SPECULAR AND DIFFUSIVE REFLECTANCE OF STAINLESS STEEL MIRRORS SPUTTERED WITH Ar$^+$ IONS

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It was shown that a light source with edge sharpness can be used for very sensitive measurements of the ratio of specular and diffusive components of reflectance of the mirror subjected to sputtering.

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INTRODUCTION

When sputtering a polycrystalline mirror, its initial smooth surface turns into the surface with a step structure. This transformation takes place due to the dependence of sputtering coefficient of every metal grain on the orientation of its main crystallographic axes relatively to the mirror surface, and the orientation of adjoining grains is, as a rule, different. Due to development of a step structure relief during sputtering, the degradation of mirror optical properties occurs. Previously such effect was observed for reflectance at normal incidence when stainless steel (SS) mirrors were sputtered with deuterium plasma ions of different energy [1].

The present work is devoted to investigation of the dynamics of reflective properties of stainless steel (analog of SS316 steel) mirrors subjected to bombardment with Ar plasma ions of fixed energies: 300, 600 and 1000 eV. Measurements of reflectance were provided by: (i) our traditional method using the Tolansky scheme [2] (normal incidence of light) in the wavelength range λ=220…650 nm [1], and (ii) the new, suggested in our group recently, the method with registration of an image of a light source with edge sharpness (λ=500 nm) after reflection (at an angle 45°) from the mirror under the test. The second method (image quality method, IQ) gives possibility to make a clear separation among specular (SR) and diffusive (DR) components of reflectance. The state of the mirror surface was controlled by the use of optical and interferometer microscopes, as well as by profilometry.

1. EXPERIMENTAL RESULTS

1.1. OPTICAL PROPERTIES

Sputtering procedures of mirror specimens were provided in the DSM stand [3], a simple double-mirror magnetic system. An ECE discharge in deuterium or argon (frequency 2.37 GHz) was served as an ion source. Specimens with the size 22x22x4 mm were fixed at a holder maintained at the room temperature. The thickness of sputtered layer was estimated by measuring the weight loss after every exposure of specimens in plasma. In Fig. 1 are presented the results of measurement of the light source image for mirrors in initial state and after the layer of ~2.5 µm was sputtered by Ar$^+$ ions with 300 and 1000 eV (a and b on Fig. 1, respectively). Fig. 2 shows the degradation of SR as the function of ion energy for sputtered layer thickness ~2.5 µm.

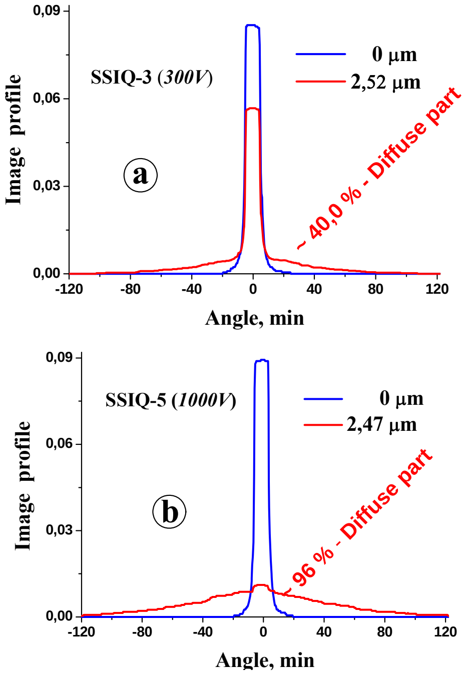


Fig. 1. IQ profiles obtained after bombardment of SS specimens by Ar$^+$ ions with energies 300 (a) and 1000 eV (b)

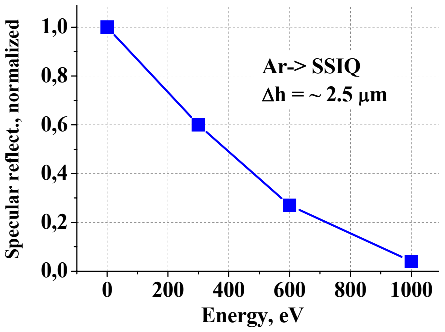


Fig. 2. Ion energy dependence of specular reflectance after sputtering the layer of 2.5 µm in thickness

For comparison: measurement of SR by the method described in [2] gives drop of reflectance ΔR = -9.5 %, but the IQ method gives ΔR = -96 %.

Thus as follows from our comparative results:

1. IQ method demonstrates the dynamics of correlation between specular reflectance (that is responsible for quality of information on mirror optical properties) and diffusive reflectance which is a characteristic of surface relief developing due to sputtering.

