*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.116 (2006)*

Density Clamping Phenomena by ECRH in LHD

S. Kubo[1], T. Shimozuma[1], K. Tanaka[1], T. Saito [2], Y. Tatematsu [3], Y. Yoshimura[1], H. Igami[1], T. Notake[1], S. Inagaki[1], N. Tamura[1], LHD Experimental Group[1]

[1] *National Institute for Fusion Science, Toki 509-5292, Japan*

[2] *Research Center for Development of FIR Region, Fukui Univ., Fukui 910-8507, Japan*

[3] *Plasma Research Center, Univ. of Tsukuba, Tsukuba 305-8577, Japan*

Introduction

Density clamping or pump out phenomena are observed both in tokamaks and helical systems during high power heating, in particular electron cyclotron resonance heating. These phenomena are discussed in terms of the enhanced electron diffusion induced by the perpendicular acceleration in velocity space and the resultant electric field [1] [2] [3]. It is also pointed out that the change in the electron temperature profile can enhance radial flux due to a non zero off-diagonal term in the transport matrix which can be appreciable by the excitation of turbulent instabilities like trapped electron modes[4].

Such degradation of particle confinement is also observed in a tangential negative ion neutral beam (N-NB) heated plasma in LHD for low density discharges, where electron heating is dominant but heating in parallel to the magnetic field. Such observation also supports the enhancement of the off-diagonal transport term. In order to distinguish both effects, series of experiments are performd.

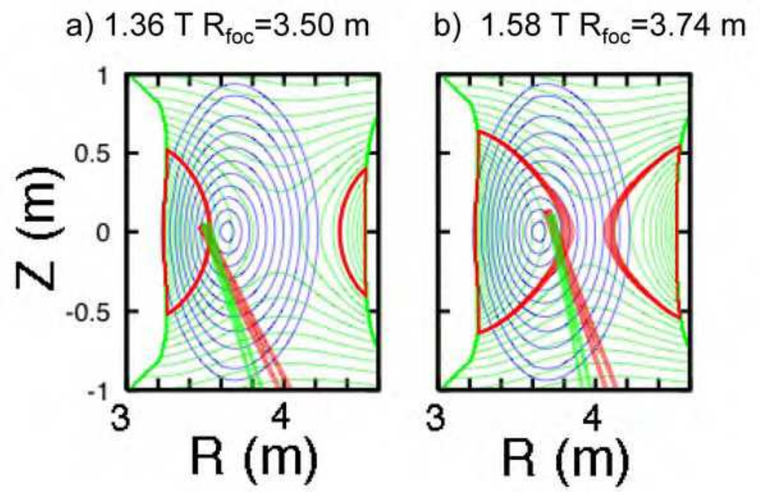

Figure 1: *Vertically elongated cross section of Mod-B, flux surfaces, second harmonic resonance layers and ECRH beams for ripple a) top and b) bottom heating geometries.*

High power second harmonic local ECRH is applied on the ripple top or bottom resonance position where the width of the loss cone is wider for bottom than that for top, but expected power deposition profile is identical to each other in LHD.

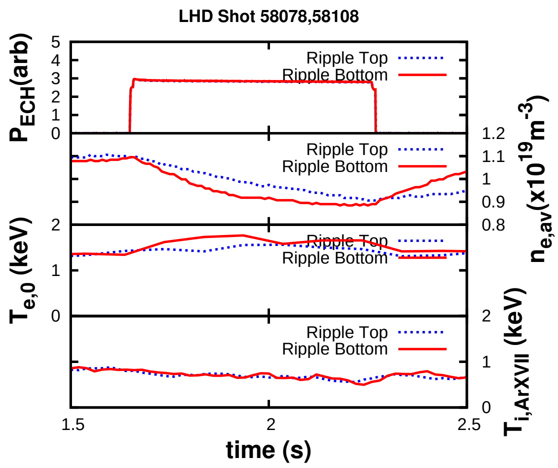

Figure 2: *Temporal evolutions of line averaged density, central electron and ion temperature for ripple top (dotted lines) and bottom (thick lines) ECRH on NB heated discharge.*

