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Metallic films for triggering vacuum-arc plasma sources

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Results of the studies on forming the conductive film in discharge gap of the trigger injector during the operation of vacuum-arc plasma source are presented. The film was deposited on the end of ceramic tube surface used for filling the discharge gap trigger injectors. Experiments were performed in the practicable conditions for technological processes of protective and decorating coating in the plasma sources with magnetic confinement of the cathode spot and chromium and titanium cathodes. It was revealed the cathode materials and conditions of the coatings deposition influence on structure and properties of the films obtained on ceramics Al_2O_3–SiO_2–BaO_2. The rate of the film growth was defined, its variation is in the range of 1.1...3.3 nm/s.

Приведены результаты исследований по формированию проводящей пленки в разрядном промежутке пускового инжектора в процессе работы вакуумно-дугового источника плазмы. Пленка осаждалась на торцевую поверхность трубки из керамики, применяемой для заполнения разрядного промежутка пусковых инжекторов. Эксперименты выполнялись в условиях реального технологического процесса нанесения защитно-декоративных покрытий в источниках плазмы с магнитным удержанием катодного пятна и катодами из хрома и титана. Установлено влияние материала катода и условий осаждения покрытий на структуру и свойства пленок, получаемых на керамике состава Al_2O_3–SiO_2–BaO_2. Определена скорость роста пленок, которая варьируется в диапазоне 1.1...3.3 нм/с.

Металеві плівки для запуску вакуумно-дугових джерел плазми. *Ю.О. Сисоєв.*
Наведено результати досліджень щодо формування провідникової плівки у розрядному проміжку пускового інжектора у процесі роботи вакуумно-дугового джерела плазми. Плівка осаджувалася на торцеву поверхню трубки з кераміки, яка застосовується для заповнення розрядного проміжку пускових інжекторів. Експерименти виконувалися в умовах реального технологічного процесу нанесення захисно-декоративних покриттів у джерелах плазми з магнітним утриманням катодної плями і катодами з хрому і титану. Встановлено вплив матеріалу катода і умов осадження покриттів на структуру і властивості плівок, одержуваних на кераміці складу Al_2O_3–SiO_2–BaO_2. Визначено швидкість росту плівок, яка варіює у діапазоні 1.1...3.3 нм/с.

1. Introduction

Thin metallic film electric explosion is one of the most effective methods to obtain start-up plasma, which is necessary to initiate vacuum-arc discharge in different plasma devices [1, 2]. This film is formed from the products of cathode materials erosion on the surface of ceramic in a start-up injector discharge gap. Under vacuum-arc plasma sources operation in the regimes of ordinary vacuum-arc discharge extinction (sputtered cleaning regime, low arc current, using cathodes made of refractory materials and etc.), the conducting film has no time to recover in between the trigger injector responses.

Absence of the film in the discharge gap of the trigger injector changes physical processes of the start-up plasma formation, which in this case arises due to the surface dielectric breakdown. Mechanism of the superficial breakdown in vacuum is rather detailed described in [3]. It is characterized with far higher voltage required for the start-up plasma formation and reliable triggering vacuum arc.

As long as the film in the discharge gap of the trigger injectors of vacuum-arc sources plays an essential role when triggering arc discharge [4], it is a matter of interest to study its formation process. Data about the film growth speed, its resistance and etc. observed as a result of experiments might give information about the vacuum-arc discharge burning duration at which rebuilt of the film after injector actuation takes place, and about the optimal parameters of triggering impulses and etc.

Despite the fact that a long time passed since the time of the first works related to the vacuum-arc devices that used a metal film for triggering [5, 6] the question of the conducting film formation is still not well studied. To a certain extend this article is to fill in these gaps. The aim of this work is to study the peculiarities of the conducting film formation on the surface of ceramics used to fill the discharge gap of start-up injector and to study the film characteristics.

