioactive isotope, the decontamination of tritium accumulated in the material is necessary to prevent the exposure of workers and to maintain the fuel cycle. The hydrogen isotope exchange method is currently being investigated as a decontamination method. In addition, a deposited layer is formed on the plasma facing wall by the sputtered atoms falling again. The purpose of this study is to investigate and model the exchange behavior of deuterium and light hydrogen plasmas in the deposited layer based on SS316 produced in the experimental fusion reactor QUEST at Kyushu University.

2. Experimental

A schematic of the experimental setup is shown in Figure 1. The deposited layer sample was formed in the equatorial part of the fusion reactor during the operation at QUEST in the summer of 2017. The deposited layer sample was alternately exposed to 1 eV deuterium or light hydrogen plasma generated by a radio frequency (RF) discharge tube, and the exchange process of light hydrogen and deuterium was observed by measuring the concentration of deuterium. The deuterium areal density of the sample was investigated by the nuclear reaction analysis (NRA) using the D (^{3}He, p) ^{4}He reaction, in which a $^3He^+$ beam accelerated by the Van de Graaff accelerator at Kyoto University was irradiated at 45° to the sample.

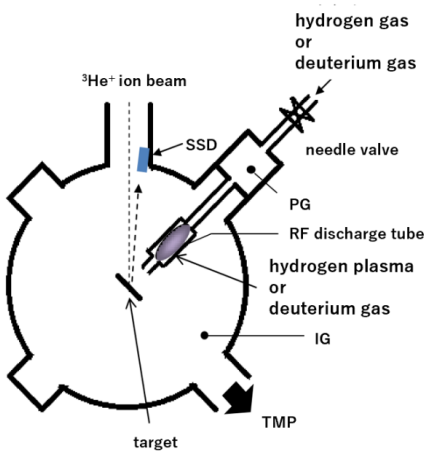

Fig. 1 Schematic diagram of the experimental

3. Results and discussions

A rate-limiting step was assumed and fitted to the time variation of deuterium concentrations obtained from experiments with alternating exposure to deuterium or light hydrogen plasma. An example is shown in Fig. 2. Zone 1 is exposed to deuterium plasma, zone 2 to light hydrogen plasma, zone 3 to deuterium plasma, and zone 4 to vacuum. In the recombination rate-limiting step, the rate-limiting steps are LH recombination, in which adsorbed atoms recombine with each other, and ER recombination, in which incident atoms recombine with adsorbed atoms. The hydrogen desorption flux H by LH recombination is expressed as $H=k_{LH}Cs^2$ using the dissolved hydrogen surface density Cs and the LH recombination constant k_{LH}. The flux R can be expressed by $R=k_{ER}FCs$ using Cs, the incident ion flux F, and the ER recombination probability k_{ER}. In this case, $k_{LH} = 1.0 \times 10^{-15}(m^2 s^{-1})$ and $k_{ER} = 9.0 \times 10^{-19}$. In the capture-decapture rate-limiting step, dissolved hydrogen is bound to a deeper potential and cannot diffuse or recombine (hereafter referred to as capture) and returns from the trapped state to the dissolved state (hereafter referred to as decapture). The capture flux I is expressed as $I = b_{in}Cs\left(1 - \frac{Ct}{Ct_0}\right)$ using Cs, the capture hydrogen surface density Ct, the number of capture sites Ct_0, and the capture constant b_{in}. The decapture flux O is expressed as $O = b_{out}Ct\left(1 - \frac{Cs}{Cs_0}\right)$ using Cs and Ct, the number of dissolved sites Cs_0, and the decapture constant b_{out}. In this case, $b_{in} = 10^{29}(s^{-1})$ and $b_{out} = 10^{26}(s^{-1})$. The fitting results show that the recombination rate reproduces the experimental values better. This differs from the results of Susuki [1], who performed similar experiments on a W sample. This is probably because considering ER recombination and the flux of capture and decapture is larger due to the small atomic density inherent in the deposited layer.

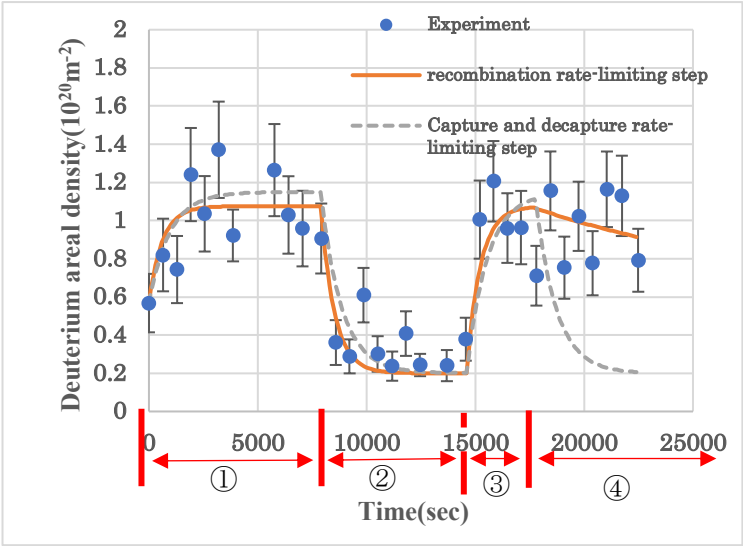

Fig. 2 Time variation of deuterium areal density during plasma exposure

References

[1] Yoshihiro Susuki, Thesis, Graduate School of Engineering, Department of Nuclear Engineering, Kyoto University (2017).