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Skeletal Dendritic Structure of Agglomerates of Visually Separate Microparticles in Dust Deposits in Tokamak T-10

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1. Introduction. An analysis of various types of dust deposits in tokamak T-10 was carried out, using the electron transmission and scanning micrography, for verifying the hypothesis [1] for the presence, in the observed long-living filaments, of a microsolid skeleton assembled, during electric breakdown, from wildly formed (carbon) nanotubular structures. Previous results [2(a)] showed the presence of (i) tubules of the size typical for individual carbon multiwall nanotubes (from few nanometers to few tens of nanometers); (ii) tubular structures of diameter 50-100 nm, which are built from smaller tubules; (iii) on the surface of the films, tubular structures of micrometer diameter which, in turn, include tubules of smaller diameter as constituent blocks. These results are compatible with hypothesis [1] in the sense that the trend of assembling bigger tubules from smaller ones, which is shown in the nanometer and micrometer ranges (in the dust deposits), may go to much larger length scales, the centimeter range, as it follows from the similarity of structures of easily distinguishable topology (namely, tubules and cartwheels) in the dust deposits and in the visible light images [3] of plasma in tokamaks TM-2, T-4, T-6, T-10.

The present analysis is aimed at resolving the fine structure of dust microparticles. This may be feasible for the particles which are partly/fully *transparent* to a transmission electron micrography (TEM). This may shed a light on the probable mechanism of formation of skeletal structures in the dust and on the origin of non-trivial structures, in particular, the cauliflower structures observed in the dust deposits in tokamaks TEXTOR [4] and T-10 [5].

2. Skeletal structure of agglomerates of visually separate dust particles. The structuring of dust particles was analyzed with the help of the transmission electron microscope TEM JEM-100CX (for magnification M=10,000, its space resolution is 5 nm). The original TEM images have been processed with the method of multilevel dynamic contrasting (MDC) [6(a)]. As a rule, the structuring revealed with the help of MDC may then be easily recognised in original, non-processed images (especially, for properly magnified high-resolution images). Figure 1 shows typical example of an agglomerate of visually separate particles.

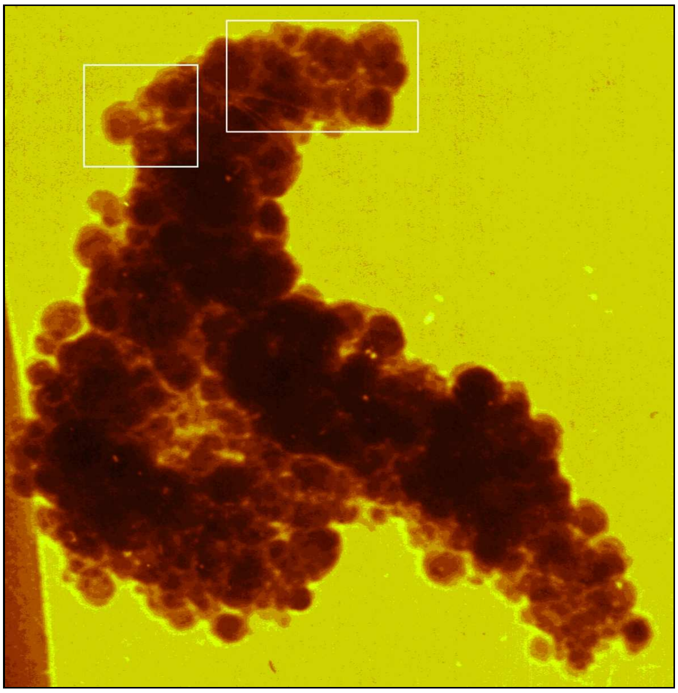

Fig. 1. The TEM image (magnification 26,000) of an agglomerate of visually separate dust particles redeposited at a glass fiber of the filter during vacuum suction of the dust from the crimp in the tokamak T-10 vacuum chamber (the fiber is partly seen as a black band on the left hand side of the image). Figure width is 590 nm. The magnified images of the windows are given in Fig. 2 and Fig. 3.

