SPECTROELLIPSOMETRIC STUDIES OF D+ ION-IRRADIATED W (110) AND (111) SINGLE CRYSTALS

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The main aim of this work was to investigate the modification of optical properties for tungsten single crystals after the high-dose treatment by deuterium plasma ions. The surfaces were subjected to high-dose D plasma ion irradiation with energy in the range E=0.1-1.77 keV with removal of 5.5-μm thick layer for (110) surface and 6.4 and 7.0 μm for (111) surface, respectively. Modification of the spectral dependences of optical characteristics for irradiated mirrors has been studied by means of spectral ellipsometric technique for probing photon energy range 0.5-5 eV. Surface microrelief changes were determined by atomic force microscopy. The correlation of the optical characteristics of the single crystals of tungsten permits to ascertain that the increase of the sputtered by deuterium ions layer thickness caused not only the decrease of the optical conductivity values in the UV more than in the IR, but also broadening of the characteristic absorption bands near 1, 1.7, 2.2 and 3 eV. Inasmuch as the atomic force microscopy showed no significant changes for surface microrelief of W (111) after the irradiation by deuterium ions (the highest roughness is 6 nm), the changes in optical conductivity spectra could be explained by mirror subsurface layer disordering after such ion bombardment.

Introduction

It is known that ion treatment of metal surface could improve its optical characteristics due to removal of the adsorbed layer as well as to deteriorate them according to surface roughening, subsurface layer disordering and its stoichiometry changes. Surface sputtering by ions and ion implantation into subsurface layer occur simultaneously during the ion treatment of surfaces. Besides, ion implantation is indispensable tool for surface modification of metals in order to produce new anti-frictional, corrosion and erosion resistant metallurgic coatings that would extend machines lifetime, their reliability and durability. But it is difficult to prepare such coatings with given properties. The problem is that general theory of mass transport and surface disordering under the high-flux ion irradiation is still incomplete. That is why the main concern was with the investigation of the optical properties modification after different ion treatments.

Experimental

The tungsten specular surfaces were prepared by polishing of the W single crystal slabs with diamond paste up to obtaining the highest value of reflectance. In order to study optical spectra changes the unirradiated mirrors of W (110) were selected (samples A and B). Then surfaces were subjected to high-dose D plasma ion irradiation with energy in range E=0.1–1.77 keV with removal of 5.5 μm thick layer for (110) (sample C) surface and 6.4 and 7.0 μm for (111) surface (samples D and F) respectively.

Tungsten (110) and (111) samples were investigated by X-ray diffraction technique before the ion treatment in order to check the crystalline grain orientation. The changes of metallic surface optical properties after irradiation by particles were determined by using the multiple angles of incidence light ellipsometry (wavelength of the incident light λ=632.8 nm, light incidence angle range 65-80^0 depends on material). Modification of the spectral dependences of optical characteristics for irradiated mirrors has been studied by means of spectral ellipsometric technique for probing photons energy range 0.5-5 eV for light incidence angle φ=74^0.

Thus, the phase shift Δ between the orthogonal components of polarization vector and the azimuth of restored linear polarization Ψ were determined versus angle of incident light or probing photon energy. Optical constants of metal surfaces were determined on the basis of appropriate model of the reflecting medium near the principle angle of light incidence $\varphi=\varphi_0$ (the phase shift at this angle $\Delta=\pi/2$).

All optical measurements were carried out in air ambience, after the irradiation metallic samples were kept in air atmosphere during the time enough for thin passivating film formation. Surface microrelief of the mirrors was studied by means of atomic force microscopy (AFM).

Results and discussion

The investigation of spectral dependences of optical conductivity for unirradiated samples A and B of monocrystalline tungsten (110) revealed that measured spectra are significantly different from the data obtained by other authors [1].

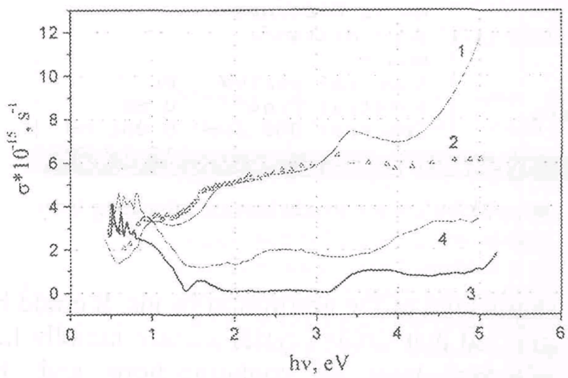

Fig. 1. Optical conductivity spectra for tungsten (110) single crystals before the irradiation, samples A, B (curves 3,4 respectively), reference data (curve 1), after the deuterium plasma ion irradiation, sample C (curve 2).

