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Observation of self-organized films structure in tokamak T-10 and plasma gun QSPA-facility

S.A.Kamneva[1], V.M.Gureev[1], L.N.Khimchenko[1], B.V.Kuteev[1], N.S.Klimov[2], V.L.Podkovyrov[2], A.M.Zhitluhin[2], B.A. Loginov[3]

[1] *RRC " Kurchatov institute ", Moscow, Russia*

[2] *SRC RF TRINITI, Troitsk, Russia*

[3] *MIET, Moscow, Russia*

Several years ago investigations of hydrocarbon globular films, deposited in the chamber of tokamak T-10 and having fractal structure of a surface have begun [1]. Similar films are also observed in others tokamaks. In these films the deuterium retention is extremely high, i.e. ratio D/C~1. Investigations of fractal structures of T-10 films carried out in a micron size range have shown that a globular film consists of globules with smaller size, which in one's turn consists from similar particles of 10-15 nm size. The films have high porous structure and large developed surface. The globular/fractal mechanism of growth and structuring of films leads to significant accumulation of working gas into the films and what is the most dangerous - to retention of tritium in ITER. Therefore, it is very important to have the information about the films surface and dusts structure in nanoscale range.

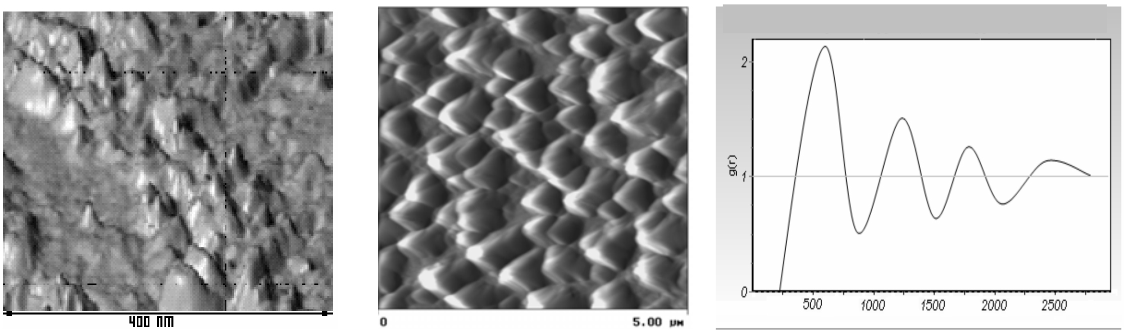
Scanning tunnel (STM) and atomic-force (AFM) microscopes are unique diagnostic devices, which were used for films surface analysis in nano range. They allow one to observe objects with the resolution of the order of a few angstroms, and also to obtain detailed information about the surface roughness and nanoclusters structure. Investigation by STM and AFM of various types of films collected from different parts of the tokamak T-10 vacuum chamber have shown that the film's surface is covered by nanoclusters and nanocones, with the characteristic size 10 - 30 nanometers [2]. In some cases nanocluster structures were aggregated in ridges with a characteristic step between them of 10 - 40 nanometers. Many theoretical and the experimental researches, which are carried out in the field of surface physics, explain formation of such structures by self-organizing of particles or clusters on the surface [3] [4].

Ordering structure in the fractal films surface has been observed in plasma gun QSPA-facility that was used for simulation of ITER ELM I type energy load. The study of this structure by STM has shown, that they consist of nano particles with a size about 20 nanometers. In the film's structure, the granules size distribution is fitted by power law i.e. $N \sim r^{-D}$ [5]. This means that to contribute significantly to a dust distribution in ITER can bring in nanoparticles with large sorption surface.

Self-organizing of particles on a surface

The experiments with deposited films were carried out in tokamak T-10. Films had a hydrocarbon composition, which was formed as a result sputtering the graphite limiter by plasma. The particles flux on elements of the chamber and a limiter reaches value of 10^{15}-10^{16} part/s resulting a monolayer of deposited particles after two discharges.

Earlier, when we tested the miniature STM on T-10, we observed initial growth of hydrocarbon film on the pyrolytic graphite sample. Before plasma exposure, it was a surface with nearly 1 nm roughness. After 10 shots we found the nanocones structure consisting of (Fig.1a) 20 nm cones on the sample, with displacement separately each other. After 30 shots there was integration of the cones into longitudinal mountain ridge-like structure. Later we repeated similar experiments in T-10 on films deposition onto the high orientation graphite samples. In (Fig.1b) structure which was deposited during 30 plasma shots is shown. It seen that the film consists of 200 nm cones, which, in one's turn consist from 20 nm cones. Summing up we may suppose that the initial stage of a surface growth is determined by formation of stable nanoparticles which size is 20 nanometers.



a b c

Figure 1. AFM image of deposited films after 10-th shot in T-10 2000 (a), after 30-th shot 2005 (b). Pair correlation function (c) for (b) structure.

