Simulation of Hydrogen Isotope Transport and Retention in He implanted Tungsten

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Tungsten (W) is recognized as primary candidate for plasma facing materials (PFMs) due to its excellent physical properties, such as high melting temperature, good thermal conductivity, low sputtering and low tritium retention rate. However, W PFM will suffer strong irradiation flux by hydrogen isotope (HI), Helium (He) ash and neutrons, which may result in radiation damage, bubble formation, and hence deteriorating the fuel retention problem. ITER requires the tritium inventory in the PFM to be controlled below 700 g for safety and economic reasons [1]. Therefore, the prediction and controlling of tritium (T) inventory in PFMs is a critical issue for future fusion devices.

In the fusion reactor, the helium (He) ash, as the production of deuterium-tritium reaction, will also be implanted into the PFMs accompanying with fuel particle. The coexistence of HI and He particles will complicate the retention problem mainly due to the formation of He-induced microstructure, as showed in Figure 1. Understanding the interactions of HI, He and He-induced microstructure is important to predict and control the T inventory.

In our previous works, a HIIPC [2] based on rate theory has been developed to simulate the hydrogen isotope (HI) transport and retention in tungsten (W) under low-energy HI particles irradiation. It found that the irradiation damage plays significant roles in the HI retention, and demonstrated the mechanisms of defects evolution as well as material surface effects on the retention [3,4,5]. However, the effects of He and He bubble on HI retention in W have been not taken into account in the previous simulation. Therefore, further developing the HIIPC is necessary for accurately estimating the T inventory in PFMs.

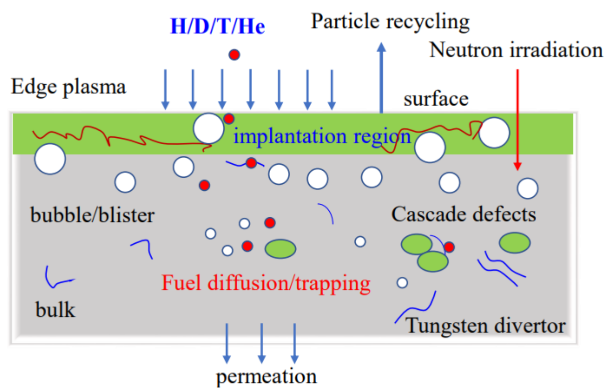

Figure 1. The interaction region of fuel particles with W PFM in the fusion environment.

In this simulation, a cluster dynamics module for describing He and Vacancy (V_1) evolution is developed and couple with the HIIPC to study the HI transport and retention in He-plasma implanted W. The upgraded code includes the processes of production, migration, capture, dissociation, clustering for three species (H, He and V_1). Firstly, the He and He bubble behaviors in He implanted W in the absence of HI is simulated. It is found that He bubble and He_mV_1 are formed in the implanted region. As He fluence increases, He bubble concentration is increased. When elevating the wall temperature, the formation of He_mV_n are observed. This is mainly due to that V_1 migration and clustering lead to the production of different size V_n, thus, He are trapped by V_n. To reveal the mechanism of He_mV_n growth, V_n clustering behavior is simulated. It shows that larger size V_n is created and then it is combined with He, thus leading to more stable He_mV_n. Then, the HI transport and retention in He implanted W is simulated to identify the HI behavior in W with the presence of He. The modeling shows that He induced bubble and He_mV_n in W play crucial roles in HI transport and retention. The formation of He bubble results in porosity in W, which affects the diffusion and retention of the fuel particle. It is also found that the stability of He_mV_n also changed the retention. With higher wall temperature, He_mV_n can be dissociated, and V_n concentration is also reduced, thus leading to the reduction of retention. These results provide useful references for predicting T inventory in future tokamak devices.

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