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Investigation of tokamak T-10 globular films microstructure.

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Introduction

Inevitable consequences of graphite limiter utilization in ITER are hydrocarbon films formation on vacuum vessel elements. Therefore one of the key processes, determine of reactor ITER economy in use, is tritium absorption of these films .

As it was mentioned earlier [1] in the vacuum chamber of tokamak T-10 have been found out carbon globular films and flakes with friable structure and with big ratio of D/C~0.8. Investigations of this films all over again on an scanning electron microscope (SEM), and then on stationary scanning tunneling (STM) and atomic force (AFM) microscopes, has found out fractality of a surface microstructures, from the characteristic dimentions ~ 100 microns and till the dimentions ~ 10 nanometers.

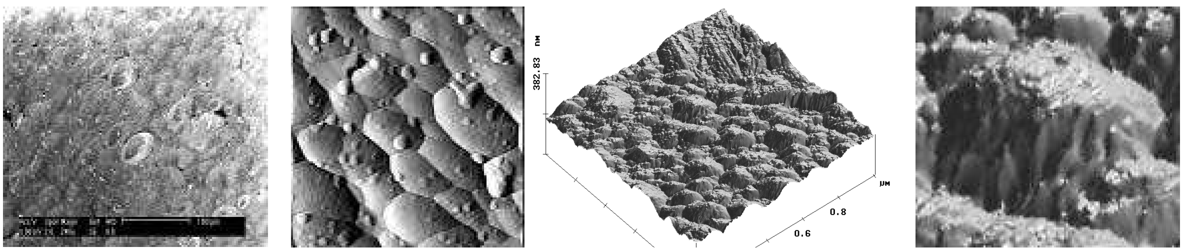
In the report results of research of a surface and internal globular films structure, estimation of a surface fractal dimension, model of films growth are submitted, the reasons of occurrence of such structure are discussed.

Experimental conditions for globular films generation.

Globular films have been found in two operating modes of T-10 tokamak. It improved confinement mode, in which big carbon flux originated from an internal part of a circular graphite limiter, under action of sputtaring by arcing [2]. And as in a mode without a circular graphite limiter where carbon recycling on a plasma periphery increase on the order of value.

Fractal analysis of a globular films surface.

The analysis of a surface was carried out by various type of microscope – SEM, STM and



a b c d

Fig.1. Films images with full size: a-300µm, b-5µm, c-1µm, d-50nm,

AFM. On a films surface the self-similarity global structure has been found out. In other words on a surface of big globals are located small, on which surface, in one's turn, are disseminated globals even the smaller dimentions (fig.1). The distributions of a global number depending on the average global size is non-Gaussian with tail in the range of big size and nearly the same for each level of microscope amplification. For an estimation fractal dimension of a topographical surface and definition of Hurst parameter the method of a covering box (Box-Counting) [3] is used. For fractal objects there is power dependence $N(r) = k\, r^{-D}$ from which fractal dimension D is defined. If the object has self-similarity fractal structure the estimation of parameter D does not depend from r in a range of self-similarity. Calculated thus fractal dimension of a topographical film surface, **D=2.15 - 2.32**, $(2 < D < 3)$. Fractal dimension is connected with Hurst parameter as D = 3 - H, [4].

Granules of the lowest dimensional are packed closely into structure. Symmetry of packing is those, that the most frequently number of granules of the near order for each chosen granule are 5. Symmetry of the fifth order (pentagonal, which usually have quasicrystal) can testify to involving stochastic processes in films formation.

Films, which were expose only at Taylor and glow cleaning discharges, have no globularity of surfaces.

The analysis of films structure.

Films investigation by Electron Paramagnetic Resonance spectrometer has shown a low level of spin anisotropy and high density ~ 10^{19} non-coupled spin per gramme, i.e. radicals, which are typical for amorphous carbon a-C:D films. Method of Infra-Red Reflection in the range of wavenumber 500 - 4000 cm-1 has shown presence in a films of a great number of free radicals CD_2 and CD_3 and aromatic group (hexagon with carbon and deuterium), peculiar to fullerene-like structure. Films luminescence spectrum research at their excitation by synchrotron radiation on accelerating ring "Suberia-1" and laser radiation has shown presence of peaks (fig. 2), many of which coincide with peaks C^{60} fullerene.

