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# Fractal growth of dust and globular films in T-10 tokamak.

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## Introduction

A lot of films samples, found in tokamaks, exhibit fractal structure of surface organized in hierarchical way of structures like globe-shape and cauliflower-shape[1], ovoidal structures, stratified and columnar shape[2]. Film samples from the T-10 tokamak reveals the self-similarity of fractal structure on 4 order of magnitude, from 10 nm up to 100μm [3]. To describe surface texture we have used fractal analysis, allowed to distinguish a variation in morphology by fractal dimension and exponent of complexity (so-called Hurst exponent). We have provided a description of the films fractal growth mechanism by diffusion limited aggregation (DLA) model [4], that is widely applicable for the discription of a lot of natural phenomena. The aspects of the films growth mechanism is considered to consist with statistics of deposited particles dynamics. We stress the importance of the edge plasma turbulence statistics: the deposited particles trajectory is not a standard random Brownian motion (classic diffusion), rather stochastic Levy-type diffusion driven by edge turbulence electric field possessed non-Gaussian statistics.

## Fractal fimension of topographic surface and statistics of the edge plasma turbulence.

We have investigated the surface texture of globe-shape and cauliflower-shape films from the T-10 tokamak [3]. In Fig.1 it is demonstrated cauliflower-like structure of the films surface. To describe the hierarchical structure of the films we have used a fractal dimension, as a measure of the self-similarity or as an index of the scale-dependency of a pattern. To use well known procedure, fractal dimention, D, was estimated of D=2.15 – 2.32. To estimate Hurst exponent of fractal surface we follow the Rolidory procedure [5], that defines as H=3-D from fractal dimention D of the surface in 3D space.

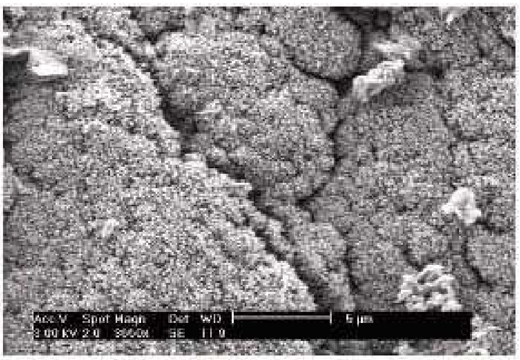
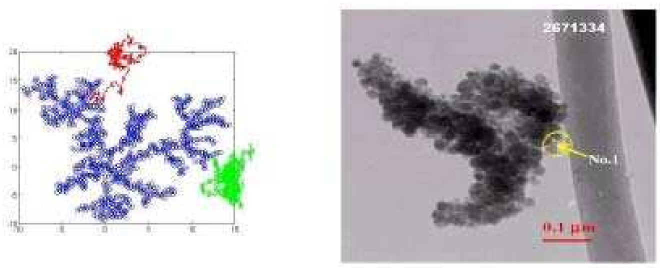


Fig.1. Micrograph of cauliflower-like carbon T-10 film

To analyze fractal structure of the edge plasma turbulence we hawe processed Langmuir probe signal such as density and particle cross-field flux. Fluctuations in density and particle cross-field flux are investigated by wavelet technique, to estimate Hurst exponent. Hurst exponent for edge plasma turbulence is of 0.6 – 0.8 with tendency to increase toward the wall.

Diffusion limited aggregation and fractal growth.

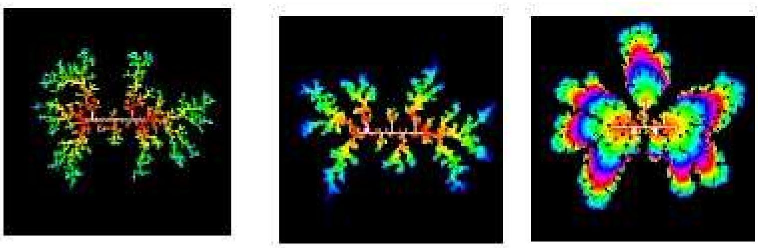
A feature of the films growth mechanism in tokamak edge plasma is that deposit edge charged particles arrives the surface not along straight-line trajectories, rather by Levy-type diffusion with non-Gaussian statistics. So ballistic deposition is not the growth mechanism to be considered as dominant one. In the DLA model, the prossess starts from a fixed seed particle. Introducing another particle at a large distance from the seed, it walks randomly until sticking to the seed or escaping to infinity. Then third particles is introduced in this system allowing to walk randomly until either attaching irreversibly to the two-particle cluster or escaping to infinity. This aggregation process is repeated many times generating the cluster with fractal structure. The DLA model supposes that the process occurs one particle at a time and diffusion dominates the convection in the transport. This case is opposite one to the classic example of Rayleigh-Benard turbulent convection that generates regular patterns. The fractal growth of the cluster is sufficiently slow and the Laplace equation rather than the diffusion equation is used to model the process of growth, in which diffusive transport controls the process. For the DLA model, the probability density of the random walking particle statistics the Laplace equation, with the clasters surface providing a surface of constant probability density. The result of diffusion limited aggregation is a fractal geometry whose dimension is linked to the dynamics of particles which diffuse to surface. The DLA approach is well suited to interpret observed texture of deposited films in tokamak. In the process of ion deposition in tokamak, we have to modify the traditional DLA approach taking into account diffusion statistics of deposited particles. In the vicinity of the surface of tokamak, deposited ions motion is driven by turbulent fluctuations of local electric fields. Fluctuation of electric fields results from strong turbulence of the edge plasma is not a trivial random process, rather than stochastic process with non-Gaussian (Levy-type process) statistic. The DLA growth mechanism with non-