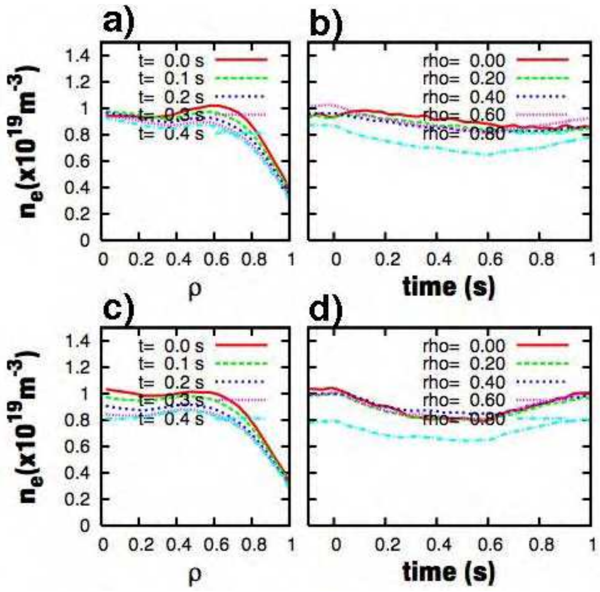

Figure 3: *Density profile at several time slices after ECH injection [a) and c)]. Time evolutions of the density at several spatial points b), and d) for ripple top [a) and b)] and bottom [c)and d)] heating cases.*

Experimental results

Ripple top and bottom heating condition

In order to enhance the difference in the electron flux by ECRH, the heating positions and magnetic field strength are selected so that the toroidal ripple top and bottom are heated but keeping the identical normalized radial position on the same vertically elongated cross section. The magnetic field strength is adjusted to meet the second harmonic resonance condition (1.5 T for 84 GHz) at desired position. These configuration are depicted in Fig.1. The power deposition profile estimated from the multi-raytracing code is identical for both cases.

Difference in the change of plasma parameters

In Fig. 2 are shown the time evolutions of density, central electron and ion temperature response to the ECRH on NB heated plasma for ripple top and bottom resonance heating cases. In both cases, density decrease is observed by applying ECRH, but the time behavior of the decrease in the density clearly changes as the heating position. The line averaged density decreases faster in ripple bottom heating case than in top one. The decrease rate saturates in the time constant of 200 ms for the bottom heating case, while that for the top heating case keeps constant during the ECRH injection of 500 ms. Electron temperature increases within 100 ms and keeps almost constant during the injection for both cases. The profile changes of density reconstructed from a multi-chord FIR interferometer are shown in Fig.3. It should be noted that the density drops at $\rho > 0.4$ but central part does not affected by the ECRH injection for top heating case, while that drops almost whole region for bottom heating case.

