Role of $E \times B$ velocity shear for triggering the I-mode and ion ITB on HL-2A

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The improved energy confinement mode (I-mode), which shows high energy confinement comparable to H-mode, and particle confinement comparable to L-mode, is one of the promising operation regimes achieved in tokamaks. The I-mode features an edge temperature transport barrier without a particle transport barrier. It is characterized by a steep temperature gradient comparable to the H-mode, while the density gradient remains similar to the L-mode. Comparing to H-mode, I-mode can avoid the accumulation of impurities and Helium 'ash' due to the absence of an edge particle transport barrier, which is beneficial for fusion reactors. Moreover, it has been found that the I-mode pedestal is ideal peeling-ballooning stable, i.e., no ELMs are expected. Therefore, I-mode is being investigated as an alternative operation scenario for future fusion devices.

The I-mode plasmas were observed for the first time on the HL-2A tokamak [2]. As shown in Figure 1(a), the I-mode is obtained in NBI-heated plasmas and the plasma density is basically unchanged after L-mode to I-mode (L-I) transition. However, the edge electron temperature gradient increased dramatically, forming an edge electron temperature transport barrier, as shown in Figure 1(b). The weakly coherent mode (WCM) can be observed in the spectrogram of density fluctuation with a frequency range of $f \sim 60-160\,kHz$ (Figure 1(c)). It has been found that there is a critical value of the $E \times B$ velocity shear for triggering the I-mode, as shown in Figure 1(d), and this value ($\sim 80\,kHz$) is much lower than that for triggering the H-mode ($\sim 120\,kHz$) [3].

In addition, an ion internal transport barrier (ITB) has been observed in the I-mode plasmas, as shown in Figure 1(e). The formation of this ion ITB is due to the turbulence suppression (Figure 1(g)) by the $E \times B$ velocity shear (Figure 1(f)). Transport analysis confirms the existence of electron ETB (I-mode) and ion ITB. The plasma confinement is significantly improved in I-mode with ITB regime, which is comparable to that in H-mode, suggesting that the I-mode with ion ITB could be an interesting operation scenario for future fusion devices.

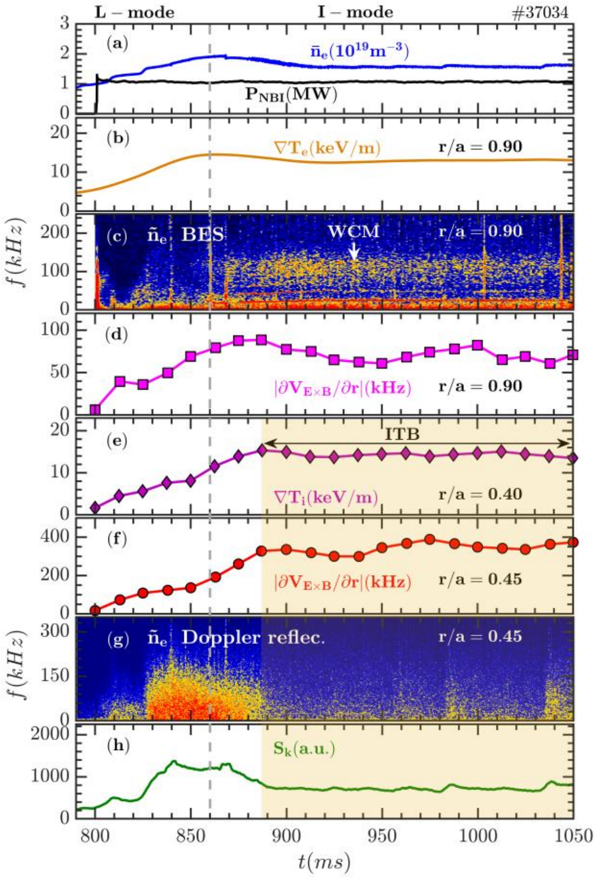

Figure 1. Waveform of an I-mode discharge with ion ITB on HL-2A: (a) NBI power (black) and central line-averaged electron density (blue), (b) electron temperature gradient ∇T_e at edge region ($r/a = 0.9$), (c) spectrogram of density fluctuation measured by BES at $r/a = 0.90$, (d) $E \times B$ velocity shear at $r/a = 0.90$, (e) ion temperature gradient in the plasma core ($r/a = 0.4$), (f) $E \times B$ velocity shear at $r/a = 0.45$, (g) turbulence spectrogram measured by Doppler reflectometry in plasma core ($r/a = 0.45$), and (h) the turbulence intensity

References

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