

## Fractal structure of low-temperature plasma of arc discharge as a consequence of the interaction of current sheets

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**Abstract.** The structure of the particles deposited from the plasma arc discharge were studied. The flow of plasma spreading from the cathode spot to the walls of the vacuum chamber. Electric and magnetic fields to influence the plasma flow. The fractal nature of the particles from the plasma identified by small-angle X-ray scattering. Possible cause of their formation is due to the instability of the growth front and nonequilibrium conditions for their production - a high speed transition of the vapor-liquid-solid or vapor - crystal. The hypothesis of a plasma arc containing dust particles current sheets was proposed.

**Introduction.** Vacuum arc technologies are the subject of many studies [1-3]. Interest in the processes in electric arcs grew after the discovery of carbon nanostructures [3]. The theoretical and experimental studies clearly observed two approaches to the processes in the plasma flow arc.

The first one takes into account only the ionic composition of the plasma and its behavior in external fields - electric and magnetic. It has been established that weak (10 mT) field leads to a focusing of the plasma flow, a further increase in magnetic field increases the ionic charges [4].

The second approach is more realistic. It is complicated by the consideration of the behavior of the plasma flow, which, in addition to the ion and electron components of the plasma, there is a drop fraction of arc discharge and solid pieces of the cathode. On these grounds it can be attributed to a dusty plasma.

It should be noted that from the cathode spot (CP), which is the basis of the plasma flow, until the condensed matter or cathode connections, is a whole series of processes of interaction of particles deposited - ions, electrons, dropping plasma fraction. It is known that metal droplets leaving the cathode rapidly evaporate and turn into plasma formation in the immediate vicinity of the CP [1]. These particles move in the imposed magnetic and electric fields and represent a superposition of interactions are usually gas-discharge plasma and plasma metal.

We have studied in detail the structure of condensed matter, deposited from the plasma stream near the cathode as a - (condensate dropping fractions), and on the walls of the vacuum chamber (soot) [5-9]. In our view, this approach allows to get closer to the problem of the relationship of processes in the plasma and the resulting structure. Methods of preparation and study of such structures are described in the works [5, 8, 9]. Of particular interest to the processes in the plasma arc appeared after the



discovery of fractal structures in the products of deposition of plasma flow on the walls of the vacuum chamber [9].

A fractal is a shape, parts of which are in any way similar to the whole. Properties fractal defined by the expression:  $M(\lambda, r) = \lambda^D M(r)$ , where  $M$  - a "property" of the fractal,  $r$  - a unit of length,  $\lambda$  - coefficient of increasing spatial size of the fractal ( $r = \lambda r$ ),  $D$  - Float (fractal dimension). If the fractal aggregate is formed from clusters, it has a value of fractal dimension  $D = 1,94$ . This is in line with the inter-cluster loose aggregates pores [10]. Fractal aggregates appear to volatile growth front when small perturbations of the front (interface) begin to grow much faster than the neighboring areas.

**Work purpose.** Thus, it is a process in a plasma arc stream as it moves from the cathode assembly of the vacuum plant type HHB-6 to the point of deposition and structures deposited from the plasma. In theory, magnetohydrodynamics cathode assembly is generally viewed as a coaxial plasma accelerator with a longitudinal magnetic field [11].

The presence of a longitudinal magnetic field in the plasma accelerator (cathode assembly) not only leads to a rotation of the plasma [11,12], but also to a number of interesting physical phenomena are not fully understood and provoke debate [13-18]. One of them is the retrograde motion of the cathode spot, and accordingly, the change of the direction of rotation of the plasma arc stream in general. Given the recent results of the study of the magnetic properties of the particles in the plasma and in the same retrograde character of their movement at certain critical values of the magnetic field [16-17], the question arises about the root cause of changes of direction - or cathode spot plasma flow?

Thus, in this paper is a continuation of studies [5-9], attempted to explain the formation and structure of condensed matter. They were precipitated from the plasma stream near the cathode (dropping condensate fraction) on the substrate in the center of the vacuum chamber (film) on the walls of the vacuum chamber (nanostructures, including fractal).

At the same time we are based on generalization of ideas and the results obtained in the study of current sheets in the plasma [19-21], including tokamak plasma, and their intermittency [22]. The analysis of the possible causes of retrograde motion of the cathode spot [14-15], rotation of the plasma [11-12]. Taken into account the results of the study of the spectral composition of the plasma arc, drip nature spots cathode spot [18] - (drip glowing spots).

**Results. The surface morphology.** The structure of the dust particles deposited from the plasma arc discharge to the metallic vacuum chamber walls cooled represents conglomerates interacting particles. The particles have a complex structure and in fact is the result of combining a large number of small particles of nanometer size (Figure 1).

Of particular note is that this dust ("metal snow" - Academician Kadomtsev) with a particle size of 10 to 1000 microns was formed as a result of hydrogen embrittlement of stainless steel at exploitation tokamak Globus-M [23]. The particles become magnetic stainless steel in the melting of its unipolar micro arcs. This adverse phenomenon (unipolar vacuum arc) leads to the destruction of one of the walls of the tokamak, facing the plasma.

We considered possible mechanisms of evolution of the dusty plasma cathode spot before its recombination on the substrate and the walls of the vacuum chamber in a simultaneous imposition of margins. Crystallization capillary plasma component and ion flux to the walls of the vacuum chamber leads to the formation of micro - and nanostructures, i.e. manifestation condensing agent in an excited state. At the same time there may be unknown to the structure modifications.

