THE MICRORELIEF STUDIES OF STAINLESS STEEL MIRRORS SPUTTERED WITH Ar^+ IONS OF DIFFERENT ENERGY

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Four stainless steel mirror specimens were sputtered to an identical mean thickness of the eroded layer 2 μm with Ar^+ ions. Each specimen was exposed to ions with one kinetic energy from the followings: 300, 600, 1000, and 1350 eV. With the methods of microscopy and profilometry of microrelief the positive correlation was shown between the r. m. s. roughness, the power spectral density of the Fourier spectrum of the longitudinal wavelengths, on one hand, and the energy of ions, on the other hand.

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INTRODUCTION

In the conditions of sputtering the polycrystalline stainless steel mirror specimens with ions, the optical reflectance degradation increases with ion energy increasing [1, 2]. If the mean thickness of the eroded layer on several specimens, measured by the weight loss, is identical, it is clear that reflectance degradation is the result of the rise of the surface roughness. The roughness grows for the reason of the increase of the difference between sputtering rates of grains with different orientation when ion energy is increasing in the experiment.

In this study, we analyzed the surface irregularity parameters, such as root mean square (r. m. s.) roughness and the longitudinal wavelength on the surface of stainless steel mirror specimens after sputtering with Ar^+ ions of the different energy.

1. EXPERIMENTS ON SPUTTERING AND METHODS OF MICRORELIEF STUDY

Before the start of sputtering procedures, the specimens were polished to obtain the surface with minimal irregularities. Each of identical specimens denoted as S1, S2, S3, and S4 was exposed to monoenergetic Ar^+ ions accelerated to the kinetic energy E_0 = 300, 600, 1000, and 1350 eV, respectively. As an ion source, the Ar plasma in a DSM-2 stand was used [3]. The mean sputtered thickness of each specimen was chosen to be equal to 2 μm for the correct comparison of irregularity parameters of the specimens.

As a result of sputtering, the microrelief appeared on each specimen. Two methods to proceed the data on microrelief heights were applied: 1) optical microscopy supplemented by atomic force microscopy (AFM), and 2) profilometry to obtain a profile of the microrelief of the surface.

For each specimen, the optical microscopy was used to produce a microphotograph with a size of 480 × 280 μm, Fig. 1.

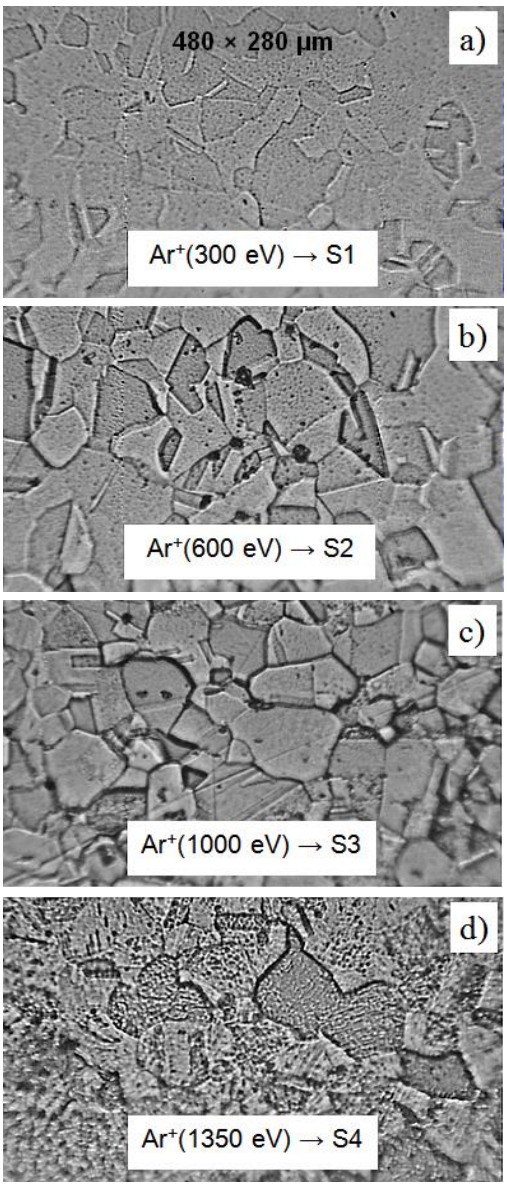

Fig. 1. The microphotographs of the specimens: a) S1, b) S2, c) S3, and d) S4

Each microphotograph consists of 1500 × 875 pixels of a gray color with different brightness. Each pixel was transformed into a cell of a matrix, containing pixel brightness *B*. The brightness was recalculated into a height *h* of the microrelief in arbitrary units ($0 \le h \le 1$), assuming direct proportionality of *h* and *B*. The optical microscopy provided the measurements in the arbitrary units only. Therefore, for each specimen the matrix data was recalculated in μm, according to the measured data of the profilometry and AFM.

