Technological Peculiarities of Fabrication and Using of Composite Powder Targets for Vacuum-Arc Sputtering[1]

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Abstract – A brief review of known methods of obtaining multicomponent plasma used for deposition of coatings of a complex element and phase structure has been given. The comparative characterisation of different types of multicomponent targets (cathodes) for sputtering, which are applied to deposition-plasma coatings, and methods of their manufacturing are adduced. The special attention is paid to methods, in which powder technologies are used. The main requirements to the composite powder cathodes and problems arising due to usage of heterophase materials for the vacuum-arc and magnetron sputtering are discussed. Advantages of the powder multicomponent cathodes in comparison with cast targets and merits of their application instead of several single-component cathodes are noted. Examples of application of sintered cathodes of the binary Ti-Cu and Ti-Si systems for deposition of coatings by the method of vacuum-arc sputtering are demonstrated.

1. Introduction

The more and more broad usage of the multicomponent plasma is a peculiar feature of experimental works published in the field of ion-plasma coatings for the last 3–5 years. The coatings that are formed on a substrate by deposition of multicomponent plasma containing ions of nitride-forming metals (Ti, Zr, Cr etc.) and some metalloids (Si, B) have nano-crystalline structure. The size of the metallic nitride crystals in a growing coating is restricted by surface films of some other phases having crystalline or amorphous structure. The nano-crystalline structure of the coatings provides a super-high hardness approaching to the hardness of diamond [1–3] and high both heat resistance and resistance to wear. In this connection, the development of methods of obtaining the multicomponent plasma having the stable in time element composition and homogeneous over the volume represents an urgent problem important in scientific and practical relation.

2. Methods of obtaining of multicomponent plasma

At vacuum-arc and magnetron synthesis of ion-plasma coatings of a complex element composition, as a rule, the plasma is obtained by sputtering of several cathodes, each of which has the chemical composition differing from the rest. The necessary element composition of the plasma is reached as a result of complex and laborious selection of individual technological regimes of sputtering each of cathodes.

An additional complication of the equipment design is needed when multicomponent plasma must contain metallic and non-metallic elements (for example, silicon or boron). In this case, combined sputtering systems are applied [4, 5]. They have structurally individual units for sputtering as electrical-conductive (metallic) targets, as well targets from materials having semiconductor or electrical-insulating properties. Therefore, the replacement of several cathodes by a single one containing all the necessary metal and metalloid components in the required ratio is an important milestone in the development of this scientific-technological line.

Such replacement will allow to simplify essentially a design of the technology equipment for deposition of coatings and to upgrade the reliability of its operation, the stability of the sputtering process, the homogeneity of the generated plasma and, in the end, to get a considerable increase in the quality of deposited coatings.

Unfortunately, techniques of the conventional metallurgy including casting, thermal forging or rolling and final processing by cutting are not suitable for the overwhelming majority of alloys, compositions of which represent the greatest concern for usage of nano-structured coatings at vacuum-arc and magnetron synthesis.

The application of so-called mosaic-type cathodes [6] was the first attempt of obtaining the multicomponent plasma by sputtering of a single cathode. Such cathodes are produced by pressing of metal or non-metallic insertions into the cathode of the main (matrix) metal. The application of the mosaic-type cathodes for vacuum-arc sputtering is not reasonable because of considerable difficulties in selection of its optimum regimes, at which the rates of the arc erosion of the base metal and press-fitted insertions would be close to each other. If the melting points of the matrix metal and press-fitted insertions greatly differ (for

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example, titanium and aluminium), to choose the sputtering mode optimal from the viewpoint of the coating quality is practically impossible. At small electric currents, the evaporation rate of the high-melting matrix metal as well as the deposition rate of the coating are too low to be efficient, while an increase of the arc current can cause the surface melting of fusible insertions and a sharp rise in the content of a droplet phase in the deposited coating [7]. Besides, the motion of the arc spot over the target surface can appear nonrandom because of different electromagnetic properties of the matrix and insertion metals. This will cause additional uncontrolled oscillations of the chemical composition of the generated plasma in time. For the guaranteed obtaining of the chemically homogeneous multicomponent plasma by the vacuum-arc sputtering, it is necessary that the size of heterogeneities of an element composition (for example, the size of phase inclusions or structural components of the cathode) would be less than the diameter of the arc spot. In this case, the simplification of the equipment design and making easier of the control over the sputtering process are combined with the homogeneity of the generated plasma and as a result with a high quality of the deposited coating.