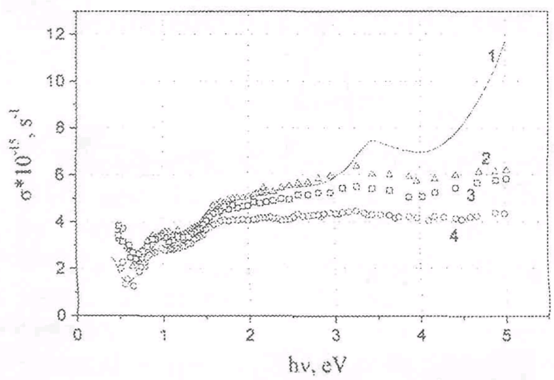

Fig. 2. Optical conductivity spectra for W (110) and W (111) single crystals according to the reference data (curve 1), after the irradiation, sample C, (curve 2), D (curve 3), and F (curve 4).

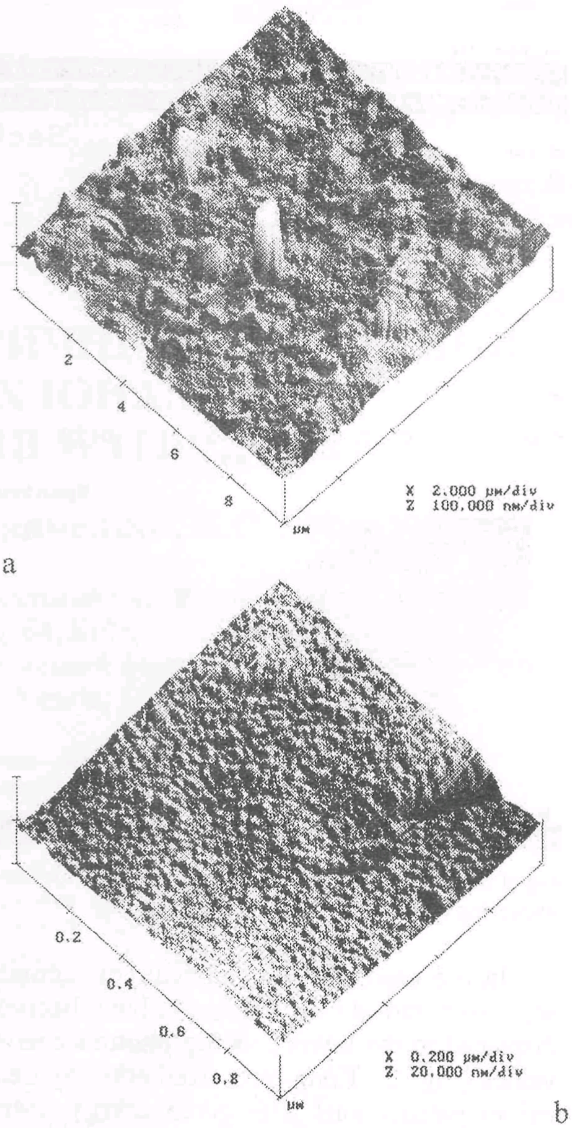

Fig. 3. Microrelief AFM 3D images for W (111) surface before the irradiation (a) and after long term sputtering (sample D) by D$^+$ plasma ions (b).

