Transport Barriers and H-mode in Regimes with Deuterium Pellets Injected into T-10 Plasma Heated by ECR

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Abstract. The results of experiments with multiple D_2 pellet injection in T-10 tokamak plasma with ECR heating are presented. The injection of pellets and EC power perpendicular launching was from low field side in discharges with plasma current 220-300 kA and EC power up to 1.5 MW. The injection of deuterium pellet results in improved energy confinement with H_H factor up to 1.3 attended by external and internal transport barriers formation. EC power necessary for transition to improved confinement was 5-10 times lower then threshold level estimation in accordance with ITER scaling. The multiple deuterium pellet injection allows us to prolong the linear dependence of energy confinement time on plasma electron density. As a result of such injection MHD phenomena like ELMs Type III were observed in some of T-10 discharges also.

1. Introduction

Injection of deuterium pellets is very interesting not only as a means of fuelling but also as a method of obtaining the improved confinement regimes. Experiments with deuterium pellets injection which were performed [1,2] and now are continuing on T-10 tokamak were oriented mainly to realization and investigation of regimes with improved energy confinement. This paper describes the results of these experiments.

2. Experimental conditions

Deuterium pellets were injected at steady state phase of discharges both in ohmic and auxiliary ECR heated plasma with I_p=220-300 kA, B_T=2.4-2.5 T, $\bar{n}_e$(OH)=(3-4)·10^{19} m^{-3}, P_{ab}^{EC}=0.4-1.5 MW. Pellet injection and EC power perpendicular launching was from low field side. Gyrotrons frequencies were 129 and 140 GHz (central heating), pellets velocity about 10^3 m/s and their dimensions – ∅=1.2-1.5 mm, l=1.5-2 mm (max. ablation radius ~0.7a_L), number of pellets per discharge – up to 5. Scenario of experiments is shown schematically in *FIG.1*. The injection of deuterium pellets results in sharp change of practically all plasma parameters. *FIG.2* represents the typical waveform of mean plasma density behavior.

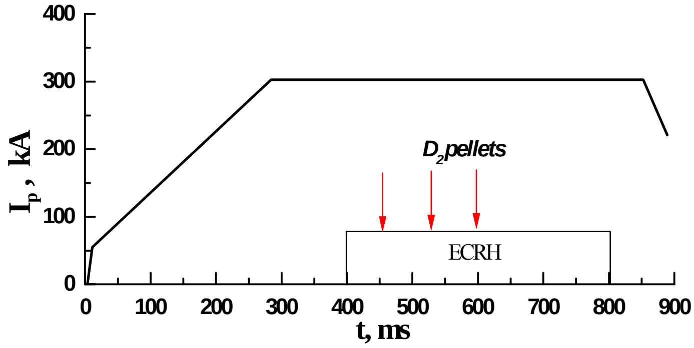


FIG. 1

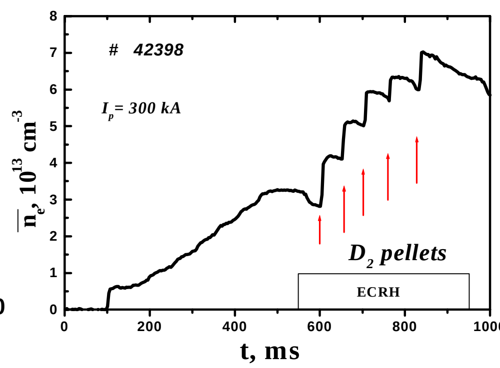
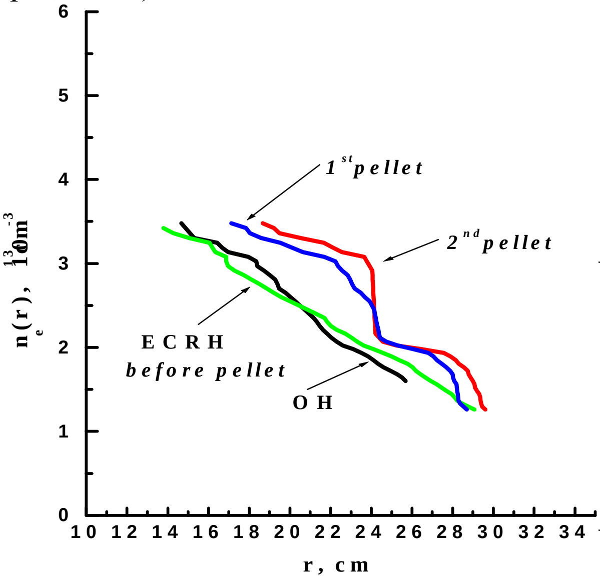


