FORMATION OF FRACTAL SUBSTANCE IN THERMONUCLEAR FACILITIES WITH HIGH HEAT FLUX TO MATERIALS

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When designing a thermonuclear reactor, it is very important to choose from the experimental results those that will really play a significant role. Further study of the ITER project has shown that the interaction of plasma with the materials of the First Wall and divertor plates plays a major role in achieving reactor parameters. The example of the beryllium wall of ITER shows how changing one structural element can affect the achievement of project goals. Therefore, a comprehensive study of the material behavior under ITER level energy flows is the basis for the correct calculation of a thermonuclear reactor.

For example, earlier [1], [2] it was shown that even in the T-10 limiter tokamak, such a quasi-stationary mode was found with the plasma shifting inward, when an ITER level flow of 50 MW/m2 was released to the limiter. The testing were conducting on graphite and ITER-grade tungsten. In both cases, powerful arcing occurred, which was the main reason for material sputtering.

On the Tokamak T-10, it was found that graphite dust deposited in the lower part of the vacuum chamber has the form of agglomerates. The size distribution of dust corresponds a power law in the size range of 20-200 nm with a fractal dimension of D = 2.3. At the same time, the deposited carbon films also had a fractal structure (Fig.1) with the same fractal dimension. A study of the films structure at a synchrotron accelerator (SI) has shown that they have an affine structure in fractal complexes up to ~30 nm in size, forming an open porosity, due to which the films have a high absorption capacity. [3]. In experiments with a tungsten limiter, the molten tungsten crystallized with dendritic structures.

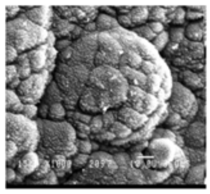

Fig.1. Carbon fractal clyster.

Experiments on tokamaks have shown that the main problem for reactor materials are non–stationary phenomena - instability of the boundary plasma - ELMs, horizontal and vertical disruptions, runaway electrons. In this case, the melt parameter can be exceeded by an order of magnitude. And if disruptions can be prevented with a certain level of plasma control, but ELMs are an integral part of improved confinement.

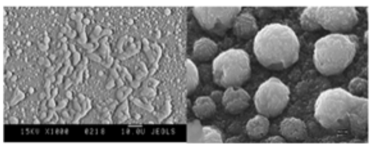

Fig.2. Tungsten fractal clyster.

Experiments on plasma-gun QSPA, simulating the sputtering effect of ITER ELMs on beryllium, graphite, and tungsten have shown that the re-sputtered material forms identical structures, independent of the type of material. Namely - fractal, dusty clusters consisting of "protoparticles" with a minimum size of about 15-30 nm, the number of which in a cluster is 10-50 thousand (Fig.2). The distribution of such dust particles correspondent the power law $N(r)=kr^{-D}$, where r is the characteristic size of the cluster, and D=2.3. The analysis of the distribution of "protoparticles" in one cluster led to the same law and the same fractal dimension.

Modeling of the formation of such a structure by the DLA method showed that such structures can obtain with high mobility of "protoparticles" on the cluster surface and the non-diffusive, turbulent nature of fluctuations in space.

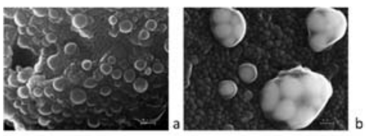

Fig.3. Protoparticles: a) tungsten and b) beryllium.

The high mobility of the re-sputtered material on the material surface was confirmed in the experiment. The impurity ion gathers turbulent, "non-Gaussian" statistics in the peripheral plasma before exiting and being neutralized on the first wall and divertor materials. Modeling also showed that such fractal structures have a developed sorption surface and porosity, which leads to strong sorption properties. For example, experiments have shown that the sorption surface area (SSA) of tungsten films with a fractal structure has 40 m^2/g.

The presence of a large sorption surface also means a large internal energy of the clusters. Due to this energy, fractal material can switch to another aggregation state even with minor impact. The experiments with tungsten fractal film showed an order of magnitude lower sputtering coefficient compared to polycrystalline tungsten. This experiment also showed other unusual properties of such films. Despite the low power of sputtered argon beam – 7 W/cm^2, the surface of the tungsten film melted, forming whiskers with a monocrystalline structure. Spontaneous crystallization of fractal clusters also occurred.

The formation of fractal matter is difficult to explain without involving the formation of **Rydberg atoms**. In our case, these are "protoparticles" (Fig. 3).

Then the explanation is on the surface: when sputtered atoms pass through the plasma, they ionize and gain turbulent statistics. During deposition and recombination, atoms can maintain an excited, metastable state. I.e., **Rydberg atoms** appears, in which the outer electron shell is locate by a considerable distance from the nucleus [4]. Due to their increased size, atoms cannot "integrate" into the crystal lattice and, therefore, having increased surface mobility and a significant lifetime in this state, they merge with similar excited atoms into clusters. One giant cluster is formed, in which the electrons of the upper shells can move to the excited orbit of a neighboring atom. Due to the effect of "surface tension", Rydberg atoms assemble into peculiar molecules, with a number of 10-50 thousand atoms. At the same time, the lifetime of such giant cluster, is some orders of magnitude longer than the lifetime of a Rydberg atom.

That is, a fractal substance is a Rydberg substance.

In ITER, such porous structures can absorb a significant portion of tritium. Even highly porous films trapped in various gaps can be a good conductor of electric current. In addition, modification of sprayed tungsten films can lead to the formation of coatings with uncontrolled properties. For example, the melting of tungsten films and the formation of monocrystalline whiskers can lead to intensive arcing.

And the study of Rydberg matter has the fundamental scientific importance.

For technological purposes, fractal matter has great prospects for obtaining materials with a new composite structure, which cannot be obtained by chemical or traditional methods of metal science, since plasma sputtering creates conditions with high exited energy per atom.

The above phenomena have a high potential for the development of new promising plasma technologies for the production of new materials for thermonuclear and thermal energy, as well as for applications in aerospace engineering and biomedical technologies.

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