

Formation of modified layers on the outer surface of cylindrical samples from E110 alloy under the influence of radial argon ions beam in the mode of multilayered films ion mixing

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Abstract. Results of experiments of modified layers formation on the long-length cladding tubes from E110 alloy (Zr – 1 % Nb) are presented in this paper. Samples were modified by surface polishing by radial Ar⁺ beam with wide-range energy spectrum, series of films from alloying elements deposition and their subsequent processing in the ion mixing mode. The concentration of implanted atoms is 1–5 at. %, with a maximum penetration depth of 1–2 µm.

1. Introduction

Modification of materials by charged particles fluxes has a positive effect on the operational properties of the material at various scales – from nanomaterials and elements of microelectronics to the constituent parts of engineering machinery. One of the promising areas for the use of ion plasma technologies may be modification of materials for the core of nuclear reactors to improve the corrosion and wear resistance of fuel claddings [1, 2]. In this case, it is important to carry out local and multicomponent doping of the material.

2. Materials and methods

This paper presents the results of experiments performed on the ILUR-03 installation, which is a system for complex ion plasma treatment of long-range cylindrical samples. Feeding and moving of the samples takes place by means of an automatic manipulator through the gateway chamber (position 1 on figure 1) with a differential pumping system, behind which there is a preliminary chamber with an outlet to a high-vacuum pump, a chamber with an ion source and a camera with a magnetron system for depositing films (positions 2–4 on figure 1, respectively).

The ion source provides the formation of a radial beam with a wide energy spectrum of 0.5–5 keV and is a cylindrical set anode placed in a magnetic field created by a system of inductors and top magnetic cores. Argon was used as a working gas 10^{-2} – 10^0 Pa pressure in the chamber and 10^{-4} Pa residual gas pressure.

Cladding tubes from E110 (Zr – 1 % Nb) alloy with outer diameter of 9.15 mm and a length of up to 500 mm were used as the samples. Modification of the near-surface layer of the sample material by an ion beam was carried out in the modes of surface cleaning and polishing before the films deposition and



in formed "substrate-multilayer film" system ion mixing mode for local doping of Fe, Mo, Y, Cr, Ni, Al, Mg [3]. The total irradiation dose was $(1-10) \cdot 10^{18} \text{ ion} \cdot \text{cm}^{-2}$.