FIG. 2

As a result of pellet injection the plasma density profile sharply changes also. From *FIG.3* one can see that after pellet injection the edge density pedestal forms which is typical for external transport barrier (H-mode). Simultaneously once more “step” on density profile in deeper plasma region appears which is typical for internal transport barrier. Injection of the next pellet did not destroy these barriers and even gives some increase of its. The density gradients in barrier region exceed 10^{21} m^{-4}, which is typical for L-H transition initiated by deuterium pellet injection [3]. It should be noted that resulting density profile after deuterium pellet injection sustains during all time of auxiliary ECR heating pulse i.e. much longer than energy confinement time. Such density profile behavior is observed only with auxiliary ECR plasma heating. With ohmic heating the density profile changes for a very short time only. The heating power level we observed in such L-H transition on T-10 is 5-10 times lower than the threshold transition power estimated according ITER scaling.

As a result of pellet injection the typical for transport barriers “steps” on electron temperature profile also appears (*FIG.4*) which sustain all the duration of auxiliary ECR heating pulse. The formation of barrier “steps” take place in those plasma regions where in accordance with model calculations rational magnetic surfaces with small values of *m* и *n* are located (i.e. with q=1; 1,5; 2).



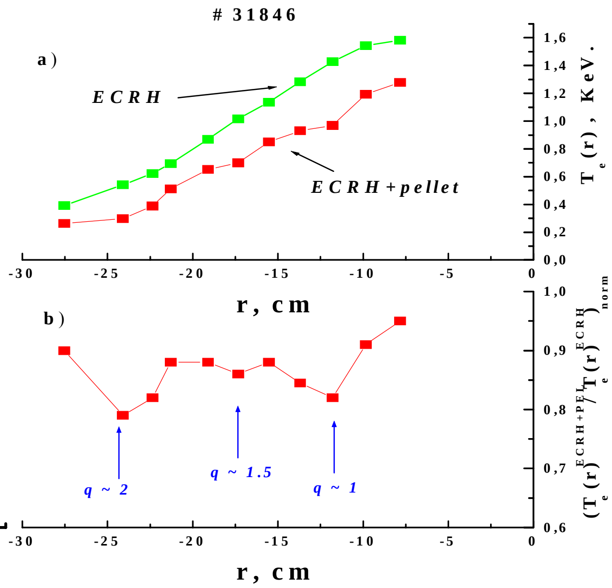


FIG. 3 *FIG. 4*

Localization of barriers “steps” in density and temperature profiles is changed in accordance with the value of plasma current in discharge (*FIG.5*).

