The comparative analysis of particles and films, and the conditions of their formation from arc-discharge plasma and at the CTF devices

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Abstract. The paper presents the comparison of the structures and physical properties of films and dust particles. They are prepared on the vacuum chamber walls from the arc-discharge plasma and tokamak plasma. The morphology of the surface, microstructure, color range, grain-size distribution, and elemental and phase composition of films and micro particles have been compared. It was found that the films and powders have properties of nanocrystal materials. The structure, surface morphology and some properties of the arc-discharge plasma particles are similar to the structures and properties of the particles deposited on the TOKAMAK walls.

1. Introduction
The issue of forming films and dust in the plasma is of particular relevance for the safe operation of CTF devices. Technological purity is very important for the devices of plasma etching and spraying. Dust particles ranging in size from tenths of microns to 10-15 microns deposit in the tokamak near-wall areas [1-7]. It is established that dust is the result of drop-and-steam erosion of the walls, the intensity of which increases when current failure occurs. The size of the droplet fraction can increase up to 100 µm. The mechanisms of its formation, transportation and agglomeration remain unexplored. Dropping erosion in tokamaks has not been experimentally studied [5]. When conducting plasma tests of tungsten, we have found dust particles of irregular shape similar to sputtered graphite and other materials. All this underscores the importance of studying all mechanisms of dust formation in the tokamak [3-6]. The tokamak vacuum chamber walls are eroded mainly by near-surface plasma (ions and atoms of the end plasma). The results of the elemental analysis of the spraying products (dust) indicate that dust can also be formed from the limiter (diverter) and from more distant parts. In the SOL area there is intense turbulence, diffusion, and a significant temperature gradient [1-7]. But the conditions in the space behind the (SOL) area and in the diverter, where there is the accumulation of films and dust, are similar to those in the devices for plasma etching and filming [1-11]. The main reason for stimulating the present work was similarity of plasma parameters. The sizes and shapes of the particles near the tokamak walls and in low-temperature arc discharge plasma are also similar (Table 1). The basis of arc discharge plasma is cathode spots [12]. The attention to processes in arc discharges has increased sharply since new carbon structures were discovered [13].

The objective of this study is to analyze and compare the structures of films and dust (soot) particles that were deposited on the walls of the vacuum chambers from laboratory arc discharge plasma [14] and tokamak plasma [4-11,16,21-25].
Table 1. Comparative analysis of parameters of high-and low-temperature plasma and dust particles.

| No. | Parameter                      | CTS device         | Device for plasma etching and spraying |
|-----|--------------------------------|--------------------|----------------------------------------|
| 1   | Plasma density                 | \(10^{14}-10^{15}\) cm\(^{-3}\) | \(10^{7}-10^{11}\) cm\(^{-3}\)        |
| 2   | Electronic temporary           | Up to 1 eV         | 2-5 eV                                 |
| 3   | Dust sources                   | Erosion of the walls | Injection from the walls, condensation of the clusters |
| 4   | Charge of dust particiles      | \(10^4-10^5\) e   | \(10^4-10^5\) e                       |
| 5   | Sizes of the dust particiles   | from 0.1 µm        | from 1 µm                              |
| 6   | Morphology of the particiles   | Flakes, cauliflowers, fractals | Flakes, cauliflowers, fractals         |
| 7   | Ion flows                      | \(2 \cdot 10^{20}\) cm\(^{2}\)e\(^{-1}\) | Depend on the heat flow on the walls |
| 8   | Mechanisms                     | Formation of molecular complexes | Formation of molecular complexes C\(_x\)H\(_y\) (up to y=30) |
| 9   | Peculiarities                  | Turbulence in the near-wall plasma, short discharge time | Large discharge time                  |

2. Subjects and methods of the study
The film and dust in the arc discharge technological cycle were placed on the underlying of steel 12X18H0T. This steel [3, 6, 10] is used for the tokamak type devices. Plasma supporting gases-nitrogen and acetylene were filed into the area of a spray titanium cathode. The powder deposited on the walls (a fraction of less than 0.075 mm) was extracted with a vacuum cleaner and separated in a magnetic field (1000 Oe) to get magnetic fractions [14].

To research the material deposited from the arc discharge plasma, we used the same set of methods and equipment as in the works, the results of which were taken for comparison [5-8, 12-16]. This ensured objectivity in comparing the structures and properties of the films and dust-like particles from the arc discharge vacuum chamber and tokamak.

