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Initiation of Polarized State in the Tantalum Oxide Thin Films Grown by Magnetron Sputtering on a Substrate of Monocrystalline Silicon (100) Followed by Argon and Oxygen Ions

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The pictures of the induced state and the surface potential distribution in thin films of tantalum oxide produced by magnetron sputtering onto a substrate of monocrystalline silicon (100) followed by low energy argon and oxygen ions was investigated by atomic force microscopy in spreading resistance and scanning Kelvin probe microscopy mode. It was shown that it is possible to polarize or depolarize the coating, and then to visualize the state of the induced polarization using an electric field applied via the conductive cantilever in contact spreading resistance microscopy mode. It was found that treatment with argon ions increases the contrast of the of the surface potential distribution maps from 1.2 V to 2,3 V for negative – 10 V voltage on the probe and from 9,6 V to 19,2 V for a positive + 10 V voltage in comparison with the oxygen ions.

Keywords: Thin films of tantalum oxide, Magnetron sputtering, Kelvin probe microscopy, Polarization and depolarization.

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1. INTRODUCTION

Interest in use of dielectric and electret materials and coatings in various branches of science and technology has grown considerably in recent years.

Electret state was found for all-important classes of biopolymers in the membranes, bone, enzymes and other body tissues. The kinetics of cell growth is significantly determined by morphology and distribution of the electric potential on the surface of the coating. An important issue is to control the process of adhesion and proliferation of cells on the surface of the dielectric coatings in the electret condition. Ability to change the electrical properties of coatings by modifying of the surface should allow to control the growth and proliferation of cells. This work is devoted to study the effect of treatment with low-energy argon and oxygen ions on the distribution of the surface potential after polarization and depolarization of thin Ta_2O_5 dielectric coatings.

2. EXPERIMENTAL PROCEDURE

Ta_2O_5 films were prepared on the surface of polished silicon wafers by reactive magnetron sputtering of Ta target in a residual oxygen medium. The substrates were ultrasonically cleaned in acetone, 96 % ethanol, distilled water, and subsequently dried in a drying oven.

Tantalum coatings were deposited in a high vacuum pumping system with a base pressure of about 10^{-2} Pa by ion source-assisted magnetron sputtering. A pure Ta target was used. The distance to substrate was about 30 cm. Power to the sputtered cathode was applied using 10 kW DC power supply operated either in current or voltage regulation mode. The magnetron system was equipped by a coil of the magnetic field, permanent magnet, RF generator and inductive coil. Argon was used as the sputtering gas. Oxygen for the reactive deposition was delivered through the ICP plasma source. Flows for both argon and oxygen were regulated using mass flow controllers operated by two-channel process control unit. The magnetron discharge power was between 1 and 4 kW, the power of the activated oxygen source was up to 1 kW, and the coating deposition rate was 8 μm/hour. The sputtering process was performed in the regimes far from the target poisoning areas to obtain ceramic coatings with highly stoichiometric composition. In addition, such deposition conditions allow avoiding micro-arcing and micro-drop formation. Modification of the coating surface was carried out in a vacuum chamber by treatment with low-energy argon and oxygen ions using ion source.

The polarization of the tantalum oxide coating was performed in a spreading resistance microscopy mode using NTEGRA AURA scanning probe microscope (NT-MDT, Russia). The tension between the surface and the probe was -/+ 10 V.

Studies on the ability of polarization and depolarization was carried out using DCP11 probes (NT-MDT, Russia) with diamond-like nitrogen-containing conductive coating with curvature radius of 35 nm. Visualization of the distribution of the surface potential was carried out using a scanning Kelvin probe microscopy.

To study the ability of depolarization first the 5×5 μm^2 of area of tantalum oxide film was polarized in spreading resistance microscopy mode by applying of positive voltage of +/– 10 V to the probe at a speed of 2.8 m/s. Then, the fragment of $2{,}5 \times 2{,}5$ μm^2 of area placed in the center of the polarized area was depolarized by negatively-voltage –/+ 10 V with a rate of 1.4 m/s.

3. RESULTS AND DISCUSSION

The samples of Ta_2O_5 coating were obtained on a single crystal silicon polished substrates. The coatings are smooth with a roughness of about 20 nm X-ray amorphous films with thickness of about 1.5 μm, consisting of globules with a diameter of about 15 nm (Fig. 1a-f).