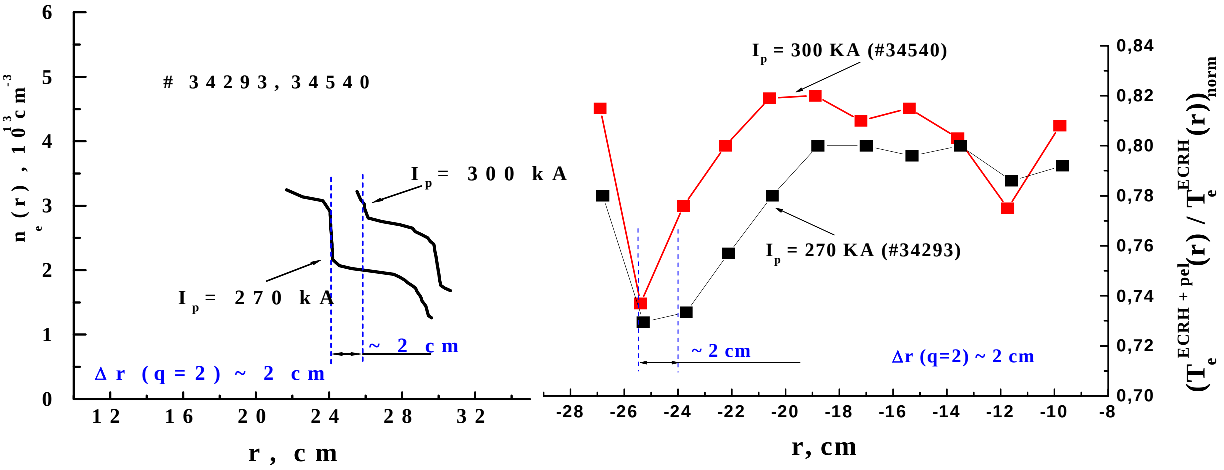


FIG. 5

The injection of next pellet didn't destroy these barriers and even makes its more pronounced. Injection of deuterium pellets does not result in formation of transport barriers in OH discharges (*FIGS. 6, 7*).

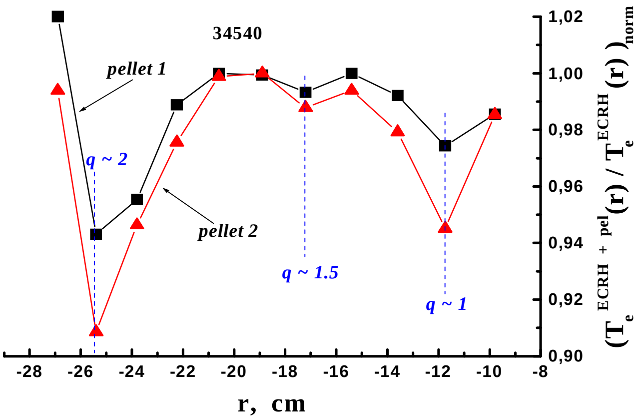


FIG. 6

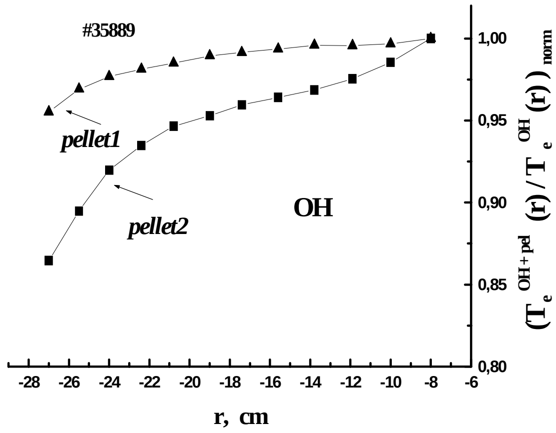


FIG. 7

The improved confinement regimes (H-mode) on T-10 tokamak with circular limiter are characterized by practically full absence of edge localized modes (ELM). Such regimes (*'Quiescent H-mode'*) were firstly observed on ASDEX Upgrade tokamak [4]. But at high plasma density obtained as a result of multiple deuterium pellet injection and with auxiliary ECR heating we observed MHD phenomena like ELM of Type III in some of T-10 discharges (*FIG.8*).

