04aC02

LHDプラズマに曝されたタングステンにおける水素滞留能変化

Retention enhancement of hydrogen isotope in tungsten exposed to LHD plasma in 2011 and 2012

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Introduction

Recently, tungsten is thought to be used as plasma facing material for fusion reactor. Tungsten is a useful material from the viewpoint of low hydrogen solubility, but the fuel retention behavior for actual fusion reactor is quite complex and would be quite different from that for pure tungsten due to higher energetic particle implantation and higher heat flux. In addition, it is quite difficult to get rid of impurity carbon completely. Therefore, in this study, pure tungsten samples were exposed to large plasma device and hydrogen isotope retention enhancement for tungsten exposed to plasma experiment campaigns in 2011 and 2012 at LHD was compared to that for pure tungsten. The hydrogen isotope retention enhancement was also compared depending on the sample position in LHD.

In this study, tungsten samples were placed on typical unique positions on the first wall of LHD during 2011 plasma experiment campaign (15th plasma experiment campaign) and 2012 plasma experiment campaign (16th plasma experiment campaign) as long-term exposed samples. Thereafter, the samples were picked up and additional deuterium ion (D_2^+) implantation was performed to evaluate hydrogen isotope retention enhancement using thermal desorption spectroscopy (TDS).

In 2012 plasma experiment campaign (16th plasma experiment campaign), the closed divertor structure, which consists of graphite parts, was installed in 8 sections to enhance the plasma performance, although that in 2011 campaign was 2 sections.

In addition, some of tungsten samples were placed in LHD flush to the first wall position with the use of a movable probe system and they were exposed to NBI heated hydrogen plasma with the total of around 100 shots. These samples were named as short-term exposed samples. By comparing them with long-term exposed samples, the initial dynamics of hydrogen retention and formation of deposition layer can be elucidated.

Experimental

Disk-type polycrystalline tungsten samples with stress relieved condition, manufactured by A.L.M.T. Corp, Japan were placed in the typical position as shown in Fig. 1 during 2011 plasma experiment campaign (15th plasma experiment campaign) and 2012 plasma experiment campaign (16th plasma experiment campaign) for long-term exposure. Some of tungsten samples were placed at first wall position by a movable probe system and exposed for NBI heated hydrogen plasma with the total of around 100 shots as short-term exposure. These samples were picked up after the plasma exposure and additional 1.0 keV D_2^+ implantation were performed with the fluence of 5.0×10^{21} D^+ m^{-2} at room temperature. Thereafter the hydrogen isotope

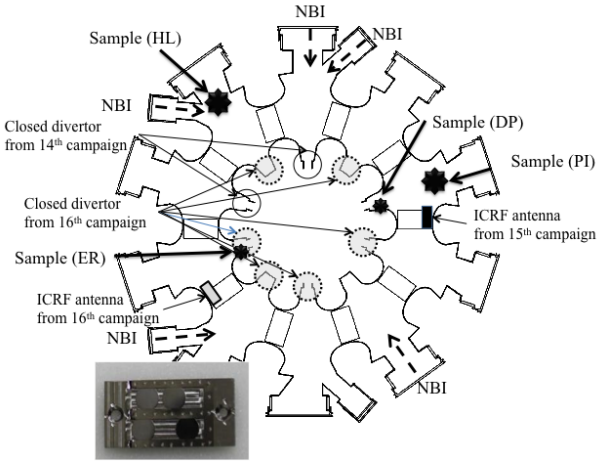

Fig. 1 Sample positions in LHD vacuum vessel

Table 1 Summary of hydrogen isotope retention capacity for tungsten samples exposed to 2011 or 2012 plasma experimental campaign.

