Influence of the Technology of Obtaining the Material of the Cathode of the Cu – Fe System at the Depth of Penetration of Ions into the Titanium Target

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Abstract. The article presents the results of the influence of the technology of obtaining the material of the cathode of the implanter of the Cu – Fe system on the penetration depth of the titanium alloy VT20. It is shown that the use of 50% Cu – 50% Fe material as the material of the cathode of the implanter, obtained by alloying copper and iron, leads to a better increase in the thickness of the ion-doped layer than the use of the cathode obtained by powder metallurgy.

Introduction

Since its early development, ion implantation has shown, in addition to tremendous possibilities, such as structuring or selective surface doping of materials, limitations such as the maximum thickness that can be changed, or simple flat geometry that allows uniform modification of the target. This prompted active development and research, which led to new tools for material modification. As is known, the nature of the dislocation structure and its quantitative characteristics in implanted metals and alloys depend on the initial state of the target, the type and energy of ions and the remaining dose, and can vary greatly, therefore, the study of various mechanisms of defect formation under conditions of ion implantation [1].

Materials and research methods

To study the effect of the technology of obtaining the material of the cathode of the implanter of the Cu – Fe system, the method of melting and the method of powder metallurgy were used.

In the first case, a sample of a given composition was melted in graphite crucibles. By the method of directional crystallization using a seed in the form of a copper rod, a rod with a diameter of 15–18 mm was obtained from an alloy 50% Cu – 50% Fe (Fig. 1, a).

To prevent oxidation of the melt during melting and holding at a given temperature, the crucible was closed with a tightly ground-in lid made of the same material. Heating was carried out to a liquid state of 1100 ° C, the holding time of the melt at a given temperature was 45 minutes.

Then the rod was cut into blanks, which were pressed in a heated state to obtain washers with a diameter of 50 mm and a thickness of 10 mm. After pressing, the washers were subjected to turning, resulting in disc cathodes of an implanter 40 mm in diameter and 5 mm thick (Fig. 1, b).

In fig. 2 shows the microstructure of the implanter cathode material. You can clearly distinguish between the immiscible phases of copper (in the photo, golden tone) and iron (greenish areas).

The structure of an iron-copper alloy with a 50/50 component content in the cast state is a set of dendrites of a supersaturated solid solution of copper in iron, evenly distributed in a matrix of a supersaturated solid solution of iron in copper.

a   b

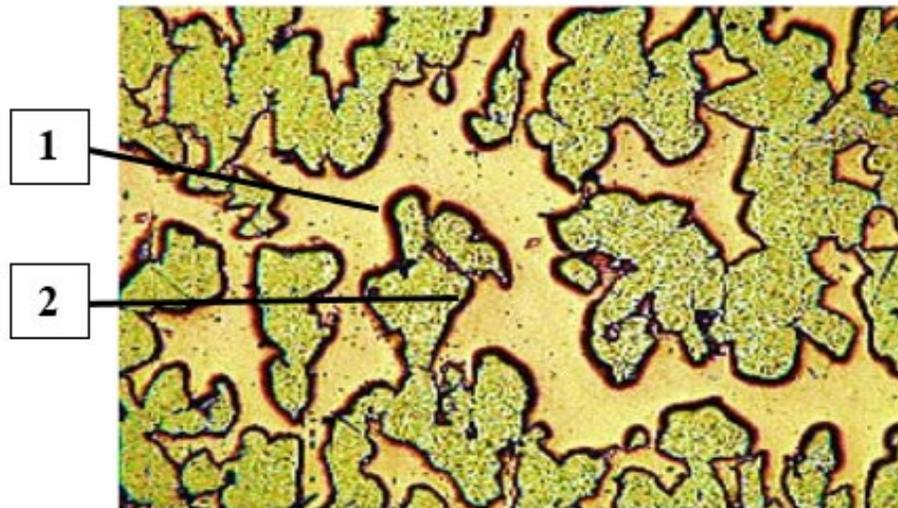***Fig. 1.*** *Rod made of 50% Cu-50% Fe alloy (a) and disk cathode of the implanter (b)*

Fig. 2. *Microstructure of the material of the cathode of the implanter made of alloy 50% Cu – 50% Fe (x230): 1 - copper; 2 – iron*

In the second case, the prepared mixture of copper and iron powders was pressed to obtain implanter cathode blanks with a size of 60x10 mm, which were then subjected to sintering at a temperature of 820–850 ° C. After sintering, the resulting billets were turned by turning to obtain the required dimensions of the implanter cathode.

To obtain comparative data on the effect of the technology of obtaining the material of the cathode of the implanter with the use of the obtained cathodes, the target was implanted from the titanium alloy VT20 at fluence values of 10^{17}, $5 \cdot 10^{17}$, and 10^{18} cm^{-2}. After implantation, the

thickness of the ion-doped layer was determined by Auger spectroscopy. The research results are shown in Fig. 3.

