ELECTRON CYCLOTRON HEATED LOW TO HIGH MODE TRANSITION IN KSTAR

[1]HOGUN JHANG, MINJUN J CHOI, HYUN-SEOK KIM, BOSEONG KIM, HAIDER RIZVI

[1]Korea Institute of Fusion Energy, 169-148 Gwahak-ro, Yuseong-gu, Daejeon 34133, Republic of Korea

Email: hgjhang@kfe.re.kr

Electron cyclotron resonance heating (ECRH) is a reliable heating source in the contemporary and future magnetic fusion devices. In fact, ECRH is supposed to be the dominant heating method in the initial operation of some planned devices, such as ITER [1] (though revised recently) and Divertor Tokamak Test facility (DTT) [2]. Achieving an H-mode in the early stage of operation with a low field and a low plasma current is necessary to assure the integrity of the device and the efficacy of edge localized mode (ELM) control tools such as resonant magnetic perturbation coils. This is essential for accomplishing the subsequent scientific goal of the ITER mission with full machine capability. In this regard, there has been a rekindled interest in the study of ECRH dominant LH transitions in terms of both the macroscopic phenomenology and a detailed study of micro-turbulence evolution. The successful LH transition using only ECRH has been demonstrated in many tokamak experiments[3,4,5]. This result, in fact, has been reckoned as evidence of the possibility to access H-mode with different heating methods. In particular, a recent AUG experiment demonstrates that the H-mode sustained by ECRH could be operated in a stationary ELM-free state [5]. This operation regime is pertinent to the enhanced D-alpha (EDA) H-mode developed on Alcator C-Mod that is characterized by dominant electron heating, low momentum input, and high density. The ELM-free state in AUG, similar to Alcator C-Mod, is shown to be correlated with the appearance of the quasi-coherent mode (QCM) emerging during the LH transition. The physical mechanism responsible for triggering QCM and its role in pedestal transport are to be evaluated further. The objective of this work is to study the experimental characteristics of the ECRH-produced LH transition in KSTAR plasmas. Specifically, we examine features of the LH transition and the H-mode state driven and sustained by ECRH. The evolution of microscopic fluctuations before, during, and after the transition is also scrutinized. Further, we explore the physics of the coherent which appears during the LH transition and prevails during the H-mode state.

In order to make a systematic study of this phenomenon, we carry out KSTAR experiments scanning the pre-transition density (i.e. the L-mode density) for a fixed maximum ECH power available at KSTAR. In this experimental set-up, one expects the appearance of a density window within which the LH transition happens, owing to the existence of the characteristic U-shaped P_{LH} curve in terms of density. It is also of interest if the minimum density value obtained in KSTAR experiments is consistent with an empirical scaling law proposed in Ref. [6]. Indeed, results recuperates the characteristic U-shape curve in transition power (P_{LH}) vs. density, exhibiting minimum density for LH transition. For some shots, we tried to inject supersonic molecular beam injection (SMBI) as an effort to reduce the power threshold. The minimum density, however, is found to be 19-27% lower than that predicted by a scaling law in Ref. [6] based on the electron-ion heat equilibration.

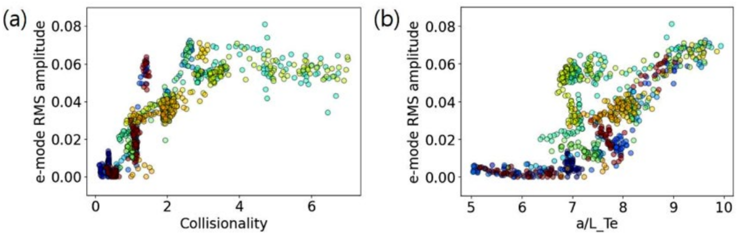

Fig. 1: T_e fluctuation amplitude as a function of electron collisionality (a) and the electron temperature scaling length (b). Data points with the same color are taken from the same discharge.

