Recent Progress on W-related PWI Studies on EAST

R.Ding, L. Wang, F. Ding, Y. W. Yu, L. Zhang, K. F. Gan, J. P. Qian, Y. Liang, G. S. Xu, B. J. Xiao, Y. W. Sun, H. Xie, G-N. Luo, J. L. Chen, X. Z. Gong, J. S. Hu, J. G. Li, B. N. Wan, H. Y. Guo and EAST team

Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, Anhui, P.R. China

Abstract

Plasma wall interaction (PWI) in tokamaks will have a serious impact on the lifetime of plasma facing components, the performance of fusion plasmas and the tritium retention in devices. Tungsten (W) is the most promising candidate material for the divertor region of next step fusion reactors, such as ITER. The Experimental Advanced Superconducting Tokamak (EAST), which can operate with long pulse, high performance plasma and W divertor, provides a good platform for the W related PWI studies under steady state plasma. In this paper, recent progress on W-related PWI studies on EAST are summarized. According to the edge spectroscopic observations, W erosion rates and impurities content in the plasma are characterized and analyzed. Correspondingly, W erosion and re-deposition at the divertor region was simulated by the Monte Carlo code ERO. Furthermore, control of W erosion via different means was studied.

1. Introduction

Plasma wall interactions (PWI) in a tokamak may lead to a wide range of plasma and plasma facing components (PFCs) degrading effects, such as surface erosion, consequent re- or co-deposition with fuel and plasma contamination [1]. Tungsten is foreseen as the most promising candidate as divertor materials for the next fusion devices (such as ITER), due to its good thermal-mechnical properties [2]. In order to test the tungsten divertor operation, the tungsten PFCs have been used in several current tokamaks. In 2014, the upper graphite divertor in EAST was replaced by the ITER-like actively water cooled tungsten divertor [3]. After that, several campaigns have been performed with the tungsten divertor for long-pulse discharges. In the following, recent progress on tungsten-related PWI studies on EAST is presented.

2. Characterization of tungsten source in EAST

As a high Z material, the sputtered W impurity would result in strong radiation losses and degradation on the plasma performance. Wall conditioning in EAST is an essential way to suppress impurity level in plasma and to reduce tungsten sputtering. As shown in Fig. 1, both Si and Li were used as the wall coating materials for more than one month each in 2016 EAST spring campaign [4]. The impurity information can be measured by a passive spectroscopic system which can measure various visible emission lines across outboard mid-plane scrape off layer (SOL) and upper W divertor. The spectroscopic observation reveals that both Si and Li coating can suppress the intrinsic impurity levels. Compared to Si coating, Li coating can more effectively suppress the in-vessel impurities, thus mitigating the W source in upper divertor. After opening vacuum vessel, impurity level increases significantly. It is also shown that W source presents a clear correlation with C and O levels.

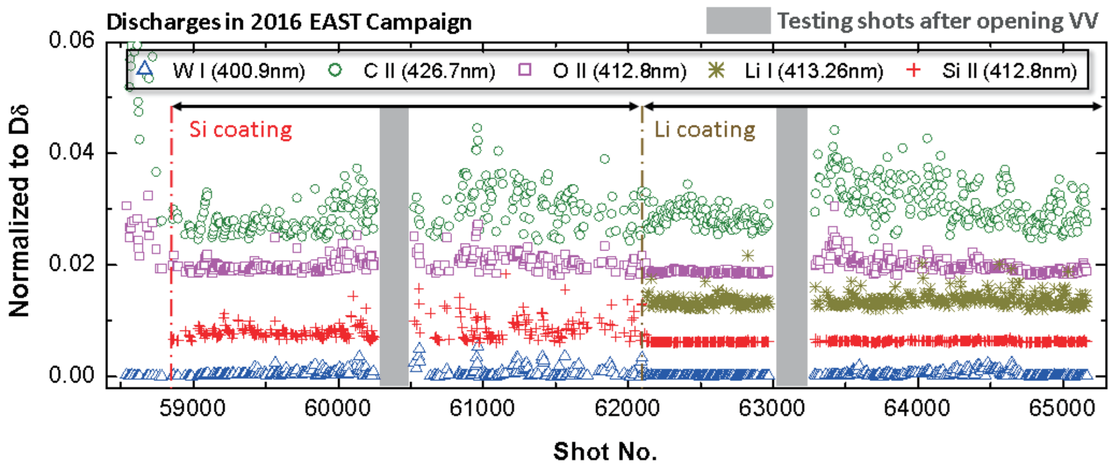

Fig.1 Intensity evolution of WI, CII, Si II, Li I and O II emissions normalized to D_δ in UO divertor region as function of shot number in 2016 EAST campaign. [4]