An increase in the fluence value in the investigated range when using 50% Cu – 50% Fe material, obtained by powder metallurgy, as the implanter cathode material, leads to an increase in the thickness of the ion-doped layer from 205 to 320 nm (by 56%). At the same time, when using the implantation cathode, obtained by alloying copper and iron, this increase was 212%.
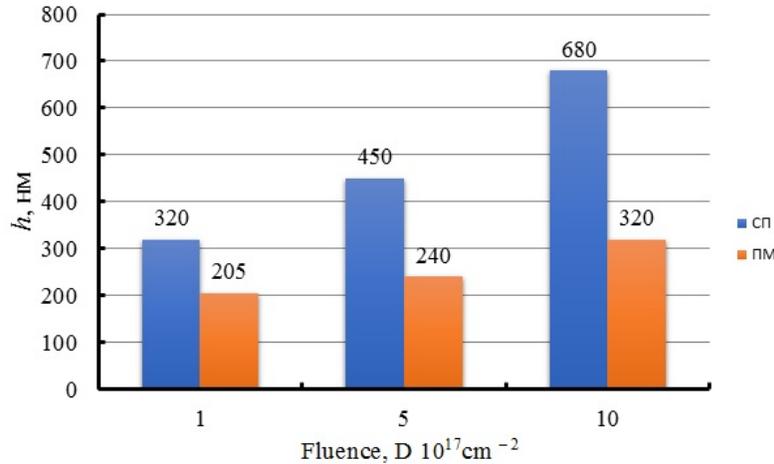

Fig.3. *Influence of the implantation cathode manufacturing technology from 50% Cu – 50% Fe material on the thickness of the ion-doped layer: SP - material obtained by fusion of components; PM - material obtained by pressing and sintering copper and iron powders.*

Considering the same conditions for the parameters of the implantation process, the difference in the thickness of the ion-doped layer can be associated with the presence of more massive ion blocks, the so-called clusters, when using a cathode made of material obtained by fusing the components.

The formation of cluster ions can be assumed based on the conditions for the formation of the ion flow based on the study of the behavior of the cathode spot of the arc on the surface of the composite cathode (Figure 4).
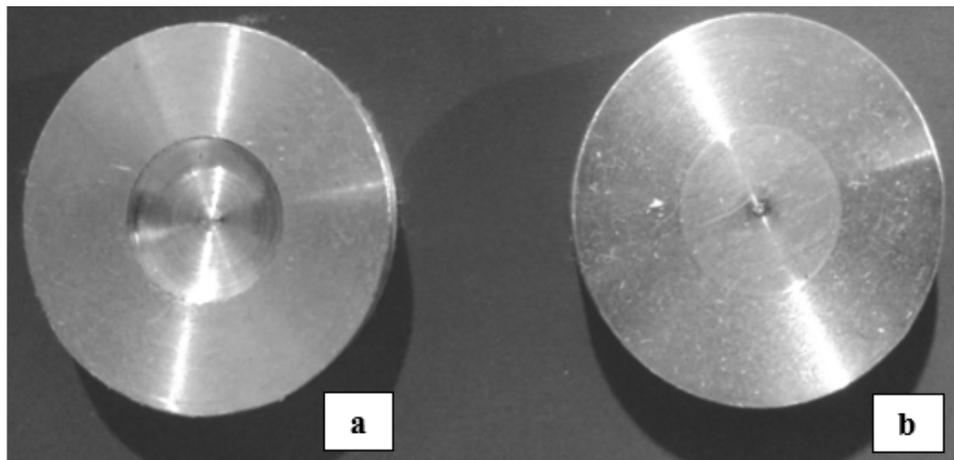

Fig. 4. *Composite experimental iron-based cathode with a central fused copper insert: a - workpiece; b - cathode after treatment*

The composite model cathode is an Armco iron disk 40 mm in diameter in the central part of which a circular hole is made, which is fused with copper. The diameter of the indicated hole is 10–12 mm. After crystallization and cooling of copper, the end working surface of the cathode was carefully machined on a lathe.

The design of the composite cathode makes it possible to estimate the speed of movement of the active arc spot over the cathode surface. It was 18-23 m / s.

The charge distribution of ions was measured using a magnetic mass separator (GSI) and a time-of-flight spectrometer (LBNL). In both cases, the ions were accelerated from the plasma at a voltage of 40 kV using a three-electrode multi-aperture extraction system. To exclude the effect of the arc pulse duration, all measurements of the charge distribution of ions were carried out every 100 ms after ignition of the discharge. During the measurements, the pressure of the residual gas in the working chamber of the setup was maintained at a level of 10–5 mm Hg.

The studies were carried out on an ion implantation unit with an IGMI-50 source operating in a pulsed mode and capable of generating polyenergetic beams of metal ions. Irradiation was carried out with pulsed beams of copper and lead ions. The average beam current was 0.1 A, the pulse duration was 300 μs, and the pulse repetition rate was 17 Hz.

Results and discussion

Studies have shown that short beams have a duration of about 5 μs, then the beam current pulses were cut out with a step of 5 μs. For the first 15 μs of arc burning, the beam spectrum contains only iron ions. After 20 μs of arc burning, both iron ions and copper ions are already present in the beam. Starting from 25 μs from the onset of arc burning, only copper ions are present in the spectrum.

