

The effect of bulk microstructure and hydrogen specie on deuterium transport in tungsten

Wednesday 4 December 2024 09:50 (20 minutes)

Implantation of energetic hydrogen ions, charge exchange neutrals and displacement damage creation by neutron irradiation will occur simultaneously during operation of a real fusion reactor. All this will have consequences on crystal structure, hydrogen isotope (HI) retention and transport that we do not yet understand sufficiently well in order to predict tritium loss in future fusion reactors. There tritium self-sufficiency is one of the vital prerequisites for a stable operation. We have studied isotope exchange in displacement damaged W and the influence of the kinetic energy on deuterium (D) uptake into a tungsten foil and its dependence on temperature.

We have studied isotope exchange on displacement damage tungsten at 370 K. The exchange was studied on recrystallized polycrystalline W sample that was first irradiated by 20 MeV W ions to create displacement damage down to 2 μm with a peak damage of 0.23 dpa. For the exchange study the sample was first exposed to 300 eV/D ions and then it was exposed to 300 eV/H ions at ion flux of $1\text{e}18\text{ D(H)}/\text{cm}2\text{s}$. One sample was exposed only to D ions to obtain the D transport dynamics in displacement damaged W. D depth profiles were measured during D or H ion exposure using 3He nuclear reaction analysis. From the D total amount as a function of the exposure time we can conclude that the exchange was slower compared to only D uptake, however H ion flux needs to be rechecked. The exchange was modelled by macroscopic rate equation modelling using TESSIM code. From the simulation we could conclude that the exchange took place with two defects.

For the study of the influence of kinetic energy on D uptake, we have irradiated thin W foils by 20 MeV W ions on one side (downstream) and exposed the foils to D atoms of 0.3 eV energy and D ions with 300 eV energy on the other side (upstream) at 600 K and 700 K foil temperature. To prevent D atom or ion uptake on the downstream an additional protective Al_2O_3 (85 nm) layer with Ag (1 μm) spacer was deposited on the damaged side. We measured D depth profiles by NRA on the downstream side to track the permeated particles that were trapped in the damaged W layer. A very short "lag time" is observed in all cases. As expected, an increase in temperature to 700 K reduces the measured retention for the ion exposure due to thermal detrapping of D from the defects. Although this detrapping is also present for the atom exposure the higher temperature leads to a more efficient D uptake at the surface which leads to larger measured D retention as compared to the 600 K exposure. In both cases we observe no diffusion front visible but D concentration is raising within damaged layer homogeneously which could be explained by grain boundary diffusion. To study how the D uptake would take place when the native deep traps would be filled in the W foil before, we have first exposed the W foil to H ions at 600 K for 24 hours and then start to expose the foil to D ions and measure the D uptake at different exposure temperatures. In the case when D ion exposure took place at 600 K prefilling of deep traps in the W foil with H atoms speeds up the D uptake by more than a factor of 4. The exposure at 400 K did not result after 96 h any measurable D uptake. Macroscopic rate equation modelling was performed where in both cases the surface model was used where with ions an additional process of sputtering of adsorbed D atoms was introduced. We have obtained a good agreement with the experiment for the temperature behaviour, faster for atoms and slower for ions at 700 K. The D amount as function of exposure time was faster in the experiments compared to simulation taking diffusion coefficient from theory. With variation of the diffusion coefficient a better agreement between simulation and experiment was obtained but the obtained diffusion coefficient was higher than that from theory calculation.

Primary author: MARKELJ, Sabine (Jožef Stefan Institute)

Co-authors: KELEMEN, M. (Jožef Stefan Institute); PUNZON QUIJORNA, E. (Jožef Stefan Institute); PELICON, P. (Jožef Stefan Institute); SCHWARZ-SELINGER, T. (Max-Planck-Institut für Plasmaphysik, Garching); MANNHARD, A. (Max-Planck-Institut für Plasmaphysik, Garching); HODILLE, E. (IRFM, CEA)

Presenter: MARKELJ, Sabine (Jožef Stefan Institute)

Session Classification: Retention