According to the spectroscopic observation, it is found that impurity production is significantly increased with higher heating power. Higher heating power will lead to higher electron temperature and ion saturation current level along the divertor target. Since the lower divertor material in EAST is carbon, higher plasma parameters at the divertor will result in higher erosion and thus higher low-Z impurities concentration in the SOL. As tungsten sputtering is mainly caused by low-Z impurities, higher low-Z impurities in the background plasma can enhance W sputtering. According to the analysis of W sputtering with different heating regimes, it is shows that there is more W sputtering by (Neutral Beam Injection) NBI and Ion cyclotron Resonance Heating (ICRH) than Electron cyclotron Resonance Heating (ECRH).

In H-mode discharges, it is shows that W erosion is mainly dominated by Edge localized modes (ELMs). During an ELM cycle, ELM-induced W erosion is about 70% of the total W erosion. The W peak erosion position at the divertor target is different for the two phases, intra-ELM and inter-ELM. The W peak erosion is close to the strike point (SP) during intra-ELM while the W peak erosion moves away from the SP during inter-ELM.

3. ERO simulation of W erosion and redeposition for EAST upper divertor

Based on the plasma operations with tungsten divertor, the 3D Monte Carlo code ERO has been used to simulate W erosion and re-deposition for the upper outer divertor region of EAST tokamak [5], as shown in Fig. 2. The simulations are performed in comparison with the measurements in attached L-mode plasma conditions. Background plasma parameters are reconstructed according to the electron density and temperature profiles measured by LPs and magnetic field configuration from EFIT calculations.

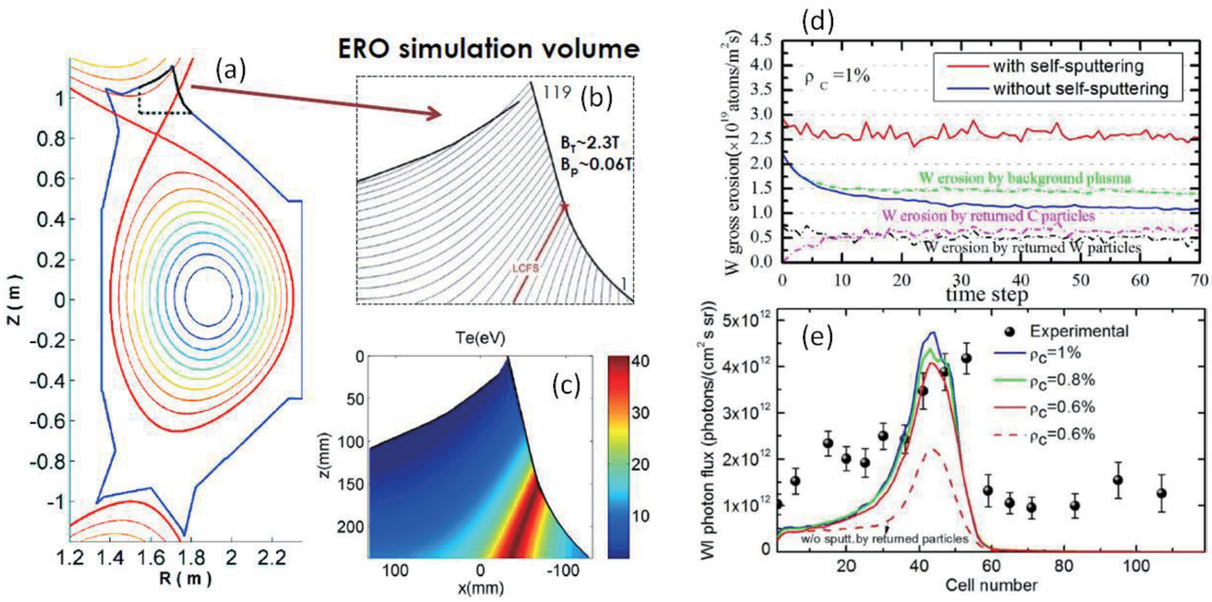

Fig.2 W erosion and re-deposition modelled by the ERO code. (a) and (b) show the magnetic configuration reconstructed by EFIT; (c) indicates the 2D distribution of electron temperature at the divertor region; (d) shows the time evolution of W erosion for the cases with and without self-sputtering; (e) illustrates the ERO modelled WI emission in comparison with the experimental measurements [5].

