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Performance Integration of High Temperature Plasmas in the LHD deuterium operation

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Simultaneous high ion temperature (T_i) and high electron temperature (T_e) regime has been significantly extended due to the optimized heating scenario in the LHD deuterium (D) campaign. Such high-temperature plasmas were realized by the simultaneous formation of an electron ITB (e-ITB) and an ion ITB (i-ITB) by the combination of high power NBI and ECRH. In the high T_i operation the EIC (Energetic ion driven interchange) modes, which causes the T_i degradation, was clearly suppressed due to the ECRH superposition. Furthermore, the e-ITB was successfully formed without degradation of the ion thermal confinement for the high T_i plasmas. This is due to the T_{e0}/T_{i0} maintaining the moderate value of 0.66. Consequently, T_{e0} could be increased up to 6.6 keV with the T_{i0} ˜10 keV (previous achievement at FEC2018 was T_{i0} = 10 keV and T_{e0} = 3.6 keV [1]).

In future reactors, the fusion reaction is expected to be sustained under the electron heating dominant condition, where both T_i and T_e are high. Thus not only the investigation of the confinement improvement but also the characterization of the thermal transport for the plasmas, of which T_i and T_e are simultaneously high, are necessary. In the present status, such a plasma condition is realized by the combination heating of a NBI and an ECRH. The effect of a T_e/T_i and/or an ECRH on the ion thermal confinement has been studied in several devices. In recent years, an integration of high T_i and high T_e with the simultaneous formation of an i-ITB and an e-ITB has been achieved in the LHD [2]. The paper shows the successful extension of simultaneous high T_i and high T_e regime in the LHD deuterium operation due to the suppression of the EIC modes and control of the T_e/T_i value.
The EIC is triggered by helically trapped ions at lower order magnetic resonant surface of m/n = 1/1. The EIC causes loss of high energy ions both in the plasma core and the edge, leading to the decrease in T_i [3]. Thus the mitigation of the EIC is a key for realizing higher T_i. Figure 1 shows the comparison of the time evolution of (a) the heating power, (b) the line-averaged-electron density n_{e-fir}, (c) the poloidal magnetic fluctuation amplitude b_θ, (d) the neutron emission rate S_n, (e) the T_{e0}, and (f) the T_{i0} without and with 2.5-MW ECRH superposition.

