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Lifetimes of Boron layers on amorphous and crystalline tungsten under deuterium and impurity irradiation

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The most prominent aspect of the recent ITER reconfiguration, the switch from beryllium to tungsten for the blanket first wall armour, is also the most challenging modification in terms of impact on the ITER Research Plan [1]. A higher tungsten source means higher potential W-contamination of the plasma. It can thus be an obstacle to reliable plasma start-up which, in most tokamaks including ITER, is performed by establishing the plasma in a configuration that is in direct contact with the main chamber walls. Wall-conditioning via Boronisation has been suggested to reduce the tungsten impurity concentration in the plasma and has been applied successfully in several mid-size tokamak devices such as ASDEX-Upgrade [2]. Key parameters influencing the performance are the lifetime of the boron layers on top of the tungsten first wall surfaces and their effective surface coverage. Since the relative importance of these two factors is still a matter of debate [3] we address both using the binary collision code family SDTrimSP. The lifetime of a given boron layer is determined by the incident flux of deuterium atoms and the sputter yield of boron by deuterium. The sputter yield is a nonlinear function of the thickness of the boron layer as well as of the energy and angular distribution of the impinging deuterium atoms. It also depends on the material structure of the tungsten substrate and the surface topology. Here we investigate in detail using static and dynamic simulations with SDTrimSP 7.03 how the sputter yield depends on the deuterium impact angle, impact energy and tungsten solid-state structure. The simulation results reveal that the common but often unrealistic assumption of a fully amorphous tungsten substrate consistently yield a too pessimistic picture of the lifetime of thin (O(deuterium range)) boron layers. For the main W crystal orientations of ITER grade tungsten the lifetime for these layers is typically 40% - 100% larger compared to the amorphous case. A similar picture emerges if the boron layer surface coverage of corrugated surfaces (i.e. technical surfaces with 1D grooves) is simulated using SDTrimSP-2D. Even small surface corrugations (e.g. sinusoidal groove profiles with a root mean square roughness of 7.5 nm) yield a significantly reduced depletion rate (by a factor of 5 and more) of the boron surface coverage compared to the case of an atomistically flat surface. The addition of heavier impurities such as oxygen or neon to the incident flux change the quantitative results but do not alter the qualitative conclusions. Therefore, the kinetic simulation results (i.e. without considering potential effects of boron chemistry) suggest that boron deposits will have a longer lifetime than predicted by from 1D simulations based on the assumption of a flat, amorphous tungsten substrate.

[1] R. Pitts, presentation at E2M-workshop, Kloster Seeon (2024), https://www.iter.org/node/20687/iter-and-asdex-upgrade-monastic-quiet
[2] K. Krieger, M. Balden, A. Bortolon et al, Nucl. Mat. Energy 34 (2024) 101374
[3] V. Rohde, R. Dux, A. Kallenbach et al, J. Nucl. Mat. 363-364 (2007) 1369-1374