A trajectory of the measurement of microrelief height was a rectangular serpentine path with a total length of 18.7 mm.

The sizes of AFM microphotographs were 50 × 50 μm. The AFM provided the highest spatial resolution in this study, with a total sampling length of 2 mm. The profilometry of relief heights was used along a straight segment 4 mm in length, on each sample. The samplings of the relief shape from an optical microscope, AFM and a profilometer were considered as the basic initial data.

2. RESULTS OF STATISTICAL ANALYSIS

As is clear from the microphotographs in Fig. 1, the relief developed as a result of sputtering procedures depends strongly on the ion energy. When increasing the energy E_0 of Ar^+ ions, the surface relief becomes more and more noticeable, as is seen by eye. On the S1 specimen surface, the irregularities are almost not seen. The surface of the S4 specimen is characterized by a wide variety of reliefs: micropores, microneedles and etching pits that can be clearly distinguished. This kind of the surface features was found only for the energy E_0 = 1350 eV of Ar^+ ions and was not observed on specimens S1 – S3.

The statistical distributions of irregularity heights for the specimens, $\Delta N/\Delta h$ were computed (Fig. 2), based on these measurements.

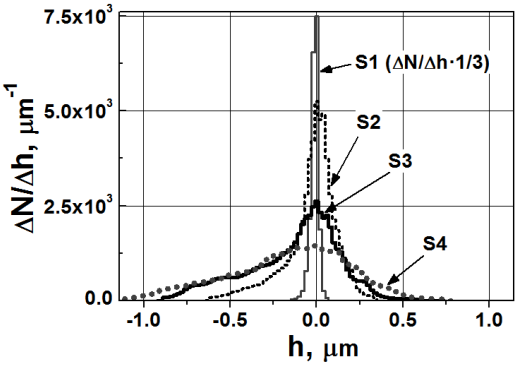

Fig. 2. The distributions of irregularity heights $\Delta N/\Delta h$. The S1 specimen ordinate is reduced by three times for clarity of comparison

Here ΔN indicates a number of heights located in the *k*-th interval, $h_k \pm \Delta h$, where k = 1…114, Δh = 0.02 μm, according to the standards [4]. The diagrams are moderately asymmetric, and have, approximately, a Gaussian shape. With increasing the ion energy, the width of the diagrams becomes larger and the height decreases.

For each specimen, a roughness parameter R_q (that is, r. m. s. height of irregularities) and a mean period S_m of longitudinal waves of the irregularities were calculated, following a procedure described in [5].

The roughness parameter R_q correlates positively with the energy of ions E_0 and takes the values 0.02, 0.16, 0.27 and 0.35 μm, as is shown in Fig. 3. The R_q value increases significantly, by 75 % relative to its average value calculated on the base of these four values.

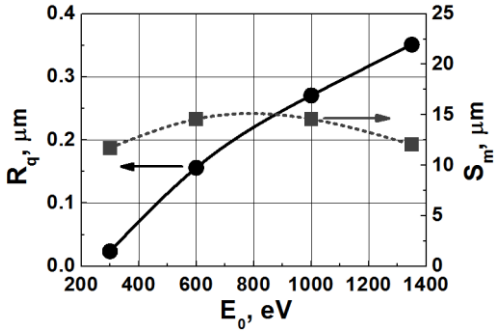

Fig. 3. The dependence of the roughness parameter R_q and the mean period S_m of longitudinal waves on the ion energy

The wavelength distributions $\Delta N/\Delta\Lambda$ depend on the wavelength Λ for the different ion energies and are close to each other, excluding the short-wavelength region, $\Lambda \le 18$ μm. Here ΔN is a number of wavelengths in the *k*-th interval of wavelengths, $\Lambda_k \pm \Delta\Lambda$, where k = 1…20, $\Delta\Lambda$ = 3 μm.

At the same time, the mean period S_m of longitudinal waves changes similar to a sinusoid half, in the range of about 11…15 μm, taking the values of 11.7, 14.6, 14.5, and 12.1 μm (see Fig. 3). The S_m changes in the amplitude slowly, by ~10 % relative to its average value. The average longitudinal size of surface irregularities, as is seen from the value of the S_m period, almost does not depend on the ion energy. The longitudinal dimensions of grains visible by eye in the microphotographs depend on the ion energy also insignificantly.

It should be noted that the power spectral density function *PSD* (Λ) provides here more reasonable dependence on the wavelength Λ than the distributions $\Delta N/\Delta\Lambda$. The *PSD* (Λ) is shown in Fig. 4 after smoothing.