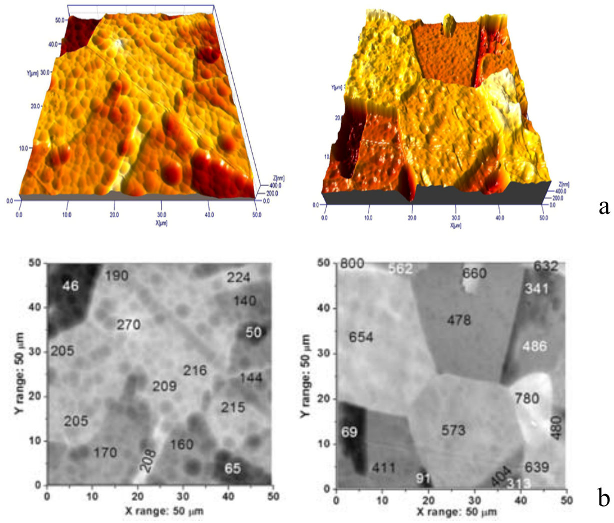
2. The higher ion energy, the faster surface roughness grows and faster specular reflectance degrades.

1.2. SURFACE CHARACTERISTICS

The analyses of surfaces with atomic force microscope (AFM) were provided after finishing the sputtering procedures (the final thickness of sputtered layer for every specimen is indicated in Table).

AFM data for two specimens are shown (Fig. 3,a) in color, and the results of processing – in gray (Fig.3,b). The oval spots on Fig. 3 are etching pits (the size 1…5 μm).

The processing of the AFM data is presented in Fig. 3,b and Table.



E_i=300 eV E_i=1000 eV

Fig. 3. AFM data for specimens exposed to ions with energy 300 eV and 1000 eV (a), and results of processing (b)

Roughness of SS specimens sputtered with Ar^+ ions of different energy to comparable depth (~4 μm)

Energy of Ar^+ ions, eV	Roughness parameters (R_a) on mirror surface after Δh thick layer was sputtered, nm	Maximal heights (R_Z), nm
300	170 ± 52, Δh = 4.1 μm	± 104
600	388 ± 76, Δh = 3.9 μm	± 134
1000	492 ± 162, Δh = 2.5 μm 787 ± 260, Δh = 4.0 μm	± 425

As seen, roughness developed due to sputtering is higher for higher Ar ion energy. It means that the difference between sputtering rate of differently oriented grains increases with increasing ion energy.

Data for Δh=4.0 μm at E_i=1000 eV were obtained from the dependence of Δm on ion fluence for this specimen, shown in Fig. 4.

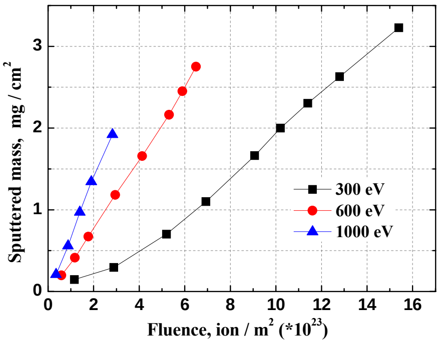


Fig. 4. Mass loss depending on the ion fluence

A linear ion fluence dependence of Δh (which is proportional to Δm – the mass loss) for ion energy 1000 eV (see Fig. 4) allows to predict the level of roughness after sputtering the layer of 4 μm thick (see Table). Thus the mean roughness value (R_a) for three different Ar ion energies after sputtering the layer 4 μm was found, Fig. 5. Such thickness layer would be sputtered by charge exchange atoms for about one year of ITER operation.

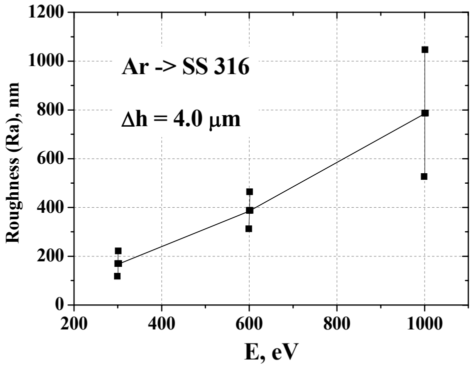
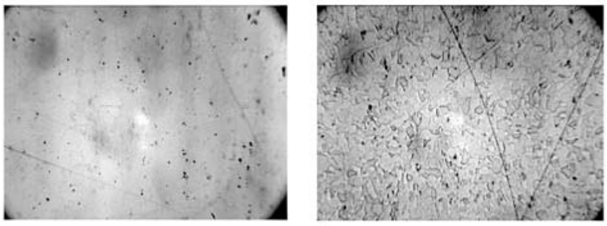


Fig. 5. Roughness of the surface after sputtering the layer of 4 μm in thickness

1.3. COMPARISON OF EFFECTS OF SPUTTERING WITH D^+ AND Ar^+ IONS

High sensitivity of IQ method gives possibility to provide comparison of sputtering effects caused by D^+ and Ar^+ ions. For this experiment two identical SS mirror specimens were exposed in deuterium (SS N1) and argon (SS N2) plasma ions with energy 600 eV. The thickness of sputtered layer was Δh~0.6 μm (the mass loss Δm~2.5 mg) and Δh~1.6 μm (Δm~6 mg). Fig. 6 shows the photos made in optical microscope at the first stage of experiment.