The simulations indicate that the influence of sputtering by returned eroded particles can significantly enhance the W gross erosion rate especially near the strike points where most eroded particles return. On the one hand, sputtering of C by the returned eroded particles can reduce the C ratio in surface interaction layer. On the other hand, the W erosion rate is enhanced due to the sputtering by both returned C and W particles. Although the W sputtering yield by C is lower than that by W, more returned C particles leads to similar erosion rates caused by returned C and W particles. There are two effects on W erosion rates by C concentration in the background plasma: C ratio in surface interaction layer and W erosion caused by C incidence. When the C concentration is low, W erosion rate increases with higher C concentration. A further increase in C concentration leads to more C in the surface interaction layer and thus lower W erosion rate. The modelling indicates that net carbon deposition occurs on the dome plate and part of the vertical plate close to the dome plate, whereas tungsten net erosion occurs on most of the vertical plate. With the C concentration of about 0.6%–1%, the modelled WI photon fluxes along the target are in a reasonable agreement with experimental measurements.

4. Control of W sputtering

W impurity in plasma will lead to a large radiation enhancement. With impurities accumulations in the core, the radiation losses can lead to a significant degradation of the plasma confinement. Reducing W sputtering is very important to reduce the W source and W concentration in the plasma core. In EAST tokamak, various methods have been developed and tested to control the W sputtering. Firstly, resonant magnetic perturbation (RMP) can effectively suppress the ELM. The ion incident flux to the divertor plate can be reduced, and thus result in lower intra-ELM erosion. The neon Supersonic Molecular Beam

Injection (SMBI) is another useful method. The SMBI in EAST is injected from Lower field side at mid-plane. It is found that during the SMBI, the electron temperature at the divertor target is lower and W sputtering flux is reduced, as shown in Fig. 3. Furthermore, real-time Li aerosol injection is shown to be a good method for reducing W sputtering. Long-pulse H modes with 18 s ELM-free phase were achieved on EAST with the help of Li aerosol injection. Li aerosol injection can enhance the radiation in the divertor region and thus lead to a lower electron temperature at the divertor target. Therefore the carbon impurity concentration in the SOL region is reduced which in the following lead to a lower W sputtering. Li wall coating effect could also be enhanced by Li aerosol injection.

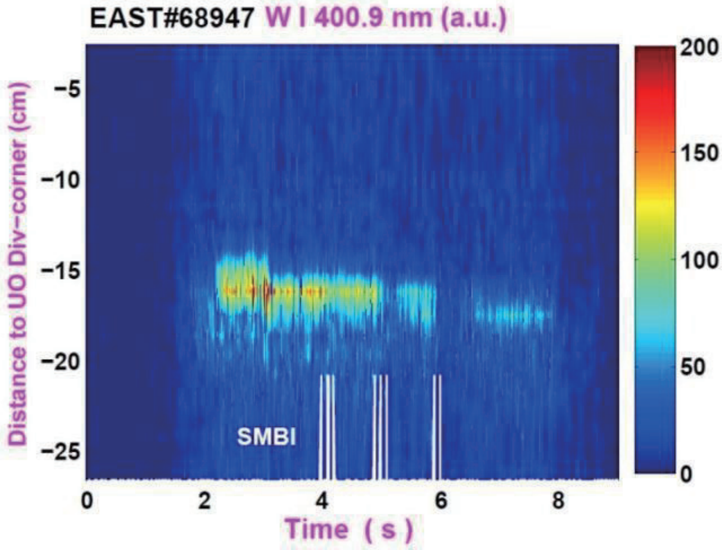

Fig.3 Time evolution of WI line emission along the EAST upper outer

5. Summary

In summary, various W-related PWI studies have been performed on EAST to understand W erosion and its mitigation. With the edge spectroscopic observation, the impurities in plasma and W erosion were characterized. The ERO code was successfully applied to simulate the W erosion at divertor region. W erosion has been controlled via different means. In the near future, the lower divertor of EAST will be upgraded to W/Cu PFCs, which allow us to better study the W-related PWI issues.

Acknowledgements

This work was partly supported by the JSPS-NRF-NSFC A3 Foresight Program in the field of Plasma Physics (NSFC: No.11261140328, NRF: No.2012K2A2A6000443).

References

[1] G. Federici, C. H. Skinner, J.N. Brooks, et al. Nucl. Fusion **41** (2001) 1967.
[2] R. A. Pitts, S. Carpentier, F. Escourbiac, et al. J. Nucl. Mater. **438** (2013) S48-S56.
[3] D. M. Yao, G. –N. Luo, S. J. Du, et al, Fus. Eng. and Design, **98-99** (2015) 1692-1695.
[4] H. M. Mao, F. Ding, G. –N. Luo, et al. Nucl. Mater. and Energy, **12** (2017) 447-452.
[5] H. Xie, R. Ding, A. Kirschner, et al. Phys. Of Plasmas, **24** (2017) 092512.