Tungsten (W) impurity reduction by ICRH in a high power and high performance H-mode discharge on EAST

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The decrease in tungsten (W) content with higher ion cyclotron resonance heating (ICRH) power is for the first time observed and explained on experimental advanced superconducting tokamak (EAST). This result further validates the feasibility of ICRH core high-Z impurities control. Control of high-Z impurities in the ITER is now more important since the decision to change the first wall material from beryllium to tungsten (W). Compared to the ECRH scheme for core W control, ion ICRH has more benefits especially in high density regime. However, ICRH could also produce additional high-Z impurities sources from the antenna, which has been observed in WEST and EAST. In addition, the ICRH is the only external method to start and sustain the plasmas in SPARC. Therefore, it is vital to study the core W control by ICRH to maintain good plasma performance and stable operation for present tokamaks and future fusion reactors.

The use of ICRH for core heavy impurities control is very attractive for EAST high performance operation, because now the PFCs of EAST are all metals, with upper and lower divertors covered by W and molybdenum (Mo) wall in the main chamber. Since all neutral beam injection (NBI) is co-current in EAST, when strong NBI power is applied, the increased toroidal rotation can produce a large centrifugal force for W, leading to W poloidal distribution asymmetry, then in the plasma core to an increase of the inward neoclassical pinch, which may result in W accumulation. Since 2020, EAST has modified the ICRH window and optimized the ICRH antennas, and we have for the first time observed that W is reduced markedly by ICRH after these upgrades in a high power injection and high performance H-mode discharge on EAST. Figure 1 illustrates the time traces of this high performance discharge (shot #107838) developed by the NBI, LHW and ICRH. The poloidal beta (β_P) and normalized beta (β_N) can be sustained around 3 and 2 respectively with large q_{95}~9, which will lead to a high bootstrap current fraction ~60% for EAST. The other two key parameters for fusion energy, the plasma confinement factor H_{98y2}~1.1 and Greenwald density fraction f_{GW}~0.8, also can be simultaneously maintained. Although this shot is mainly developed by NBI, the electron heating is still dominant (central electron temperature T_{e0}~4keV, ion temperature T_{i0}~2keV) as shown in figure 1 (d), which is more relevant to ITER research. When the ICRH is raised by only 0.8MW (from 2MW to 2.8MW), the intensity of W unresolved transition array (W-UTA) spectral structure in the region of 45-70 Å (which is composed of W^{27+}-W^{45+} line emissions) decreases by 20% with a 10km/s reduction in the central relative toroidal rotation. However, the electron temperature and ion temperature show no change, but the electron density increases slightly with higher ICRH power. The chord integrated intensity profiles of W^{44+} measured by Extreme Ultra Violet (EUV) shows a reduction of more than 30% in the core, and the W^{44+} density profiles by EUV inversion also becomes less peaked as shown in figure 2. At the same time, there is also no increase of high-Z impurity source, which may be related to the occurrence of detachment. Theoretical modeling results indicate that the reduction in toroidal rotation leads to less W poloidal asymmetry and neoclassical pinch, which is more efficient in alleviating the core W accumulation than the improvement of isotropic hydrogen (H) minority temperature as shown in figure 3.

In conclusion, by the optimization of ICRH antenna and the modifying of the ICRH window, the ICRH core W control is for the first time observed in a high power injection and high performance H-mode discharge on EAST. Decrease of the toroidal rotation by additional ICRH is the main reason for the reduction of the core inward neoclassical pinch and for core W control. Compared with rotation reduction, the change of H minority isotropic temperature has little effect on the W transport for 0.8 MW power increase in ICRH. The high density and well lithiated wall discharge conditions may ensure effective control of the high-Z impurities sources.

ACKNOWLEDGEMENTS

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, under Award DE-SC0010685, and by the fellowship of china national postdoctoral program for talents under BX20220304.

