The competition between metallic nanostructure formation, erosion and co-deposition in He plasmas of the tokamaks ASDEX Upgrade, EAST, and WEST

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In particular in linear devices, the interaction of helium (He) ions with tungsten (W) can lead to the formation of W nanostructures or so-called W fuzz under specific plasma and surface conditions (He impact energy >20eV, W surface temperature >1000K, He fluence > $10^{24}m^2$). In ITER nanostructure formation conditions can potentially be met in the W divertor. Indeed a competition between W nanostructure formation, W nanostructure destruction by either erosion or annealing, and co-deposition by impinging beryllium (low-Z material) from the first wall can occur under He bombardment. A model for the interplay of W nanostructure formation and destruction has been developed, and predictions for the ITER He/H start-up as well as for D-T plasmas were made.
In order to provide benchmark cases for the model, a series of tokamak experiments were carried out in ASDEX Upgrade (AUG), EAST, and WEST with exposures of fusion-relevant metallic samples in He plasmas under L- or H-mode conditions. Initial studies investigating W nano-structure processes in tokamaks were performed earlier in TEXTOR, CMOD, and AUG, but these plasmas suffered either from insignificant contribution of intra-ELM W erosion by He ions, the dominant sputtering process in H-mode with semi-detached divertor, or from a high low-Z impurity concentration in the plasma. To investigate the particular role of intra-ELM sputtering, dedicated H-mode plasmas with significant ELM impact were executed on W samples installed in the AUG divertor manipulator and on Mo samples installed at in the EAST midplane manipulator. Complementary, W-coated plasma-facing units in WEST were exposed to high He fluence at the end of the initial operational phase under W nanostructure formation conditions.
The AUG W samples were pre-exposed either in the neutral beam facility GLADIS to a He/H mix or in the linear plasma device PSI-2 to He providing different degrees in surface morphology changes ranging from He nanobubbles to fully developed W fuzz. Pre-characterisation of the morphology was done by using FIB cuts and SEM cartography to permit a one to one comparison following the tokamak exposure. The competition between W fuzz formation and destruction along the impinging ion flux and temperature profiles at the outer target plate took place in L- and H-mode plasmas with spatially well separated strike-lines for under conditions for W nanostructure growth. Indeed, W fuzz formation was observed under ELMy H-mode conditions in particular within the FIB cuts around the strike line position, but also W erosion, surface smoothening, and deposition by W and low-Z materials at other locations occurred. The role of W deposition by W influx from the main chamber and co-deposition of residual C and B in AUG will be addressed.
Complementary studies on Mo samples, pre-exposed to PSI-2 He plasmas and providing a thick Mo fuzz, were done in two separated EAST experiments in either L- or H- mode. Post-mortem analysis revealed little impact of the L-mode plasmas on the surface morphology and insufficient sputtering of the samples by impinging He ions and charge exchange neutrals. However, complex modifications in H-mode plasmas occurred as revealed post-mortem by SEM and NRA. The important role of low-Z co-deposition (e.g. Li and C) on the evolution of the nanostructures in the magnetically diverted EAST discharges will be discussed. All these tokamak results will feed into predictions of a potential existence window for W fuzz formation in ITER during its different phases of operation with He plasmas or with He ash from DT fusion reactions.