SIMULATION OF NEUTRON INFLUENCE ON TUNGSTEN MIRRORS

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The effect of neutron irradiation on behavior of optical characteristics for two types of tungsten mirrors was modeled. Preliminary irradiated rcW and WJ-IG mirrors with 20 MeV W^{6+} ions were used for experiments. Changes in the surface morphology and optical characteristics of the samples were investigated in the sputtering process.

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INTRODUCTION

First mirror (FM) turned to plasma with its working surface is the responsible element of optical systems of optical and laser plasma diagnostics in ITER. FMs will be subjected to influence of all kind radiations emanating by burning plasma leading to degradation of their optical properties. Surface erosion under impact of charge exchange atoms, mainly deuterium and tritium atoms - CXA, as well as deposition of impurities, will significantly influence the mirrors properties. The main requirements at a material choice are high enough reflectivity and resistance to radiation damage related with neutron fluxes and CXA bombardment with wide energy spectra.

Due to a number of unique properties, such as low sputtering yield and high melting temperature, tungsten (W) is now considered as a perspective material for the elements which are plasma facing components in ITER and probably in DEMO. The total tungsten surface area in ITER chamber is about 100 m^2 [1]. W is also being considered as a perspective material for FMs placed in ITER in locations where erosion due to CXAs strongly dominates. As a result of irradiation by neutrons and CXAs it is possible the appearance of defects and changes in the mirrors surface morphology. One of the ways to investigate the influence of defects from neutrons effect is to simulate atoms displacement in solids by irradiation with high-energy ions.

Initially, the experiments simulating neutron effects on reflectance were provided with Cu and SS mirrors [2,3], which were exposed to high-energy (1-3 MeV) ion beams Cu^+ and Cr^+, respectively. It was found that degradation of these mirrors under long term sputtering with hydrogen plasma occurs with approximately similar rate as that for the mirrors not preliminary bombarded with high energy metal ions.

EXPERIMENT

The experiments relating to the behavior of reflectivity and surface morphology of preliminary irradiated W mirrors due to long term sputtering were carried out with the use of 600 eV argon ions as projectiles. Two types of 99.99% polycrystalline tungsten specimens produced by ALMT Corp., Japan, were: ITER-grade tungsten (below WJ-IG) and the one recrystallized at 2073 K for 1 hour after cutting and polishing (rcW). One side of the mirror specimens were irradiated with 20 MeV W^{6+} ions to the damage levels 0.3 dpa and 3.0 dpa. Depth distributions of dose had maximum at ~1.4 µm and lengthened down to the depth ~2.2 µm [4]. The back side of the specimens served as a reference surface.

The sputtering process of the surface mirror was organized as multiply repeated procedures in stand DSM-2 [5]. After each sputtering procedure the specimen was taken off from the vacuum chamber and its mass loss and optical properties were measured. Optical measurements include measurement of the reflectance coefficient R(λ) in the wavelength range λ=220…650 nm at normal incidence of light and measurements of spectral dependence of ellipsometric parameters. Micro-images of the specimen surface were obtained using an optical microscope. After finishing exposures to argon ions, the surface of specimens was analyzed with scanning electron microscope (SEM) and atomic force microscope (AFM). The 2D spatial distribution of scattered light and X-rays diffraction (XRD) were measured also. rcW surface was additionally analyzed with application of confocal laser scanning microscopy (CLSM) and electron backscatter diffraction (EBSD).

RESULTS

The results obtained for non-irradiated and irradiated to 3 dpa and 0.3 dpa sides of both kind tungsten show that mass loss is almost identical for both specimen sides and linearly increases with increasing ion fluence. From these data it may be concluded that there is small difference between rate of sputtering for sides irradiated and non-irradiated with W^{6+} ions. For rcW specimens the difference in height for adjacent grains increases with sputtering time (data of interference microscope and CLSM).

Layer sputtering with thickness ~ 4 µm affected the surface morphology. Fig. 1 demonstrates change of interference patterns on the rcW surface after sputtering. We can see the fringes shift from grain to grain what means appearance of step structure on rcW mirrors as a result of long-time polycrystalline materials exposition, however, in-grain relief does not develop.

