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Hydrogen retention in carbon–tungsten co-deposition layer formed by hydrogen RF plasma

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Abstract

Carbon–tungsten co-deposition layers (C–W layers) were formed by sputtering method using hydrogen or deuterium RF plasma. The deposition rate of the C–W layer by deuterium plasma was faster than that by hydrogen plasma, where the increase of deposition rate of tungsten was larger than that of carbon. This indicates that the isotope effect on sputtering–depositing process for tungsten is larger than that for carbon. The release curve of hydrogen from the C–W layer showed two peaks at 400 °C and 700 °C. Comparing the hydrogen release from the carbon deposition layer and the tungsten deposition layer, it is considered that the increase of the release rate at 400 °C is affected by tungsten and that at 700 °C is affected by carbon. The obtained hydrogen retention in the C–W layers which have over 60 at.% of carbon was in the range between 0.45 and 0.16 as H/(C+W).

Keywords: Co-deposition; Carbon; Tungsten; Hydrogen retention; RF plasma

1. Introduction

Plasma facing materials in a fusion reactor are eroded by high head load and interaction with energetic particles. Part of the impurities emitted from plasma facing material forms a re-deposition layer or dust in the vacuum vessel. In D–T experiments at JET and TFTR using graphite material as plasma facing components, a large amount of tritium was mainly accumulated in carbon-based re-deposition layers and dust [1,2]. In a fusion experimental reactor such as ITER, it is designed that tungsten is installed in the divertor region because of its low sputtering yield, high melting point and low solubility of tritium [3,4]. However, a strike zone of divertor plate is planned to be protected by a graphite material because of good stability at high temperature.

It has been observed in large tokamak devices, such as TEXTOR and ASDEX Upgrade, that the C–W mixed material was formed [5–7] and that some of them formed carbide layer [5], when graphite material and tungsten was simultaneously exposed to plasma. Presumably, carbon–tungsten mixed materials will be formed on the surface of the inner components in ITER. In order to estimate tritium inventory in the vessel of ITER and a future fusion reactor, it is necessary to investigate tritium retention in carbon–tungsten mixed materials. However, there is not sufficient data for carbon–tungsten mixed materials.

In this study, carbon–tungsten co-deposition layers (C–W layers) were formed by sputtering method using hydrogen or deuterium RF plasma. Hydrogen retention in the formed layer was quantified by the thermal desorption method. The release behavior of hydrogen from a C–W layer was compared with that from a carbon layer (C layer) and a tungsten layer (W layer) which are formed by the same method.

2. Experimental

Two capacitively coupled RF plasma (CCP) devices installed parallel-plate electrode were used in this work.

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One, which is named as CCP II, was used for the production of C–W layers and W layers. Another, which is named as CCP I, was used for the production of C layers. A schematic diagram of CCP I and the experimental procedures for the production of the deposition layer have been stated in detail in the previous paper [8]. The height and diameter of the cylindrical vacuum chamber of CCP II made of stainless steel are 30 cm and 20 cm, respectively. Isotropic graphite plate (IG-430U: Toyo tanso Co.) and tungsten plate (99.95% Nilaco Co.) were mounted side by side on the RF electrode as shown in Fig. 1. The size of each plate is same as 5 cm × 2.5 cm and the effective sputtered area is 4.5 cm × 3 cm. In order to prevent the RF electrode component from sputtering, a ground shield covered the whole RF electrode except a part of target. A long stainless steel holder was mounted on the ground electrode at ground potential. Quartz substrates (1 cm × 1 cm, thickness of 0.1 cm) were lined on the holder in radial direction of the chamber at 1-cm interval in order to investigate the distribution of the C–W layer. The amount of the deposition layer was determined from the weight of the substrate before and after plasma discharge. Weight changes of the substrates were measured by an electric balance with a sensitivity of 0.01 mg, against a weight of the substrate of about 0.15 g. Typical discharge conditions are summarized in Table 1. The temperature of atmosphere in the chamber during plasma discharge was measured at 3 cm above on the surface of the ground electrode with by a thermocouple. The plasma parameters such as electron density, electron temperature were measured by Langmuir probe method at 1.5 cm above on the surface of the ground electrode.