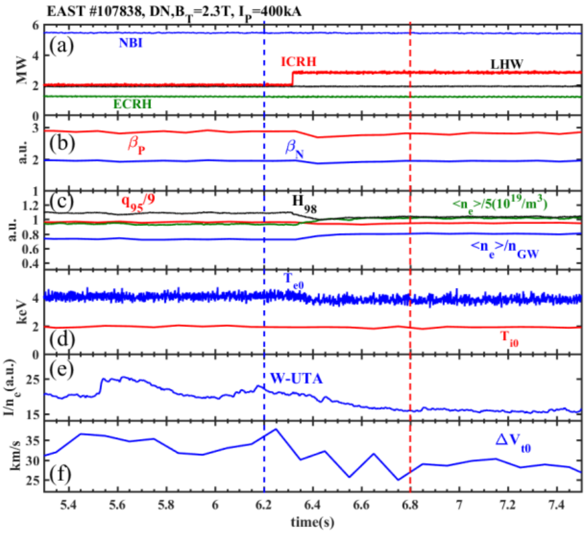

Figure 1. The time traces of (a) heating power, (b) plasma beta, (c) line-averaged density, Greenwald density fraction, q_{95} and H_{98}, (d) central electron and ion temperature, (e) intensity of W-UTA line normalized to electron density (f) central relative toroidal rotation velocity of EAST discharge #107838.

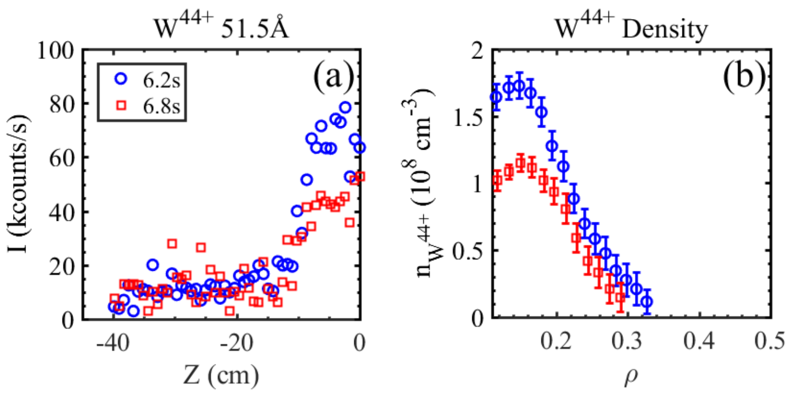

Figure 2. (a) chord-integrated line intensity and (b) density distribution of W^{44+} measured by EUV.

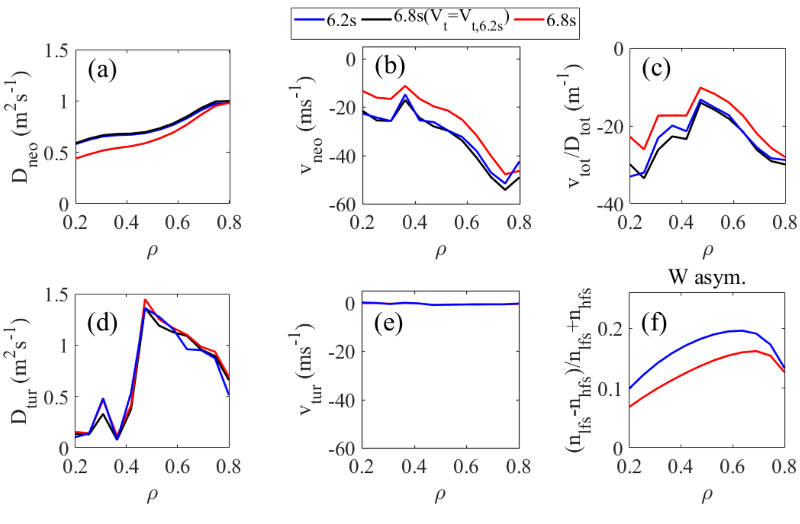

Figure 3. The distribution of (a)-(e) the neoclassical and turbulent transport coefficients calculated by NEO and TGLF respectively and (f) W poloidal asymmetry calculated by NEO. The blue and black line correspond to the time slice of t=6.2s and t=6.8s, respectively. The black line results from 6.8s background plasma profiles except the rotation profile, the rotation profile is from 6.2s, which indicates the higher H minority isotropic temperature at t~6.8s does not play key role to decrease the inward neoclassical pinch by comparing the black and blue line.

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