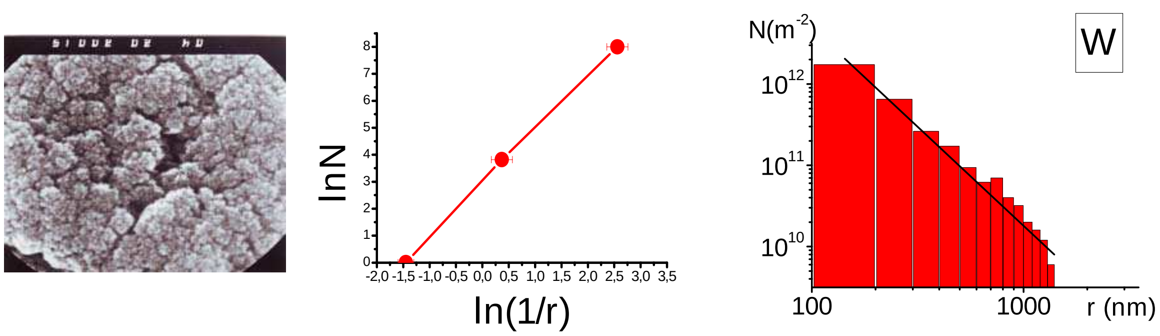
The phenomena of self-organizing of particles on the surface are widely investigated in the physicist of thin films. Phenomenon of surface structuring are explained by effects of self-organizing of particles or clusters on the surface. As known, self-organization on the surface is a stationary state with regular structure on the surface after spontaneous and non-equilibrium processes in open systems. That is such conditions are created, at which surface itself aspires to creation of the ordered structures. Structuring may change properties of the surface, such as reflection of particles from a surface (recycling), adsorption, thermo and auto electronic issues, conductivity, optical properties. Taking into account these properties may change representations about particles and energy balance in ITER diverter. For the description of these structures the pair correlation function – PCF, was used. It is defined as $g(r) = \frac{1}{\sigma}\frac{n_{2d}(r,\Delta r)}{2\pi r \Delta r}$; where σ is the specific density of nanocones at a surface. PCF defines the probability to find a particle within radius r and r+Δr. The function is presented on Fig.1c. It looks closer to the PCF of a crystal rather than for a disordered structure. Ordering with typical scale of 300 nanometers was evaluated from the pair correlation function. The experiments, which have also shown formation of nanocones were performed in the operating conditions when the particles flux to the wall was 10^{15}-10^{16} particle/s.

As was found from the experiments globular films have an ordered structure. Comparison of the pair correlation function of films deposited in T-10 vacuum chamber during 1 day and 3 months have shown that a structuring does not change with film growth. Moreover, after long exposition, the films surface becomes fractal from lattice-like keeping the orderliness for each level of fractality.

Fractal surfaces of re-deposited films.

A different type of re-deposited films structure was served from sputtered CFC and tungsten samples in plasma gun QSPA-facility that was used for simulating ITER ELM I type [4]. The targets were irradiated in a series of repetitive plasma shots (up to 100) with energy density equal to 0.5 - 1.6 MW/m^2 and duration of 0.5 ms was o. In experiments was observed a formation of fractal dust ("cauliflower" type) both for tungsten and for the CFC. Study by SEM has shown that the shape of these particles is irregular with size in the range of 0.1 - 3 micrometers (Fig. 2a).

The typical size of the dust particles is in the range of 20 nm - 3.0 microns. In the film's structure, distribution of granules over scales is fitted by power law N~ r^{-D} (Fig.2c) with significant contribution nanoparticles. For CFC and tungsten α ≈ 2.2 and 2.3 respectively.



a b c

Fig.2 – (a) dust particle, (b) fractal dimension, (c) power law dependence N~ r^{-D}

Particles size distribution shows that a significant part of particles is located in nanoscale range. Each particle has fractal structure, i.e. the same power-law distribution. For tungsten and carbon films (dust films) surface the fractal dimension is of D=2.19 and 2.30 respectively (Fig.2b). Using these data we can evaluate the specific sorption area (SSA) of tungsten dust in QSPA. Every fractal particle consists from 10-15 nm nanoclusters, which number equals $N = \left(\frac{r_{cl}}{a_0}\right)$ r_{cl} – radius of fractal particles. If a_0=10nm then SSA$\Rightarrow$

$$\frac{S_0}{\rho V} = \frac{\int_{a_0}^{r_{\max}} Ar^{-\alpha} 4\pi a_0^{\,2}\left(\frac{r}{a_o}\right)^d dr}{\rho\int_{a_0}^{r_{\max}} Ar^{-\alpha}\frac{4}{3}\pi a_0^{\,3}\left(\frac{r}{a_0}\right)^d dr} \approx \frac{6}{\rho d_0}$$

As a result we get 15 m^2/g. Investigations of QSPA films allowed leading quantitative estimations of capture tritium in ITER.

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