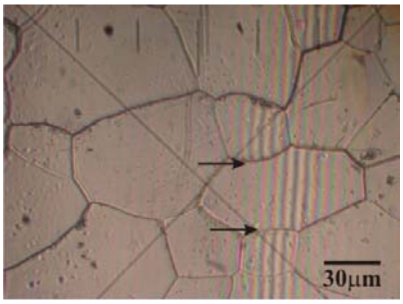

Fig. 1. Interference patterns on the irradiated side of rcW specimen after last exposition

Fig. 2 shows the part of the specimen surface near the grain with crystallographic axis orientation close to [111]. This grain dominates over adjacent grains whose orientation is different from [111] about 9º, and the value of height difference (Δz) varies from 0.4 to 1.3 µm.

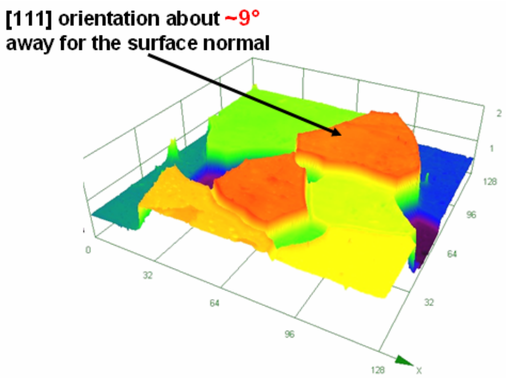

Fig. 2. Step structure of rcW mirror surface after layer sputtering by thickness ~4 µm. All dimensions are in µm

On Fig. 3 the irradiated (W^{6+}) side of WJ-IG specimen after sputtering procedures is shown. Notice that interference patterns become not seen already after low fluence of D^+ ions and a chaotic roughness appeared.

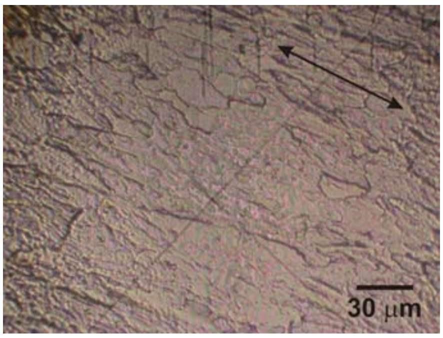

Fig. 3. Interference microscope data for WJ-IG mirror irradiated side surface after last exposition

The development of surface inhomogeneity on WJ-IG specimens began after the first exposure. A 3D data from AFM of the WJ-IG mirror is shown in Fig. 4. Such "strange" surface inhomogeneity may be related to a complicated procedure of preparing this type of mirrors: (rolling, swaging and/or forging) [6].

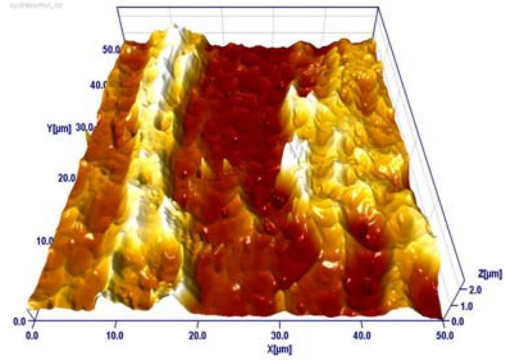

Fig. 4. Surface structure of WJ-IG specimen after sputtering layer with thickness ~ 4 µм. AFM data

Fig. 5 shows the reflection coefficient R(λ) of WJ-IG and rcW mirrors with 3 dpa damage dose, depending on the thickness of the sputtered layer at a wavelength of 600 nm. At normal incidence of light R(λ) for rcW mirror is practically unchanged, while for the WJ-IG specimen strong reflectivity degradation was observed in the serial sputtering process and increasing of sputtered layer thickness. This behavior of WJ-IG mirrors is related to the development of roughness on the specimen surface.

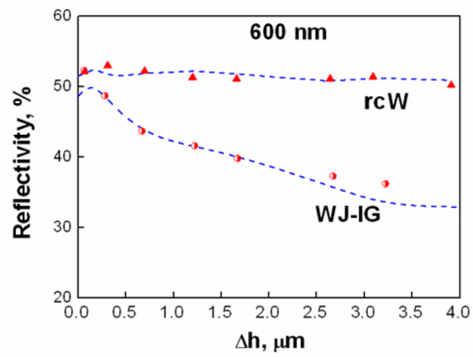

Fig. 5. Dependence of reflection coefficient *on the sputtered layer thickness for WJ-IG and* rc*W mirrors irradiated to 3 dpa (points) and not irradiated (dotted curves) sides at wavelength 600 nm*

Fig. 6 shows the ellipsometric parameter Δ spectra for WJ-IG mirror non-irradiated (initial) and irradiated sides (3 dpa) with tungsten ions after cleaning, first and last sputtering procedure.

