Effect of ion irradiation on tribological properties of composite coatings

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Abstract. The paper discusses the results of the research in the effect of ion irradiation on tribological properties of multiphase ion-plasma coatings. It is shown that all the investigated coatings behave differently under ion irradiation: the Zn-Al, Fe-Al, Zn-Cu-Al coating is radiation-resistant and the friction coefficient does not virtually change; the Cr-Mn-Si-Cu-Fe-Al coating exhibits twofold increase in the friction coefficient, and that for Mn-Fe-Cu-Al coating decreases threefold. These changes are related to changes which occur in the coating surface under ion bombardment.

1. Introduction

Ion irradiation, considered as an unwanted phenomenon in airspace and reactor engineering, now has become one of the techniques to modify the material surfaces, including nanomaterials, to provide them with desired properties [1-8].

Ion bombardment of a solid surface implies several aspects. First, exposure of surfaces of different materials to metal ions makes the basis of the ion-implantation technique [9, 10]. The ion energy of tens or hundreds of keV allows the penetration depth of up to 1μm. Ion-implantation results in the formation of the near-surface alloy layer with different chemistry which, in its turn, changes its physical-and-mechanical properties. There is no distinct interface common to deposited layers. Ion-implantation is an active and non-equilibrium process and it allows creation of materials with structure and composition which cannot be obtained with conventional metallurgical techniques. Ion-implantation technique enables to dope any element of a desired quantity.

The second aspect of ion bombardment is related to nanostructuring of deposition directly in the production process [11, 12].

The third aspect of ion bombardment considers the effect of ions of different gases on the material surface when it has already been formed [13]. This is of current relevancy for spacecrafts in the Earth ionosphere [14].

The main effect of ion bombardment on the coating properties can be observed at the stage of their formation due to the stress relaxation in the region of ion action and restructuring of the crystal structure. Point defects, which are active adsorption centers, are formed on the surface.

The number of point defects can be increased either by increasing the ion flow energy, or by an increase in the ion beam density. Simultaneously with the formation of defects, the reverse process of their recombination, "annealing", occurs. It decreases the defect concentration. As a result of these two processes, the amount of nucleation sites becomes equilibrium which can be affected through changing the parameters of ion irradiation.

2. Experimental

In the experiments, we used the composite cathodes prepared by induction melting. These cathodes were used to perform deposition on the steel substrate with ion-plasma installation HHB-6.6I1 under different process conditions. Atomic force microscope NT-206 was used to conduct a nanoscale examination of the coating surface.

Irradiation of the coating with argon ions was carried out by means of the multi-ampere ion source with a hollow cathode. The arc current was 1 A, and the potential of the substrate was maintained equal to 300 V.

The information-measuring system for tribological studies is described by us in [15]. It consists of two main components: the experimental setup and upper level software.

To apply the nanocoating the following basic process approaches are used: 1) ion-assisted deposition; 2) multilayer deposition with layers of nanometer thickness; 3) multiphase deposition; 4) a combination of these methods. We used ion-assisted multi-phase deposition.

3. Results and discussion

Figure 1a shows an electron microscopical image of the coating performed by simultaneous sputtering of the Cr-Mn-Si-Cu-Fe-Al cathode and a titanium cathode in nitrogen atmosphere. Figure 1b presents the same coating after argon ion irradiation.

It can be seen from Figure 1a, the average grain size is (100–150) nm. This type of coatings is referred to as submicrocrystalline coating [16]. The results of the quantitative analysis of the Cr-Mn-Si-Cu-Fe-Al + Ti coating in a nitrogen atmosphere in different parts of the surface showed that the contents of chromium, titanium and nitrogen are close to each other. This suggests that in addition to titanium nitride formation, chromium nitride is formed as well. Figure 1a also shows that the microcrystallites of titanium nitride and chromium have a preferred orientation (presumably in direction (200)), which is different from the spherical symmetry of the pure titanium microcrystallites.

a b

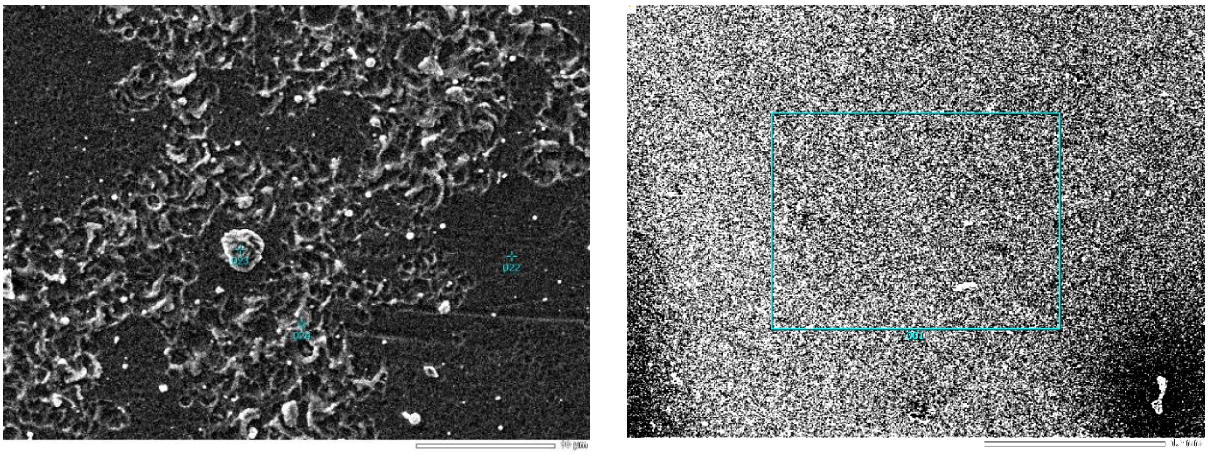

Figure 1. Electron microscopical image of the Cr-Mn-Si-Cu-Fe-Al + Ti coating in nitrogen atmosphere (a); and after ion bombardment (b).