Atomic concentration (at.%) and weight percent of carbon and tungsten in the C–W layer were analyzed by energy dispersive X-ray (EDX: Genesis2000, EDAX Inc., Mahwah, NJ, USA) equipment at the Center of Advanced Instrumental Analysis, Kyushu University.

Hydrogen retained in C–W layer, C layer and W layer was released by thermal desorption method in argon atmosphere. The amount of released hydrogen was quantified by a gas chromatograph.

Table 1
Typical discharge conditions

Sputtering gas	H_2	H_2	D_2
RF power [W]	100	200	200
DC self bias [kV]	1.5	2	2
Electron density [cm^{-3}]	3.4×10^9	3.6×10^9	4.0×10^9
Electron temperature [eV]	2.8	3.5	4
Plasma space potential [V]	8.6	10.5	11
Ion flux [cm^{-2} s^{-1}]	3.4×10^{15}	4.0×10^{15}	4.8×10^{15}
Temperature of atmosphere [°C]	65	120	100
Target-substrate distance [cm]		10	
Effective sputtered area [cm^2]		4.5×3.0	
Gas pressure [Pa]		10	
Gas flow rate [cm^3 min^{-1}]		1.2	
Discharge period [day]		5	

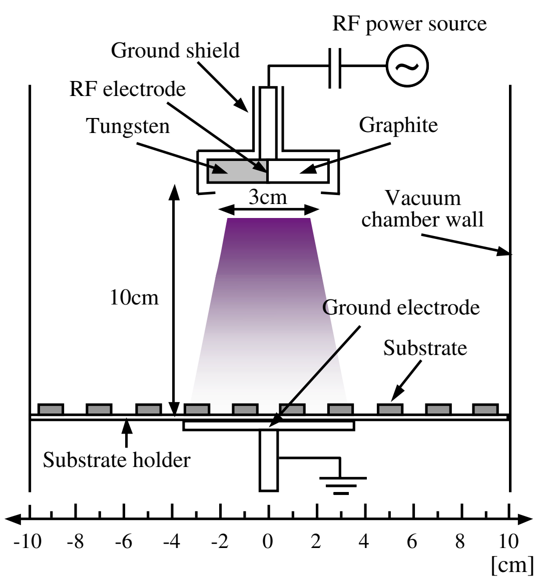

Fig. 1. Installed positions of target and substrates.

3. Results and discussions

3.1. Distribution of carbon–tungsten layers in vacuum chamber

The distribution of the C–W layer formed on quartz substrates under each discharge conditions is shown in Fig. 2, where the numbers on the abscissa indicate the distance from the center of the radial direction to each substrate. The ground electrode is located from −3.5 cm to 3.5 cm. The C–W layers were formed convexly and symmetrically in radial direction. The weight of the deposited C–W layer increases 3.3 times, on the average of every position, when increasing RF power from 100 W to 200 W. An isotope effect was observed on the deposition rate of the C–W layer. The deposition rate at each position by deuterium

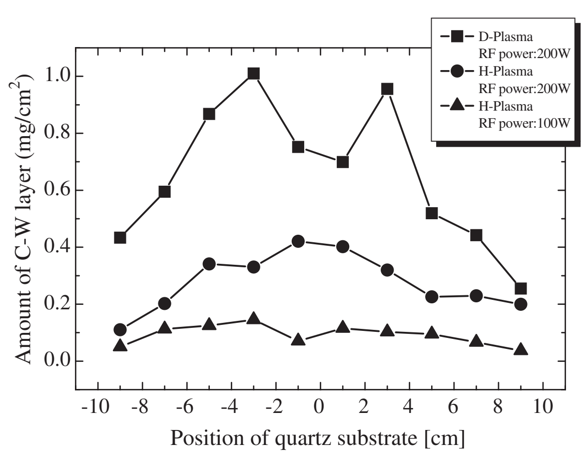

Fig. 2. Amount of deposited C–W layer.