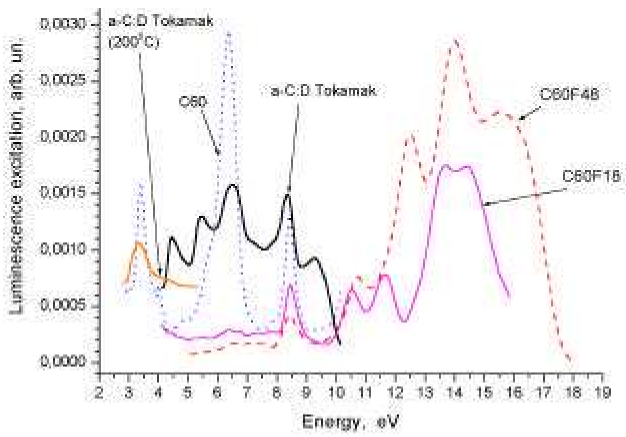


Fig.2. Films luminescence spectrum, excited by synchrotron radiation

Fractal properties of turbulent periphery plasma

It is natural to assume connection of globular films growth with parameters of plasma flux turbulence (Hurst parameter) (fig.3) near T-10 wall, which distinctive feature is the significant non-Gaussian distribution of fluctuations the amplitude of a SOL plasma parameters. Near to a tokamak wall on radius 34 cm, the turbulent particle flux is characterized by Hurst parameter H=0.62, that is process is not classical Brownian movement [5]. For comparison Hurst parameter of globular film surface topography is resulted. Thus, fractal properties (statistics) of a topographical surfaces of films and fractal properties (statistics) of periphery plasma fluctuations belong to one class of stochastic processes with Hurst parameter H>0.5. As the statistics of periphery plasma electric fields fluctuations – E, is non-Gaussian, then E×B drift of carbon ions (clasters) forms trajectories of movement, till the moment of aggregation, not as classical Brownian diffusion, but Levy movement with primary flyway trajectories. Such ballistic movement of sticking particles also defines the character of fractal films growth.

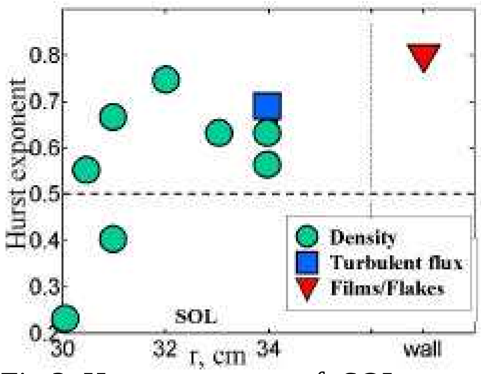


Fig.3. Hurst parameter of SOL turbulent plasma and globular films.

Model of Diffusion Limited Aggregation (DLA)

For an explanation of globular films growth the universal model - Diffusion Limited Aggregation (DLA), described process of fractal claster and films growth [6] is used. DLA - is one of the most important models of fractal growth, which is described by Laplace equation. It does not contain characteristic scale of length, and thus, the behaviour which it generates on one scale, can be reproduced on all other scales, leading to scale invariancy of process, to fractality. In standard model particles move randomly under the law of Brownian movement, there is a tendency of sticking of the next particle to claster edges. In result, the structure becomes an image similar to a snowflake, with the ramified branches.

Peculiarity of films deposition prosses in tokamak, in our opinion, consists in the non-Gaussian statistics of deposited particles, that is caused by statistics of plasma fluctuations (turbulent particle flux and electric fields) with Hurst parameter H > 0.5. For the description of globular films deposition process in tokamak the computer code has been developed on the basis of model DLA with application of Levy statistics of particle movement Hurst parameter H=0.5-0.8. The form of a claster surface, received during modeling, well denote on typical films peculiarity : globalarity, fractal structure, primary symmetry of the fifth order (pentagonal).

Summary

The fractality of films surfaces D=2.15-2.32 can indicate a high degree of porosity.

It is obvious, that the reason of globular films growth is periphery plasma T -10:

- In globular films there were a much of radicals CD_2, CD_3, OH find out, which are formed in reactions of oxygen with metane in tokamak boundary plasma. Also the fullerene-like molecules were detected, which demand of sufficient atoms reaction energy.

- Non-Gaussian distribution of global number from the it size on a films surface, obviously , is caused by non-Gaussian statistics of deposited particles (carbon, radicals or nanoclasters) from plasma, having the same statistics of turbulent particle flux near the wall and fluctuations of electric fields. Just as symmetry of the fifth order of global borders indiates on this point of view.

The results of globular films growth modelling point at the surface shape dependence from statistic parameters of boundary plasma. The best coincidence of the films surfaces shape and shapes of simulated global is ensue at inclusion Levy random movement in model.

The presented mechanism of films growth (aggregation), basically, is applicable to any impurity (from atoms or nanoclasters to dust), arrived from turbulent plasma. Obviously, that not only films porosity, but also the possible mechanism of tritium co-deposition with impurity and formations of stable chemical compounds within a films (for example, hydrogenated fullerenes) can create for ITER a serious problems.

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