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Nano-tendril bundles behavior under plasma-relevant electric fields

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Plasma-wall interaction is one of the most critical factors determining plasma parameters in fusion devices. Plasma parameters, material properties, and morphology of plasma-facing components (PFCs) determine this interaction. PFCs must satisfy the needed requirements, such as operation under high thermal and particle irradiation. In the case of tungsten (W) PFC, its surface morphology may change under helium plasma impact, which results in the formation of helium bubbles [1], tungsten fuzz growth [2], or the formation of nano-tendril bundles (NTBs) [3]. The change in the PFCs morphology can dramatically influence the plasma-wall interaction. The appearance of tungsten fuzz increases arc ignition probability [4], leading to an enhanced erosion of PFC.

NTBs are intertwined fibers of fuzz that grow on a tungsten surface at temperatures from 870 to 1300 K due to irradiation of helium plasma that contains impurities (e.g., Ne, Ar, N2) with incident ion energies from 70 to 350 eV [5,6]. These structures can reach a height up to 100 μm with a tip radius of 10 nm and a bottom radius of 10 μm. If these structures cover the surface of PFC, the electric field near NTBs tips can be significantly enhanced. A strong local field can lead to the initiation of field emission from the surface covered by NTBs. As these structures consist of fuzz fibers, they are easily overheated due to the reduced thermal and electrical conductivity [7]. The rise of the structure's temperature due to Ohmic heating by the field emission current can lead to the initiation of thermofield emission, in which current density is higher than both thermal and field separately. Further avalanche-like rise of emission current can initiate an explosive emission with NTBs destruction and erosion of the surface.

In this work, we studied the behavior of NTBs under external electric fields experimentally and with computer modeling. Experimental results were obtained in the vacuum diode. We found that the emission current from NTB samples can reach the value of several 100 μA depending on the geometry of structures. Additionally, experiments revealed the electric field critical value's existence, reaching which led to the destruction of the main emitters on the sample. The modeling was used to study the behavior of a single NTB with different geometries under an externally applied electric field. The Laplace equation was solved for the determination of electric field distribution. The time-dependent heat transfer equation, including Joule heat source, radiation losses, and Nottingham effect, was investigated to study the possibility of the destruction. The obtained results show the possibility of NTBs destruction under plasma-relevant electric field leading to increased erosion.

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