It appears that not only the visually quasi-spherical particles possess an internal skeletal structure (Fig. 2), but the neighboring particles often belong to a common skeletal structure (Fig. 3). The skeletal structure seems to be a base of the entire agglomerate. Significantly, the ball shaped or similar structures located near the transparent edge of the agglomerates as a rule appear to be a cartwheel-like structure located at the axle-tree connected with the skeletal structure of the entire agglomerate (see schematic drawing in the frame in Fig. 3).

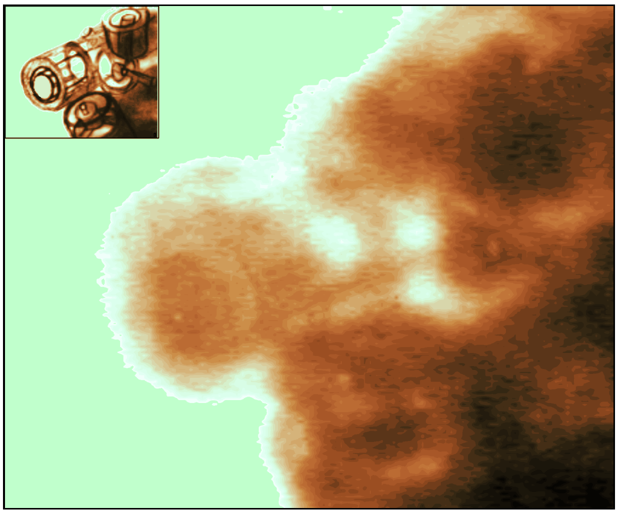

Fig. 2. The left upper edge of the agglomerate of Fig. 1. The visually separate, quasi-spherical particle appears to be a projection of the edge of a tubular structure which is a part of the skeletal structure of the agglomerate. Figure width is ~120 nm. A schematic drawing shown in the frame in the left upper corner is obtained with the help of mosaic MDC method (see Sec.2 in [2(b)]).

It follows from Figures 1-3 that the agglomerates of visually separate dust particles appear to be such a particle which contains (i) skeletal blocks arranged in a more or less ordered unified skeleton and (ii) an amorphous component whose distribution is peaked around basic blocks of the dendrite to form the visually separate quasi-spherical blocks. Roughly speaking, the quantity of amorphous component in these dust particles seems to be not sufficient to fill in the gaps between neighboring blocks of the skeleton.

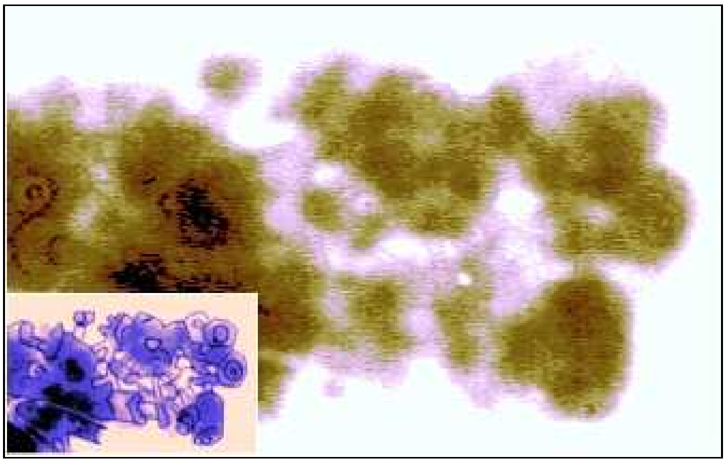

Fig. 3. The right upper edge of the agglomerate of Fig. 1. It shows a bunch of dendritic structures (presumably, cartwheels on their own axle-trees). Figure width is ~180 nm. A schematic drawing shown in the left lower corner is obtained similarly to that in Fig.2.

