Investigation of Carbon Films on Material Probes in the Vicinity of Local Island Divertor in the Large Helical Device

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(Received 9 March 2007 / Accepted 27 March 2007)

Two sets of material probes were installed in LHD in the vicinity of the Local Island Divertor (LID) head made of carbon fiber composite. One set of the material probes faced the LID head, while the other set was placed in a shallow line of sight to the head. Carbon films on the former and the later sets of probes are expected to be formed by the deposition of physically sputtered carbon atoms and chemically sputtered hydrocarbon, respectively, during the LID discharges. Surface morphology and thickness of the films, and the amount of retained hydrogen in the films were investigated, and hydrogen concentration in the probes was estimated. The hydrogen concentration in the carbon films on the probes placed in a shallow line of sight of the head was significantly large with the atomic ratio of H/C = 0.6-1.1.

Keywords: carbon film, hydrogen retention, Local Island Divertor, Large Helical Device, tritium concentration, carbon dust, ITER.

DOI: 10.1585/pfr.2.011

One of the major concerns in ITER is the safety of tritium retention in carbon dust or film [1]. Though the deuterium retention in the carbon films or flakes prepared by deuterium arc discharge with carbon electrodes has been investigated [2], the properties of hydrogen isotope retention in carbon film produced in fusion devices has not so far been sufficiently investigated. In order to investigate the hydrogen retention properties of the carbon films in LHD, a technique using a material probe [3] was employed. In addition to an intrinsic helical divertor experiment [4], local island divertor (LID) experiments have been conducted in LHD since 2003. Figure 1 shows the scheme of the LID configuration. A divertor head covered by the neutralizer plates made of carbon fiber composite (CFC) is inserted into the $m/n = 1/1$ magnetic island in a horizontally elongated cross-section where the width of the island is at its maximum (about 20 cm). The pumping duct surrounds the divertor head, and functions as a baffle. Outer separatrix of the island connects the divertor head as the divertor legs, and the last closed flux surface is determined by the inner separatrix of the island. Plasma-surface interaction occurs ideally only at the divertor head, and thus the wet area ($< 0.1\,\mathrm{m}^2$) is less than one tenth of that of the helical divertor. Therefore, the divertor head receives relatively high heat and particle fluxes in comparison to the helical divertor, and the eroded carbon is co-deposited with hydrogen on the plasma facing components. In the experimental campaign in 2005, four sets of material probes made of Si were installed in the vicinity of the LID head. The number of the discharges with the LID configuration were 707. The locations of the material probes are also shown in Fig. 1. One set of probes was placed inside the pumping duct (1U, 1L) facing the head. The other set of probes was placed in a shallow line of sight of the head (2U, 2L). After the experimental campaign, the probes were extracted and their surface morphology, depth profiles of atomic composition,

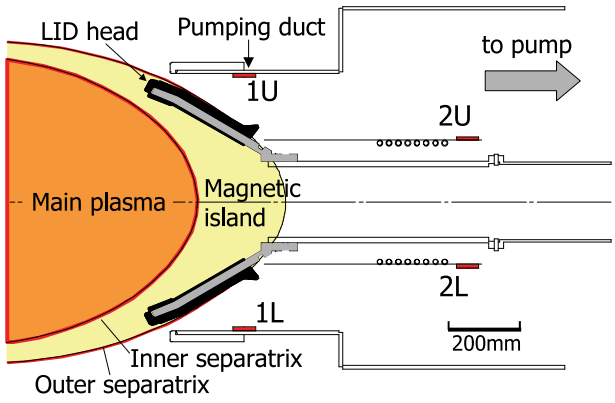

Fig. 1 Schematic view of the LID configuration. The LID head is inserted into the $m/n = 1/1$ magnetic island. The black parts on the LID head are made of graphite or CFC, and the gray parts are the base structure of the head which is made of SUS316. Material probes (1U, 1L, 2U, 2L) were installed inside the pumping duct as shown in this figure.

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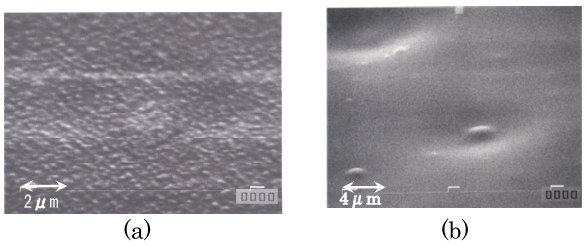

Fig. 2 SEM images of the surface morphologies of the probes, (a) 1U and (b) 2U.