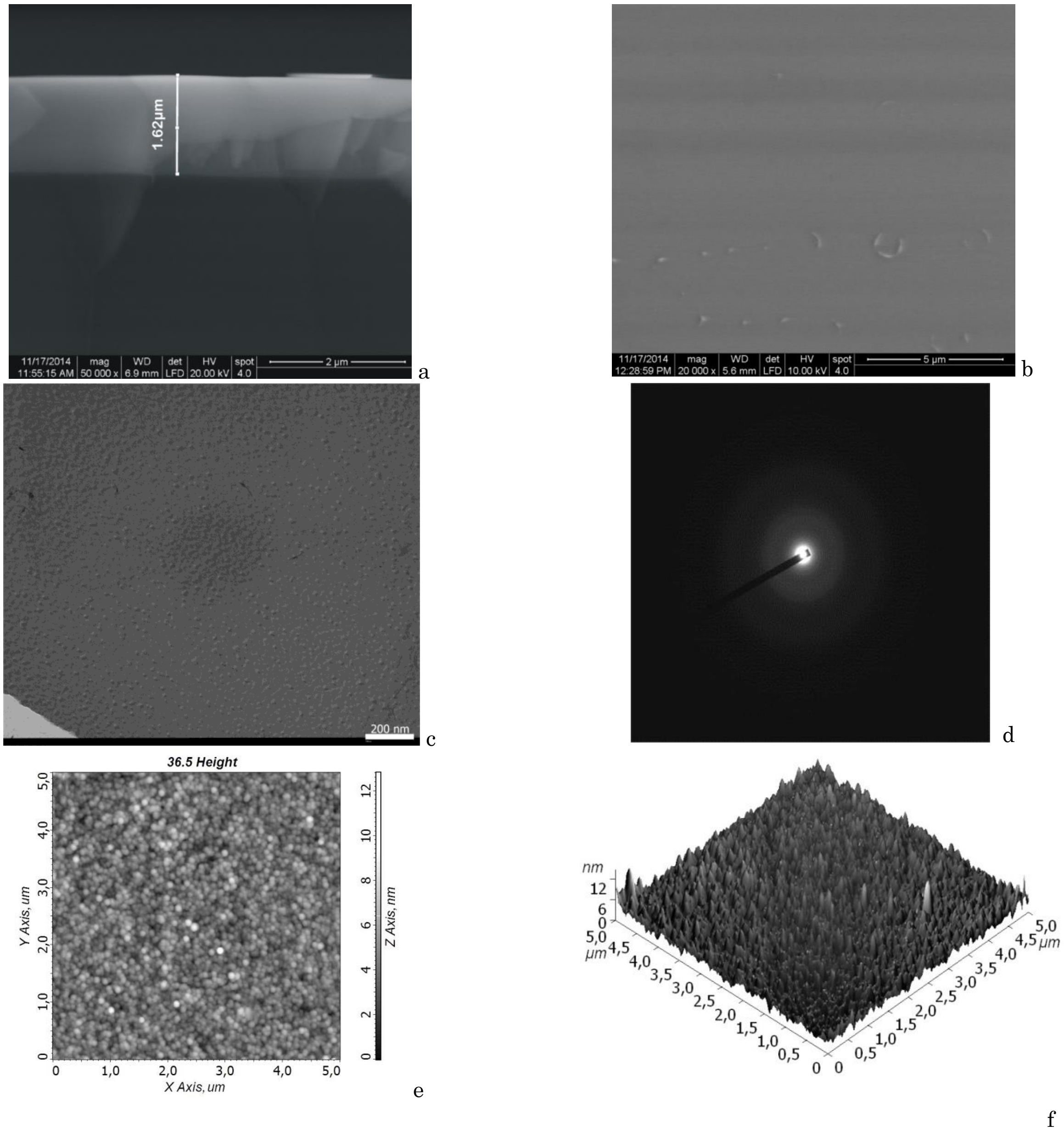

Fig. 1 – SEM cross section (a) and planar view (b) images of the Ta_2O_5 coatings; planar view TEM image (c) and electron diffraction pattern image (d) of the Ta_2O_5 coatings; AFM 2-D (e) and 3-D (f) images of the Ta_2O_5 coatings surface

Investigation of the coatings by TEM, SEM and AFM methods showed that treatment of the coating by argon and oxygen ion beams does not alter the structure and morphology of the surface.

Results of the study of the polarization response of the tantalum oxide coating processed by low-energy argon and oxygen ions to the probe impact having electrical potential of both signs with respect to the coatings surface, are presented in Fig. 2, 3.