2. Experimental

According to the goal of defining the peculiarities, speed of growth and electrical characteristics of the conducting film structure we performed our studies over its formation on the surface of ceramics in the discharge gap of the initiating device under conditions of a real technological process of protective decorative films application. The scheme of the experiment is given in Fig. 1.

Plasma sources A and B were regular for "Bulat-6" devices, in which following measurements were held: diameters of cathodes were equal 80 mm, the trigger injector was placed on the surface of an auxiliary anode, that faced the vacuum chamber. Discharge gap of the trigger injector was filled with ceramics – ceramic tube with resistance MLH-2, where resistive layer on the ends of the tube was erased. Ceramic bushes (same as in the trigger injector of plasma sources) were used as samples, on the ends of which the film was depositing. The samples were secured to the excitation anodes.

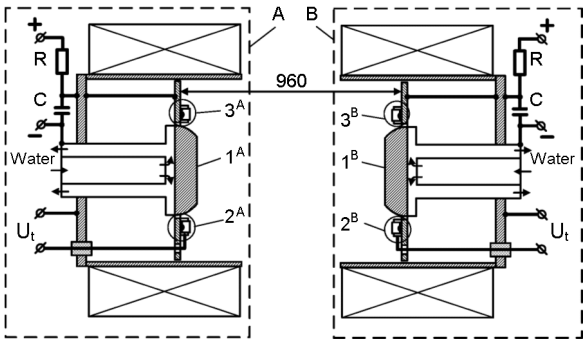

Fig. 1. Scheme of the ceramic samples displacement in plasma sources during the film formation on the ceramic surface research: A, B — plasma sources; 1^A — chromium cathode; 1^B — titanium cathode; 2^A, 2^B — discharge gaps; 3^A, 3^B — ceramic samples; U_t — ignition voltage; R, C — system initiation elements.

Process of the film formation on the ceramic samples had several stages. At first, the source A was working during 600 s at pressure of residual gas in the chamber $1{,}33 \cdot 10^{-3}$ Pa (cathode — chrome X99). After that A source was turned off and the source B turned on (cathode — titanium BT1-0). The source B worked for 1200 s in nitrogen atmosphere at pressure of $2 \cdot 10^{-1}$ Pa. Arc current in the both sources was 100 A. The ceramic samples after the experiment were unmounted and their end surfaces were investigated using raster electronic microscope REM-106.

Resistance measurement was held on the developed desk, providing movement of spring loaded feeler of digital multimeter UT-70D with accuracy 0,01 m. Multimeter was connected to a computer and provided resistance measurements with resolution 0,01 Ohm and accuracy ±0.3 %.

As long as dielectric basis for the MLH resistor can be made of different materials [7] elemental composition and structure of the samples were preliminarily defined. These researches (results are given in Fig. 2 and Fig. 3) were held by means of electronic microscope REM-106 with the energy-disperse microanalysis system.

Data presented in Fig. 2 show that the ceramic samples are made of celsian ceramics Al_2O_3–SiO_2–BaO_2 [8], including multiple voids of different size (Fig. 3).

3. Results and discussion

Morphology of the film on the surface of ceramic bush end near the chromium cath-

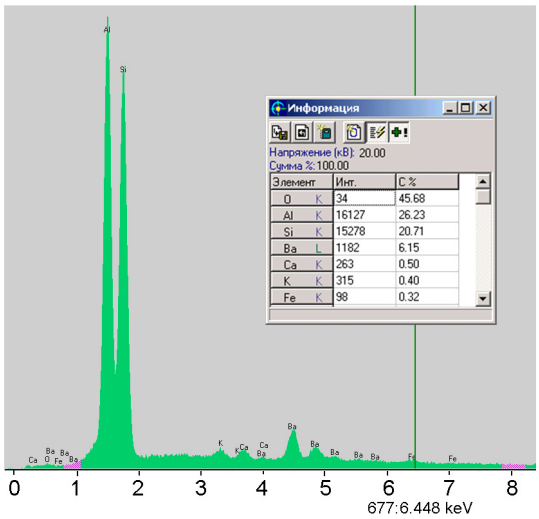

Fig. 2. Elemental composition of the ceramic samples.

ode (source A) is shown in Fig. 4. It is well seen that chromium based coating is not uniform: there are areas of solid coating with mirror sparkle that are situated closer to the central part of the ceramic tube. In Fig. 4 on the top of the photo there can be seen such an area.

