CONFERENCE PRE-PRINT

MODELING OF WALL MATERIAL EVOLUTION AND THE IMPACT ON EDGE PARTICLE RECYCLING FOR LONG PULSE DISCHARGES IN EAST

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Abstract

The wall material evolution during EAST 400s long pulse discharges has been investigated by plasma-wall integrated modelling. 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. During EAST long pulse discharges, modelling results indicate that there exist periodic formation and diminishment of W-Li multilayers at outer strike point (OSP) of 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 plasma facing material (PFM). 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. 1D simulation of SOL plasma with different recycling D^0 energy demonstrates that the D recycling energy can directly affect the plasma distribution. 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 particle recycling evolution on different wall locations has been investigated. Modelling 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.

1. INTRODUCTION

Edge particle recycling is believed to be one of the dominators that controlling the edge plasma distribution and shows great impact on the core plasma performance [1,2]. However, most of the particle recycling modelling focus on the steady-state plasma phase with the fixed wall materials [3-5]. In experiments, the global particle balance analysis indicates that the edge particle recycling rate varies during tokamaks long pulse discharges [6]. The steady-state modelling cannot reveal the dynamic particle recycling physics.

The basic D recycling process on plasma facing materials can be divided into three parts: the direct reflection, the slow reemission and the retention. Previous molecular dynamic simulations proved that the wall material components play a critical role in fuel recycling by influencing the processes of reflection, reemission and retention rates [7]. Therefore, evaluation of materials composition is the key for dynamic particle recycling study.

EAST is super-conducting tokamak with full metal wall. Lithium (Li) coating is a routine and effective way on EAST to reduce the edge particle recycling [8]. With plasma impinging, the erosion and redeposition of the Li coating inevitably affect the composition of PFM. Therefore, study of the Li coating evolution and the related impact on particle recycling is essential.

