Microscopy study of the growth and erosion of fuzz on tungsten by helium plasma exposure in ASDEX Upgrade

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Tungsten (W) will be used as plasma-facing material in the ITER divertor due to its superior properties leading to good power handling, low fuel retention and low sputtering. Its advantages have previously been demonstrated in hydrogen and deuterium plasmas, e.g. in JET and ASDEX Upgrade. However, helium (He) plasma operation is considered in the start-up phase of ITER, which might lead to microscopic changes in the W divertor as observed for various He exposure conditions in laboratory studies. Helium can form bubbles in W and subsequently under the right conditions, a nano-fibrous surface layer, referred to as W-fuzz. In order to assess whether and to which extent this happens in a tokamak environment and how preformed W-fuzz survives under high power loads, a dedicated experiment was performed during the He plasma campaign of ASDEX Upgrade.

The effect of He bombardment on a W-fuzz surface was studied by exposing a set of 12 pre-characterized and partially He pre-exposed samples to a series of 10 H-mode and 6 L-mode He plasma discharges. The samples were arranged in two poloidal stripes embedded in a dedicated Mo-coated W divertor tile, and two strike-line positions were used to separate the L and H-mode exposures. He pre-exposed samples (with fuzz or only roughened) were prepared in the high heat-flux neutral beam test stand GLADIS (Garching) as well as in the linear plasma device PSI-2 (Jülich). The pre- and post-exposure surface morphology and composition was analyzed in detail by scanning electron microscopy combined with energy-dispersive X-ray spectroscopy and focused ion beam cutting.

The analyses revealed that: (i) Above the H-mode strike line in the scrape-of-layer (SOL), where the samples reached the maximal surface temperature, new fuzz has been formed with a thickness of a few hundred nanometers. Its microstructure shows no significant lateral variation and is independent of the initial surface structure before AUG exposure. (ii) Directly at the H-mode strike line, ~200 nm of the initial W-fuzz structure on He pre-exposed samples has been eroded. (iii) At and below the H-mode strike line, strong arcing occurred on the sample with a thick pre-established W-fuzz layer. The arc traces reduced, however, the fuzz thickness only slightly. (iv) At the strike line of the L-mode sub-series (~7 cm below that of the H-mode sub-series), only marginal erosion and slight deposition is observed on He pre-exposed samples. (v) Thickness and composition of deposited material varies with poloidal position, with a maximal thickness of 1 µm. The deposited material is formed predominantly of W from other areas in the divertor and main chamber (with some additions of Mo and Ni+Fe).