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The influence of D presence on defect creation during displacement damaging of tungsten

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This contribution reports on the results of two different experimental strategies that were applied in recent years to study the effect that hydrogen isotopes (HIs) have during high energy collision cascades in tungsten. The aim of all these studies is to understand mechanisms that will prevail in a future thermonuclear device such as DEMO were displacement damage by 14 MeV fusion neutrons will be created in the bulk of plasma-facing materials while they are exposed to high fluxes of hydrogen isotopes at elevated temperatures.
In the first experimental strategy particle beam experiments were applied. To study the synergism between defects and HI, W samples were simultaneously irradiated by MeV W ions and exposed to low-energy D. The latter was either provided as a beam of atoms (< 0.3 eV/D) or low energy ions (300 eV/D) not to create any additional defects but only to decorate the ones that were created by the MeV tungsten ions. Quantitative 3He nuclear reaction analysis (NRA) was used to derive absolute deuterium concentrations in situ. Thermal desorption spectroscopy (TDS) was applied ex situ to derive detrapping energies. Experiments were conducted at different temperature ranging from 450 K to 1100 K. To get a measure for the evolution of defect densities with temperature the samples were afterwards additionally exposed to D at the lowest temperature in order to populate all the defects created beforehand. However, despite the fact that the two particle beams can be varied independently the synergism between the displacement damage and HIs cannot be directly inferred from the simultaneous experiments alone. This only becomes possible by a direct comparison with sequential experiments where displacement damage was first created in hydrogen free tungsten and only afterwards D was offered - conducted with the very same experimental parameters as the simultaneous experiments [1,2]. As a result, an increase in maximum D concentration by a factor of two was observed for the simultaneous experiment as compared with the sequential exposures for low temperatures, decreasing for higher temperatures and vanishing around 800 K.
In order to explain the observed results a new rate equation model was developed by coupling a displacement damage creation model with the kinetics of D transport and trapping. The model enabled us to explain the change in D concentration by the trapped amount of D during the simultaneous exposures. The increase of the defect density due to the presence of D was parametrized by a so-called stabilization factor and the number of defects populated by D [3]. The term 'stabilization' follows theoretical calculations predicting that trapped D in a vacancy prevents vacancy annihilation with self-interstitials [4] and, therefore, stabilizes the defect. The empirical model allows to predict HI transport and retention in the temperature range up to 1100 K for realistic first wall fluxes of up to 1019 m-2s-1.
In the second experimental strategy, multiple sequential W irradiations and deuterium (D) plasma exposures were conducted to show the influence the presence of D during displacement damage has. When displacement-damaged and D-decorated tungsten was again irradiated with 20 MeV tungsten and decorated with D an increase in defect density by nearly a factor of two beyond the saturation value known for irradiation of hydrogen-free tungsten was observed [5]. Repeating tungsten damaging and decoration for a third time, D retention increased further. Rate equation modelling of all three irradiation sequences using the empirical model developed for the simultaneous experiments mentioned above is capable of reproducing the experimental results and predicts a final saturation value for multiple W irradiation and D decoration cycles of 4 at.% for a D decoration temperature of 370 K [6]. In a recent study the influence of the concentration of D before the second damaging was varied. The defect density clearly increased with the initial amount of trapped D. Quantitative analysis revealed that for initial D concentrations cinit up to 0.76 at.% the final D concentration after the second W irradiation and D plasma loading is equal to cinit + c0,max, meaning the effect is additive. The same holds true also for the total D amount derived from NRA and TDS. Only for the highest initial D concentration of 1.8 at.% the final concentration is not additive but cinit + 0.8×c0,max in accordance with [3] indicating a saturation behavior at larger D concentrations.

References:

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