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A comprehensive study of T_e fluctuation characteristics has been carried out using ECEI data. Figure 1 the T_e fluctuation amplitude as a function of the electron collisionality (a) and the electron temperature scaling length (L_{Te}=-T_e/∇T_e) (b). Plasmas in the L-mode edge at different time points and shots are utilized to obtain Fig. 1. Data points with the same color represent that they are taken from the same discharge. We have chosen only the modes rotating in the electron diamagnetic direction. A notable feature in Fig. 1 is that there exist threshold values for both collisionality and L_{Te} beyond which the fluctuation amplitude increases rapidly. The increase in amplitude and the threshold behavior of fluctuations with respect to collisionality suggest that the electrostatic dissipative trapped electron mode (DTEM) [7,8] could be a candidate instability driving the near-edge turbulence in ECR-heated L-mode plasmas.

During LH transition, the fluctuation characteristics show a dramatic change as a function of applied power. When the applied ECRH power increases, a clear dispersion diagram of T_e fluctuations is observed.

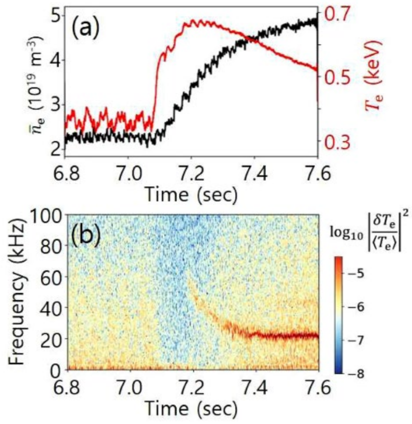

Fig. 2: (a) Time evolutions of the line average density (black) for the KSTAR shot #23359 and T_e at r/a =0.81 (red). (b) Spectrograms for T_e fluctuations showing the emergence of the coherent mode during the LH transition. The transition begins at t=0.71 sec. A frequency chirping coherent mode emerges as the plasma enters a well-established H-mode phase as shown in (b).

In particular, we observe a coherent mode which initiates at higher frequency (~60 kHz) and chirps down to ~20 kHz as the LH transition proceeds. See figure 2 for the emergence of the coherent mode during the LH transition. This observation is in line with that in AUG where a similar coherent mode is observed during ECH driven LH transition [5]. The coherent mode is found to be localized near the pedestal top. As in the AUG case, the presence of the coherent mode keeps the type-I ELM from occurring. A possible correlation between ECM and the disappearance of type-I ELMs is shown to occur in our experiments. The potential role of ECM in regulating large ELMs, therefore, is likely to be a universal phenomenon. A theoretical study of ECM identity and its chirping behavior is of great interest not only from a theoretical perspective but also for practical purposes. An interesting observation related to coherent mode is that edge turbulence, once reduced during the LH transition phase, revives at a H-mode state. The revival of turbulence lowers the pedestal top pressure, which could be a possible origin of the absence of type-I ELMs after the coherent mode emerges, as shown in Fig. 3.

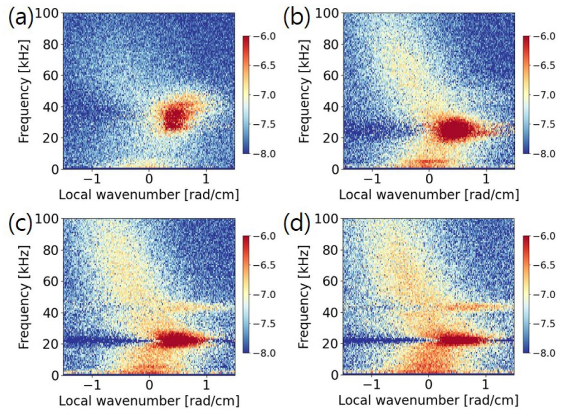

Fig. 3. Dispersion plots of T_e fluctuations during and after the LH transition period, clearly exhibiting evolution and recurrence of fluctuations at the H-mode phase. Coherent mode begins to nucleate at t≈7.15 sec with f～60 kHz.

A detailed theoretical and computational study of the identity of the coherent mode is under investigation. Our study is primarily focused on the possibility of kinetic beta-induced Alfven eigenmode (KBAE) which can be present due to the variation of the edge q-profile by the bootstrap current. This study is ongoing and will be reported in the conference.

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