2. DYNAMIC MODELING OF MATERIAL EVOLUTION ON STRIKE POINT

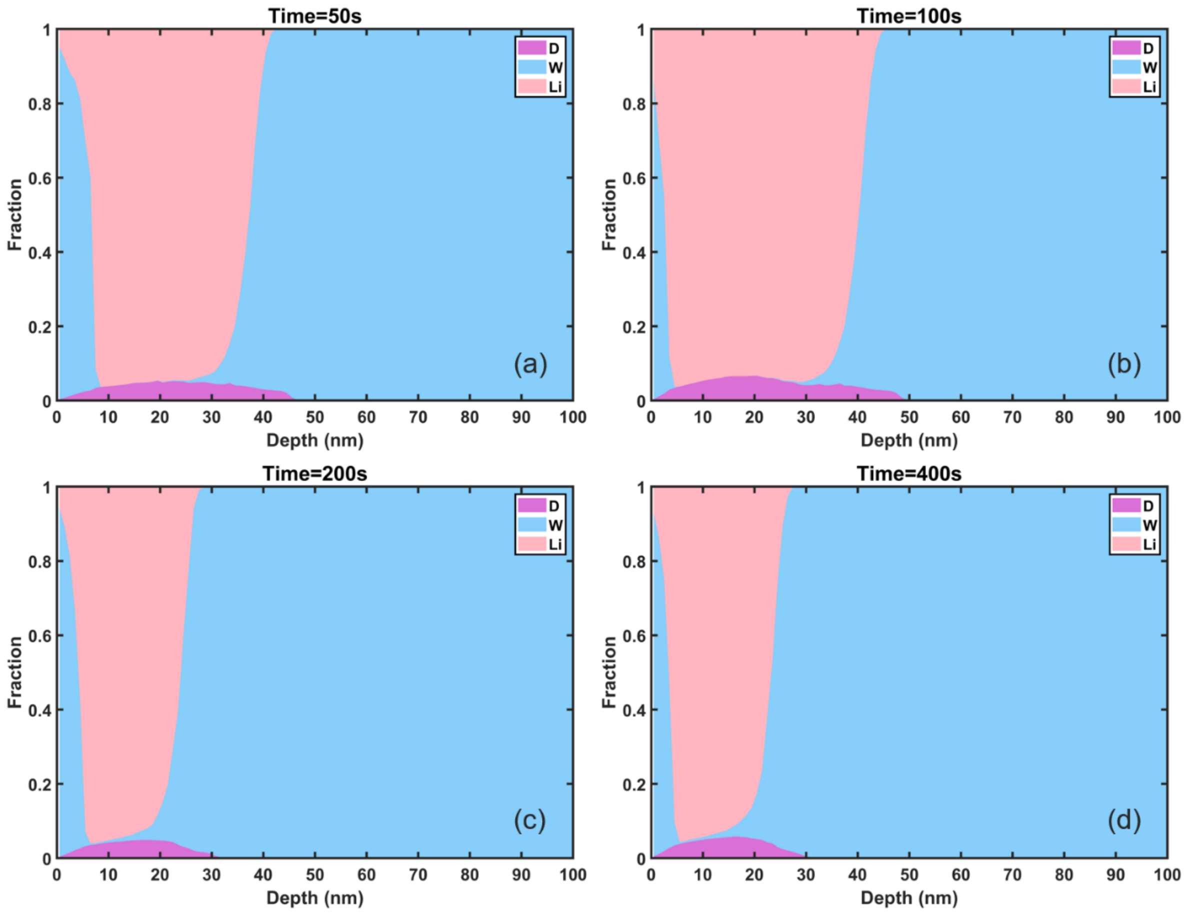

FIG. 1. The materials components evolution on the OSP of EAST for different time slides during 400s long pulse discharges.

SDTRIM.SP dynamic simulation has been carried out based on typical high recycling divertor plasma conditions at EAST OSP. The initial material is W. The total impinging particle flux density is $1 \times 10^{20}\ m^{-2}s^{-1}$ with 96% D and 4% Li. The impact energy is assumed to be $E_{imp} = 3ZT_e + 2T_i$, with $T_e = T_i = 30\ eV$ and averaged charge state Z=1. The material evolution under the plasma impinging for the 400s long pulse discharge is shown in Fig. 1. With Li impinging, Li cannot directly deposit on the W surface because of the strong erosion rate. Whereas Li can penetrate W and create a Li enriched layer under the W surface. W enriched layer at the top can protect underlying Li from quick erosion, leading to periodic formation and diminishment of W-Li multilayers, as shown by Fig. 1(a) – Fig. 1(d).

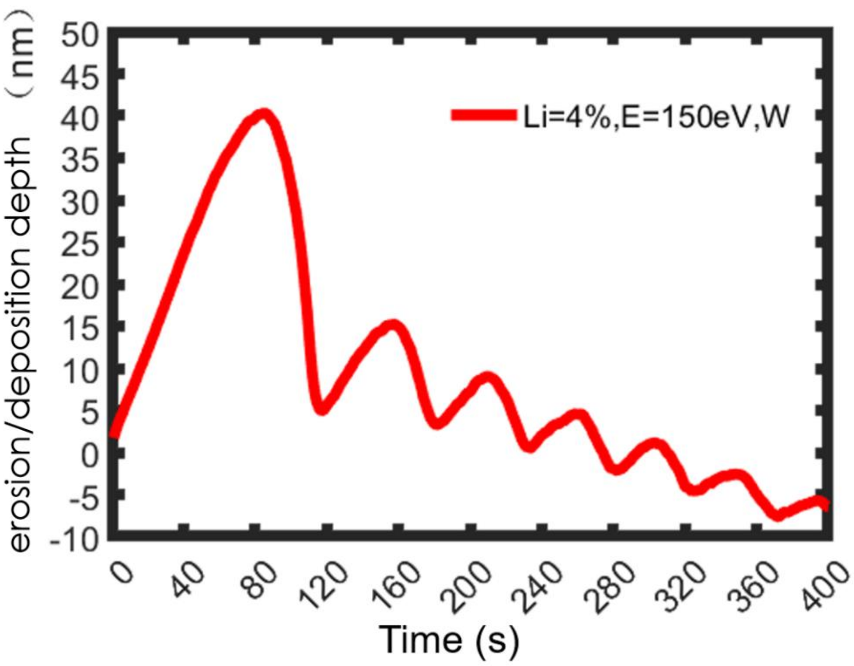

FIG 2. The erosion and redeposition depth evolution during the 400s long pulse discharge.

