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OBSERVATION OF H-MODE BY EDGE HEATING SOLELY BY ELECTRON CYCLOTRON HEATING IN A DIVERTOR CONFIGURATION OF JFT-2M TOKAMAK

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H-mode is observed by the edge heating of the JFT-2M plasma solely by the electron cyclotron heating (ECH). The threshold power for the H-mode transition is as low as 120 kW, which is the least threshold power observed in the JFT-2M tokamak. It is surprising that complete edge electron heating can produce the H-mode with such a small ECH power without the additional heating power at the plasma core. This result clearly shows that the H-mode mechanism lies at the very edge (near the separatrix) of the tokamak plasma in the divertor configuration.

Keywords: H-mode, Electron Cyclotron Heating, JFT-2M Tokamak, Tokamak Confinement

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ＪＦＴ－２Ｍトカマクダイバーター配位での電子サイクロトロン加熱による周辺加熱のみによるＨモードの観測

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電子サイクロトロン加熱（ＥＣＨ）のみによるＪＦＴ－２Ｍプラズマの周辺加熱でＨモード生成を観測した。Ｈモード遷移のパワーのしきい値は120 kWと低く，これはＪＦＴ－２Ｍトカマクで観測された最低のしきい値である。このようなプラズマの周辺加熱のみで，中心部の追加熱パワー無しにこのような低いパワーでＨモード遷移が起きることは驚嘆に値する。これらの事実は，Ｈモードの機構はプラズマのごく周辺部（セパラトリクス近傍）に関係していることを明白に示すものである。

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1. Introduction

Since the first discovery of the H-mode, which has an improved particle/energy confinement during the additional heating phase, in the ASDEX tokamak[1], the physics of the H-mode has become one of the major problems in the research of the tokamak confinement. The H-mode was found in the plasma under the various additional heating methods, such as neutral beam injection heating (NBH) and radio frequency heating the frequency of which is in the range of the ion cyclotron frequency (ICRFH). Recently, the H-mode was found to occur even by the electron cyclotron heating (ECH) of the plasma edge preheated by the NBH in JFT-2M tokamak[2,3], and in the core ECH of Doublet III tokamak[4]. In the Doublet III tokamak, H-mode has not been found by the edge heating.

In the previous experiment[2,3], the ECH power was restricted to 100 kW. This time, the ECH power is raised to maximum 230 kW, and it is found that H-mode is produced by the edge heating solely by ECH.

2. Apparatus

The JFT-2M tokamak is a non-circular D-shaped tokamak which has plasma major radius of 1.31 m and minor radii of 0.35 m × 0.53 m in its full size operation. Maximum strength of the toroidal field is 1.5 T.

The frequency of the ECH is 59.8 GHz. The second harmonic extraordinary mode, the wave electric field of which is almost perpendicular to the magnetic field, is launched from the low field side of the tokamak plasma. The launch angle is 80° (~ perpendicular) with respect to the magnetic field vector[5].

3. Experimental Results

The plasma configuration taken in this experiment is the lower-single-null divertor configuration as shown in Fig. 1.

It is observed that H-mode occurs by the edge ECH when the second harmonic electron cyclotron resonance (ECR) layer is located at 0.85a, where a denotes the minor radius of the plasma, as shown in Fig. 2. The clear drop in the intensity of the deuterium Balmer line with

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bursts is observed. The average density increases at the H-mode transition, and saturates when bursts appear in the D_α signal. The saturation in density is typically shown during the burst H-mode induced by NBH or ICRFH. Though the plasma core region is cut off for the second harmonic extraordinary mode of 59.8 GHz at the local density of $n_e = 2.8 \times 10^{19}$ m^{-3} (just before the ECH), the ECR layer located at 0.85 a is accessible for the wave (the cutoff density is 2.2×10^{19} m^{-3}). The edge electron temperature at position 0.88 a is large during the H-mode. The increment of the stored energy measured by the diamagnetism is 4 kJ, whereas the increment during the L-mode is 2.6 kJ. It is noted that the increment of the Shafranov lambda (Λ+1/2 = β_p+l_i/2 -1/2 where β_p and l_i denote the poloidal beta value and the internal inductance, respectively) is small in spite of the large increase in the stored energy. This indicates a decrease of the internal inductance, and suggests broadening of the current profile during the H-mode by edge ECH.