A polarized area has sharp boundaries and is quite stable over time.

Results of studies of depolarization of tantalum oxide coatings treated with low-energy argon and oxygen ions shown in Fig. 4, 5. It can be concluded from analyzing of the maps and distribution profiles of the surface potential that the depolarization was successful and evenly. Depending on the applied voltage between the probe and the surface coating it can be created as the two regions with opposite polarization vectors in them, as the region in which the polarization vector has the same direction, but changing in magnitude. Thus, it was found that the coating of tantalum oxide has a high capacity for depolarization.

4. CONCLUSIONS

It was found as a result of experiments on the polarization and depolarization that acting on Ta_2O_5 coatings by ion treatment we can create potential relief of desired shape and size. It has been found that different types of coatings surface modification (treatment with argon ions and oxygen) lead to changes in the response of the effect of the electrostatic field. This allows influencing on the charge states on the coating surface in a wide range, which in turn should allow effective control of cell adhesive properties and of the processes of cell proliferation on the surface of the dielectric coatings.

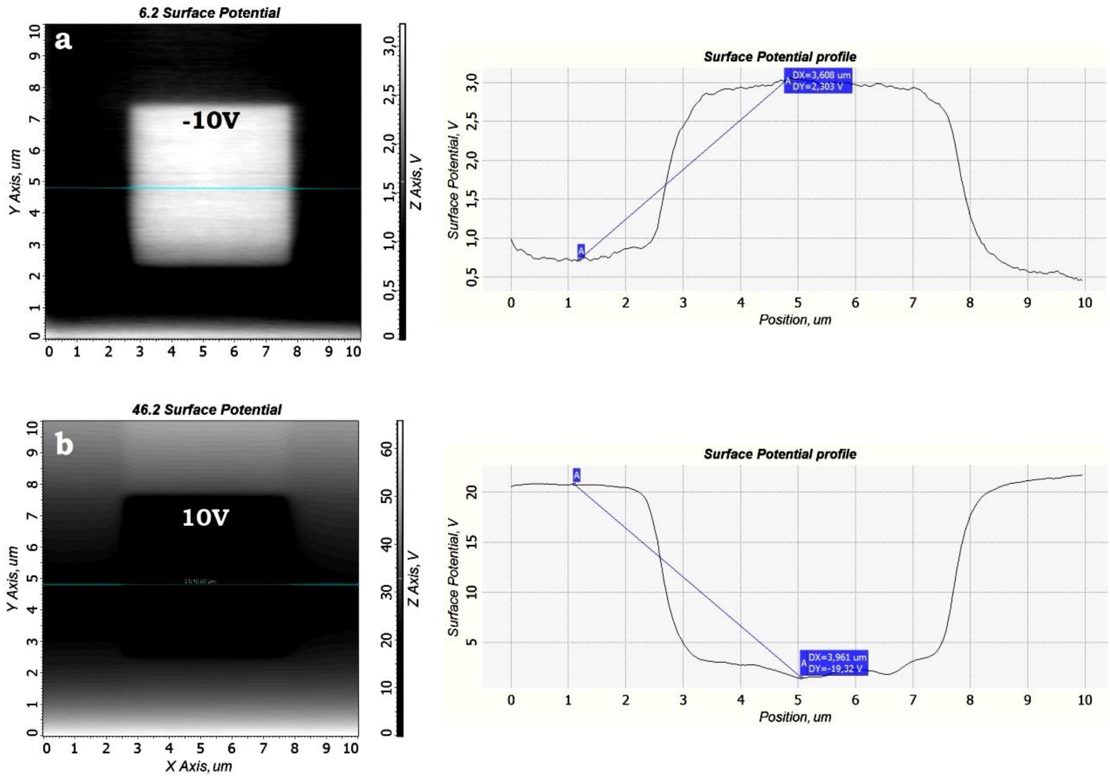

Fig. 2 – Distribution map and surface potential profile of the Ta_2O_5 coating treated with argon ions after the polarization by negative voltage of – 10 V (a) and by positive voltage of + 10 V (b)