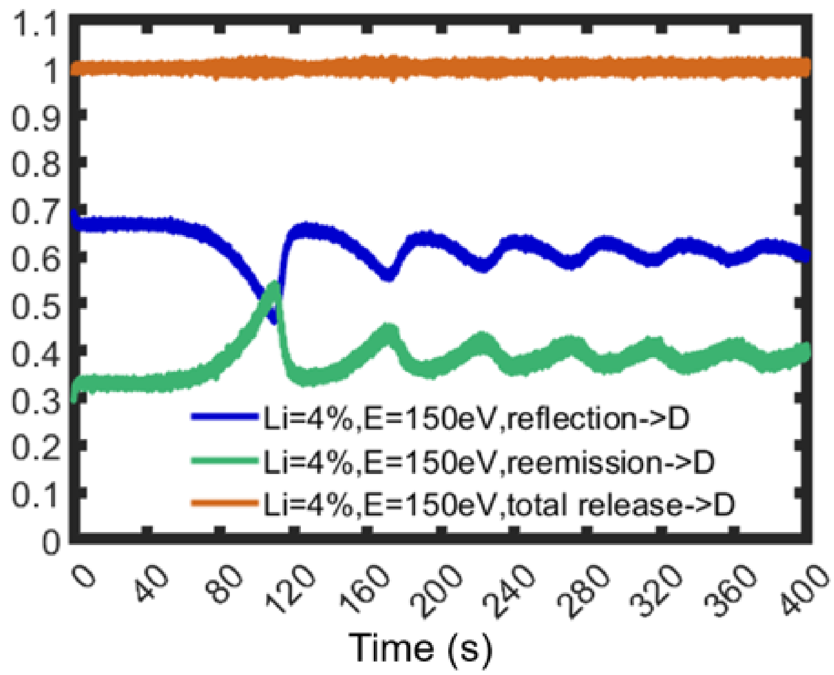

FIG 3. The D reflection rate (blue line), reemission rate (green line) and the total recycling rate (red line) during the 400s long pulse discharge.

