Properties of the particles deposited from a low-temperature plasma arc discharge

N A Smolanov
Ogarev Mordovia State University
E-mail: smolanovna@yandex.ru

Abstract. The possible mechanisms for the formation of fractal particles of the plasma arc have been studies. The existence of dust structures of two types strongly and weakly magnetic was found. Paramagnetism of particles is the result of the synthesis of titanium carbonitride with embedded (encapsulated) magnetic substrate elements. The magnetization of particles indicates the presence in the test nanostructure particles. Inhomogeneous distribution of electric charges in motion conducting bodies (drops) in a magnetized plasma is the reason for the formation of dust particles.

1. Introduction
Thin films are the main product in electric deposition. Dust particles and solid deposits in low-temperature plasma units are considered "hazardous" materials. They were found in HID devices back in 1874 and were seen simply as the mud [1]. Studies of structures and properties of these materials allow the understanding of their mechanisms of formation. Similar dust particles are formed in the tokamak as a result of the erosion of graphite and metal walls [2-3]. Processes in the cathode spot are the basis of their education. Therefore, the structure and properties of these materials provide an understanding of the mechanisms of their occurrence and the processes occurring in the plasma. Analysis of the results of recent work has revealed the structure of the cathode spot [4] and the properties of dusty plasma [5, 6]. The same nature of the processes occurring in the cathode spot and dusty plasma in an external magnetic field was set.

Products cathode spots are the result of explosive emission and secondary ion bombardment [7-9]. It was found that at a certain value of the external magnetic field, the cathode spot of a vacuum arc moves in the opposite direction of the force of Ampere. The phenomenon of changing the direction of rotation of the cathode spot is known for a long time, but not completely understood. A number of studies found similar behavior of dusty plasma in a magnetic field. The presence of dust granules of the magnetic moment due to the elemental composition and surface loop current generation of rotating charged particles [6, 10]. The magnetic properties of dusty plasmas are determined by various factors, depending on the magnitude of the magnetic induction. In a weak magnetic field is magnetized only the electronic component of the plasma, in the middle field (0.1-0.3 T) magnetized ions, and only in
strong fields (2-3 Tesla) themselves are magnetized dust granules. As the external magnetic field can be dusty plasma rotation stop, followed by a change of its direction (retrograde). However, the reason of occurrence of threshold character rotation, as in the case of reverse movement of the cathode spot is still unclear [4-6]. In this paper, the possible mechanisms of dusty plasma evolution from the cathode spot before its recombination on the substrate and the walls of the vacuum chamber were considered. Particular attention is paid plasma mass - separation of particles in the plasma system of magnetic fields cathode assembly [11]. In a plasma accelerator as in all ion-plasma systems can develop different types of plasma instability. Possible trajectories of dust particles of different charges and masses examined. It was found that when driving a drop in the plasma flow inside the convective mass transfer can occur, drop under pressure flows of ions and electrons, and in some cases there is a rotation of the drops and their destruction ("Coulomb" explosion). Metal droplets leaving the cathode and evaporates rapidly converted to plasma formation in the immediate vicinity of the cathode surface. Some of them, however, is deposited near the cathode. Drops, crystallized and deposited near the cathode plane, have the elemental composition heterogeneity (Figure 1). We have shown that in an arc discharge in the presence of magnetic and electric fields, the structure of condensed matter near the cathode has a helical character due to the rotational movement of dust (drip) of the particles as a whole [11].

Dust particles can be divided into 2 groups. The first group (slow) is held gas-dynamic plug and settles near the cathode and substrates in the chamber. The second group is the fast ions and droplets formed in the cathode spot with the emission from the excited state create nanostructures with rapid (adiabatic) cooling the walls of the vacuum. The presence of 2 types of particles in the plasma emission arcs supported in a number of effects [11-14].

![Fig.1. Electron microscopy of drop and table content elements in it (droplet size 6 mcm)](image)

**2. Work purpose**

In this paper, which is a continuation of studies [11-14], an attempt to explain the formation of dust structures condensed from the plasma arc discharge of particles and their magnetic properties were made. Of particular interest to the processes in arc discharge plasma arose after the discovery of our fractal structures on the walls of the vacuum chamber [13]. This makes it relevant to study mechanisms of films and microparticles in a plasma arc. There is reason to believe that inter-process droplet erosion in the fusion plasma and the formation of droplets from the cathode spot of the arc discharge, there are some similarities. The structure of the cathode plasma jet in a vacuum arc in the presence of magnetic and electric fields is the subject of many studies, but the structure and properties of plasma deposited particle flux often are often unexplored.
Therefore the aim of this work was a detailed study of fine powder, deposited on the walls of the vacuum chamber by spraying a titanium cathode (VT1-0 alloy) arc method. At the same time we are based on generalization of ideas and the results obtained in the study of current sheets in plasma [15, 16], the plasma rotation [4-6, 8]. Taken into account the results of the study of the spectral composition of the plasma arc, the nature of the cathode spot drip stains [17, 18] (glowing drip stains).