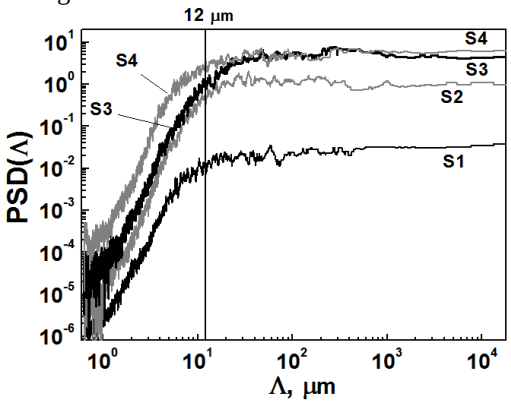

Fig. 4. The power spectral density function PSD (Λ) increases and shifts to the short-wavelength range with increasing the ion energy

The function *PSD* (Λ) was found on the basis of the Fourier spectrum of height samplings.

The *PSD* functions of the specimens increase in the amplitude and shift toward a short-wavelength region noticeably with increasing the ion energy.

The *PSD* (Λ, *S1*) function is the lowest one. The *PSD* (Λ, *S4*) function is substantially higher, especially in its short-wave part, $\Lambda \leq 12$ μm. This part corresponds to micro-pores and micro-needles that appeared on the specimen S4 that was sputtered with ions of energy E_0 = 1350 eV. The micro-objects are clearly visible in (see Fig. 1,d) but are not visible in the distributions $\Delta N/\Delta\Lambda$. This is due to the fact that waves of low amplitude, located near the middle line of the microrelief profile and intersecting this line, are taken into account in the distribution $\Delta N/\Delta\Lambda$. But such low waves located on the prominent or the lowest surfaces of grains are not taken into account in the distributions since such waves do not intersect the middle line.

CONCLUSIONS

The surface irregularity parameters, such as r.m.s. roughness and the longitudinal wavelength on the surfaces of four polycrystalline stainless steel mirror specimens were analyzed, using the samplings of heights measured by the optical microscopy, AFM, and profilometry. The specimens were sputtered with Ar^+ ions in the DSM-2 stand with plasma, each specimen with one energy from the followings: 300, 600, 1000, and 1350 eV. The mean sputtered thickness was taken to be 2 μm, identical for all specimens.

It was shown that with increasing the energy E_0 of ions:

– The irregularity heights, as seen in the height distributions $\Delta N/\Delta h$, increased noticeably, and the roughness parameter R_q increased significantly, by 75 % relative to its average value.

– On the contrary, the longitudinal wavelength distributions $\Delta N/\Delta\Lambda$ are close to each other, excluding the short-wavelength range. And the mean period S_m of a longitudinal wavelength changes in the amplitude not so noticeably, by ~10 % relative to its average value. In other words, the average longitudinal size of surface irregularities almost does not depend on the ion energy. At the same time, the longitudinal dimensions of the grains depend on the ion energy insignificantly.

– The power spectral density *PSD* (Λ), built on the basis of Fourier transform, increases and shifts to a short-wavelength region. In contrast to $\Delta N/\Delta\Lambda$ distributions, the *PSD* functions depend on the ion energy noticeably.

In prospect, the developed methods and obtained results can be considered for mirror specimens made of other kinds of metal.

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ИССЛЕДОВАНИЯ МИКРОРЕЛЬЕФА ЗЕРКАЛ ИЗ НЕРЖАВЕЮЩЕЙ СТАЛИ, РАСПЫЛЕННЫХ ИОНАМИ Ar^+ РАЗНОЙ ЭНЕРГИИ

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Четыре образца зеркал из нержавеющей стали были распылены до одинаковой средней толщины эродированного слоя 2 мкм ионами Ar^+. Каждый образец экспонировался к ионам со следующей кинетической энергией: 300, 600, 1000 и 1350 эВ. С использованием методов микроскопии и профилометрии микрорельефа была показана положительная корреляция между среднеквадратичной шероховатостью, спектральной плотностью мощности спектра Фурье продольных длин волн с одной стороны, и энергией ионов с другой стороны.

ДОСЛІДЖЕННЯ МІКРОРЕЛЬЄФУ ДЗЕРКАЛ З НЕРЖАВІЮЧОЇ СТАЛІ, РОЗПИЛЕНИХ ІОНАМИ Ar^+ РІЗНОЇ ЕНЕРГІЇ

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Чотири зразки дзеркал із нержавіючої сталі були розпилені до однакової середньої товщини еродованого шару 2 мкм іонами Ar^+. Кожен зразок експонувався до іонів з наступною кінетичною енергією:300, 600, 1000 і 1350 еВ. З використанням методів мікроскопії і профілометрії мікрорельєфу було показано позитивну кореляцію між середньоквадратичною шорсткістю, спектральною густиною потужності спектра Фур'є поздовжніх довжин хвиль з одного боку, та енергією іонів з іншого боку.