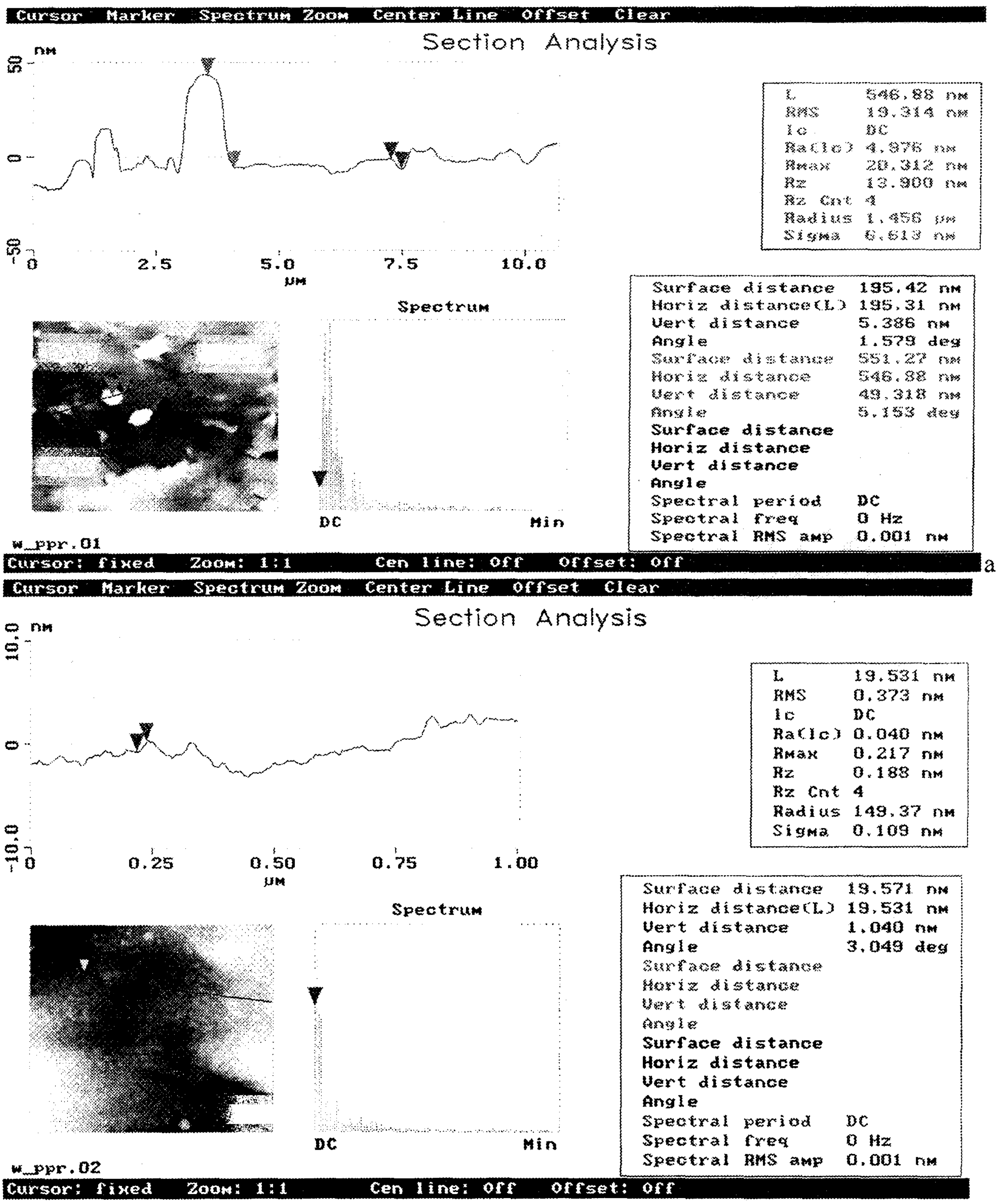

Fig. 4 Surface structures and their parameters for the W (111) samples before the irradiation (a) after long term sputtering (sample D) by D^+ plasma ions (b).

In our case values of optical conductivity are lower and absorption bands have become displaced to the lower probing photons energy values (Fig. 2). Long-term irradiation by deuterium plasma ions with given energy distribution (sample C) led to enhancement of the optical conductivity values as well as to the sharpening of the absorption bands. It could be inferred that single crystal surface initially has adsorbed layer of contaminations and the subsurface layer structure was damaged in a consequence of mechanical polishing. Such ion treatment caused sputtering of the damaged layer and surface contaminations as it was clarified in our earlier works for other metals [2]. The correlation of the optical characteristics of tungsten single crystals of permits to ascertain that increase of the sputtered by deuterium ions layer thickness (samples C, D, F) caused not only decrease of the optical conductivity values in the UV more than in the IR, but also broadening of the characteristic absorption bands near 1, 1.7, 2.2 and 3 eV (Fig. 2).

In order to determine the reasons of optical properties changes after the D plasma ion treatment tungsten single crystal (111) unirradiated sample as well as sputtered one were probed by atomic force microscopy. The microrelief AFM 3D images of these samples are shown in Fig. 3, and surface structures and their parameters are presented in Fig. 4. One could observe that surface roughness parameters are only slightly changed after the ion treatment except separate spikes related probably to the surface contamination of the unirradiated sample that should not have strong effect on optical data. That is why the changes in optical conductivity spectra could be explained by mirror subsurface layer disordering after such ion bombardment.

Conclusions

Ellipsometric studies of W single crystal (110) and (111) specular surface irradiated by nonmonoenergetic ion beams with E=0.1–1.77 keV and with different thicknesses of the removed layer showed high stability of the mirror optical properties. Spectral ellipsometric studies of the single crystals W (110) and (111) points to subsurface layer disordering while the surface roughness was almost unchanged after the long term deuterium ion treatment.

References

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СПЕКТРОЕЛІПСОМЕТРИЧНІ ДОСЛІДЖЕННЯ ОПРОМІНЕНИХ ІОНАМИ D^+ МОНОКРИСТАЛІВ W (110) І (111)

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Метою даної роботи було дослідження зміни оптичних властивостей монокристалів вольфраму після опромінення високою дозою іонів дейтерієвої плазми. Поверхні було опромінено високою дозою іонів дейтерієвої плазми з енергією в діапазоні E=0.1–1.77 кеВ з усуненням шару товщиною 5.5 мкм для поверхні (110) та 6.4 і 7.0 мкм для поверхні (111). Зміна оптичних властивостей опромінених дзеркал вивчалася спектральним еліпсометричним методом з енергією зондуючих фотонів у діапазоні 0.5–5 еВ. Зміни мікрорельєфу поверхні досліджувались методом атомної силової мікроскопії. Кореляція оптичних характеристик монокристалів вольфраму дозволяє твердити, що збільшення товщини розпиленого іонами дейтерію шару викликає не тільки більш помітне зменшення величин оптичної провідності в ультрафіолетовій області, ніж в інфрачервоній, а й збільшення ширини характеристичних смуг поглинання поблизу 1, 1.7, 2.2 і 3 еВ. Оскільки атомна силова мікроскопія не виявила *значних змін у мікрорельєфі поверхні W (111) після опромінення іонами* дейтерію (найбільша нерівність 6 нм), зміни у спектрах оптичної провідності можна пояснити розупорядкуванням дзеркального приповерхневого шару після такого іонного бомбардування.