Modeling of wall material evolution and the impact on edge particle recycling for long pulse discharges in EAST

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The wall material evolution during EAST 400s long pulse discharges has been investigated by plasma-wall integrated modeling. The results reveal that a lithium (Li)-enriched layer can develop underneath the surface of the tungsten (W) material in divertor. This multilayered structure significantly influences local particle recycling processes, thereby affecting the distribution of edge plasma. The erosion and redeposition of plasma facing material (PFM) during long pulse discharges not only impact the edge plasma distribution but also determine the PFM's lifetime. This is a critical issue that fusion devices are facing and must be addressed before the construction of DEMO reactors.

An iterative simulation loop between OEDGE and SDTRIM.SP is established and used to simulate the material evolution during EAST long pulse discharges. In these simulations, the plasma computational grid is extended to the first wall, which allows a global wall material migration. The material evolution is simulated by SDTRIM.SP, utilizing the initial wall material composition derived from the LIBS measurement [1]. For each time step, the edge plasma distribution including impurities eroded from the wall is updated by the OEDGE code package. This provides the particle flux distribution along the wall, which is essential for the material evolution calculation. Under typical high-recycling divertor conditions of EAST, the divertor targets suffer net erosion, with the eroded materials depositing on certain areas of the first wall, as illustrated in Fig. 1. A detailed analysis of the material compositions reveals that during discharges with active Li injection, the plasma impinging can effectively erode the Li deposition on the divertor surface, leaving a W enriched layer at the top, which subsequently protects underlying Li from erosion. Li in the plasma can penetrate the material and deposit at several nm away from the surface, thus forming a multilayered structure. A similar W-B multilayered structure is verified by dedicated postmortem EDS analysis of the divertor target after recent EAST boronization experiments, as shown in Fig. 2.

During EAST 400s long pulse discharges, modeling results indicate that there exist periodic formation and diminishment of W-Li multilayers at some locations near the magnetic strike point on the divertor. As plasma impinges, the surface W enriched layer gradually diminishes, leading to a transition in the dominant surface material from W to underlying Li. This evolution of the material components can significantly impact the reflection and reemission of D on PFM [2]. As revealed in Fig. 3, although the total D recycling rate at EAST OSP is approximately 1 during the discharge, the D reflection and reemission rates fluctuate according to the evolution of material components. Unlike the D reemission, which releases D at an average energy equivalent to the wall temperature, the D reflection launches D at a much higher averaged energy even above 100 eV. Fig. 4 shows the n_e and T_e distribution for cases with the recycling D_0 energy equals the reflection energy and reemission energy respectively. The dynamic evolution of the D reflection energy and probability inevitably influences the particle recycling process and thus the edge plasma distribution. This phenomenon is evidenced by the corresponding variation of D_α and Langmuir probe data in EAST long pulse discharges. Modeling advances in this work demonstrated that it is essential to consider the wall materials evolution to obtain the accurate background plasma solution, especially for long pulse discharges.

Material evolutions are comparatively studied for EAST Li and B wall conditioning experiments. Results indicate that under typical EAST high-recycling divertor conditions, an initial 100 nm B coating on the divertor W surface can last for about 50s, more than two times longer than 100 nm Li coating. The phenomenon of periodic formation and diminishment of W-B multilayers also exists in the B active injection discharges, but compared to the Li active injection discharges, the influence on the particle recycling is smaller.

References:

[1] Hu Z., et al. *Physica scripta* 2017.T170 (2017): 014046.

[2] Long Q., et al. *Nuclear Materials and Energy* 41 (2024): 101840.

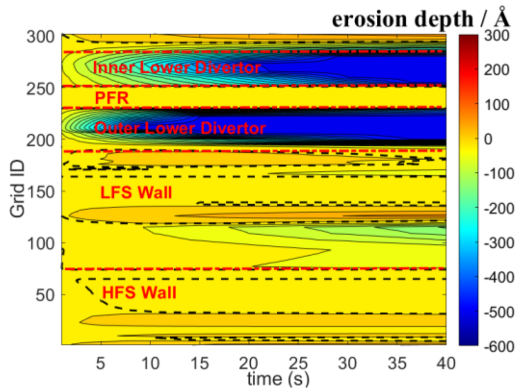

Fig. 1 The erosion and redeposition depth of EAST wall material during the discharge.

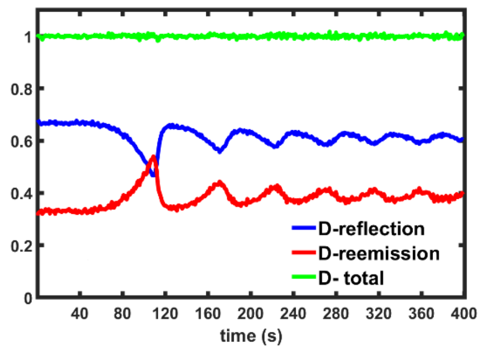

Fig. 3 D reflection, reemission and total recycling rates at the OSP during the EAST 400s long pulse discharge.

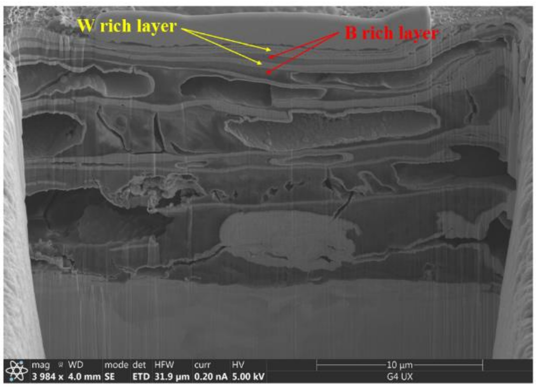

Fig. 2 The W-B multilayered structure detected by postmortem EDS analysis of the divertor target after EAST boronization experiments.

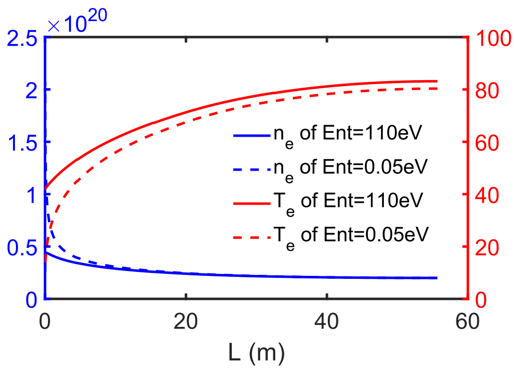

Fig. 4 n_e and T_e distribution along the magnetic flux tube for D_0 energy equals the reflection energy (solid lines) and reemission energy (dashed lines) respectively.