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Fusion Engineering and Design 81 (2006) 247–252

Fusion Engineering and Design

www.elsevier.com/locate/fusengdes

Erosion of carbon deposition layer by hydrogen RF plasma

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Received 29 January 2005; received in revised form 1 September 2005; accepted 1 September 2005
Available online 20 December 2005

Abstract

A carbon deposition layer was formed by sputtering method in hydrogen RF plasma at an RF power of 150 W and then eroded in a plasma at an RF power of 250 W. The sheath bias between plasma and the carbon deposition layer was measured to be about 10 V by Langmuir probe method. The erosion yield (C/ion) of carbon deposition layer was determined to be 0.31, which is one order of magnitude larger than that of isotropic graphite, 0.026. It was found that the plasma facing surface of the eroded carbon deposition layer became mesh-like and the inside of the layer became more porous. The atomic ratio of hydrogen to carbon (H/C) in the carbon deposition layer eroded for more than 6 h obviously decreased as compared to the initial value.

Keywords: Carbon deposition layer; Erosion yield; H/C; RF plasma

1. Introduction

Carbon deposition layers or carbon dust are formed in the vessel of a fusion experimental device when graphite is used as plasma facing material [1–4]. It is known that the carbon deposition layer or dust can contain a large amount of tritium [1,2]. In ITER, graphite material will be used at the divertor region. In order to discuss tritium inventory and impurity transport in the vessel, it is necessary to understand the erosion and deposition behavior of carbon. Plasma–wall interaction such as ion implantation or sputtering at the energy region of keV has been formerly investigated in many studies [5–8]. Recently, chemical erosion of graphite material in the low energy region of a few 10 eV was investigated in detail to understand the erosion reaction of a divertor tile, and fundamental behavior began to be clarified [9–11]. However, a significant study on re-erosion of carbon deposition layer has not yet been performed. Because carbon deposition layers are extensively observed in the vessel of large experimental devices, re-erosion of that deposition layer frequently

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doi:10.1016/j.fusengdes.2005.09.030

occurs after changes in plasma configuration. In recent experiment in JET, it was found that the deposition observed at the water cooled louvers is caused by the stepwise transport of carbon from the strike point in the divertor region [12]. This indicates that the understanding of the re-erosion of the deposition layer is a very important issue.

Discharge cleaning using helium, oxygen and hydrogen isotopes has been performed in JET, TFTR [13,14] and JT-60 U from a viewpoint of reduction of tritium inventory, and an effective method for tritium removal has been developed [15]. However, the reactions between plasma and wall during the discharge cleaning are not clarified yet due to vastness of the experimental device. Erosion rates of re-deposition layers formed in tokamaks and C:H films produced in the laboratory experiments have been investigated by oxygen gas exposure or oxygen plasma irradiation [16–18]. But there are few experimental data for the erosion rate by hydrogen plasma exposure [19].

In a previous study by present authors, it has been found that carbon deposition layer is uniformly formed on the substrate located on the ground electrode at an RF power of 150 W under hydrogen pressure of 10 Pa, but no deposition layer is observed there at an RF power of 250 W under same hydrogen pressure [20]. We considered that this is due to the effect of erosion by incident ions. In this study, carbon deposition layers formed in hydrogen RF plasma at an RF power of 150 W were exposed to the plasma at an RF power of 250 W in order to investigate erosion phenomena of carbon deposition layer in the low energy plasma discharge. A sheath bias between plasma and the deposition layer is estimated to be about 10 V from measurements with a Langmuir probe. The amount of hydrogen retained in the layer was investigated by a thermal desorption method.

2. Experimental

Deposition and erosion of carbon deposition layers were performed in a capacitively-coupled RF plasma (CCP) device equipped with parallel-plate electrodes. A schematic diagram of CCP and experimental procedures for formation of carbon deposition layers have been presented in detail in a previous paper [20]. An isotropic graphite plate (IG-430U: 100 mm × 100 mm, Toyo tanso Co.) was mounted on the upper electrode plate which is supplied with RF power at 13.56 MHz. The cylindrical vacuum chamber (350 mm × 250 mm) and the lower electrode plate (100 mm × 130 mm), which is grounded. The distance between graphite plate and the lower ground plate was 70 mm. The pressure in the chamber was previously evacuated to approximately 10^{-3} Pa by a turbo molecular pump. During plasma discharge, only a rotary pump was used to evacuate the hydrogen gas introduced into the vacuum chamber via a mass flow controller. Carbon deposition layers were formed on quartz substrates (20 mm × 5 mm, thickness 1 mm) mounted on the ground electrode. During the plasma discharge no external heating of the substrate was performed.

The hydrogen gas pressure is held constant at 10 Pa. Plasma parameters such as ion flux and electron density were measured by Langmuir probe method at 10 mm above the quartz substrate located at the center of the ground electrode in advance of deposition and erosion experiments. Sheath bias between plasma and the deposition layer is estimated to be 10 V at an RF power of 150 W, and 11 V at an RF power of 250 W. This indicates that the ions impinge on the substrate with the energy of about 10 eV under either condition. The substrate temperature was previously measured under each condition by a thermocouple. Experimental conditions and plasma parameters are summarized in Table 1. For the comparison of erosion rate, the isotropic graphite chip (10 mm × 5 mm, thickness 1 mm) was exposed to hydrogen RF plasma at an RF power of 250 W.

The amount of deposited or eroded carbon 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

Table 1
Experimental conditions and plasma parameters

	Deposition	Erosion
RF power (W)	150	250
H_2 gas pressure (Pa)	10	10
Gas flow rate (cm^3/min)	0.6	1.2
Graphite-substrate distance (cm)	8	8
Substrate temperature (°C)	94	130
Electron density (cm^{-3})	6.6×10^8	9.4×10^8
Electron temperature (eV)	2.0	3.3
Sheath bias (V)	10	11
Ion flux ($cm^{-2}\,s^{-1}$)	5.6×10^{14}	1.9×10^{15}