SS N1 D^+ Δm= 2.57 mg SS N2 Ar^+ Δm= 2.42 mg

Fig. 6. Photos of specimens in optical microscope

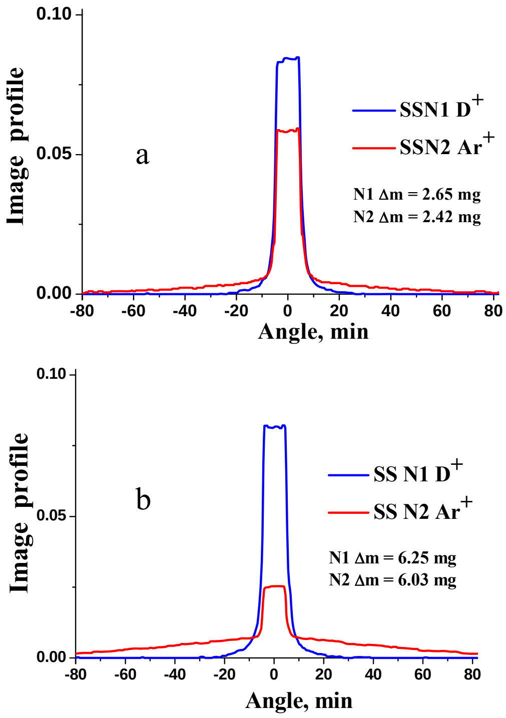


Fig. 7. IQ profiles after sputtering the same thickness layer with D and Ar ions. a – Δh~0.6 µm (~2.5 mg), b – Δh~1.6 µm (~6 mg)

It is seen that, as distinct from sputtering with D^+ ions, the Ar^+ ion sputtering results in appearance of some surface roughness, what is an evident indication on stronger difference of sputtering rate for grains with different orientations than in the case of D^+ ions. Correspondingly, the specular reflectance drops much faster after bombardment with Ar^+ ions than after D^+ ions, as Fig. 7 demonstrates.

The effect of Ar^+ ion sputtering on IQ reflectance degradation for N2 is significantly greater than the contribution of D^+ ions sputtering for N1 specimen. IQ reflectance of N2 specimen dropped catastrophically.

CONCLUSIONS

1. The methods used for investigating the quality of reflectance by measuring the profile of an image of a sharp light source (IQ method) is very sensitive to the mirror surface state and can be used as an alternative to the standard methods (i.e. integrating optical sphere).
2. Difference in sputtering rates of grains with different orientations is stronger in the case of Ar^+ ion sputtering than in the case of D^+ ion sputtering.
3. The fact of faster degradation of specular reflectance under Ar^+ ion bombardment indicates on faster rise of surface roughness in comparison with similar layer thickness sputtered by D^+ ions.
4. The angle distribution of scattered light does not follow cosθ dependence.

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ИЗМЕРЕНИЕ ЗЕРКАЛЬНОГО И ДИФФУЗНОГО КОМПОНЕНТОВ КОЭФФИЦИЕНТА ОТРАЖЕНИЯ ПРИ РАСПЫЛЕНИИ СТАЛЬНЫХ ЗЕРКАЛ ИОНАМИ Ar^+

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Измерение изображения резко очерченного источника света, отраженного от зеркала (IQ-метод), является очень чувствительным методом регистрации соотношения зеркального и диффузного компонентов коэффициента отражения при распылении испытуемых образцов.

ВИМІРЮВАННЯ ДЗЕРКАЛЬНОГО ТА ДИФУЗНОГО КОМПОНЕНТІВ КОЕФІЦІЄНТА ВІДБИТТЯ ПРИ РОЗПИЛЕННІ СТАЛЕВИХ ДЗЕРКАЛ ІОНАМИ Ar^+

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Вимірювання зображення різко окресленого джерела світла, відбитого від дзеркала (IQ-метод), є дуже чутливим методом реєстрації співвідношення дзеркального та дифузного компонентів коефіцієнта відбиття при розпиленні випробовуваних зразків.