3. Results. EPR - spectroscopy
Particulate deposited on the walls of the vacuum chamber of HHB-6 in the process of ion-plasma deposition of multilayer coating films on the substrate (steel 12X18H10T). selection of fractions with typical particle sizes [16] is produced by magnetic separation of the starting powders in the form of soot. EPR spectra were recorded on rf PS100X (frequency 9.3 GHz). The particle sizes obtained by applying potential on a submarine to magnetic separation, are within 5-100mkm. When the particle deposition without applying a potential (anode - of the vacuum chamber wall) of the basic number is in the range 70-130 microns.

Table 1. The elemental composition of the powders (substrate potential of -250 V)

| Fraction       | Ti    | N    | O    | C     | Fe    | Cr  |
|----------------|-------|------|------|-------|-------|-----|
| non-magnetic   | 44.23 | 9.69 | 35.29| 10.30 | 0.12  | 0.03|
| magnetic       | 51.60 | 7.40 | 29.97| 10.21 | 0.26  | 0.10|

It was found that the change in the substrate potential, which produced the precipitation leads to the appearance of the EPR signal with a g-factor is probably due to the presence of nanoparticles. in the form of fullerenes with inclusions of atoms of magnetic elements. After dissolving with toluene, and then filtering the signal in the ESR spectrum disappears

Analysis of the EPR spectra showed (Fig. 2, 3) that the powders are characterized by magnetic properties with different g-factors. A feature of the EPR spectrum of the test powder is its asymmetric line shape. Note also that with a decrease in the size fractions in the absorption spectrum there are additional lines. Magnetic separation and leads to the appearance of new lines in the absorption spectrum of the magnetic particles and weakly magnetic fractions is not observed in the initial state.
At T = 78 K in a non-magnetic powder with a size of 30-60 microns appears hyperfine structure and additional absorption line (N = 1590 kOe, g = 4.18). The number of absorption lines of the magnetic fraction obtained in the absence of potential on the substrate - one (g = 2.47), while in the non-magnetic - 5 (g = 4.21; 3.08; 2.28; 1.99; 1.94) (Figure 2). Annealing in air at 300°C during 1 hour leads to a change in the spectra. In the magnetic fraction is a broad line (g = 2.33), while the non-magnetic fraction - two (g = 2.22; 2.00) (Figure 3). When you change modes produce particles observed a shift of one of the absorption lines in the region of the weak, and the other lines - in the region of strong fields. This changes the g factor.

4. The magnetization of the particles.
Magnetic properties (hysteresis) of particles of different factions and states (starting, after magnetic separation) were tested for vibration magnetometer MicroSense (EZ11 model). As an example, Figure 4 shows the non-normalized magnetization curves of particles with a diameter less than 20 microns in the initial state (curve 1) and after magnetic separation (highly magnetic fraction - line 2 and weakly - curve 3). A similar behavior of electric arc spray products was observed in [13]. The appearance of the magnetization curve of the hysteresis loop 2 is the result of the formation of dust deposited in small ferromagnetic particles. It should be noted that in an external applied magnetic field with a strength of up to 8 kOe, magnetization curve reaches its saturation. Thus, it was found that the magnetic properties of the magnetic powders after their separation are determined by the presence of ferromagnetic impurities. Their content depends on deposition conditions and the size fractions. The elemental composition of the particles is shown in Table 1.
5. Discussion.

Thus, the question about the reasons for the formation of the fractal structure of the dust particles from the arc in the magnetic field is reduced to the study of the electric field caused by the uneven distribution of electric charge in a moving conducting bodies (drops) in a heterogeneous low-temperature plasma. Unsteady collective electromagnetic field leads to the appearance in the plasma containing charged particles, oscillatory processes. The presence of the electrons and ions of their own magnetic moments may lead to unsteady oscillatory complex collective processes in the plasma. Emerging with stationary magnetic structure caused by electrically charged particles, electrons. Therefore, the movement of the conductive liquid droplets in the plasma flow, their instability and decay, largely determined by the density of the charge distribution on the surface of the droplets (droplet rotation).

Several studies have shown that the maximum curvature of the surface of the conductor and the surface charge density may have different locations on the surface of the conductive body (drops) [19]. The area where the distribution of the surface charge density of the conductor is greatest substantially different from the region of maximum curvature of the body surface. well developed (fractal) surface hardening of droplets of varying dispersion, size, shapes (from cubic to spherical), and the structure of the nanoparticles (homogeneous and composite particles with the hard magnetic material of the core and the soft magnetic shell) is appeared [20]. Such variations lead to a change in the hysteresis loop (Figure 4). It is possible to non-central location of the titanium atom in the lattice of the resulting compounds. The resulting asymmetry of the EPR signal indirectly confirms this. Also keep in mind that in a dusty plasma rejecting the gyromagnetic ratio of 2 is split ion-cyclotron mode (at g < 2) and split-polarized electromagnetic branch (g > 2) [21].

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