The result obtained can be explained by the directed movement of the cathode spot from the peripheral sections of the composite cathode to its center. Therefore, it can be argued that the cathode spot passes from a more refractory metal to a less refractory metal. In this case, the reverse transition is not fixed.

This is explained by the fact that it is energetically more favorable for the arc to burn on a less refractory surface [2]. Indeed, regardless of the surface on which the arc is currently burning, the arc current remains constant, since a modulator with arc current stabilization is used to power the arc discharge. In this case, the voltage drop across the arc for a less refractory material will be less than for a more refractory metal. The presence of this voltage jump on the arc during the transition of the cathode spot from iron to copper is confirmed by the presence of a beam of Cu2 + ions in the charge spectrum at this moment, which then disappear from the spectrum. That is, at this moment, the voltage drop across the arc is greater than during further work from the copper surface of the composite model cathode.

It should be noted that when working with a purely copper cathode, Cu2 + ions were observed only during the duration of the ignition pulse, while in the results obtained, they are observed after the end of this pulse.

Using the results obtained, an estimate was made of the smallest velocity of the cathode spot movement [3]. Based on the assumption that the cathode spot is based on the cathode edge at the point closest to the copper impregnation, and taking into account that there are no copper ions on the oscillogram corresponding to a 25 μs delay, the minimum speed of the cathode spot is 18 m / s. It should be noted that this value was obtained on the assumption of a rectilinear motion of the cathode spot from the place of formation to the copper insert.

Observation of the movement of the cathode spot of the arc showed that when using the composite cathode of the implanter, the cathode spot mainly moves along the radial part of the

cathode disk from its peripheral part to the central part. The image of the movement of the cathode spot of the arc over the cathode surface of the ion implantation device is shown in accordance with Fig. 5.

Fig. 5. *Moving the cathode spot of the arc over the cathode surface of the ion implantation device when using a composite cathode with a central hole.*

This is explained by the fact that it is energetically more favorable for the arc to burn on a less refractory surface. Indeed, regardless of the surface on which the arc is currently burning, the arc current remains constant, since a modulator with arc current stabilization is used to power the arc discharge. In this case, the voltage drop across the arc for a less refractory material will be less than for a more refractory metal. The presence of this voltage jump on the arc during the transition of the cathode spot from iron to copper is confirmed by the presence at this moment in the charge spectrum of a beam of Cu^{3+} ions, which then disappear from the spectrum. That is, at this moment, the voltage drop across the arc is greater than during further work on a copper surface.

The appearance of large-mass cluster ions significantly changes the pattern of the effect of the ion flux on the irradiated target surface (Fig.6); destruction of the cluster is observed when it interacts with the target surface.
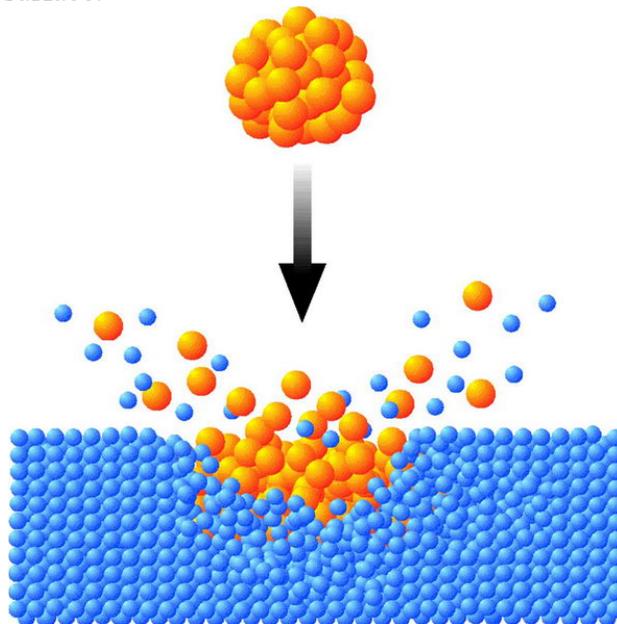

Fig. 6. *Scheme of irradiation of a titanium target with cluster ions*

When a cluster is destroyed, some of the atoms that make up the cluster are reflected from the target surface together with the surface sputtered atoms. At the same time, due to the greater mass of the cluster, it acquires a large energy impulse, which ultimately provides a greater penetration of the ions that make up the cluster into the target material. In this case, a sublayer with a strongly deformed atomic structure is formed directly under the ion-doped target layer.

Summary

Thus, on the basis of the research results, it can be concluded that an increase in the fluence value in the investigated range of 10^{17}–10^{18} cm^{-2} when using 50% Cu – 50% Fe material obtained by powder metallurgy as the cathode material of the implanter leads to an increase in the thickness of the ionic doped layer from 205 to 320 nm (56%). At the same time, when using an implanter cathode obtained by alloying copper and iron, this increase was 212% and reached 680 nm. When working with a purely copper cathode, Cu2 + ions were observed only during the duration of the ignition pulse, while in the results obtained they are observed after the end of this pulse.

Acknowledgement

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