Irradiation of the Cr-Mn-Si-Cu-Fe-Al + Ti coating with argon ions causes grinding of the grain structure (Fig. 1b), so that the grain size becomes less than 100 nm. This type of structures is called nanocrystalline structures [16].

Ion bombardment of the Fe-Al + Ti and Zn-Al + Ti surfaces does not result in grain grinding as that observed for the Cr-Mn-Si-Cu-Fe-Al + Ti coating. This is due to the weak effect of ion irradiation on the Fe-Al and Zn-Al coatings [17].

We attribute the radiation resistance of the Zn-Al coating to its pronounced globular structure. The presence of the "ball" system leads to elastic scattering of argon ions, so that the local deformation becomes negligible. This is confirmed by the behavior of the Young's modulus, which remains unchanged during irradiation. The radiation resistance of the Fe-Al coating disorder is associated with its amorphism. Strong "amorphization" of the coating makes it radiation insensitive.

The above properties of the structure of multiphase coatings are also reflected in their tribological properties. Table 1 shows the friction coefficients before and after ion bombardment.

Table 1. Friction coefficients for coatings after ion irradiation.

Coating	Friction coefficient	
	Before irradiation	After irradiation
Zn–Al+Ti	0.349	0.344
Fe–Al+Ti	0.374	0.367
Zn–Cu–Al+Ti	0.243	0.241
Cr–Mn–Si–Cu–Fe–Al+Ti	0.711	1.422
Mn–Fe–Cu–Al+Ti	0.367	0.122

As can be seen from Table 1, all the investigated coatings behave differently under ion irradiation: Zn-Al, Fe-Al and Zn-Cu-Al coatings are radiation-resistant and the friction coefficient virtually does not change; the friction coefficient for Cr-Mn-Si-Cu-Fe-Al coatings increases twofold, and that for Mn-Fe-Cu-Al coatings decreases threefold. These changes are caused by the changes which occur in the coating surface under ion bombardment.

4. Conclusion

The results obtained make it possible to draw the conclusions.

- Ion bombardment is a promising technique to regulate the structure and properties of coatings and can be used to create a variety of combined methods for deposition.
- The tribological properties of coatings, closely related to their microstructure, can be considerably changed under ion irradiation.

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References:

[1] Rybin V V, Zhivushkin A A, Berezhko A I et al. 2001 *Voprosy materialovedenia* **2** 166.

[2] Ivanov L I, Platov Yu M 2004 *Radiation physics of metals and its applications* (Cambridge International Science Publishing) p 356.

[3] Andrievskii R A Effect of irradiation on the properties of nanomaterials 2010 *Physics of Metals and Metallography* **110** 229.

[4] Ghyngazov S A, Vasil’ev I P, Surzhikov A P, Frangulyan T S, Chernyavskii A V 2015 Ion processing of zirconium ceramics by high-power pulsed beams *Technical Physics* **60** 128.

[5] Stepanova O M, Krivobokov V P 2010 Erosion of solid surface under irradiation by high-power submicrosecond ion beams *Bulletin of the Russian Academy of Sciences: Physics* **74** 122.

[6] Berlin E V, Koval N N, Sheydman L A 2012 *Plasma chemical-thermal surface treatment of steel products* (Moscow: Technosphere) p 640.
[7] Rogozhkin S V, Aleev A A, Zaluzhnyi A G, Kuibida R P, Kulevoi T V, Nikitin A A, Orlov N N, Chalykh B B, Shishmarev V B 2012 Effect of irradiation by heavy ions on the nanostructure of perspective materials for nuclear power plants *Physics of Metals and Metallography* **113** 200.
[8] Uglov V V, Remnev G E, Kvasov N T, Safronov I V 2014 Dynamic processes in metal nanoparticles under irradiation *Journal of Surface Investigation* **8** 703.
[9] Russell Ch, Ruge I 1983 *Ion implantation* (Moscow: Science) p 360.
[10] Pogrebnyak A D, Remnev G E, Chistyakov A S, Ligachev A E 1987 Modification of the properties of metals by high-power ion beams *Soviet Physics Journal* **30** 39.
[11] Panin V E, Sergeev V P, Panin A V 2008 *Nanostructuring of the surface layers of structural materials and nanostructured coatings* (Tomsk: Tomsk Polytechnic University Publishing) p 285.
[12] Lyakhov N Z, Psakhie S G 2008 *Surface nanoengineering. Formation of non-equilibrium states in the surface layers of materials by electron-ion-plasma technologies* (Novosibirsk: Publishing House of SB RAS) p 275.
[13] Yurov V M, Vertyagina E N, Guchenko S A 2011 *Sovremennye naukoemkie technologii* **5** 63.
[14] Nadiradze A B, Korsun A G, Kurshakov M U et al. 2011 *Electronic J. Trudy MAI* (Moscow: Moscow Aviation Institute) **43** 11.
[15] Kolesnikov V A, Baysagov Ya Zh, Yurov V M 2011 *Fundamentalnye issledovaniya* **12** 121.
[16] Reshetnyak E N, Strel'nitskij V E 2008 Synthesis of hardening nanostructural coatings *Problems of Atomic Science and Technology* **2** 119.
[17] Yurov V M, Laurynas V C, Guchenko S A, Zavatskaya O N 2013 Structure and properties of multiphase ion-plasma coatings (Karaganda: Publishing House of the Kazakh-Russian University Press) p 150.