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Isotope effects on formation and sustainment of electron internal transport barrier

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The transport of different hydrogen isotopes is a crucial issue in the physics of magnetically confined plasmas. The isotope effect is much clearer in structure formation property than the plasma confinement time scaling in tokamaks. Electron internal transport barrier (e-ITB) is observed in a low density and an intensive core electron cyclotron heating (ECH) discharge [1]. A positive radial electric field (E_r) structure is formed in the core. The E_r structure is likely abbreviated as the neoclassical E_r. Although isotope effect in e-ITB has not been examined. Hydrogen isotope effects on the structure formation and sustainment/collapse of the e-ITB have been studied based on recent experimental observations which have been clarified using rich and advanced diagnostics in LHD.

The structure formation threshold of the e-ITB has been investigated for hydrogen and deuterium plasmas in LHD [2, 3]. The e-ITB criticality is quantitatively studied by a perturbative approach. At line-averaged electron density $\bar{n}_e \sim 1.4\times10^{19}$ m^{-3}, a large electron temperature gradient modulation appears in the core in the D plasma, while not in the H plasma. Figure 1 shows the isotope dependence of the threshold values of the heating power of ECH (P_{ECH}) normalized by $\bar{n}_e$. The ITB threshold $P_{ECH}/\bar{n}_e$ value monotonically decreases as the ion mass increases. The role of the radial electric field for the isotope effect in the ITB threshold is discussed in a perturbative manner. Direct measurement of the electrostatic potential by heavy-ion beam probe (HIBP) suggested that the input power normalized by plasma density required for the radial electric field structure formation was lower in plasmas with heavier ions [4].

The mechanism of minor collapse (or sustainment) of e-ITB and its isotope effects have been studied considering the effects of magnetic island [5]. The minor collapses of electron internal transport barrier (e-ITB) were repeatedly observed by controlling the rotation transform profile with electron cyclotron current drive (ECCD) and neutral beam current drive (NBCD) to create a magnetic island around the e-ITB foot and increase the pressure gradient in the e-ITB region (Fig. 2(a)). The pressure gradient near the e-ITB foot increases due to the formation of magnetic island and reaches a threshold value of about 12 keV/m (Fig. 2(b)). When the pressure gradient reaches this value, the e-ITB collapses. The experimental results showed the possibility that the formation of $n/m = 1/2$ magnetic islands around the e-ITB foot causes a strong pressure gradient and MHD instability, and the resulting turbulent transport propagates heat pulses outward, leading to minor collapses in the e-ITB. The frequency of minor collapses is about 0.8 times higher in deuterium plasmas than in hydrogen plasmas, suggesting that the e-ITB is sustained in deuterium plasmas even at higher electron temperature gradients than in hydrogen plasmas.

The present works contribute both to understanding the dissipative structure formation affected by basic properties of the media and to the future fusion reactor development utilizing improved confinement scenarios.

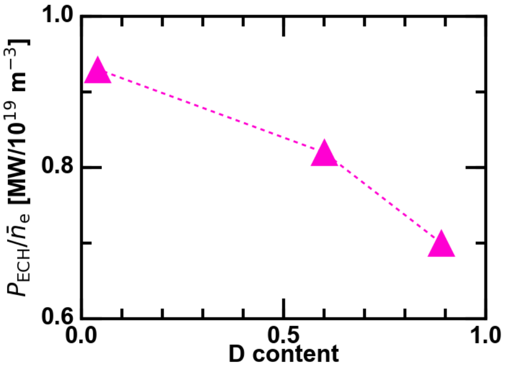

Fig. 1. Isotope dependence of the threshold values of heating power of ECH (P_{ECH}) normalized by line averaged electron density ($\bar{n}_e$).

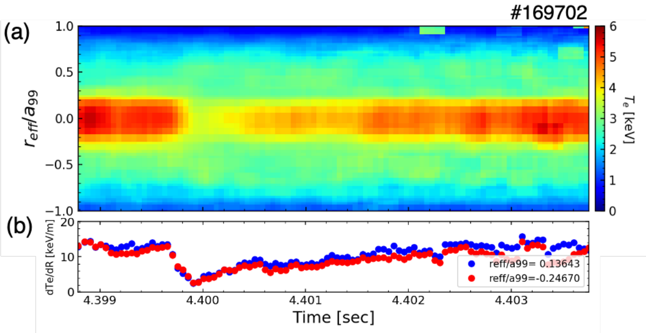

Fig. 2. The time evolution of (a) the electron temperature profile and (b) the electron temperature gradient near the e-ITB foot observed by the newly developed high time resolution (repetition rate: 20 kHz) Thomson scattering measurement.

References

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