(a) (b)

Gaussian diffusion results in the variation of the morphology, fractal surface textures such as cauliflower-like and globe-like shapes.

In plasma of fusion devices, theoretical models of dust agglomeration adopt the spheroidal symmetry of dust particles. It is shown the result of fractal cluster simulation by using DLA model with Levy-diffusion processed the same statistics as the edge tokamak turbulence with Levy diffusion possessed the same statistics as the edge tokamak turbulence (with Hurst exponent of H=0.6-0.8)(Fig.2). This result of computer simulation and experimental observation contrast with the spheroidal symmetry of dust particles observed in low temperature plasma processing interpreting as result of ballistic deposition process. So, diffusion limited aggregation with non-Gaussian diffusion have to be taken into account by theoretical considiration of dust claster and films growth in tokamak. Gaussian statistics result in a tendency to stick of particles to the tops of clasters brunches leading to the tree-like fractal growth. By contrast, the case of non-Gaussian statistics of ions diffusion in the edge tokamak plasma (superdiffusion with "flights") lead to a penetration of deposited particles into the gaps of cluster resulting in cauliflower-like shape of fractal cluster. It is shown a results of fractal growth in 2D plane with classical diffusion (H=0.5)(Fig.3a) and superdiffusion (H=0.7)(Fig.3c). The image of typical surface computed is quailitatively incompatible with image of the fractal surface texture of T-10 tokamak films.



(a) (b) (c)

For the films, collected in the T-10 tokamak, analysis of the granularity shape have shown a distribution of granules with order of symmetry. There exist a maximum related to 5-th order symmetry. Symmetry of fifth order (pentagon) is considered in the area of the quasicrystals without translational symmetry, morphology of self-organizied systems. Therefore films fractal structure is rather not a trivial reconstruction of graphite structure that originally possessed summetry of periodic crystal lattice. It could be explain in the DLA approach.

Discussion

A detail discussion of ion and charge particles diffusion in sheath layer is beyond the scope of this article, however some aspects of charge particles motion at the surface we have to remind. In the vicinity of surface, some fraction of particles are trapped by several forces (electrostatic, gravity, pressure gradient, thermophoresis and other) acted on them. Motion of the trapped particles is governed by fluctuations of wall potential leading to diffusive deposition. Property of plasma turbulence in sheath layer is still open questions. The actual electric field at the surface of the cauliflower-like and globe-like is complex, it has irregular structure over the fractal surface. The ionic flaxes toward the surface responding the electric field, are not isotropic ones. Experimental observation of non-Gaussian statistics of edge plasma turbulence have to be taken into account.

Some time the migration of atoms and voids on the lattice of wall lead to existing fractal structure. Taking a model of thermal Brownian motion of atom and voids on the surface is characterized by diffusion coeffisient of D= 2 $10^{-13}$ ÷ 3.3 $10^{-20}$ $m^2sec^{-1}$ for different materials. Impurity flux onto the surface is estimated by $10^{18}$ – $10^{19}$ particle $m^{-2}s^{-1}$. Therefore on globular- shape claster surface with minimal observed scale of 50 nm in diameter, one atom is deposited per 1-10 microsecond, and migration is estimated of $10^{-13}$ – $10^{-8}$m. It is much less then observed minimal scale of fractal cluster.

It is discussed now the proposal to use metals (tungsten and berillium) as plasma fasing materials for the first wall in large tokamaks such as JET and ITER. Taking into account a universality of diffusion limited aggregation model, fractal growth of the redeposited films from the eroded tungsten and berillium is expected in the tokamak chamber. In this case, porosity of such fractal films will lead to a problem of tritium inventory.

## Conclusions

Fractality (porocity) of the deposited films is one of the critical issue related to the safety hazard such as tritium inventory in large fusion device.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