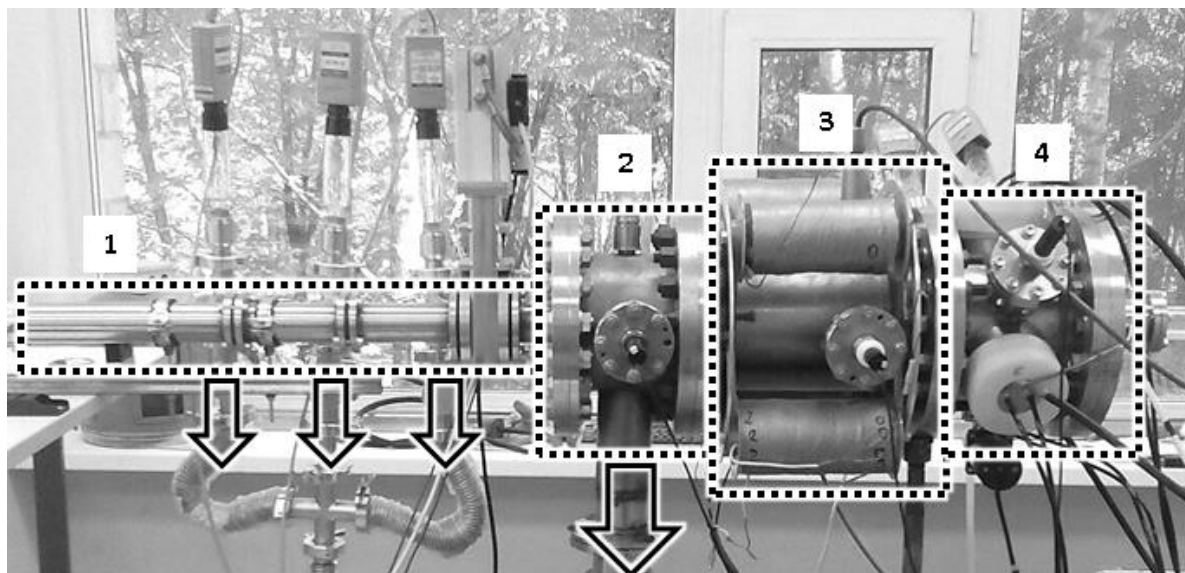


Figure 1. Installation ILUR-03: 1 – gateway vacuum chamber; 2 – preliminary evacuation chamber; 3 – zone radial ion beam action; 4 – zone of films deposition. The arrows show the pipelines of the vacuum system.

3. Results and discussion

As can be seen from figure 2, the ion-modified surface reveals a higher topography homogeneity, especially in the micrometer and submicrometer scale. Large technological scratches are smoothed, the boundaries of crystallographically differentially oriented crystallites are not observed.

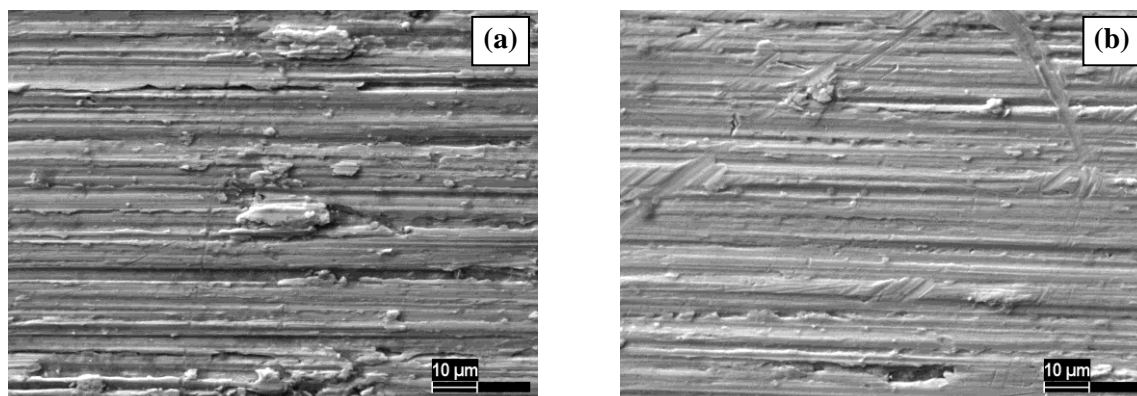


Figure 2. Images of the outer surface of the samples in initial state (a) and after ion polishing (b) obtained by the SEM method with $\times 1000$ magnification.

Deposited film from various alloying elements atoms repeats the topography of the initial surface and has a finely dispersed structure with characteristic size of $\sim 100 \text{ nm}$ (figure 3). After "substrate-multilayer film" system mixing by ion beam, surface has a structure similar to that before the alloying elements films deposition, which can be seen in figure 4.

Depending on the film thicknesses and their relative arrangement ratio, the distribution of the elements near the modified surface may have domed or sloping shape with a characteristic drop to the equilibrium concentrations value (figure 5). The maximum concentration of the implanted elements is $\sim 1-5 \text{ at. \%}$, which exceed their equilibrium solubility limit in the alloy.

