Thin-film bioinert vacuum ion-plasma coatings for medical implants

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Abstract. The article discusses bioinert coatings used to protect the surface of implants from aggressive effects. Studies on adhesive strength, corrosion and wear resistance are presented, showing that the nanostructured coating obtained by the developed technology has enhanced performance properties. The studies were conducted using modern techniques for assessing the properties of coated materials. The main stages of the technology of vacuum ion-plasma deposition of coatings are described.

In modern traumatology, bone injuries are treated with implants made of materials such as titanium and its alloys, special alloy steels and alloys based on alloy steels. All of them are approved for use as modern materials for traumatology. They have the ability to withstand significant mechanical stress. Unfortunately, these materials are negatively affected by the biological fluid, causing corrosion damage. Corrosion products fall into nearby biomaterial, contributing to the emergence of metallosis. This leads to the formation of a fibrous capsule around the implanted material, and also causes loosening of the implant, inflammation of the tissues. The result of this process can be various complications that reduce the effectiveness of treatment. And although in general, implants used in modern medicine have high mechanical compatibility with biological tissue, although they have insufficient satisfactory biocompatibility.

The problem of increasing the biological compatibility of implants used in traumatology, orthopedics, and reconstructive surgery remains relevant. In Western countries, for example, the USA, Japan, Germany, as well as other developed countries, the problem is usually solved in two directions. The first is the creation of new structural biomaterials. At the first stage, the need arises to study the physicomechanical properties of the introduced material, to determine how wear products affect the body, whether the implant is destroyed, to determine the patterns of exposure to chemicals that make up the human body on the implant material, as well as other external factors, to perform a number of other physical, chemical, biological studies. That is, the direction associated with the development of new medical materials requires significant material, financial and time costs. The second area of research is surface modification of materials in order to increase their biological compatibility and activity, which can be achieved by the synthesis of various kinds of coatings. The use of high-energy ion fluxes during the formation of such surface layers allows one to control the composition, microgeometry, structure, and physicochemical properties.

The described direction is undoubtedly more relevant, because it involves the use of steels and alloys that have repeatedly confirmed characteristics, such as strength, durability, biocompatibility and...
others. As a result, studies are carried out only to determine the physico-chemical-mechanical properties, tribological and biomedical properties of the modified surface.

An effective way of forming on various parts made of metals and alloys of bioinert nanostructured vacuum-plasma coatings, which are characterized by high mechanical properties. In addition, biomedical factors, such as implant survival conditions, must be considered.

The following requirements are set for biocompatible materials [1]:

- the use of such materials does not cause an inflammatory reaction at the site of contact;
- lack of toxic and allergic effects on the human body;
- possession of a non-carcinogenic effect;
- the possibility of developing an infection is excluded;
- preservation of functional properties the entire term of operation.

The product made of the presented materials before the synthesis of the nanostructured Ti-TiN protective coating is subjected to a whole range of measures: the first stage of surface preparation is mechanical cleaning, during which the part is polished to the required roughness, then the product is cleaned by ultrasonic treatment and subjected to chemical cleaning. The cleaned product is loaded into a vacuum chamber, air is pumped out, and at a certain pressure, discharge treatment is carried out by the PINK plasma generator. By acting on the surface of the workpiece with a non-independent high-current diffusion discharge, it can be practically cleaned at the molecular level. Then, before applying the coating, cathode ions are heated [2].

The obtained nanostructured coating, which has high adhesive strength, good wear and corrosion resistance, increased strength and hardness, was synthesized in an arc discharge plasma using a modernized NNV 6.6 – 11 installation (figure 1).

**Figure 1.** Scheme of the upgraded vacuum ion-plasma installation: 1 – vacuum chamber; 2 – a cooling anode; 3 – cathode made of deposited material; 4 – substrate; 5 – power supply EDU; 6 – bias voltage power supply; 7 – a table with appliances; 8 – solenoid.

The synthesized coating is a composite h = 5-7 microns. The synthesis process is carried out in high vacuum. This eliminates almost completely foreign impurities. To form a transition layer, at the first stage of the deposition process, the application of technically pure titanium is underway. The formed layer is designed to coordinate the thermomechanical properties of the main nanostructured layer of the multilayer coating and the workpiece. He, in addition, participates in the formation of the microstructure, and also protects the substrate from certain types of corrosion.

The proposed technology allows to guarantee the receipt of high-quality protective coatings. When it is used, a nanostructured coating on the implants is synthesized, forming layers on their surface with a certain morphology, satisfactory adhesive properties, maximally approximating the implant material in terms of functional properties to bioinert materials with enhanced properties [3].
One of the most important parameters of biocoatings is the adhesive strength of coatings to the metal surface of the implant. The longevity of the implant and the effectiveness of the treatment as a whole depend on it. The adhesion of multilayer Ti-NiN coatings deposited on a titanium alloy was measured by sclerometry (scratch test) [3]. The study of the imprint of the diamond pyramid with magnification using an optical microscope showed the absence of cracking of the coating material near the exposure zone, which indirectly indicates a high adhesion of the coating. In figure 2 shows a photograph of the beginning of the destruction of the Ti-TiN coating with an increase in the load on the indenter during scratching.

![Assessment of the adhesive strength of the nanostructured coating Ti-TiN on the sample by scratching.](image)

An analysis of the results of a study of the corrosion resistance of parts with various types of coatings showed that the corrosion rate of a nanostructured coating is 15% lower than that of samples with a multilayer coating, 25% lower than that of a sample with a single layer coating, and 30% lower than that of a sample without coating. Thus, we can conclude that the sample with a nanostructured Ti-TiN coating is the most corrosion-resistant in comparison with the studied ones.

Studies have been conducted on the type of deposited coating for wear resistance. The wear resistance of the coatings is evaluated on friction machines (international standards DIN and ASTM). During the study, the friction coefficient is continuously recorded according to the “ball-rotating disk” scheme. In addition, it is possible to conduct a fractological study of the coating wear track and the ball wear pad. The friction coefficient and the wear rate of the coating and counterbody were measured on an automated friction machine (Tribometer, CSM Instruments, Switzerland), controlled by a computer using a standard ball-disk test scheme.

Comparison of the results of tribological testing of samples (figures 3, 4) without coating and nanostructured coating are given in the table 1.

**Table 1. The results of tribological testing of samples without coating and nanostructured coating.**

| Name               | Coefficient of friction, $\mu$ | Statistical partner wear rate, $g \cdot 10^3$ | Sample Wear Rate, $g \cdot 10^3$ |
|--------------------|-------------------------------|---------------------------------------------|----------------------------------|
|                    | precursory when tested         |                                             |                                  |
| Without coating    | 0.142                         | 0.489                                       | 0.224                            | 0.038                            |
| Nanostructured coating | 0.106                      | 0.576                                       | 0.105                            | 0.015                            |

Studies have shown that samples with a nanostructured coating have higher wear resistance than samples without a coating and have a significant effect on the redistribution of heat flow in the contact zone.
Figure 3. The results of tribological testing of the sample without coating.

Figure 4. The results of tribological testing of the sample with nanostructured Ti-TiN coating.

References
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