Designing of equipment for the synthesis of coatings from nitrides and carbides of intermetallic Ti-Al systems by condensation of plasma flows generated with vacuum arc

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Abstract. The quality characteristics of Ti-TiN multilayer vacuum ion-plasma coatings are studied, among which are as follows: roughness and adhesive strength. It is shown that additional ion bombardment contributes to obtaining high-quality coatings. Ion bombardment has a significant impact on the state of metal surface layer. In the process of ion bombardment, the conditions for formation of active adsorption centers as well as formation of a fine-grained structure, nanoscale grains and layers are created.

1. Introduction

The development of new materials for coatings with high physicochemical properties along with the technologies for their production is one of the promising prerequisites for industry growth [1, 2]. One of these coatings is composite multicomponent materials based on Ti-Al intermetallic compounds that have unique properties. Coatings represent a unique class of materials that retain an ordered structure up to the melting point.

There are various methods for producing coatings in a vacuum on the working surfaces of workpieces and products. Taking into account specific processes of coating formation, they can be divided into two main groups. The first group includes methods in which the coating is first deposited onto a surface, and the final state is formed mainly due to the diffusion between the coating and the structures of a substrate material. The second group includes coating formation methods due to certain chemical and plasma-chemical reactions of particle fluxes on the surface of workpieces.

Ti-Al intermetallic coatings can be obtained through the high-intensity implantation of aluminum ions into a pure titanium metal, electric-spark alloying or electric arc spraying, layer-by-layer coating [3–5]. A breakthrough method is to obtain Al-Ti intermetallic compounds as well as their nitrides and carbides directly on the surface of a workpiece by means of vacuum arc plasma condensation [6].

A study of the characteristics of plasma, ionic and electronic technologies shows that each of the methods is implemented on the specialized equipment and provides a fairly limited range of surface properties of workpieces. To ensure the whole range of service properties of a workpiece under the conditions of high dynamic loads, aggressive media and temperature fluctuations, it is necessary to develop a coating with a required chemical and phase composition and provide the necessary coating thickness and accuracy of a form. Achieving this goal requires a lot of experimental research, various processing modes and the use of cathodes with a different chemical composition, which is time consuming and costly.
The application of the developed technology into production requires modernizing the existing or creating new equipment for its implementation. Systematic analysis of scientific literature and conference proceedings shows that the development and modernization of vacuum setups is carried out under a certain technological process. In this case, individual elements of a setup (vacuum system, vacuum chamber, sources of particles, etc.) need to be calculated and designed [7, 8].

Designing equipment applicable for ion- and plasma-induced treatments is a challenging task, because it involves a large number of impacts, and a combined effect entails an even greater variety of options. A positive design solution can be derived by addressing the following issues:

- Definition of the production for which the equipment is designed (degree of automation, single-chamber or production line);
- Performance rate (the number of incoming workpieces, the efficiency of a vacuum system, output parameters of power sources and those of particles, the degree of automation);
- The dimensions of a vacuum chamber (the dimensions of a workpiece, the number of incoming workpieces, mechanisms and drives);
- Treatment dimensions (the size of a vacuum chamber, output parameters of power sources and those of particles, the number of sources of particles, space particle orientation relative to the surface of workpieces during processing);
- Output parameters of a surface after processing (chemical composition, structure, hardness, roughness, etc.);
- Processing accuracy (uniformity and depth of a chemical and heat treatment zone, uniformity and thickness of coatings);
- Preliminary economic assessment of the designed equipment (technological cost of processing, innovation risk ratio).

Designing a vacuum setup starts with the layout of a vacuum chamber and the sources of particles. Techniques that enable to assemble a vacuum setup as a whole, in view of mass production, productivity, the required number of part sources, their combination and workload, accuracy, processing cost, etc. are imperfect or require refinements.

2. Results and discussion

A model is proposed for elaborating a vacuum chamber design. The structural and information model for the design methodology is shown in figure 1.
The model is composed of the following units:

Feed data unit. In this unit, feed data is accumulated and generated for further design. The following information is put, namely: the dimensions of a workpiece, the number of simultaneously processed workpieces depending on a production program, the chemical and phase composition of a coating, coating thickness and form accuracy.

Unit for selecting the shape and size of a chamber. Subject to the overall dimensions and the number of simultaneously processed workpieces at the first stage, a space and mutual arrangement of the processed workpieces occurs. The shape and size of a vacuum chamber is then determined, taking into account the required space between the workpieces and the walls of the vacuum chamber. There can be several options of this kind.

Unit for selecting the type and number of plasma generators. Based on the dimensions of a workpiece or an ensemble of workpieces, the type of plasma generator is selected in this unit based on the potential processing area. The number of required single-cathode plasma generators is then determined subject to the chemical and phase composition as well as the coating thickness.

Unit for calculating processing modes. In this unit, based on the type of a plasma generator, processing modes are calculated to provide the necessary chemical and phase composition of the coating.

Once the shape and dimensions of the vacuum chamber are determined, the type and number of plasma generators are selected, the processing modes are calculated, the information finds its way to the unit for positioning vaporizers. To deposit multi-metal chemical coatings using single-cathode plasma generators, it is necessary to determine their mutual space arrangement whereby the required phase composition will be ensured. This unit enables, by altering the angle between the axes of the vaporizers, to determine potential zones in the vacuum chamber where the required phase coating will be formed. The current model [9] makes it possible, by virtue of the processing modes, to calculate the parameters and represent the zones of intermetallic phases formed at an arbitrary point of the vacuum chamber, various planes around the cathode axis for spraying coatings with or without rotation. In this case, it is possible to adjust the location of arc vaporizers at different angles relative to each other (figure 2).

![Figure 2](image-url)

**Figure 2.** Alternative arrangements of vacuum chamber for the synthesis of Ti-Al nitride and intermetallic carbide coatings.

Having obtained an approximate arrangement of the vacuum chamber, the information is further transferred to the calculation unit for ensuring shape accuracy and coating thickness uniformity. In the
unit, based on the model [10] of the space and mutual arrangement of workpieces, the type of movement of workpieces in the vacuum chamber, the space arrangement of the vaporizers and processing modes, the shape accuracy and coating thickness uniformity are calculated taking into account the mutual shielding of workpieces.

In the event of an unacceptable report, it is necessary to return to the unit for determining the shape and dimensions of the vacuum chamber.

3. Conclusion
By simulating several layouts and choosing the most appropriate option, one can form a set of requirements to be incorporated into design documentation for a vacuum chamber of a facility to ensure the synthesis of Ti-Al nitride and intermetallic carbide coatings with a desired phase composition.

Thus, resulting from the analysis of coatings deposions and peculiarities of the designed sputtering setups for the synthesis of Ti-Al nitride and intermetallic carbide coatings, the main parameters are identified. The necessary feed data together with interdependent factors are highlighted; the design model for sputtering setups is proposed. Based on the model, it is planned to develop a software product that will simplify the task for engineers when designing facilities and for technologists when selecting processing modes.

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