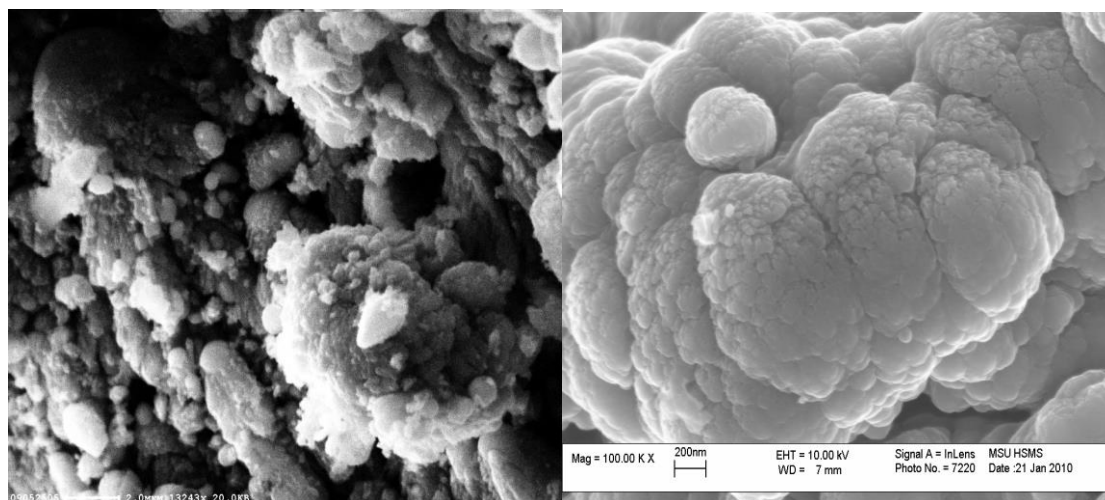


Fig. 1. The morphology of the powder magnetic and non-magnetic fraction

**Small-angle x-ray scattering (SAXS).** SAXS analysis results showed that the analyzed fine powder can be regarded as a structure of alternating metal-containing elemental and phase compositions from the fractal aggregates. It is found that the powder particles have structural studies in homogeneity nanometer scale, and their mean values lie within a fairly narrow range of about ~20-30 nm [8,9]. The fractal dimension of the particles of in homogeneities of different fractions (20, 63, 100, 140 and 180 microns) shown in Table 1 [9]. This corresponds to a loose aggregate of clusters with inter-cluster pores.

Table 1. The fractal dimension of in homogeneities [9]

Fractal, mcm	Linear scale of irregularities, nm		
	90-52	50-40	33-5
20	1,04	1,92	2,51
63	1,08	1,51	2,38
100	1,14	1,99	2,48
140	1,00	1,62	2,36
180	1,32	1,77	2,34

Fractal particles due to the conditions of formation of particulate matter, the composition of the plasma flow parameters of the electric and magnetic fields in the inter-electrode space. As already mentioned above, the formation of fractal aggregates similar occurs in conditions of instability of the growth front, when a small perturbation of the front (interface) begin to grow much faster than the neighboring areas [10]. We assume that we are studying fractal structures from the plasma arc are the

result of the special properties of the current layers with intermittency [19-22], and the turbulence of the plasma flow [11,12].

**Discussion. Possible causes of fractal particles.** Flows of ions from the cathode spot moving in an arc discharge can be considered as interacting current layers. It is highly conducting layers in the plasma separating the magnetic fields of various kinds [19, 20]. Jump magnetic field leads to the appearance of a thin layer of an electric current. As a result of what is happening in the reconnection layer (intermittency) [22] the magnetic field lines of the magnetic field topology changes that accompanied the transition of its energy into heat radiation energy of magnetohydrodynamic flows and particle acceleration. Thus, the magnetic field generated by current layers, the source of energy dissipation which is the reconnection of magnetic field lines. The theory of current sheets requires a "special" magnetic field lines in a plasma, which arise under the influence (impact) disturbances at distances exceeding the dimensions of the neighborhood layer. Therefore, not every configuration of the magnetic field can create a special line, when the electric and magnetic field are parallel to each other [16]. It is possible that a similar situation may occur in the vicinity of the cathode spot of the arc discharge in a coaxial magnetic field, when a negative potential is applied to the substrate and an electric field in the electrode space. Then for dissipation of the magnetic field in a small region of the plasma, in particular in the area of the cathode spot, there are conditions for the growth of particles with a fractal structure with a highly developed surface.

Several studies have found that in laboratory conditions the plasma formed non-neutral - containing non-zero transverse  $B_{\perp}$  and a longitudinal  $B_{\parallel}$  magnetic field component (or the y- and z-components of the field). In this case, for the formation of the current layer need only one pair reconnect field components.

For an explanation on the basis of current layers of other effects, such as retrograde motion of the cathode spot and the change of plasma rotation at the critical value of the magnetic field, we note that the opening angle of the cathode spot products (ions, dropping fractions) near the cathode obeys the cosine. This can greatly affect the resulting magnetic field geometry.

**Conclusion.** Thus, the fractal structure of the dust (soot) particles deposited on the walls of the vacuum chamber, both in low-temperature plasma, and plasma fusion is due, in our view, a manifestation of (action) of the current alternating layers.

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