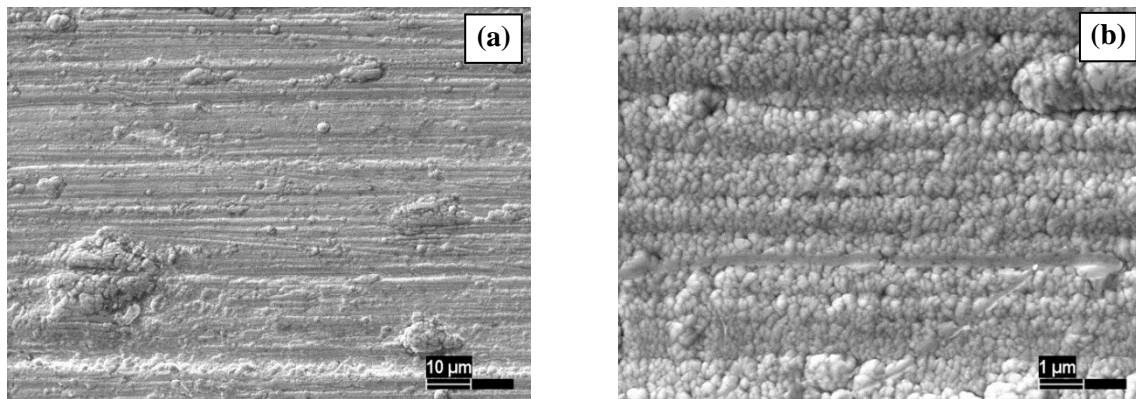


Figure 3. Images of the sample with a deposited film from FeCrNi atoms outer surface with $\times 1000$ (a) and $\times 10\,000$ (b) magnification, obtained by SEM.

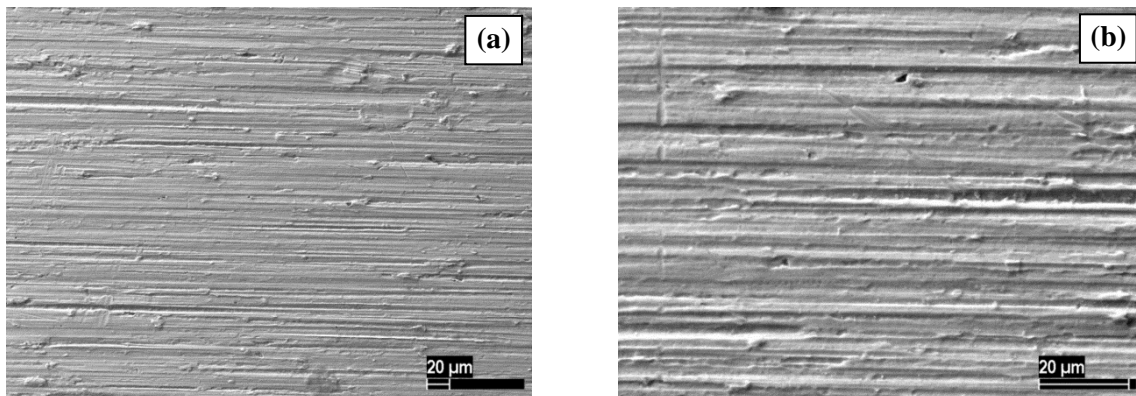


Figure 4. Images of the alloying by FeCrNi atoms sample outer surface with $\times 250$ (a) and $\times 1000$ (b) magnification, obtained by SEM.

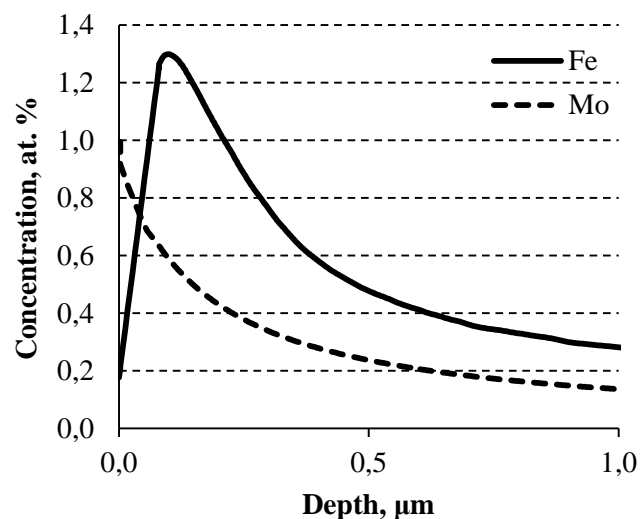


Figure 5. Distribution of elements in the near-surface layer of material doped as a result of Fe and Mo films ion mixing by Ar^+ .

5. Conclusions

Modified layers with a content of alloying elements of Fe, Mo, Y, Cr, Ni, Al, Mg up to 1–5 at. % and maximum penetration depth up to 1–2 μm were obtained near the surface of cylindrical samples from sponge based E110 alloy under the action of radial beam of Ar^+ ions as a result of polishing and ion mixing of multilayer films.

References

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