Intra-ELM Tungsten Erosion Behavior in He and D Plasma Discharges in EAST

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The EAST divertor tungsten erosion processes during ELMs are quantitively reproduced by using the Free-Streaming model (FSM) [1] for both deuterium and helium plasma discharges. Two tungsten erosion peaks during each ELM burst were observed by WI spectroscopy, which indicates erosion caused by main ions and impurities respectively. Since He naturally exists in the D-T plasma, and ITER will foresee the first H-mode in He plasma, study of tungsten erosion under He plasma operation is urgently needed. In this work, the intra-ELM tungsten erosion is identified and characterized by the ELM frequency (varying from 10 Hz to 200 Hz) and auxiliary heating power (3 MW to 5.6 MW), based on the experimental data of recent EAST helium plasma operation campaign. Result shows that the intra-ELM tungsten source increases linearly with the ELM frequency, and no plateaus or 'roll-over' is found, which is contrast to previous deuterium plasma results on DIII-D and JET [2,3]. The ELM-averaged W erosion rate, however, shows a strong correlation only to the auxiliary heating power. Compared to the D discharges, the Inter-ELM W sputtering yields of He discharges is observed to be 3 times larger for a divertor target plasma temperature of 40 eV, whereas the intra-ELM W sputtering yields is mainly caused by the energetic C^{6+} originating from the pedestal, thus determined by the plasma temperature at the pedestal top.

High time resolution (10 us) WI spectroscopy data shows that there are two tungsten erosion peaks during each ELM burst, which indicates two different erosion mechanisms. The first W erosion peak, in consist with the peak of ion saturate current from divertor probe measurements, is caused by the impinging of the energetic main ions, while the second W erosion peak, which is even higher than the first one, indicates a time delay of energetic C^{6+} during the ELM transport form pedestal region to the divertor target. The time delay of C^{6+} can be as much as 0.5 ms for the He plasma. For the deuterium plasma, because of the larger discrepancy of the thermal speed between C^{6+} and main ions, a time delay of 1.5 ms is observed in the experiment.

FSM is employed in this work to simulate the energetic particle transport from the outer mid-plane to the divertor target for both the main ions and impurities. The discrepancies of transport time among D^{+}, He^{2+} and C^{6+} yielded from the simulation agree with the experimental measurements. For both D and He discharges, the tungsten erosion is well reproduced by the simulation and the result proves the second W erosion peak is caused by the streaming energetic C^{6+}. The tungsten erosion caused by C^{6+} can be 40% and 70% higher than the erosion caused by the main ions for He and D discharges respectively.

[1] Fundamenski W, et al. Plasma Physics and Controlled Fusion, 2005, 48(1): 109.
[2] Abrams T, et al. Physics of Plasmas, 2019, 26(6): 062504.
[3] Den Harder N, et al. Nuclear fusion, 2016, 56(2): 026014.