There are many droplets that mainly have spherical shape and sized about 1 μm and less. Elemental analysis of the droplets in chromium coating shows that they are almost equally divided on chromium and titanium droplets. For example, in Fig. 5 in the group of three droplets in the center of the photo the average droplet consists of chromium while the smaller and bigger ones are titanium droplets.

Considerable quantity of titanium droplets on the surface of the film that forms close to chromium cathode can be explained by the fact that during the last stage of the technological process only B source was in operation (titanium cathode). It is remarkable that there are not titanium droplets obtained on the other end of this ceramic bush. It can testify that droplets having overcome the distance of around one meter reach the end of ceramic bush close to cathode being deflected from the lateral surface of chromium cathode.

Thickness of the chromium based film, which was measured on the fracture of the ceramic, was about 2 μm and less in the area of solid coating on the rest surface ~1 μm (Fig. 6). This corresponds with the film growth speed in a range of 1.7...3.3 nm/s at current of 100 A.

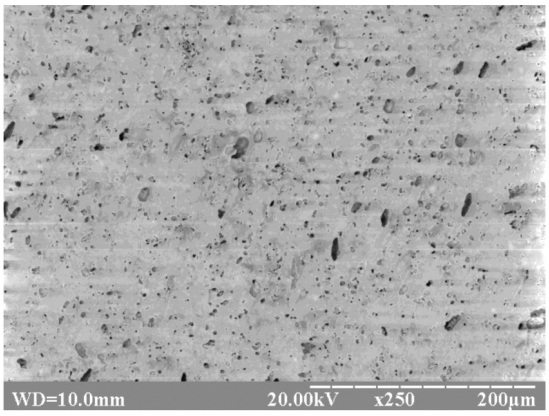

Fig. 3. Surface morphology of the ceramic samples.

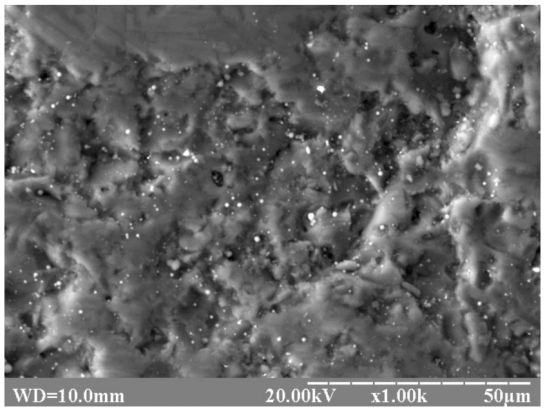

Fig. 4. Film on the ceramic nearby chromium cathode (source A).

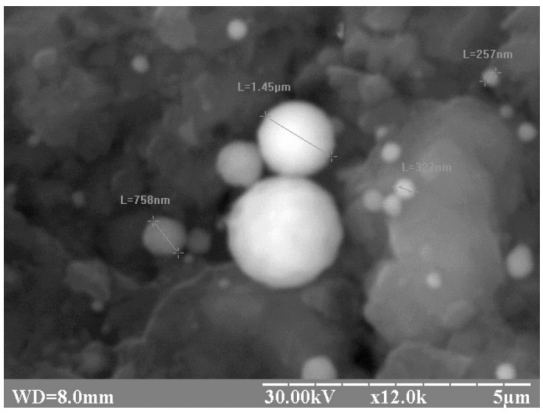

Fig. 5. Droplets shape on the surface of the chromium based film.

