Films and fractal units under cathode disposal of titanium

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Abstract. Analysis of the processes in the cathode spot of the vacuum arc were carried out. Possibly, these processes lead to the formation and growth of fractal aggregates from arc discharge plasma. The results obtained in the study of the structure of dust particles of the arc discharge plasma underlie the hypothesis. One of the possible reasons for the formation of fractal structures is the occurrence of current sheets and droplet spots when cathode spots approach each other.

1. Introduction
Ion-plasma technology is one of the methods for producing thin films and metallic nanostructures of various types. Processes in the cathode spot, leading to the emission of atoms, ions, electrons and other particles, including the fine dispersion droplet fraction, underlie their formation [1]. The first stage of plasma generation is the cathode spot. Largely, this has not been studied to a complete understanding. However, over twenty different and even mutually exclusive explanations of phenomena are counted in cathode spots [2].

Practical interest in the cathode spot is caused by the problems of increasing the yield of ions and nanoparticles from the products of arc discharge, and also reducing the fraction of the droplet fraction. Interest in processes in electric arcs and dust particles increased after the discovery of carbon nanostructures. The structure of the cathode plasma jets in a vacuum arc in the presence of magnetic and electric fields has been the subject of many studies. However, the structure and properties remain unexplored in particles precipitated from a plasma flow. The results of recent studies have shown that dust structures in plasma technologies may have interesting and useful properties due to their small size and high chemical activity.

Borosilicate glass particles ranging in size from 10 to 120 microns [3] are used to study and rotate dust structures. Moreover, spherical plastic particles with a diameter of several microns are also used to study dusty structures. Particles are injected into the discharge at various parameters [4]. In our papers related to the production of thin films by the CIB method, dust particles arise as an undesirable product. Therefore, the quality of the films deteriorates.

However, the study of the structure and properties of these particles makes it possible to understand the processes of their formation and interaction between themselves and the surrounding flow of arc discharge plasma [5]. The results of recent papers, which is a continuation [6–11], will be presented in the report.

We have established that in an arc discharge, compounds with a fractal structure that have the property of self-similarity can occur [12, 13]. It is believed that the instability of the growth front is the reason for the formation of fractal aggregates [14].

Goal of the work – the search for such conditions in the plasma stream of the arc discharge.
2. Results
The 3 main sections of the results underlying the position of our hypothesis will be presented in the report. We present them briefly.

1. The results of the study of fractal aggregates of dust particles of the arc discharge. The fractal dimensions of particles of different fractions that have values: 20 mcm – 2.41; 60 mcm – 2.28; 100 mcm – 2.37; 140 mcm – 2.27; 180 mcm – 2.45, we obtained from the arc discharge plasma [8,9]. The study of the structures of microparticles was carried out by X-ray diffractometry (diffractometer DRON-6; Hecus S3-MICRO small angle X-ray diffractometer). In this way, the objectivity of the results obtained by studying the structures of dust particles from the vacuum chamber of the arc discharge was ensured. The obtained results confirm the conclusions of the papers that the process of formation of dust particles can occur in three stages: the initial growth phase, the agglomeration phase and the saturation phase.

2. The results of the analysis of known models of cathode spots. Note the main features of the cathode spots. 1. – The source of ions, electrons, droplets and solid particles is the cathode spot. They can be controlled by external electric and magnetic fields. They are difficult to investigate due were fast of processes and small sizes [1, 15]. 2. – Plasma formations are possible near the cathode spot (drip spots). The parameters of droplet spots are close to those of the cathode spot plasma [5, 16]. 3. – There are two possible modes of behavior of droplets during the formation of plasma around them. «Cold» mode observed without electron thermal emission. «Hot» mode is associated with the evaporation of electrons [17]. 4. – Drops when moving can rotate, collectively mix and coagulate at solidification. [18]. According to these signs, droplets are like dust particles of plasma.

An electric current is induced in a microparticle (drop) moving in a non-uniform magnetic field. This current interacts with an external magnetic field. This fact is very important in explaining the structure of particles that have passed the interelectrode space. The formation of dust structures (soot) in the form of solid deposits occurs when the low-temperature plasma interacts with an external magnetic field and with the walls of the gas-discharge gap (vacuum chamber). Previously, such formations were perceived as dirt.

3. The results of the analysis of literature data on current layers and their properties. Dynamic structures with intense plasma motions are called current sheets. Plasma flows generation is a characteristic property of current layers. Current layers exist both in space and can be created in laboratory experiments [19–24]. We assumed that in our case the current layers are a flow of metal ions and a droplet fraction with charge-carrying drops.

Thus, the current layers occur when the cathode spots of the arc discharge approach each other (figure 1) [19]. The movement of the cathode spot along the cathode plane is generally random. However, when an external magnetic field is applied, exhibits a retrograde character. Therefore, it is practically impossible to register and measure currents in the current sheet when the cathode spot is moved by probe methods. The indirect evidence of the existence of the zero line of the current layer (neutral current layer) is the emergence and formation of fractal structures. A plasma formation separating oppositely directed magnetic fields with lines of force extended along the surface of the layer is called a neutral current layer. Inside the layer drip spots occur when the cathode spots approach each other (figure 2) [24].

The dimensionless parameter corresponding to the formation of current layers along the zero line was determined by S. I. Syrovatsky [20, 22–24]. The magnetic field created by the current sheet is a source of energy. The dissipation of this energy means the reconnection of magnetic field lines and the creation of instability of the growth front. The formation of fractal-like aggregates can occur precisely here. This process can be attributed to the phenomenon of drift-dissipative instability. This process is a one type of plasma micro instability. The structures arising from this are associated with the dissipation (dissipation) of energy. Such structures are called dissipative structures. The formation of such structures is not associated with a phase transition and a change in temperature. They can exist only if particles with the environment exchange sufficiently powerful flows of matter or energy. Such a situation may occur on the border of two or
several adjacent cathode spots [24]. Rupture of the current sheet leads to a significant drop in plasma density. Also to the emergence of an unstable growth front and the formation of fractal structures of dust particles from the arc discharge plasma.

![Figure 1. Geometry of the emission center: 1 – cathode, 2 – plasma, 3 – current lines [19].](image1.png)

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![Figure 2. Currents of the current layer formed between magnetic flows [24].](image2.png)

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3. Conclusion

The conclusion is made on the basis of a study of the structures and properties of dust particles from vacuum arc discharge plasma. The possibility of manifestation of processes in the cathode spot with the participation of current sheets leads to the formation and growth of fractal aggregates.

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