3. Powder composite cathodes for deposition of nano-structured coatings

Complex nitrides of the Ti-Al, Ti-Si, Ti-Al-Si, Ti-Cu systems have the highest values of hardness and the heat resistance [3–5, 7]. According to the phase diagrams, each of the mentioned above binary systems forms a few (3–5) intermediate compounds (fig. 1). The brightly expressed segregation and a high brittleness of the alloys produced by casting practically exclude the possibility of obtaining by this method of the multicomponent material with a homogeneous microstructure and the plasticity sufficient for its machining. In our opinion, for manufacturing of ready for use cathodes from homogeneous materials of a prescribed composition can be used powder metallurgical techniques like following:

- cold pressing and sintering of powders,
- hot isostatic pressing (HIP),
- self-propagating high temperature synthesis (SHS).

Multicomponent pseudoalloys made from powder mixtures have the chemical composition more homogeneous through the volume, and it is possible to control their phase composition and porosity by varying technological regimes of sintering or synthesis. In the most cases, the parts obtained from powders do not need consequent machining, as it is possible to set the necessary shape and dimensions at the stage of forming powder mixtures.

The hot isostatic pressing allows producing practically pores-free material, but now it is applied only in the experimental purposes because of the expensiveness and complexity of the equipment.

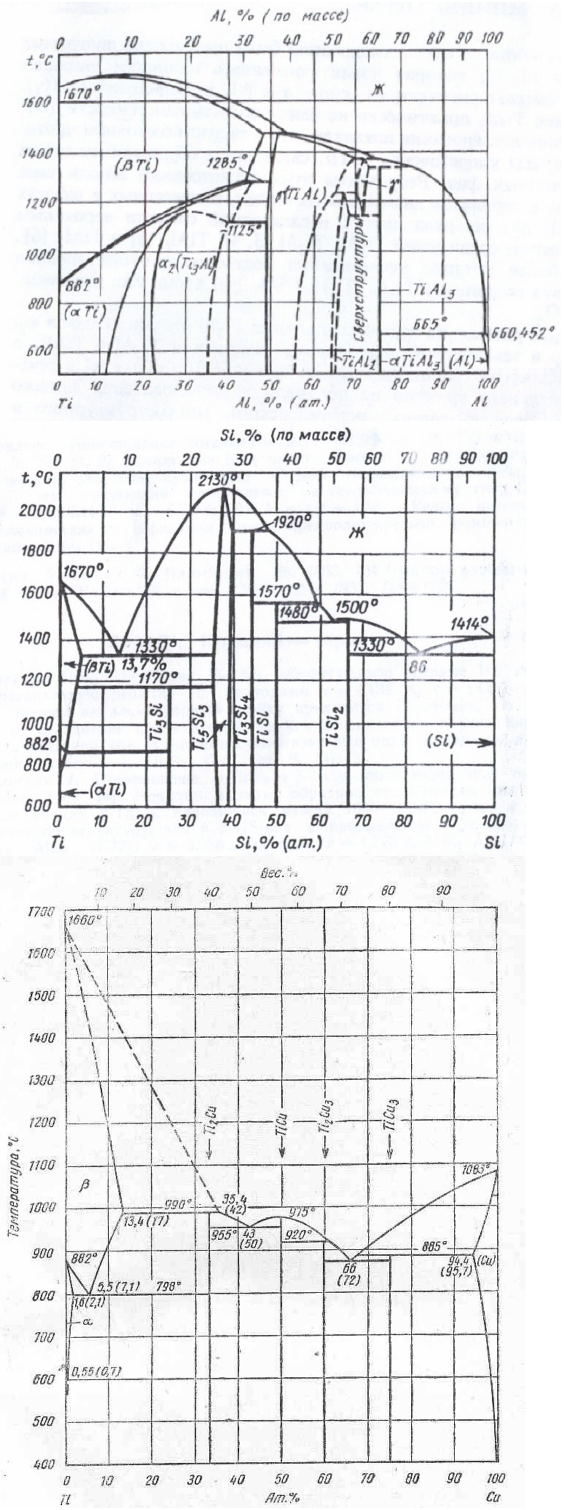

Fig. 1. Equilibrium diagrams of Ti-Al, Ti-Si and Ti-Cu binary systems [8, 9]

The element composition of powder cathodes obtained by SH-synthesis is rather narrow, as the reaction appears to be possible only in powder mixtures of definite components in the particular ratio, ensuring a sufficient reaction heat [10]. Because of this, the SHS technology is completely not usable for manufacturing cathodes with small additives of the second component (for example, silicon or copper to titanium).