There is another film structure on the surface of the sample close to titanium cathode (source B) shown in Fig. 7. In this case the coating is matt and solid having yellow tone in some areas. It is more uniform having higher droplet fraction. There are some areas covered only with a thin layer of titanium coating.

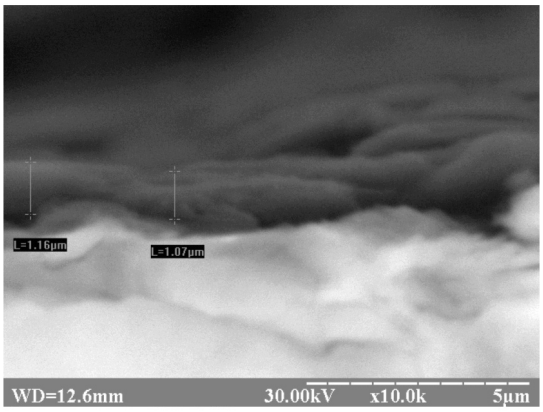

Fig. 6. Chromium coating ceramic fracture.

Unlike chromium coating the titanium one has many bigger droplets of titanium sized 5 μm and more. They have prolate form. Chromium droplets on the titanium coating are not observed per se. Out of more than 100 measurements one zone with chromium content of about 62 % was detected. Obviously it is due to the location of the chromium droplets under the layer of titanium. It also confirms the fact that there were found chromium contents up to several percents in the coating.

Thickness of the coating measured on the fracture of the sample ceramics (Fig. 8) varies in a range of 1.3...1.9 μm, that corresponds with the film growth speed in the range of 1.1...1.6 nm/s.

Having close values of mass-transfer coefficients of chromium and titanium [9], there is the less (about twice) film growth speed on the sample placed in B source comparing to A source. Probably it happens due to the film formation in the source B is going on mainly under high pressure ($p = 2 \cdot 10^{-1}$ Pa), while in the sample in the source A — mainly under low pressure ($p = 10^{-3}$ Pa).

It is known that transfer to the solid film at its deposition starts with thicknesses of more than 10 nm [10]. To achieve the solid film in the discharge gap of the start-up injector at its growth speeds in the range of 1...3 m/s, 10 s time gaps between injector responses is required. Still practically stable production of triggering system is obtained at lower time ranges of the film forming (up to several milliseconds). During this period of time only an island structure manages to form on the surface of the injector ceramics. In this case most likely breakdown happens due to redistribution of impulse triggering voltage in between the "islands" of the film. Appearing in the most advantageous place it spreads in the discharge gap of the injector.

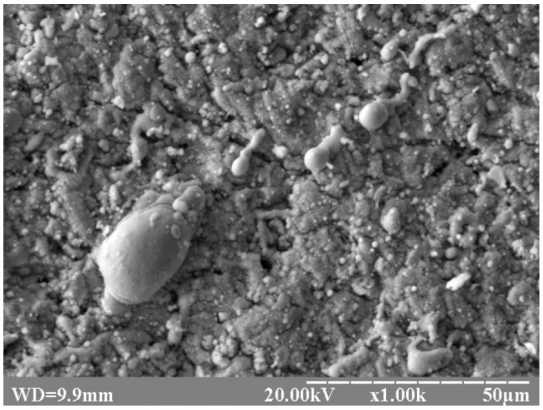

Fig. 7. Film on ceramic nearby titanium cathode (source B).

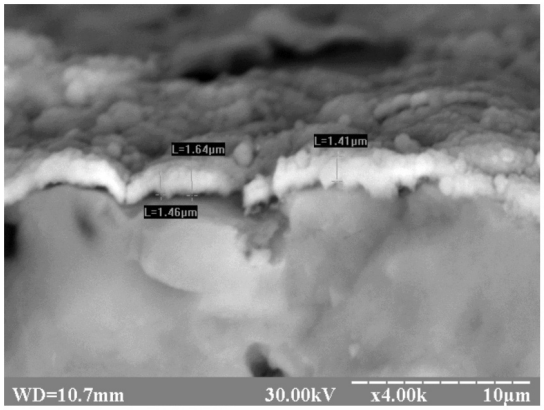

Fig. 8. Titanium coating ceramic fracture.