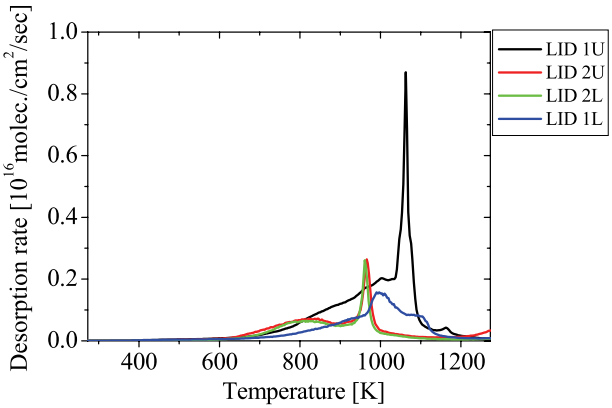

Fig. 3 Thermal desorption spectra of hydrogen of the 4 probes.

and hydrogen retention were investigated using scanning electron microscope (SEM), Auger electron spectroscopy (AES) and thermal desorption spectroscopy (TDS), respectively.

Figures 2 (a) and (b) show the SEM photographs of the 1U and 2U surfaces. The surface of 2U was very smooth, but sub-micron size protuberant structures were observed on the surface of 1U. This difference of surface morphology might have been caused by the deposition angle of carbon in relation to the probe surfaces. If the incident angle of carbon atoms relative to the probe surface is shallow, the carbon may deposit selectively on the protuberant parts. The smooth surfaces of 2U and 2L might have been caused by the deposition of hydrocarbons and/or low energy carbon atoms and the deposition of carbon reflected by the wall.

Highly uniform carbon depositions were observed on the surfaces of all the probes according to the depth profile of atomic composition measurement using AES, and the oxygen concentration was only 1%. The thickness of the carbon films was measured by using a surface roughness meter, and it ranged from 200 to 700 nm as shown later in Fig. 4.

Thermal desorption spectra of the four probes are shown in Fig. 3. Most of the retained hydrogen desorbed in the form of molecular hydrogen. The retained hydrogen also desorbed in the form of methane but its fraction was

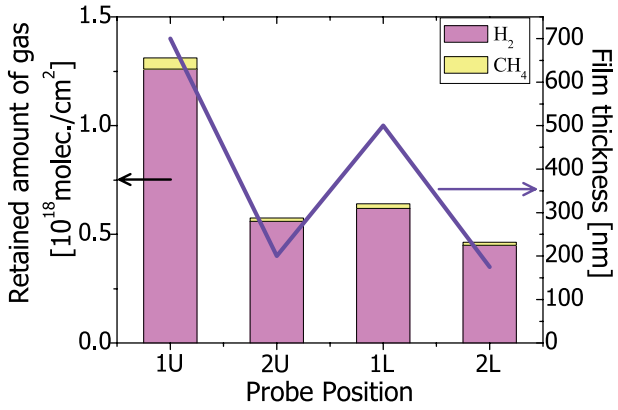

Fig. 4 Retained amounts of hydrogen and thickness of the deposited carbon films on the 4 probes.

only several percent. The temperature of the pumping duct during the LID discharges rose to 570 K. The desorption rates for the 4 probes started to increase in the temperature range of 500-600 K, which is consistent with the pumping duct temperature. The desorption spectra of 1U and 1L have a peak around 1000 K and 1050 K, respectively. This tendency is similar to that of graphite. However, the spectra of 2U and 2L were very different from that of 1U and 1L. A desorption peak was observed at a lower temperature regime, around 950 K. This suggests that the carbon film structures on 2U and 2L are very different from that of graphite; that is, the binding state of hydrogen differs from that of graphite. Figure 4 summarizes the amount of retained hydrogen and the thickness of deposited carbon of the 4 probes. In this experiment, the mass densities of the carbon films on the 4 probes were not measured. Therefore, it is necessary to assume the mass density in order to estimate the hydrogen concentration in the films in the form of the atomic ratio, H/C. The mass density of carbon film produced by carbonization in TEXTOR is 1.4 g/cm^3 [5]. This density is lower than the typical mass density of isotropic graphite (1.8 g/cm^3). Here we assume that the mass density of the present carbon film ranges from 1.0 to 1.8 g/cm^3. The hydrogen concentration can be obtained from the mass density, the film thickness and the retained amount of hydrogen. The hydrogen concentrations in the carbon films on 1U, 2U, 1L, and 2L are estimated to be H/C = 0.42-0.60, 0.70-1.1, 0.31-0.45, and 0.65-0.94, respectively. The hydrogen concentration in graphite after hydrogen ion irradiation from room temperature to 600 K is approximately H/C = 0.2-0.4 [6, 7]. The H/C ratios on 1U and 2U are close to this value. This result suggests that carbon film with a graphite-like structure is produced in the vicinity of the LID head. However, on 2U and 2L, the hydrogen concentrations are approximately double that of the graphite case. This result suggests that the carbon film on 2U and 2L is not graphite but is perhaps amorphous with relatively a high hydrogen concentration. Further investi-

gation of the carbon films will be conducted using Raman spectroscopy.

This work was supported by the Collaboration Research Programs in National Institute for Fusion Science, NIFS06KLPP301 and NIFS04KOBS005, and partly supported by the JSPS-CAS Core-University Program in the field of "Plasma and Fusion Research."

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