Stochastic clustering of material surface under high-heat plasma load in fusion devices

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Materials of various chemical composition and initial crystalline virgin structure (tungsten, carbon materials and stainless steel) have been studied after the irradiation by high heat plasma fluxes in nuclear fusion facilities [1]. High-temperature plasma load on the plasma facing material in fusion devices during transients (disruption, ELMs, VDE etc.) produces several multiscale effects including surface erosion, redeposition of eroded materials, melting and melt motion over the surface, inhomogeneous solidification leading to specific surface clustering conditions which are strictly different from any other conditions of solidification and clustering of materials previously analysed. This study has demonstrated evidences of inhomogeneous stochastic clustering of the surface with properties of the self-similarity of granularity from nano- to macroscale. In particular, the hierarchical granularity and self-similarity with cauliflower-like shape of tungsten surface have been revealed for the first time. The clustering of materials irradiated by high-temperature plasma qualitatively differs from the ordinary Brownian surface roughness and from clustering under other conditions. This difference is shown by comparing the results with those for the molybdenum sample after exposure in the magnetron plasma discharge and for the industrial steel casting with the ordinary roughness formed typically at solidification after melting. The specific property of material solidification and clustering under plasma influence in fusion devices is due to a material's (ions, clusters, melt on the surface etc.) motion under the influence of stochastic electromagnetic field formed by the near-wall turbulent plasma. This field ensures memory effects, long-term correlation and conditions for the growth of agglomerates with a self-similar structure [2, 3]. In addition to such a process, effects of irregular motion and relaxation of the material (melt) on the surface contribute to the process of clustering at the extreme heat load on the material surface. These multiple effects are responsible for the fractal growth mechanism at scales from several tens of nanometers to hundreds of microns [2, 3]. Collective (synergistic) effects, rather than the specific physical and chemical properties of the virgin materials, dominate in such stochastic clustering. The reported experimental results possibly indicate universal mechanisms of stochastic clustering of materials under the high-heat plasma load in a fusion device. The quantitative characteristics of the statistical inhomogeneity of such surface structure, in particular, the broadening of the multifractal spectrum by 0.5–1.2, are in the range observed for typical multifractal objects in nature. The work was supported by the Grant RSF № 16-19-10531.

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