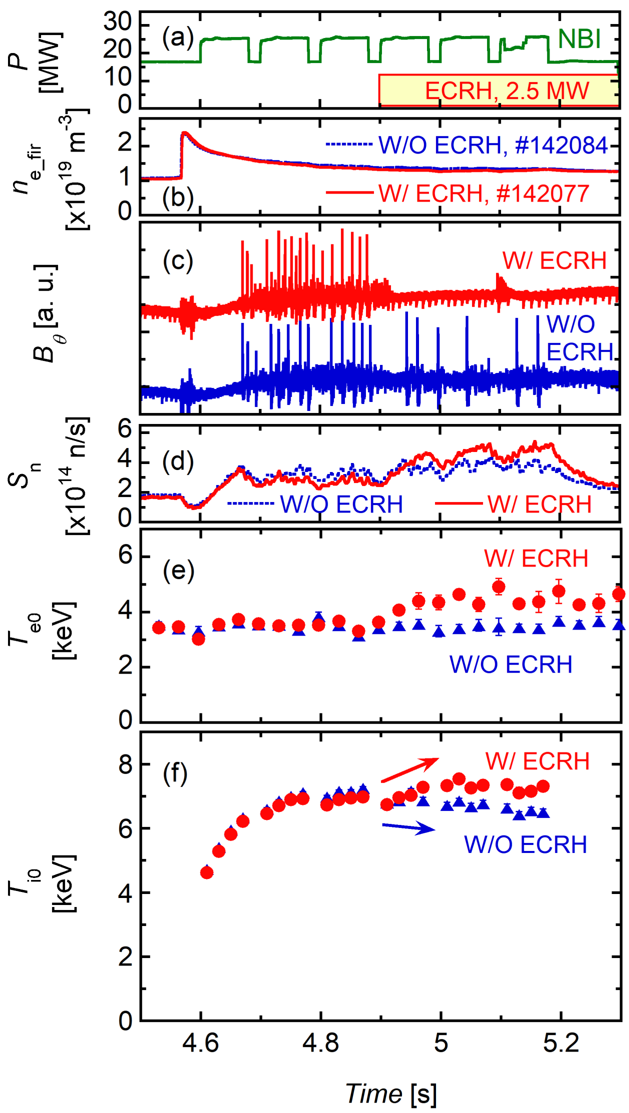

Figure 1: Effect of ECRH on EIC suppression. The time evolution of (a) the heating power, (b) the line-averaged n_e, (c) the magnetic fluctuation, (d) the neutron emission rate, (e) the central electron temperature, and (f) the central ion temperature without and with 2.5-MW ECRH.

The NBI power was similar (~25 MW) and the operated magnetic configuration was same as R_{ax} = 3.58 m and B_t = 2.87 T. The C pellet was injected at 4.57 s to control the impurity and to increase the S/N of CXS measurement. The bursty increase of b_θ and the synchronized drop in the S_n correspond to the EIC occurrence and the loss of the high energy ions, respectively. Due to the ECRH superposition the EIC event was clearly suppressed. Consequently, the S_n, which is reflected the amount of the confined high energy ions, increased and this contributed to realizing the higher T_{i0}. Note that the b_θ increase at t = 5.1 s was due to the NBI breakdown.
Although the ECRH is effective to mitigate the EIC, the increase in T_e/T_i causes the destabilization of the ITG mode [4], leading to the degradation of the ion thermal confinement. Figure 2 shows the dependence of the normalized scale length of T_i on the T_e/T_i at the effective minor radius of r_{eff} = 0.1 m.

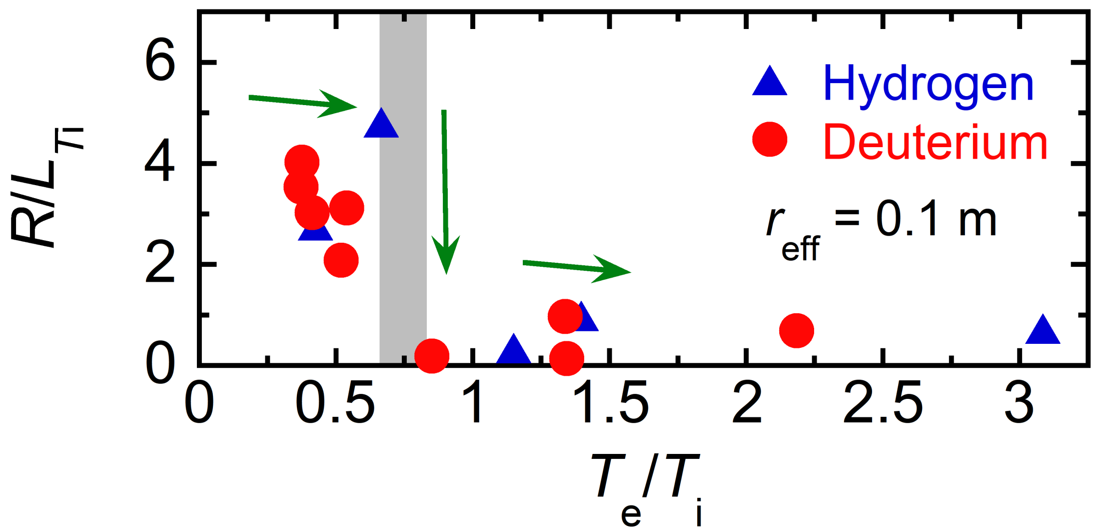

Figure 2: The dependence of the R/L_{Ti} on the T_e/T_i at r_{eff} = 0.1 m.