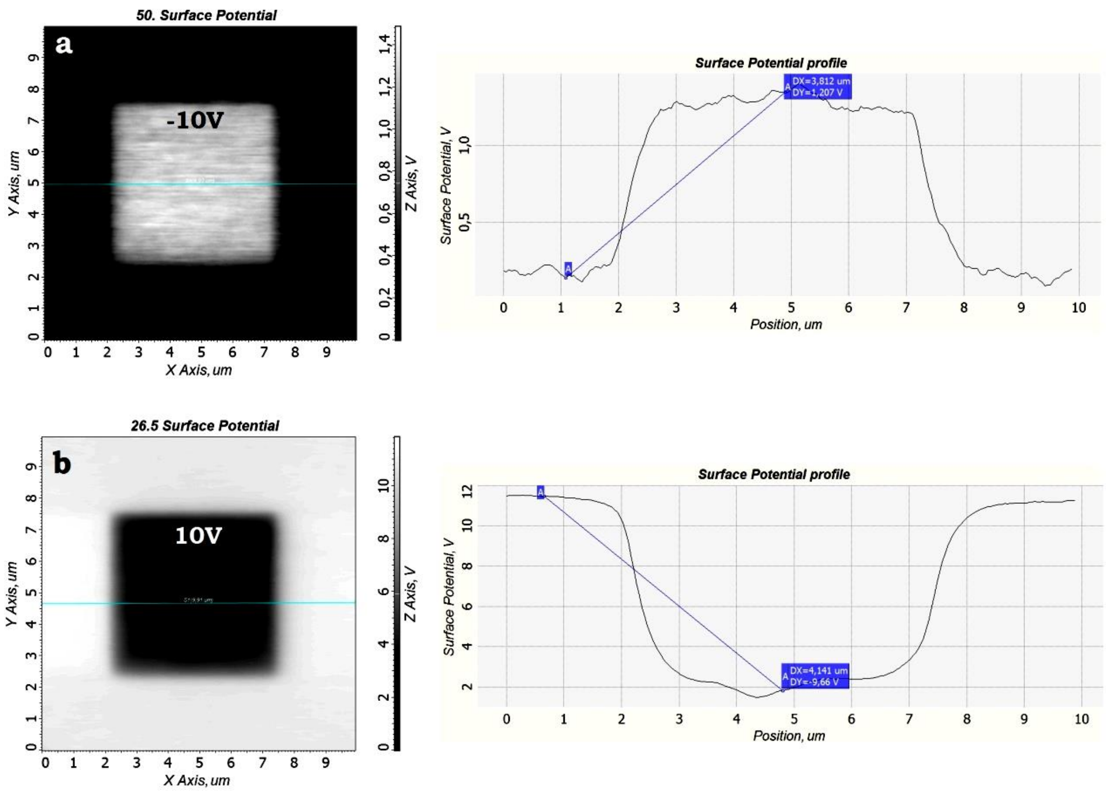

Fig. 3 – Distribution map and surface potential profile of the Ta_2O_5 coating treated with oxygen ions after the polarization by negative voltage of – 10 V (a) and by positive voltage of + 10 V (b)