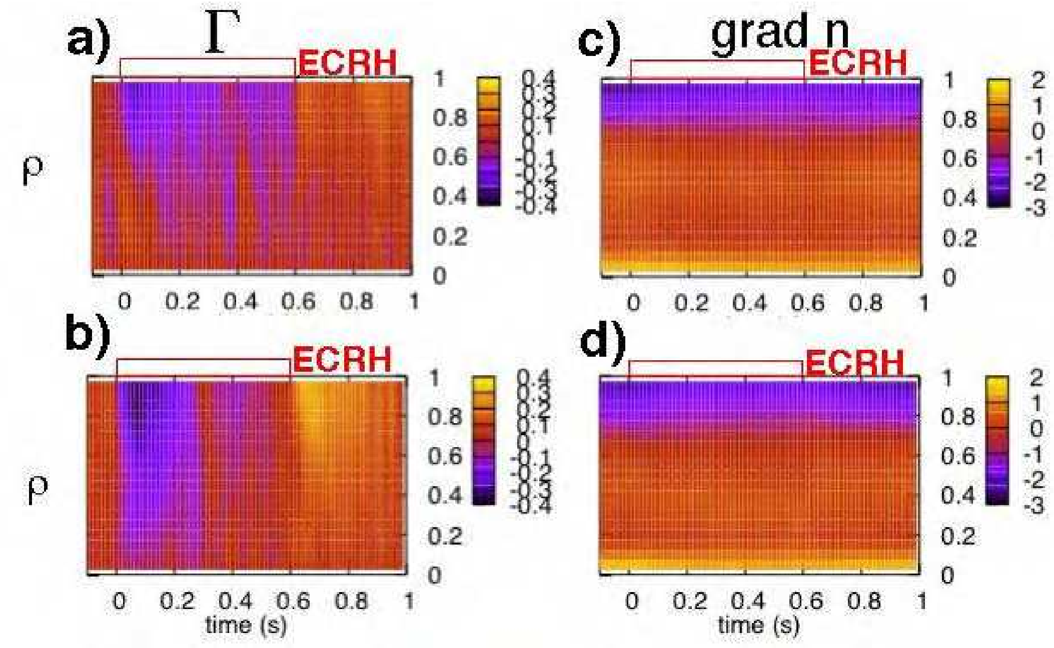

Figure 4: *Particle flux deduced from Eq. (3) for ripple a) top and b) bottom cases. c) and d) show a temporal change in the density gradient for each case.*

Discussion

Neglecting the source and sink term other than that due to ECRH, diffusion equation can be written by electron density $n_e(r,t)$and temperature profiles $T_e(r,t)$ as

$$\Gamma_e(r,t) = D_{e,n}(r,t)\frac{\partial n_e(r,t)}{\partial r} + D_{e,T}(r,t)\frac{\partial T_e(r,t)}{\partial r} + \Gamma_{ECH}(r,t). \tag{1}$$

Here, $D_{e,n}(r,t)$ denotes the normal electron diffusion coefficient, while $D_{e,T}(r,t)$ does an off-diagonal element due to electron temperature gradient. Then the diffusion equation is

$$\frac{\partial n_e(r,t)}{\partial t} = -\frac{\partial}{r\partial r}\Big(r\Gamma_e(r,t)\Big). \tag{2}$$

Integrating over radius of Eq. (2) gives

$$\Gamma_e(r,t) = -\frac{1}{r}\int_0^r r'\frac{\partial n_e(r',t)}{\partial t}\mathrm{d}r'. \tag{3}$$

Thus total electron flux can be deduced from Eq. (3) by the experimentally observed quantity $n_e(r',t)$. In Fig.4 are shown the change in the particle flux deduced from Eq. (3) for the ripple a) top and b) bottom cases. Fast increase of the flux at $\rho > 0.3$ is clear in the ripple bottom heating case than that in the top case. The density gradient profile changes are also shown in Figs.4 c) and d) for comparison. As is expected from Eq. (1), the correlations between a) and c) or b) and d) indicate the effect of normal diffusion coefficient, but there seems no clear correlation between them. Second term in Eq. (1) describes the off-diagonal term from the temperature gradient. As is described above, the temperature profile change occurs only at the beginning 100 ms after ECRH injection for both cases. So the correlation between the deduced flux and the temperature gradient should also be weak. These results indicate that the change in the deduced particle flux for the ripple top and bottom cases are directly driven by ECRH, although the dynamical dependence of the diffusion coefficient on the temperature and its gradient, off-diagonal term and the effect of the radial electric field should be considered more carefully.

Conclusion

By applying ripple top and bottom second harmonic ECRH, the density clamping phenomena are investigated. The difference in the temporal behavior of the electron density can be explained qualitatively by the direct electron flux by ECRH due to the enhanced ripple loss. The effect of the formation of radial electric field might have mitigated the degradation. Experimental and theoretical investigations of the effect of radial electric field are left for future work.

Acknowledgement

The authors would like to express their thanks to the continuous efforts of technical staff of ECRH and LHD to perform the experiments. This work is mainly performed under budget code NIFS05ULRR501-3.

References

[1] K. Ito *et al.*, J. Phys. Soc. Japan **58**, 482 (1989).

[2] H. Sanuki *et al.*, Phys. Fluids, **B2**, 2155 (1990).

[3] H. Idei *et al.*, Fusion Engineering and Design **26**, 167 (1995).

[4] C. Angioni *et al.*, Nuclear Fusion **44**, 167 (2004).