These data were obtained in the high T_i operation with the superposed on-axis ECRH power from 0 to 5.4 MW. The significant degradation of the R/L_{Ti} was observed both in the H and D plasmas when the T_e/T_i exceeded ˜0.7. These results show that not only the mitigation of EIC by ECRH but the control of T_e/T_i in the moderate range is important for realizing high T_i and high T_e simultaneously.
Presently we could successfully obtain the high T_i plasma (10 keV) with the increased T_{e0} up to 6.6 keV by the on-axis ECRH with 1.8 MW (1/3 of the LHD-ECRH full power). The T_{e0}/T_{i0} was 0.66, which value was slightly lower than the threshold of R/L_{Ti} degradation shown in Fig. 2, and the EIC was also mitigated in the discharge. Figure 3 shows the radial profile comparison of (a) T_e, (b) the electron thermal diffusivity χ_e, (c) T_i, and (d) the ion thermal diffusivity χ_i between the high T_i plasmas without and with 1.8-MW ECRH.

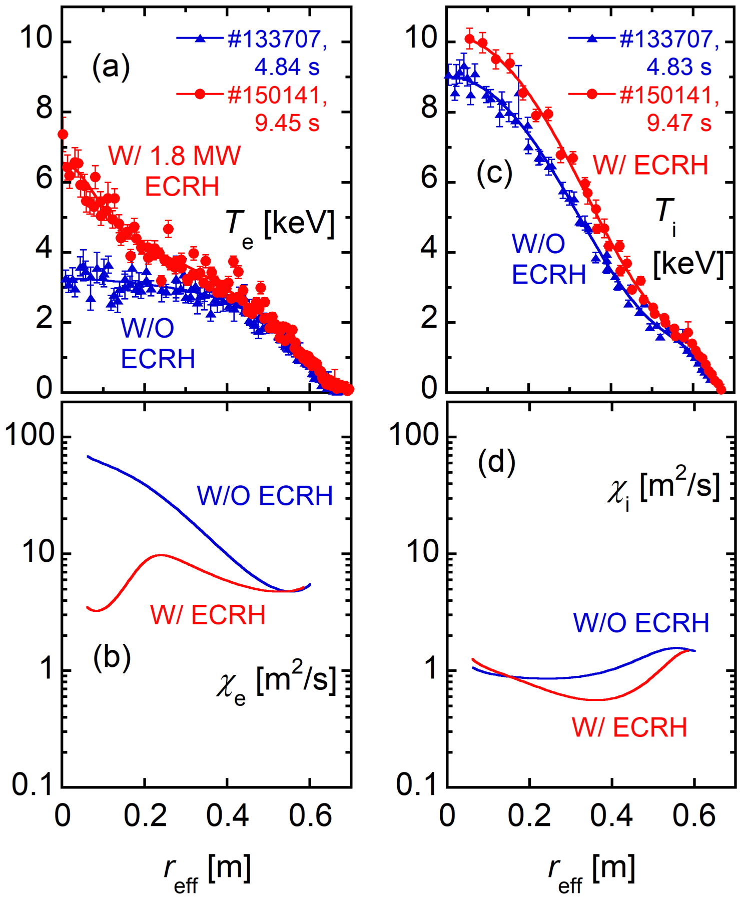

Figure 3: The radial profiles of (a) T_e, (b) χ_e, (c) T_i, and (d) χ_i without and with 1.8-MW ECRH.

The NBI power was similar (~30 MW) and the operated magnetic configuration was same as R_{ax} = 3.6 m and B_t = 2.85 T. The plasma W/O ECRH was obtained before FEC2018. The EIC events and the accompanying loss of the high energy ions were observed during the discharge W/O ECRH. Applying the on-axis ECRH superposition, T_e gradient increased and the χ_e decreased especially in r_{eff} < 0.2 m due to the e-ITB formation. For the ion, the reduction in the χ_i was observed around the plasma half radius associated with the EIC suppression and the peaked profile was maintained in the plasma central region with the T_{i0} of 10 keV.
Figure 4 is the summary of the extension of the high temperature operational area in the LHD.

