§2. Hydrogen Isotope – Materials Dynamics for Recycling Evaluation

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i) Introduction

Tungsten will be used as a primary candidate material for plasma facing materials due to its lower tritium retention and high thermal conductivity. However, complex interaction with neutron, energetic particles and impurities will change the surface condition and enhance tritium retention on tungsten. It is important to predict actual tritium retention in fusion reactor, and enhancement of hydrogen isotope retention should be elucidated. In the present study, tungsten samples were experienced to hydrogen discharges during 15th plasma experimental campaign in LHD. Thereafter, the deuterium ion was implanted into these samples and hydrogen isotope retention enhancement was estimated by means of TDS. The surface morphology and depth profiles of atomic concentration were also observed by TEM and GD-OES.

ii) Experimental

The disk-type samples with 10 mm diameter and ~ 0.2 mm thickness were prepared from a rod of tungsten prepared under stress-relieved conditions. The samples were polished mechanically and pre-heated at 1173 K for 10 minutes in vacuum to remove the surface impurities and damages induced by the polishing processes. The tungsten samples were placed at three positions in LHD. namely PI (near 3-O port), DP (near 3-I port) and HL (near 10-O port), and were exposed to hydrogen plasma throughout 15th plasma experimental campaign. In addition, Cu^{2+} irradiated and un-irradiated samples were introduced into LHD vacuum chamber through the movable material probe system to evaluate the irradiation damage effect on hydrogen isotope retention enhancement. They were exposed to 134 shots of hydrogen plasma at first wall position. Thereafter, the samples were picked up and made postmortem analysis. The 1.0 keV D_2^+ was implanted with the flux of 1.0×10^{18} D^+ m^{-2} s^{-1} up to the fluence of 5.0×10^{21} D^+ m^{-2}, and the deuterium retention behaviors were studied by Thermal Desorption Spectroscopy (TDS) with the heating rate of 0.5 K s^{-1} up to the temperature of 1173 K. The Glow Discharge-Optical Emission Spectroscopy (GD-OES) was also performed to study the depth profiles of constituent atoms in the sample.

iii) Results and discussion

The D_2 TDS spectra for PI, HL and DP samples, which consisted of three desorption stages at ~ 600, 800 and 1000 K. These desorption behaviors were quite different from that for 1.0 keV D_2^+ implanted tungsten, where most of deuterium was desorbed less than 600 K. Total deuterium retention for PI, HL and DP samples were enhanced about three times as large as that for pure tungsten. XPS analyses and SEM observations showed that the deposition layer of thickness of about 1 μm was formed and consisted of C-C bond on all LHD sample surfaces, implying that the deuterium desorption above 800 K would be caused by the deuterium trapping by carbon. The thicker deposition layer was formed on the DP sample. In addition, the Raman spectroscopy showed that the high heat load for HL initiated the crystallization of impurity layer during the plasma operation. TEM observation indicates that the introduction of damages by energetic particles and deposition of impurity layer were simultaneously proceeded and both of which will influence on the hydrogen isotope retention enhancement. On the other hand, it was found that the carbon-dominant mixed-material layer with the thickness of ~ 4 nm was formed on the both of Cu^{2+} irradiated and un-irradiated samples. The D_2 TDS spectra for the plasma-exposed samples were also extended toward higher temperature side, which was attributed to the deuterium trapping by carbon, as shown in figure. In addition, Cu^{2+} irradiation enhanced the deuterium retention with higher desorption temperature, indicating that the deuterium was trapped by impurities with higher stability and/or trapped in stable irradiation damages.

It is concluded that the both of carbon deposition layer and damage introduction can enhance the deuterium retention. But, large contribution for the deuterium retention enhancement would be caused by the deposition of carbon impurity layer indicating that large tritium retention enhancement could be possible even if the small amount of impurity is deposited on all metal first wall for future fusion reactor.

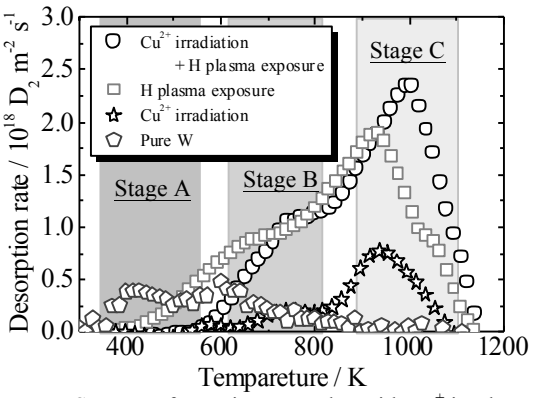

Fig. D_2 TDS spectra for various samples with D_2^+ implantation