Will tungsten fuzz form in ITER?

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It is now well-known that under exposure to a helium (He) plasma at elevated temperatures, a tungsten (W) surface is modified by the growth of a fibreform nano-structure referred to as "fuzz". Formation of W fuzz occurs when a specific set of conditions are met such as surface temperature (900 K$<T_{surf}<$2000 K), ion energy ($E_{ion}>$20 eV) and fluence ($>10^{24}m^{-2}$). Over the years, concerns have been raised that, should fuzz form on the W divertor targets in ITER, it might have adverse consequences for material lifetime and plasma contamination. These concerns include the risks of exfoliation of this fragile nanostructure and the possible increased probability of unipolar arcing, both of which could lead to enhanced dust formation and W release to the plasma. The key open question remains, however, of whether or not fuzz will actually form in ITER.

To identify areas where fuzz formation conditions could be satisfied, the ion flux and energy, and surface temperature profiles along the high heat flux regions of the divertor targets are calculated using a range of SOLPS simulations covering a range of plasma scenarios, from pure He discharges during non-active operations to high power D-T discharges,. Since fuzz formation is hindered by beryllium (Be) deposition, the output from WALLDYN simulations is used to identify Be-free regions. To include the effects of Edge Localized Modes (ELMs), the equilibrium growth model proposed in [1] is extended to take into account ELM-induced erosion and the effect of the transient temperature excursion. In addition, both the decrease of fuzz erosion rate and thermal conductivity with increasing thickness are treated consistently.

Fuzz formation appears possible at the outer target over a poloidal extent of 4-9 cm, while the inner divertor target appears to be deposition-dominated. Assuming that the peak temperature during ELMs does not exceed the value at which annealing is observed (~2200 K), it is found that the ELM-induced transient heating only leads to a 15% increase in the fuzz thickness. For a prompt re-deposition fraction of ~99.9%, as in [2], ELM-induced erosion appears too weak to play a role. The main finding is that as fuzz grows thicker, its thermal conductivity decreases and peak temperature attained during an ELM increases. Given the competition between growth and annealing rates, a critical thickness exists above which fuzz annealing dominates for a given ELM energy. For T_{surf}=1200 K, a maximum thickness of ~2 μm is determined for E_{ELM}=0.1MJ.m^{-2}, while no fuzz formation appears possible for $E_{ELM}>$0.5MJ.m^{-2}. The higher the base temperature, the lower the ELM energy density beyond which no fuzz formation is possible.

The existence of a critical fuzz thickness effectively decreases fears of macroscopic surface erosion and arcing, while the very fast annealing of the fuzz at elevated temperatures relaxes the concern of enhanced material losses during arcing.

[1] R.P. Doerner et al, Nucl. Fusion 51 (2011) 043001

[2] D.P. Coster , et al. , Proc. of the 40th EPS Confer- ence on Plasma Physics, Espoo, Finland, 2013, volume 37D, European Physical Society, ECA, Geneva, 2013, p. P1.104