Films resistance along the radius of the ceramic tube (approximately that is the way of breakdown in the discharge gap of the start-up injector) for titanium and chromium based coating are shown in Fig. 9. Dashed lines on the diagrams show resistance of a conductor with 1 μ^2 cross-section. Values obtained for the chromium based films satisfactory correspond to the resistances of the micron thick films [10].

Lower resistance of the titanium based films comparing to solid titanium is the most likely due to presence of the different chromium fractures which have lower resistivity than titanium.

When studying the ceramic samples end surfaces that were far from the cathode (out of sight from the working surface of the cathode) there were found droplets of the cathode where the sample had been placed. The droplets of the opposing cathode were not observed.

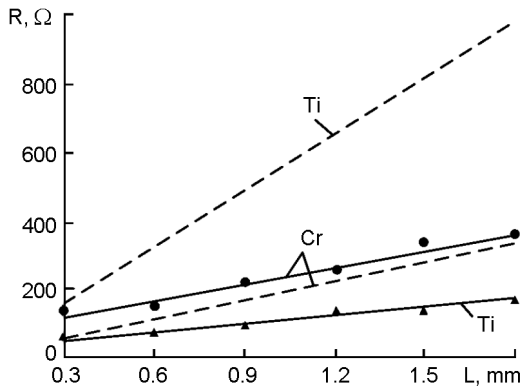

Fig. 9. Chromium and titanium based films resistance.

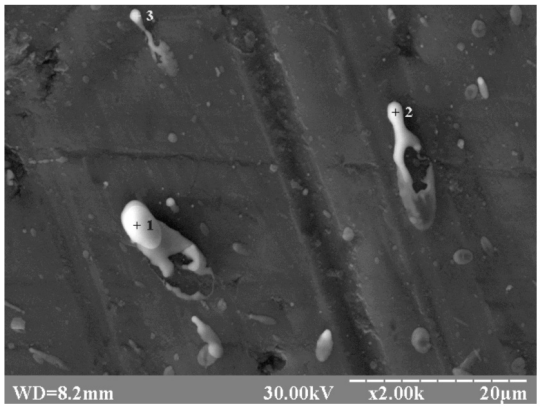

Fig. 10. Droplets on the end of ceramic sample away from the chromium cathode: *1*, *2*, *3* – points of microanalysis.

In Fig. 10 the end surface of the sample from A source is shown (Fig. 1) away from the cathode with chromium droplets.

The droplets elongated form testifies that they move at angle to the deposition surface and are in a liquid state. One of the possible reasons of the droplets reaching the surface (that is out of sight from the cathode working surface where they are formed) can be their interaction with ions which change the direction of the droplets movement due to created pressure.

4. Conclusions

As a result of the study of the film conducting on the surface of ceramics used for filling the discharge gap of start-up injectors of vacuum-arc plasma sources the following conclusions were obtained: Film growth in the discharge gap of start-up injector takes place at speed of several nanometers per second. The film formation speed range in the sample close to chromium cathode was obtained — 1.7...3.3 nm/s, in the sample close to titanium cathode — 1.1...1.6 nm/s. Difference in the growth speeds is most probably due to the forming at different pressures in the chamber and the lower pressure gives the higher speed. Resistance of the films mostly containing one material approximately meets the values for micron films of the material. When operating several plasma sources with cathodes made of different materials the films resistance is defined by the ratio of fractions with different resistivity. Coatings that form on the surface of the start-up injector ceramics contain high amount of droplets from cathode materials. It is obvious that such film structure will define electrical blow peculiarities on the conducting film when the start-up injector responses.

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