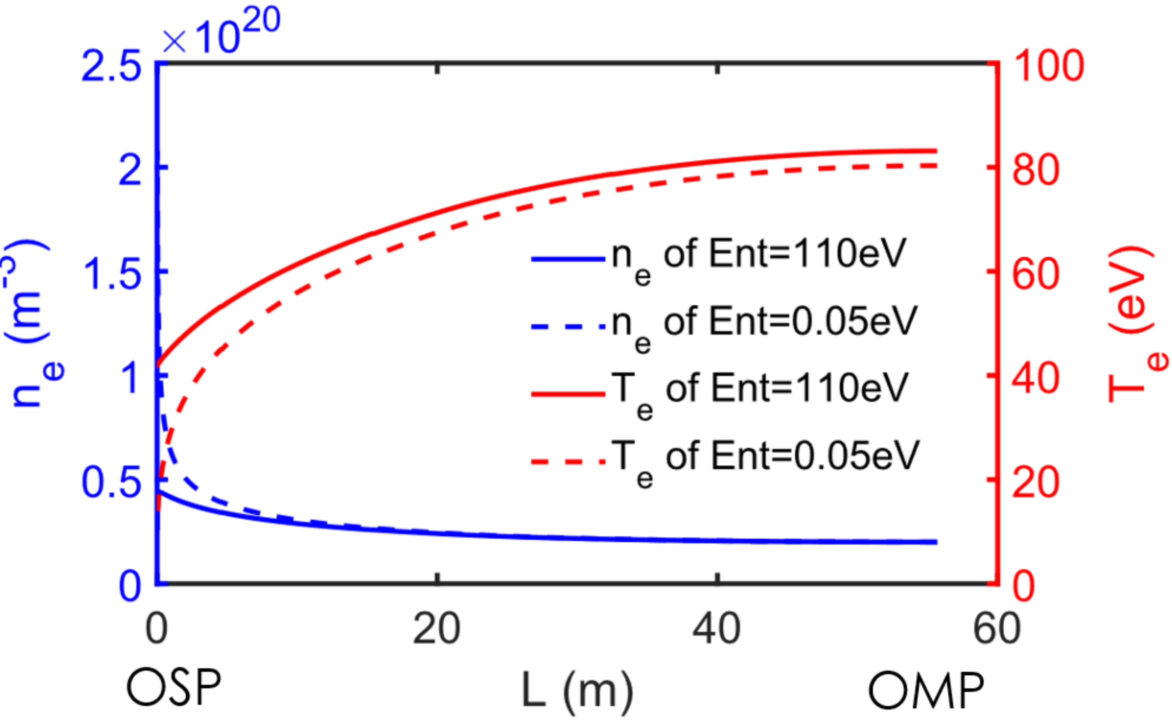

FIG. 4. The plasma distribution from the OSP to the OMP for different recycling D energy. Red lines are the electron temperature distributions, and the blue lines are the electron density distributions. The solid lines and the dashed lines are the plasma distributions for recycling D energy equals to 110 eV and 0.05 eV, respectively.

The material depth evolution corresponding to the materials evolution of Fig. 1 is shown in Fig. 2. At the beginning of the 80s, Li deposited under the W surface, leading to a net deposition process. With the plasma impinging, the surface W gradually eroded and thus the protecting effect diminishes, which results in a net erosion process. The change of the surface materials changes the D reflection and reemission rate. As shown 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 ne and Te distribution for cases with the recycling D energy equals the reflection energy (110 eV in this work) and reemission energy (0.05 eV), respectively. With a higher D recycling energy, the penetration ability of the recycled D becomes stronger, leading to lower plasma density and higher plasma temperature at the divertor region. Therefore, we can conclude that the dynamic evolution of the D reflection energy and probability inevitably influences the particle recycling process and thus the edge plasma distribution.

3. INTERGRATED MODELING OF WALL MATERIAL MIGRATION

To investigate the D recycling property at different wall locations, an iterative simulation loop between OEDGE and SDTRIM.SP is established. In these simulations, the plasma computational grid is extended to the first wall, as shown by Fig. 5, which allows a global wall material migration. The material evolution is simulated by SDTRIM.SP, with the initial wall material assumed to be 50 nm Li on W substrate. 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 and most of the wall surface suffer net erosion, with the eroded materials depositing on the private flux region (PFR) and some areas of the inner lower divertor region, as illustrated in Fig. 6.

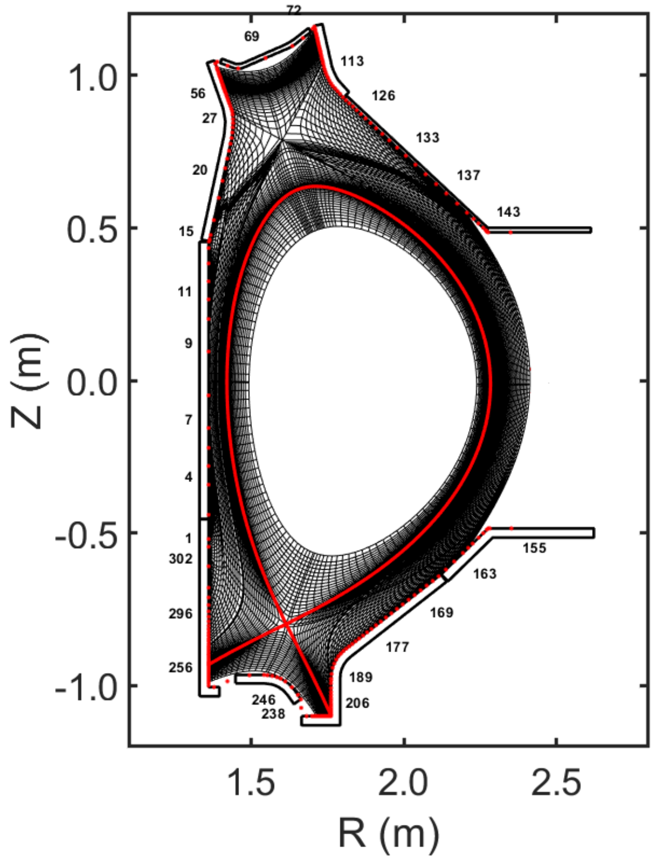

FIG. 5. Computational grid and the wall index for the integrated modelling.