	Pure W	PI		DP		HL		ER
		2011	2012	2011	2012	2011	2012	2012
H	---	6.1×10^{20}	2.7×10^{21}	1.7×10^{21}	7.4×10^{21}	5.6×10^{20}	2.4×10^{21}	1.5×10^{21}
D	1.4×10^{20}	3.6×10^{20}	6.4×10^{20}	1.3×10^{21}	3.0×10^{20}	3.2×10^{20}	9.7×10^{19}	8.1×10^{19}
Desorption Temperature	< 600 K	800-1000 K	700-1000 K	700-900 K	700-900 K	800-1000 K	700-1000 K	< 600 K
Surface characteristics	irradiation damage	thin deposition (0.3 μm)	thin deposition (0.5 μm)	thick deposition and rough surface (5.0 μm)	thick deposition and rough surface (6.0 μm)	thin deposition (0.1 μm)	thin deposition (0.2 μm)	very thin deposition (almost no deposition)
Retention enhancement	--	6.9	24	21	55	6.3	18	11

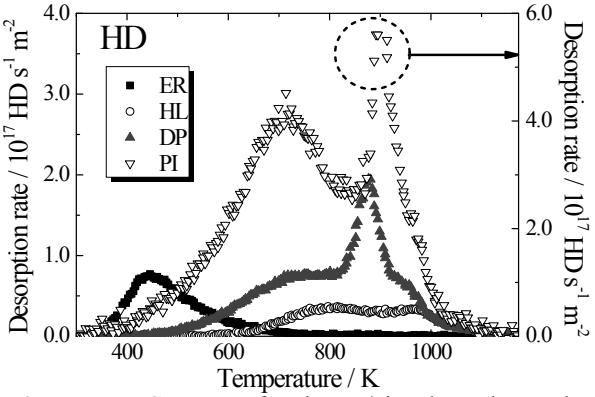

Fig.2 HD TDS spectra for the D_2^+ implanted samples exposed to 2012 plasma campaign.

retention and desorption behavior was evaluated by TDS. The depth profiles of elements were observed by GD-OES and surface microstructure was evaluated by TEM. The XPS was applied to evaluate the chemical state of carbon-mixture deposition layer and crystallinity was estimated by Raman spectroscopy.

Results and discussion

Thicker carbon-mixed deposition layer was formed on the surface of all the samples, especially thicker deposition layer was found for DP samples exposed by both of 2011 and 2012 plasma experiment campaigns. For 2012 plasma experimental campaign, the closed divertor structure, which consists of graphite parts, was installed in 8 sections, which leads to enhance the amount of carbon in divertor at LHD. The TEM and XPS analyses revealed that not only the formation of carbon-mixed deposition layer but also the irradiation damages were introduced for the tungsten samples.

Fig. 2 shows the TDS spectra for D_2^+ implanted tungsten that exposed to 2012 plasma experimental campaign. The shape of TDS spectra except for ER sample was quite different from that for D_2^+ implanted pure tungsten and typical desorption stage was found at 800K-900K. In especially, large desorption stage for DP sample was found at 900 K. Major desorption stage for pure tungsten was located at 400K-600K, leading that the trapping state of hydrogen isotope was quite different and most of hydrogen isotope was trapped by impurities like carbon and oxygen. However, for ER sample, the desorption behavior of hydrogen isotope was quite similar to the D_2^+ implanted pure tungsten. These facts indicate that most of hydrogen isotope would be trapped by surface carbon-mixed deposition layer and/or irradiation damages. Table 1 summarizes the hydrogen isotope retention enhancement for tungsten exposed to 2011 or 2012 plasma experimental campaign. Higher hydrogen retention enhancement was achieved for DP samples, which have thicker deposition layers and hydrogen isotope retention enhancement was twenty times as high as that for pure tungsten. In especially, higher hydrogen retention was derived for the samples exposed to 2012 plasma experimental campaign, where thicker deposition layer was achieved. This fact implies that hydrogen trapping affinity was quite high during hydrogen plasma discharge.

It can be said that hydrogen isotope retention enhancement would be controlled by the formation of carbon-mixed deposition layer compared to the introduction of irradiation damages.

Acknowledgement

This study has been supported by NIFS collaboration program No. NIFS11KNWF001.