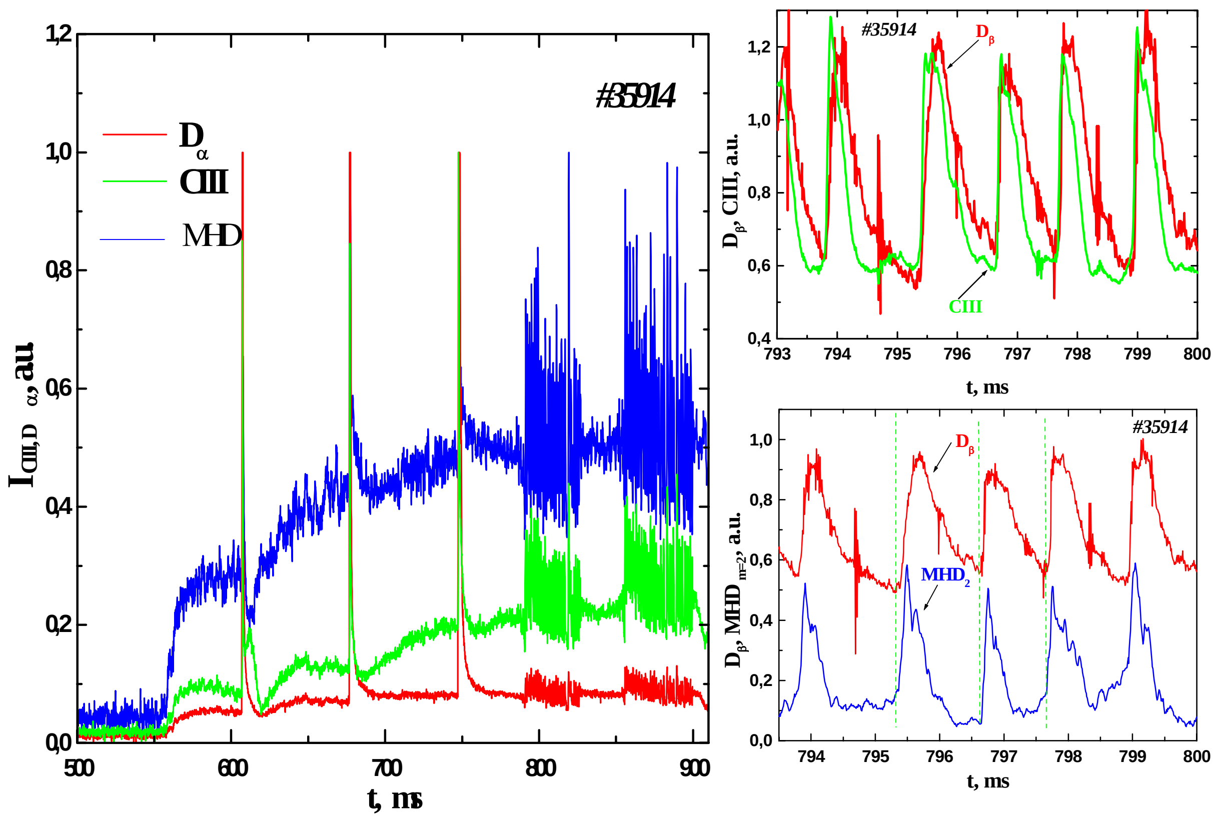


FIG. 8

Such oscillations with duration of ~40-50 ms and frequency ~1 kHz appeared after third pellet injection and are attended by oscillations of spectral line (deuterium and carbon) intensities.
ELM III-like oscillations results in deterioration of plasma parameters and energy confinement. During such oscillation consequence the partial destruction of external transport barrier take place (edge density profile changes) with it's afterwards restoration after disappearing of oscillation consequence. ELM-like oscillations affects also even on a deeper plasma region (r~24 cm) with partial destruction of internal transport barrier. The central ion temperature measured by neutral particle analyzer drops by ~10% which results in fast decrease of neutral yield by ~1.5 times (*FIG.9*).