The technology incorporating cold pressing and subsequent sintering of powder mixtures is most suitable for the industrial production of the multicomponent sputtering cathodes with a minimal prime cost. However, now this technology is practically not applied even in the experimental manufacture of sputtering targets. The main reasons of such a situation are the considerable volume growth during sintering of the compacts pressed from the powder mixtures of the most promising compositions, and practically complete absence of researches of microstructure and properties of sintered alloys, in particular, on the basis of the mentioned above systems. So, now the binary and triple powder alloys are practically not used because of a high porosity caused by the volume growth of the compacts during sintering. Accordingly, there is only fractional information in the literature about sintered composites used as cathode materials for deposition of plasma coatings [7].

Thus, in spite of the fact that the powder techniques are widely applied commercially for a long time, their application for manufacturing multicomponent sputtering cathodes demands conducting scientific studies with the purpose of searching the new technological solutions which ensure obtaining the cathode materials of a high quality. Besides, the research of regularities of the microstructure and properties formation during sintering of the binary and triple powder mixtures is necessary not only for working up techniques of obtaining sputtering cathodes, but also for the further development of the scientific fundamentals of the phenomenon of sintering systems with interacting components.

As it was noted, the main problem in manufacturing of the powder cathodes is the considerable volume increase of the compacts resulting in the formation of a high porosity of the sintered materials. This problem arises during sintering the most perspective compositions from the powder mixtures on the base of titanium. The high porosity of the target is extremely undesirable, as it results in an irregular erosion of its surface during sputtering and can cause a breakdown of the cathode under the action of thermal stresses in the field of temperature gradients.

Except the residual porosity, the microstructure and the phase composition of the sputtered targets are to be carefully controlled. It is important because of the following reasons. Firstly, the material of the target should not contain fusible phases, which form liquid droplets when the cathode is sputtered by the arc.

Secondly, the chemical composition of the plasma in a crater of the arc discharge during vacuum-arc sputtering of the heterogeneous target's material will depend on the local phase composition on the cathode's surface, if dimensions of the phase inclusions will appear commensurable with the diameter of the arc discharge spot. However, the question about an influence the phase non-homogeneity of the sputtered target on plasma characteristics and on the deposited coating quality remains open now.

It is possible to expect that the heterophase structure of multicomponent targets should result in additional structural stresses under of cyclical heat and cooling of the cathodes especially at vacuum-arc sputtering. Therefore, the possible influence of these stresses on the elasto-plastic behaviour of the target's material during sputtering of cathodes is necessary to investigate also.

4. An experience of applying of sintered cathodes for synthesis of vacuum arc sputtered coatings

Modern powder composite cathodes are mainly produced by the method of self-propagating high-temperature synthesis [10–12]. Few attempts of obtaining and usage of hot-pressed powder cathodes are known [13]. Application with this purpose of a conventional powder metallurgical technology including cold pressing and sintering of powder mixtures is not described in the literature.

The authors of this presentation conduct researches on sintering of Ti-Cu, Ti-Si, Ti-Al, and Ti-Al-Si powder systems for the last several years with the ultimate goal to develop a trial technology of obtaining multicomponent cathodes for vacuum-arc and magnetron synthesis of nano-structural coatings. The results of investigation of sintered Ti-Cu cathodes and vacuum-arc coatings obtained by sputtering of the cathodes are described in works [7, 14]. The similar results for the Ti-Si system are demonstrated in work [15]. There are some preliminary data that are not published yet for the Ti-Al, Ti-Al-Si systems.

Summarising the obtained results, it is possible to assert that the usage of the developed sintered materials for vacuum-arc sputtering considerably improves all the performances of nitride coatings in comparison with the characteristics of coatings obtained by vacuum-arc sputtering of titanium cathodes.

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