3. Comparison of color characteristics
Features of hydrocarbon structures of the tokamak T-10 are color range, layer microstructure, and metal impurity (predominantly iron) [3, 7, 10]. The source of the metals in the films are a glow discharge and failures. Yellow-brown smooth films, reaching 0.5 mm in thickness, predominate. Color can be determined not only by iron compounds [3]. For comparison, Figure 3 shows the cladding obtained by us from arc discharge, when a certain proportion of reaction gases (C/N/O) inflows in a vacuum chamber during cathode sputtering of titanium.

The color of the films from the tokamak usually reflects the D/C atomic ratio. In case of arc spraying titanium nitride (carbonitride) of stoichiometric or similar composition gives similar in color film. In the material of yellow (black) films from the tokamak there are traces of spraying tokamak structural components of stainless steel. Metal atoms can be a precursor of forming carbon spheres. This idea [3, 7] deserves further discussion (carbide cycle mechanism) [15].
The films of a certain thickness or composed of several layers films in tokamaks begin to flake off stainless steel substrates as a result of internal tensions and the different thermal expansion coefficients with the formation of scales (flakes) [compare Figures 5 and 6]. We have found that in scales (parts of the film) there are trace metals, whose source can be glow discharge being used to clean the camera [3]. For comparison, Figure 5 shows a picture of the scale from the arc discharge chamber, formed after 5-7 cycles of plasma flow deposition with dropping fraction near a spraying titanium cathode. There are obvious matches in shapes and sizes.

The globular and columnar structures of the films from tokamaks and low-temperature arc discharge plasma can be presented in a model of structural zones of vacuum condensates [17-19].
6. Fractal character of the films
The fractality of deposited films is an important factor for accumulating tritium in a fusion reactor. The authors [3, 7] compare the fractal structure of the films on the tokamak walls with tree rings, which allow retracing the long history of the tokamak T-10 (Figure 8). The similar structures (Figure 9) are formed on the vacuum chamber walls and around cathode sprayed from arc discharge plasma [20]. Fractal growth of films in the thermonuclear facility is caused by a strong turbulence of near-wall plasma, which excites thermal fluctuations in depositing flow. Inhomogeneity of the flow of deposited particles results in interactions similar to those in low-temperature plasma [3-5, 21-23].

7. Comparison of dust structures
The structures resulted from the erosion of graphite walls and metal constructions inside the tokamak have been compared with similar materials obtained from low temperature plasma by means of arc sputtering of titanium with spraying nitrogen and acetylene in a combustion zone (Figures 10, 11). In decomposing acetylene in arc discharge for forming titanium carbonitride films, there is growing a-C:H layers [14] similar to the layers depositing while decomposing ethylene in hydrogen plasma [24, 25]. This results not only in increasing the deposition rate, but also in breaking the carbon structure of films caused by forming sp³-carbon bonds [25]. The possibility of reactions of this type is described in a recent review of academician A. K. Rebrov [26].
8. New (unknown) structures
Of particular interest are new (unknown) structures of CTS plasma and arc discharge plasma. They are resulted from the conditions of their formation: a high speed of steam-liquid-solid or vapor-solid synthesis. The study of the carbon dust structure from the tokamak T-10 [9] has showed that it has a phase that is not in initial graphite. The found phase is characterized by the existence of much larger crystals. The formation of this phase is determined by the pressure of vapor and time of crystallization in the device. Unknown frame structure of carbon nanotubes in sizes from a few to hundreds of nanometers have been also obtained inside the tokamak T-10 [27].

We have also found particles of ASTM structures, which are unknown in databases, in the structures of the carbon black material deposited on the vacuum arc discharge chamber walls (installation of HHB-6). One of the obtained phases corresponds to the point space group Fd3m (diamond) [14].

9. Results
1. Compared films and powders obtained through depositing from arc discharge plasma and CTS plasma are nanocrystalline materials.
2. Their structures, surface morphology and some properties are similar.
3. Fractal character of the studied materials can prove the identity of processes starting in the cathode spots of vacuum discharges.
4. The obtained films and microparticles can be considered as a result of the interaction of plasma-dust structures in the electric and magnetic fields.

10. Conclusion
Some works note that such studies are important for not only analyzing the hydrocarbon films and particles, but also for studying thermonuclear fuel cycle, modeling and designing new installations. Coupled with the increasing interest in dust plasma, there is a need for more precise and reasonable use of the classification of formed structures, including nanostructures (hierarchy or morphology). In this regard, a Manual of Classification of Nanostructures proposed by material scientists may be very useful [28].

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