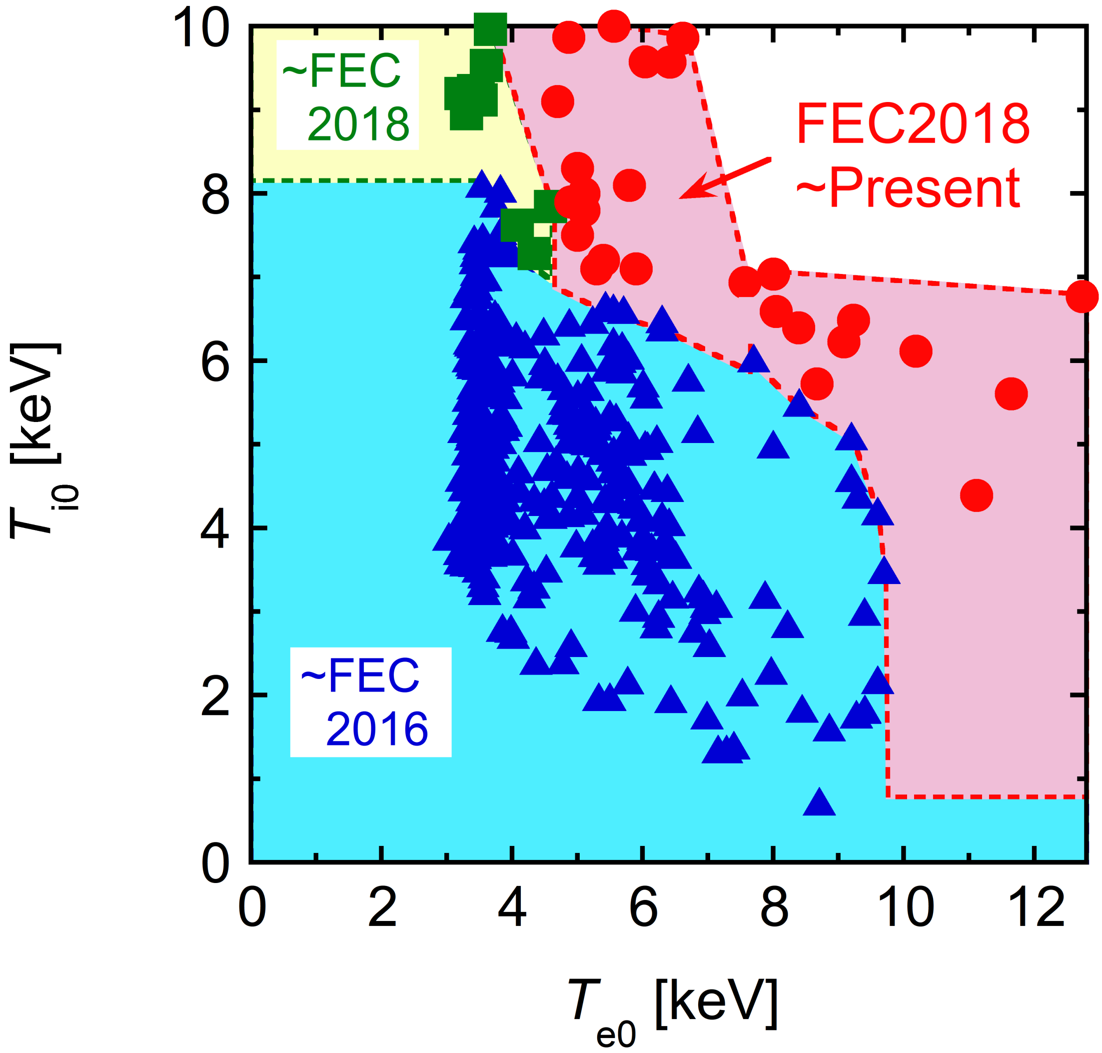

Figure 4: Summary of the extended high temperature regime in the LHD.

The simultaneous high T_i and high T_e regime was significantly extended from previous IAEA FEC. In the LHD deuterium experiment, we have attained the T_i of 10 keV due to the better confinement accompanied with the stronger i-ITB compared with hydrogen plasmas [1, 5]. Present results of the extension of the high temperature regime reinforce the feasibility of the helical reactor and enable us to investigate the plasma confinement property close to ignition temperature condition.

[1] H. Takahashi et al., Nucl. Fusion **58** 106028 (2018).

[2] H. Takahashi et al., Nucl. Fusion **57** 086029 (2017).

[3] K. Ogawa et al., Nucl. Fusion **58** 044001 (2018).

[4] M. Nakata et al., Plasma Phys. Control. Fusion **58** 074008 (2016).

[5] T. Kobayashi et al., Sci. Rep. **9** 15913 (2019).

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