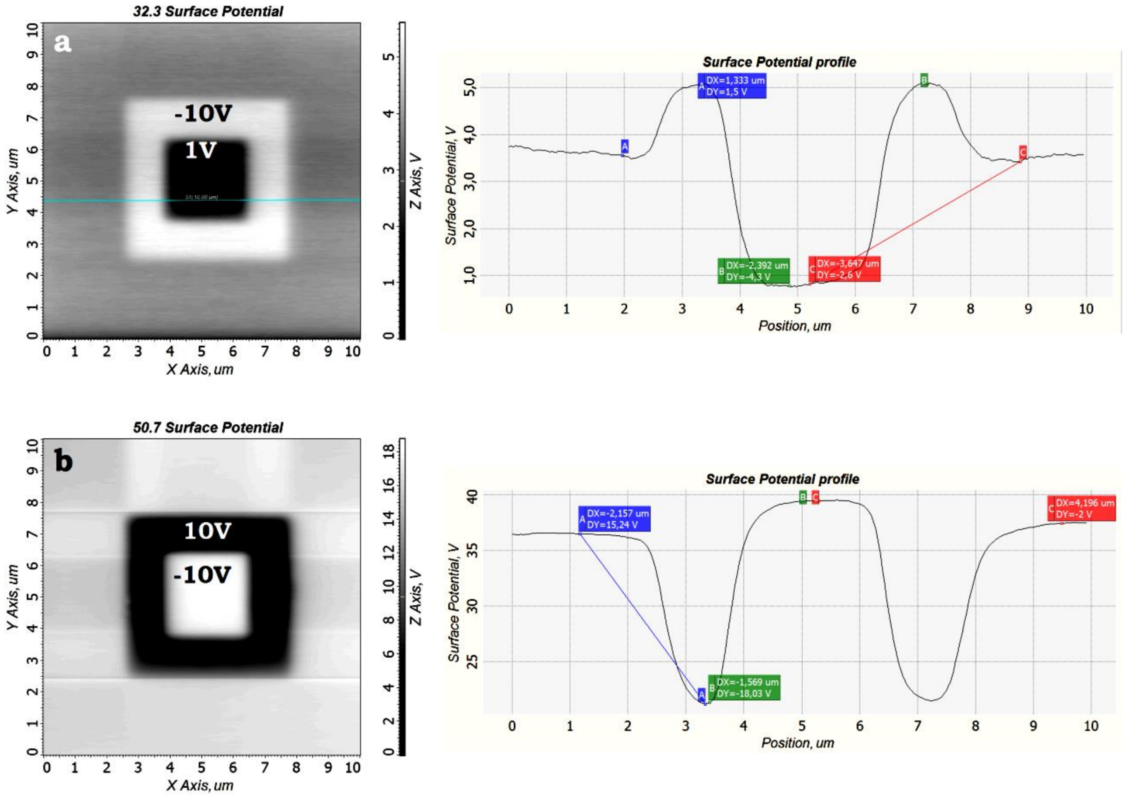

Fig. 4 – Distribution map and the surface potential profile of the Ta_2O_5 coating treated with argon ions after depolarization

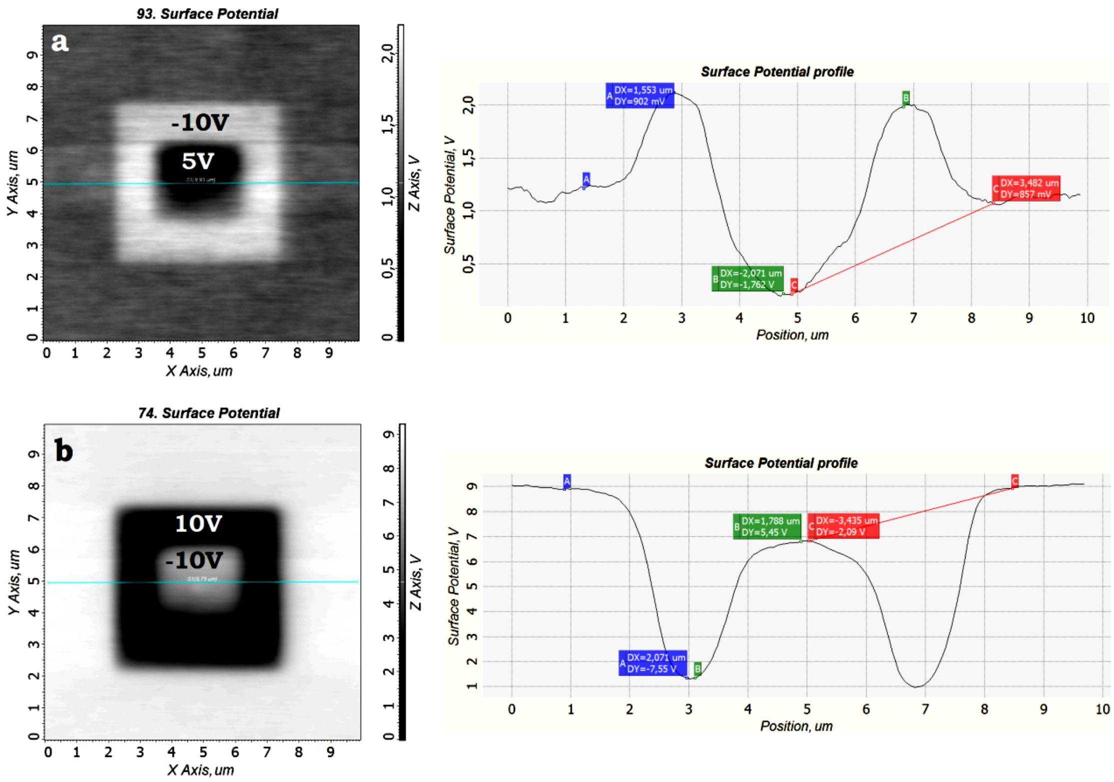

Fig. 5 – Distribution map and the surface potential profile of the Ta_2O_5 coating treated with oxygen ions after depolarization

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