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On the carbon and tungsten sputtering rate in a magnetron discharge

V. Tiron, S. Dobrea, C. Costin, G. Popa *

Faculty of Physics, "Al. I. Cuza" University, 700506 Iasi, Romania

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A B S T R A C T

Magnetron discharge as sputtering source can serve as an alternative tool for the study of the plasma-wall interaction, with applications for ITER divertor. The present work reports on the influence of the target power density and the nature of the projectile on the erosion of C and W targets. The experimental results concern the sputtering rate of carbon and tungsten targets of a d.c. magnetron discharge in argon and helium atmosphere, at different gas pressures in the range of 10–100 mTorr and discharge power densities up to 40 W cm^{-2} while the discharge current intensity was used as control parameter. In this investigation, carbon and tungsten sputtering rates were measured using two conventional methods based on gravimetric mass loss and profilometry. Target erosion profiles were compared with the profiles of the ion energy flux bombarding the target, calculated from a 2D fluid model.

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1. Introduction

Physical sputtering is one of the most serious processes of erosion of the innermost surfaces of fusion machines. The most important elemental species of wall material in fusion machines are the light elements as beryllium (Be) and carbon (C) and heavy elements as tungsten (W), material in the form of tiles covering the metal vessel [1]. Due to the high retention of H isotopes and high chemical sputtering yields [2], carbon surfaces have to be replaced, eventually by high-Z materials, such as tungsten. In the future ITER machine, W and C surfaces will interact with gases as argon and helium, Ar being considered as cooling agent for the divertor and He being obtained as reaction product in the fusion process [3]. Moreover, interactions of helium, hydrogen and other energetic atoms and ions with W and/or C surfaces are the most important processes in the divertor region of the ITER from where impurities, "helium ashes" and important fraction of kinetic energy are removed from thermonuclear plasma. Consequently, the study of Ar and/or He atom/ion interaction with W and/or C surfaces, as e.g. physical sputtering process, has a great interest for ITER project.

On the other hand, in the deposition technology, the predominant factor controlling the structure and properties of the deposited thin film is the mobility of condensing atoms on the substrate. When a thin layer grows with a low surface mobility of the deposited atoms, it exhibits a porous structure while dense coatings with good physical properties are obtained when the atoms mobility increases [4]. The atom mobility can be controlled either by substrate temperature (thermal diffusion) or/and energy of the bombarding species by increasing the cathode voltage or substrate bias. In the case of high-Z materials, such as tungsten, where the thermal diffusion is low, the deposition is mainly controlled by the bombarding particles energy [5].

In the present work, we report on the influence of both target power density and nature of the projectile particles (Ar$^+$ and He$^+$) on the erosion of C and W targets in a plane magnetron discharge. Two methods, based on gravimetric mass loss and profilometry, were used to calculate the sputtering rate for each target–gas combination. The erosion profile obtained for W–Ar combination was compared with the profile of the ion energy flux bombarding the target, calculated from a 2D fluid model [6].

2. Experimental details

In a plane magnetron discharge with cylindrical symmetry the negative glow has a toroidal shape formed in the region were secondary electrons emitted by the cathode are trapped by the magnetic field generating high-density plasma. The ions originated within the negative glow are accelerated in the cathode fall sputtering the target material. Thus, an erosion region called '*race-track*' appears on the target surface. The race-track area is assumed to be equal with the projection area of the negative glow plasma torus on the cathode surface. This area is estimated from the radial distribution of the global light intensity emitted by the plasma [7]. A photo-camera centered on the cathode axis was used to take top view pictures of the plasma light. The radial light distribution was extracted from the pictures using *Image-J* free-ware software. The

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* Corresponding author.
E-mail address: ghpopa@uaic.ro (G. Popa).

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mean value of the power density loaded on the target was calculated dividing the input discharge power by the race-track area.

The tungsten and carbon disk targets of 55 mm in diameter and 2 mm thickness were sputtered either in Ar or in He atmosphere at different pressures, in the range of 10–100 mTorr using a plane magnetron discharge with cylindrical symmetry. A current-regulated d.c. power supply of 1500 V/800 mA was used to provide a discharge current intensity between 100 and 600 mA and a corresponding target power density in the range of 3–40 W cm^{-2}. The amount of sputtered target material was determined as difference of the target weight measured before and after plasma sputtering and compared with the values measured from erosion profile. Each erosion profile of the target was obtained after two hours of sputtering, under different discharge conditions and target–gas combination, using a profilometer.

The W and C thin films were deposited on a substrate fixed at 9 cm above but parallel to the target. Prior to deposition the substrate was heated up to 200 °C and this temperature was maintained constant during film deposition. The deposition temperature was measured by a thermocouple fixed on the substrate. The deposited films were characterized using atomic force microscopy (AFM) technique in order to obtain information about film thickness and roughness. The AFM images were performed in ambient conditions using standard silicone nitride tips (NSC21), with tip radius of 10–20 nm. The analysis was made in tapping mode with 0.1 nm resolution in *z* direction.