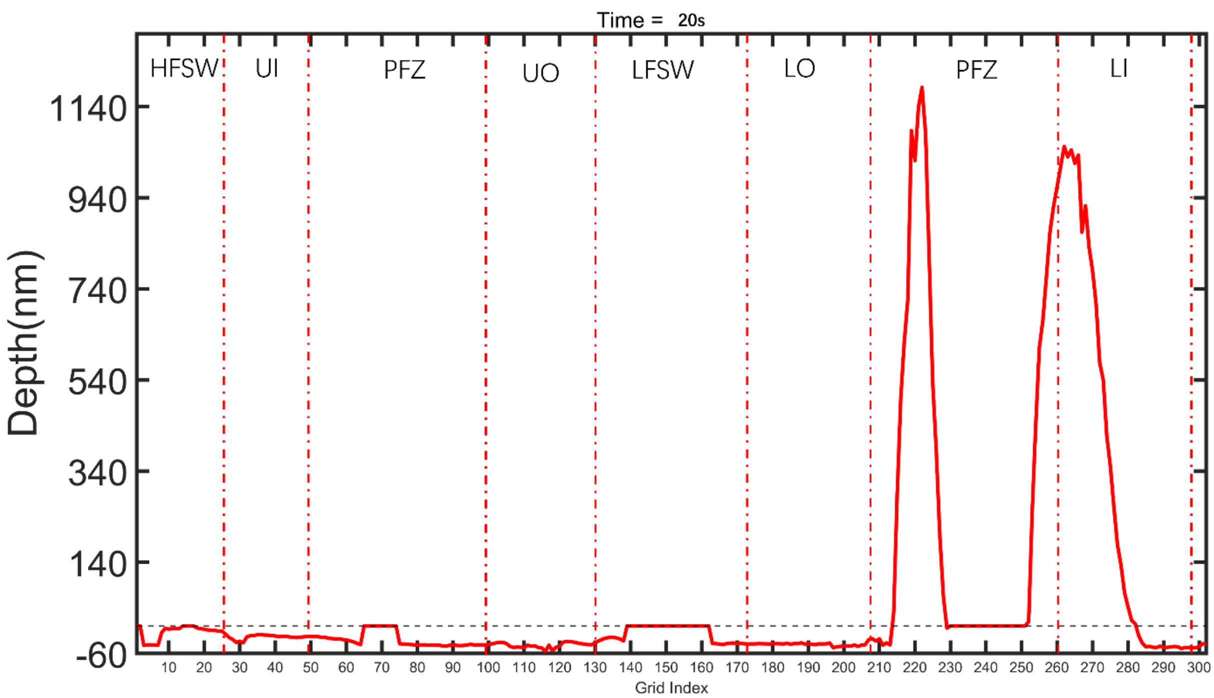

FIG. 6. The erosion and deposition depth along the whole wall region after the plasma impinging for 20s.