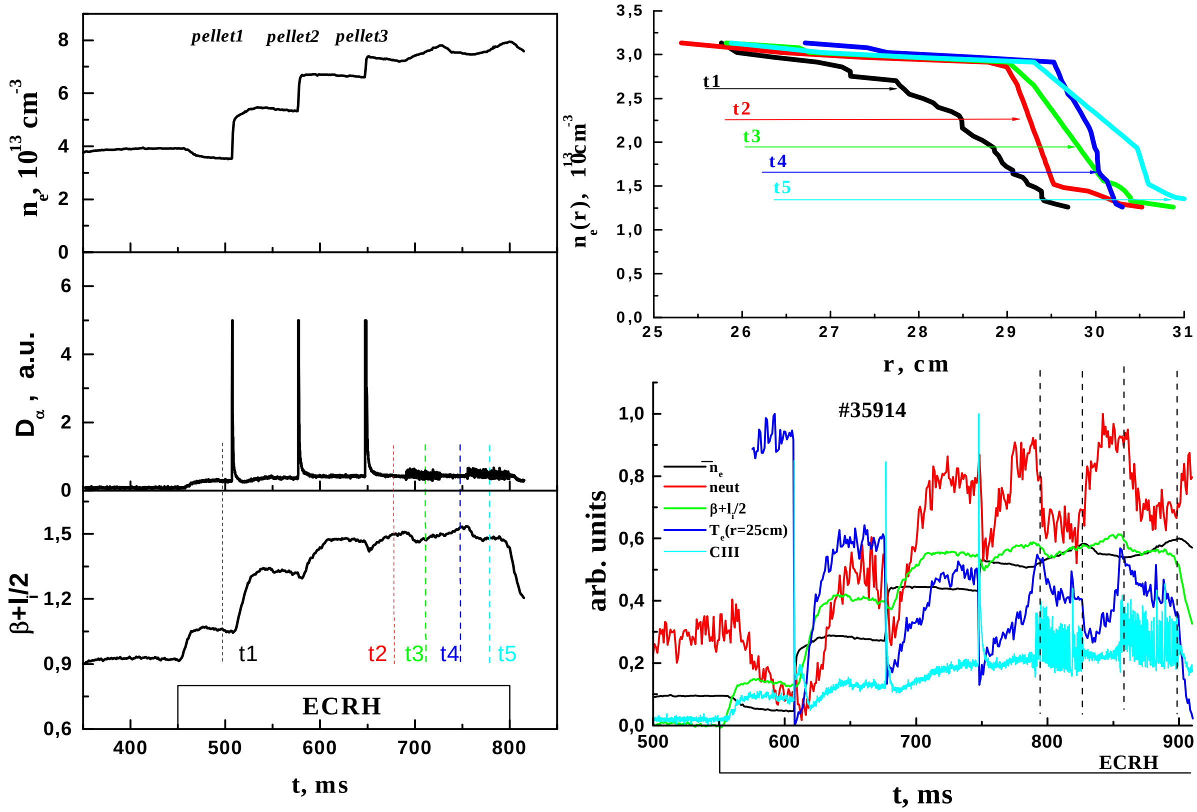


FIG. 9

After ELM III disappearance ion temperature and neutron yield restore quickly. Partial destruction of internal transport barrier during ELM III and it's afterward restoration correspondingly displays in electron temperature.
The improved confinement regimes obtained as a result of deuterium pellet injection are characterized with once more peculiarity. It's known that at plasma density sustaining by gas puffing the energy confinement time saturation take place both in ohmic regimes and at auxiliary ECR heating [5]. The multiple deuterium pellet injection during auxiliary ECR heating with P_{input}~1-1.2 MW allows us to prolong the linear dependence of energy confinement time on plasma density in conditions of improved confinement with H_H factor of 1-1.3 (*FIG.10*).

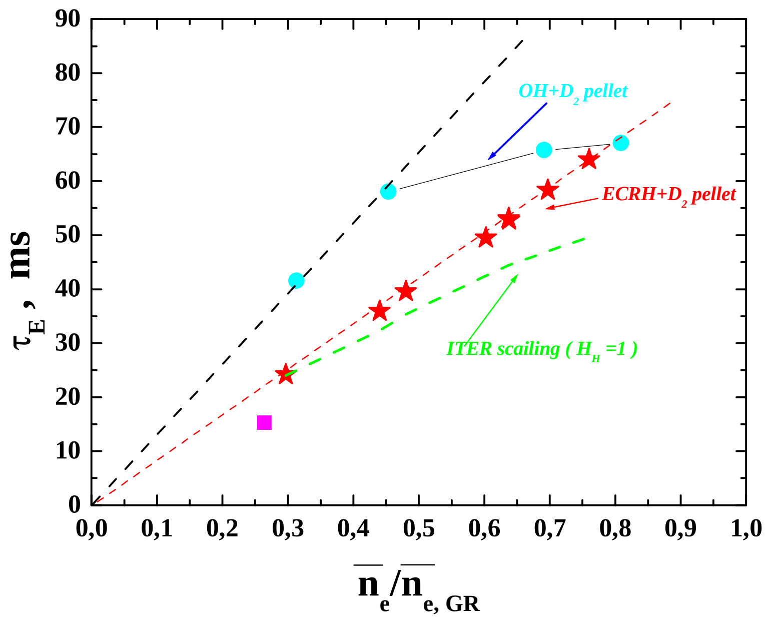


FIG. 10

SUMMARY

1. Injection of deuterium pellets in T-10 tokamak plasma with auxiliary ECR heating results in improved energy confinement and formation of external and internal transport barriers.
2. EC power necessary for L-H-like transition is 5 to 10 times lower then threshold level estimated in accordance with ITER scaling.
3. As a result of multiple deuterium pellet injection MHD oscillation like ELM Type III were observed in some of T-10 discharges.
4. The multiple deuterium pellet injection with auxiliary ECR heating allows us to prolong the linear dependence of energy confinement time on plasma electron density.

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