Interdependent effects of multiple plasma impurities on the fuel retention in tungsten

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Hydrogen fuel retention is a crucial issue for the availability of a fusion reactor. The retention in tungsten in known to depend on i.e. material structure, surface temperature T_s, incident ion energy E_i, flux and fluence. Plasma impurities, such as helium produced in nuclear reactions or gases used for the edge plasma cooling, can also have significant effects on the fuel retention. Systematic studies of the individual influence of helium, argon, neon and nitrogen on the deuterium retention in tungsten were recently performed for a range of T_s of 500-770 K and impurity fractions of 3-10% [1]. The incident ion flux and fluence were ~10^{22} $m^{-2}s^{-1}$ and ~1×10^{26} m^{-2}, respectively. The prominent effect of helium reducing the D retention by a factor of 3-100, with a stronger reduction at higher T_s, was confirmed. In contrast, nitrogen had a strong impact increasing the retention by a factor of ~10 and ~100 for 500 and 770 K, respectively. The effects of argon and neon were similar when E_i is well above the sputtering threshold. At T_s = 500 K, both impurities increased the D retention by a factor of 2-4, while at 770 K their effect was the opposite. When E_i approached the sputtering threshold, and sputtering became less dominant, neon reduced the D retention also at 500 K.

Observations in [1] suggested that D retention is sensitive to the conditions of the surface layer of a depth comparable to the D implantation range. He nanobubbles produce a porous layer which opens additional pathways for D to escape thus reducing the D retention. Exposure to nitrogen results in the formation of a tungsten nitride layer with a thickness less than the D implantation range. The reduced D diffusivity in the W-N layer hinders the release of implanted D, resulting in a higher D retention. The effects of Ar and Ne can be understood as a combination of (i) the formation of additional lattice defects in the surface layer serving as a D release barrier, (ii) sputtering and (iii) D precipitation triggered by impurities.

In this work, we extended the studies towards the dual effects of simultaneously present impurities. At the conditions similar to [1], recrystallised tungsten samples were exposed to D+He+Ar, D+He+N and D+N+Ar plasmas in the linear plasma device PSI-2. For every exposure condition used, the reference case of pure D plasma was also investigated. The D retention was measured by thermal desorption spectrometry and nuclear reaction analysis.

At T_s = 500 K, while the addition of He reduced the D retention by a factor of ~3-5 and Ar increased it by a factor of ~2-3, D+He+Ar reduced the retention compared to the pure D case by moderate 40%. It appears that the strong positive effect of He was overridden by Ar, which sputtered the He nanobubble layer. The positive effect of He also vanished when N was added (D+He+N plasma), with the D retention remaining at the level of the pure D exposure. Sputtering is presumably also the reason for a significant influence of argon on the effect of nitrogen. At T_s = 800 K, while nitrogen increased the D retention by a factor of ~100, for D+N+Ar the rise of retention was 2-3 times less strong.

[1] A. Kreter et al., Nucl. Fusion 59 (2019) 086029