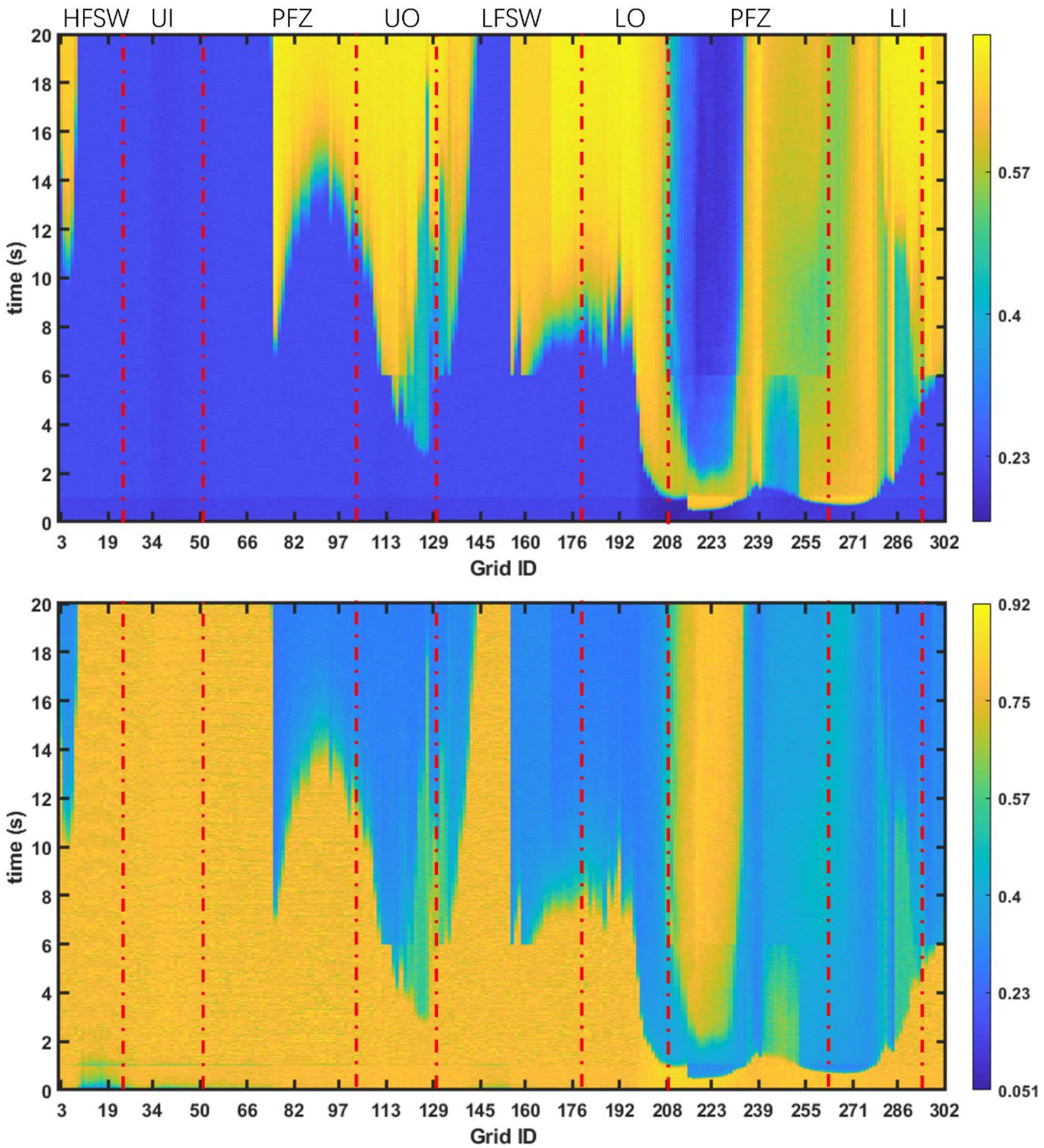

FIG. 7. The evolution of the (a) D reflection rate and (b) D reemission rate at different wall locations during the 20s discharge.

The D reflection and reemission rates on the whole wall surface during the 20s discharge are shown in Fig. 7. For most of the lower divertor and the upper outer divertor regions, the Li overlayer erode during 20s, and therefore there exit a significant increase of the D reflection rate and a decrease of reemission rate when the dominant surface material is W instead of Li. While the Li coating last longer than 20s in the upper inner divertor and some of the high field side wall regions, making the D reflection rate and reemission rate keeping almost constant. The variation of the D recycling properties during the discharge for different wall locations demonstrated that it is essential to consider the wall materials evolution to obtain the accurate background plasma solution, especially for long pulse discharges.

4. CONCLUSIONS

Based on typical EAST divertor conditions, the materials evolution and the related impact on particle recycling have been investigated. The surface material of Li significant decreases the D reflection and increases D reemission compared to W. The different recycling energy by the reflection and reemission processes can change the D ionization position and thus affects the edge plasma distribution. Integrated modelling reveals that wall materials evolve differently at different wall locations during the discharge and shows big impact on the D recycling properties along the wall during long pulse discharges.

ACKNOWLEDGEMENTS

The work was supported by the National MCF Energy R&D Program of China under Contract Nos. 2022YFE03180100 and 2019YFE03080100, the National Natural Science Foundation of China under Contract Nos. 12375232, 12261131496, 12022511, and 12075279. The numerical calculations in this paper were performed on the Hefei advanced computing center and the supercomputing system in the Supercomputing Center of University of Science and Technology of China.

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