3. Results and discussion

The Fig. 1 shows the radial distribution of the global light intensity emitted by the plasma, for W–Ar combination, obtained from the discharge pictures taken at different discharge conditions. The plasma torus expands when the discharge current intensity increases and the projection area of the plasma torus on the cathode surface grows from 4.5 cm^2 corresponding to 100 mA to 10.5 cm^2 corresponding to 600 mA. Further on, knowing the discharge current intensity, the applied discharge voltage and the race-track area we can estimate the mean value of the power density loaded on the target.

The effect of the target power density on the sputtering rate and film characteristics was investigated in the power range of 25–360 W, providing a power density between 3 and 40 W cm^{-2}. For the target–gas combinations of W–Ar, W–He and C–He, the operating gas pressure was 10 mTorr. In order to provide the same range of the target power density, the gas pressure in the case of C–Ar combination was increased to 100 mTorr.

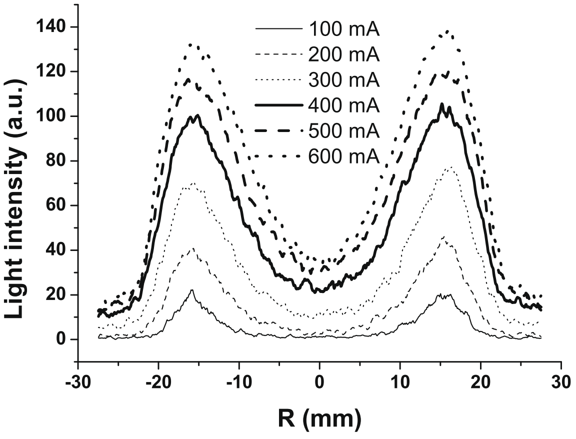

Fig. 1. Radial profile of the global light intensity measured for W–Ar combination, at different discharge current intensities.

Fig. 2 illustrates the erosion profile after two hours of sputtering of tungsten (Fig. 2(a)) and carbon (Fig. 2(b)) targets in Ar atmosphere, with the power density as parameter. The amount of sputtered material can be estimated from these erosion profiles. For the same range of the target power density, the depth erosion profile is about 6 times higher in the case of W–Ar with respect of C–Ar combination. The shape of carbon erosion profile is quasi-symmetric with respect of the erosion peak ($r \sim 15$ mm) while tungsten erosion is larger toward the cathode axis ($r = 0$). Moreover, the tungsten target is sputtered also on the cathode axis (Fig. 2(a)), which is not the case of the carbon target (Fig. 2(b)).

A two-dimensional fluid model developed for a plane magnetron discharge with cylindrical symmetry [6] was applied for W–Ar combination in order to calculate the ion energy flux bombarding the target. The numerical results of the fluid model are plotted in Fig. 3 for the same discharge conditions as in Fig. 2(a). A fairly good agreement is noticed between the measured sputtering profile (Fig. 2(a)) and the profile of the ion energy flux predicted by the model (Fig. 3) except that the calculated ion energy flux does not explain the observed asymmetry in the sputtering profile. This difference might be explained by two phenomena that are not taken into account within the numerical model: (i) re-deposition of the sputtered material which has been experimentally observed mainly on the exterior side of the race-track and (ii) modification in time of the erosion target profile due to the sputtering effect.

Fig. 4 displays the sputtering rate of W and C targets by Ar^+ and He^+ bombardment. Sputtering rate of both W and C increases with the target power density. The large difference between W and C sputtering rate in Ar atmosphere (two orders of magnitude,

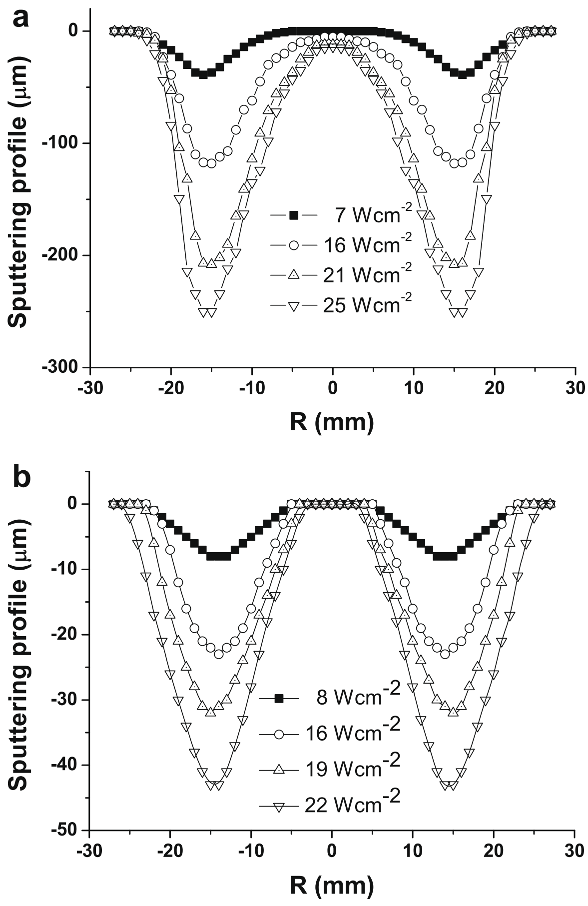

Fig. 2. Radial erosion profile of tungsten (a) and carbon (b) targets by Ar^+ bombardment, for different power densities.

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