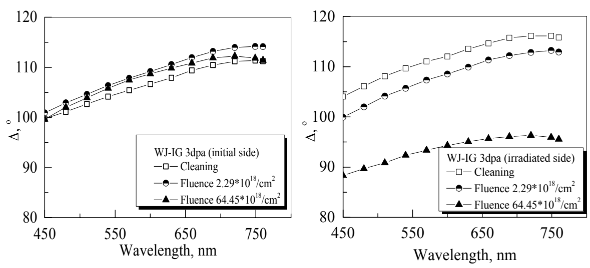

Fig. 6. Ellipsometric parameter Δ on the wavelength for WJ-IG mirror for non-irradiated (initial) and irradiated sides after cleaning, first and last sputtering procedure

Δ value for non-irradiated (initial) side of the specimen is practically unchanged. We can see change of the parameter Δ, which decreases with increasing ion fluence for the irradiated side of the mirror. This behavior indicates that for this type of mirror it is important if the sample was pre-irradiated or not. Changes in the ellipsometric parameters for recrystallized samples weren't observed and it may be concluded that the sputtering procedures do not affect the behavior of normal incidence reflectance for mirror of this type of tungsten.

Sample surface is characterized by level of scattered light intensity. An example of such a distribution is shown in Fig. 7 for the WJ-IG mirror (3 dpa). Significant intensity anisotropy in azimuth is well seen.

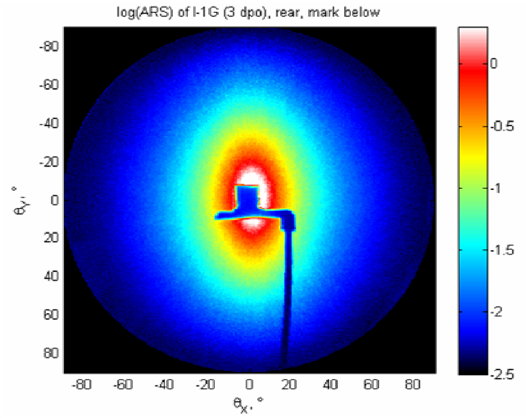

Fig. 7. Normalized data distribution of scattered light for irradiated side (with 3 dpa damage) of WJ-IG mirror

CONCLUSIONS

The research related to simulation of neutron influence on two types of tungsten mirrors surface with 0.3 and 3 dpa damage dose were provided. There was not found difference in behavior of measured optical parameters and surface structure for irradiated with W^{6+} ions and not irradiated specimen sides and in the rate of sputtering.

Reflectivity of rcW mirrors at normal incidence changes only within 2 % in all studied spectral range after sputtering to the depth ~ 4 μm, in spite of appearance of a typical step structure, what is due to normal incidence of light. The measured ellipsometric parameters also showed that specimens surface irradiation with 20 MeV tungsten ions did not affected its optical properties.

For WJ-IG samples, in contrast to rcW mirrors, after the upper layer with thickness ~ 4 μm was sputtered, the degradation of optical characteristics was observed to approximately 20 %. Roughness on these specimen surfaces became to appear already after the first sputtering procedure with 600 eV Ar^+-ions. During the study some differences in behavior of ellipsometric parameter Δ on sputter time were observed for irradiated and non-irradiated side of the mirror.

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МОДЕЛЬНЫЕ ИССЛЕДОВАНИЯ СВОЙСТВ ВОЛЬФРАМОВЫХ ЗЕРКАЛ ПРИ НЕЙТРОННОМ ОБЛУЧЕНИИ

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Изучалось влияние нейтронного облучения на поведение оптических свойств двух типов вольфрамовых зеркал rcW и WJ-IG. Зеркала предварительно облучались ионами W^{6+} с энергией 20 МэВ. В процессе распыления исследовались изменения морфологии поверхности и оптических характеристик образцов.

МОДЕЛЬНІ ДОСЛІДЖЕННЯ ВЛАСТИВОСТЕЙ ВОЛЬФРАМОВИХ ДЗЕРКАЛ ПРИ НЕЙТРОННОМУ ОПРОМІНЕННІ

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Вивчався вплив нейтронного опромінення на поведінку оптичних властивостей двох типів вольфрамових дзеркал rcW та WJ-IG. Дзеркала попередньо були опромінені іонами W^{6+} з енергією 20 МеВ. Під час процесу розпилення досліджувалися зміни морфології поверхні та оптичних властивостей зразків.