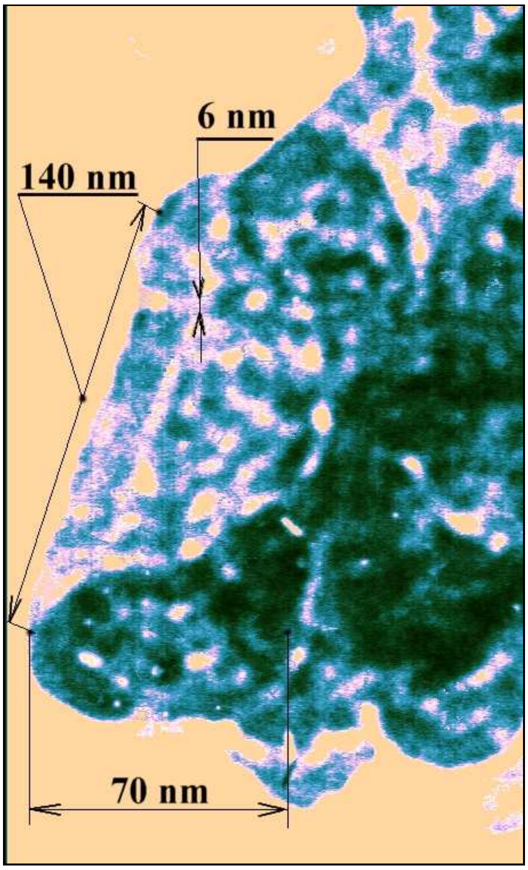

Figure 4. The TEM image (magnification 34,000) of a small fragment of the dust particle, of ~1.2 micrometer diameter, extracted from the oil used in the vacuum pumping system of tokamak T-10. Image's height is 270 nm. The tubule whose edge with the distinct central rod is seen in the lower left part of the figure, is of ~70 nm diameter and ~140 nm long.

3. Compatibility of dendricity and tubularity in microdust skeletal structures. An analysis of the entire available data allows us to reconcile two trends in the observed structuring: namely, the formerly observed tubularity [2(a)] and the dendricity shown in Figures 2,3. Here, the best argument seems to be a microparticle (Fig. 4) which possesses a tubular structure and is absolutely free of amorphous component (thanks to rectification of the dust deposit originally extracted from the oil used in the vacuum pumping system of tokamak T-10). It is seen that the central internal rod plays the role of a trunk because the radial links exist not only in the edge cross-section of the cartwheel but also between the trunk and the side-on tubules in the intermediate cross-sections. Thus, the tubular building block seems to be such a particular product of a general dendritic mechanism, which gives the *optimal* building block for the buildup of skeletal objects of macroscopic size (note that just tubular blocks were suggested [1] to be responsible for the self-similarity of macroscopic skeletons).

4. Similarity of agglomerates in tokamak dust and ultra-disperse materials of anomalous blackness. A comparative analysis of submicron agglomerates of 10-100 nm sized particles in (i) the carbonaceous dust deposits in tokamak T-10 [2] and (ii) ultra-disperse materials of anomalous blackness (namely, carbon black) shows the similarity of structuring. In particular, one may recognize the cartwheel-like structuring in the electron micrographs [7] of the carbon black. The search for such a similarity is suggested by the expected correlation between the hypothetical anomalous optical properties of «dark filaments» observed [6(a)] in laboratory electric discharges and various astrophysical objects and the well-known anomalous blackness of some ultra-disperse materials. Regardless of microscopic mechanism of the above anomaly, the revealed correlation supports hypothesis [6(b)] which suggested the simultaneous opacity and darkness of «dark filaments» to be caused by a skeletal structuring of such filaments. As far the cartwheel is a skeletal structure of the most distinctive topology, the presence of cartwheels in the agglomerates of the carbon black makes the hypothesis [6(b)] plausible and analyzable in the frame of dusty plasmas and the products of such plasmas.

Conclusion. The agglomerates of visually separate particles which sometimes resemble a cauliflower-like structuring are shown to possess a common dendritic skeleton with the distribution of amorphous component being peaked around basic blocks of the dendrite. The latter may lead to visual imitation of an agglomerate of separate particles.

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