These experimental results show clearly that the H-mode can be produced without additional heating of the plasma core, and provide additional direct confirmation that the H-mode mechanism is closely related to an increase in the plasma edge electron temperature.

Figure 3 shows the density region where the H-mode transition occurs when the ECR layer is located at 0.85 a, It shows the power threshold of minimum 120 kW for the H-mode transition as well as the existence of the low density limit at $\bar{n}_e = 2.2 \times 10^{19}$ m^{-3} with the maximum ECH power of 230 kW now available. The broken line shows the threshold power for the H-transition solely by the NBH. It was tanken at the same experimental condition. Comparison of the data points with the broken line shows that the threshold power for the edge ECH is smaller than the threshold power of NBH (core heating) at around $\bar{n}_e$ = 3.0×10^{19} m^{-3} in spite of the edge power deposition of ECH.

Further, a short ECH pulse of the pulse length of 20 ms can induce the H-transition as shown in Fig. 4. A marked feature is that a burst free H-mode lasts as long as 50 ms after the ECH pulse is off. The density increases continuously after the ECH is off, and the high edge temperature is maintained throughout the H-mode. The time scale of the duration of the H-mode seems to be related to the decay speed of the edge electron temperature.

4. Conclusion

H-mode was shown to occur by the edge heating by ECH. Therefore no core additional power is required for the H-mode transition. The threshold additional power for the H-mode transition solely by ECH edge heating is smaller than the threshold additional power by the core heating by NBH.

Acknowledgement

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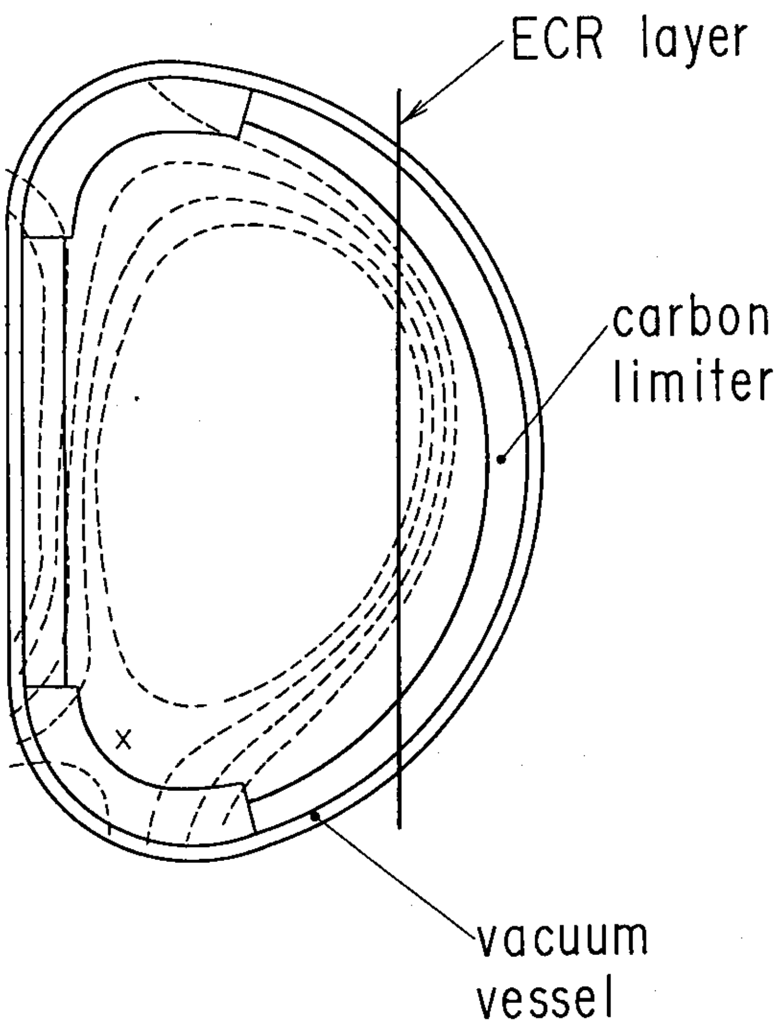

Fig. 1 Position of the second harmonic ECR layer in the lower-single-null divertor configuration in the JFT-2M tokamak. Null point location is indicated by cross simbol. B_{t0} = 1.23 T. I_p = 201 kA. r_0/a = 0.85. a = 0.266 m.

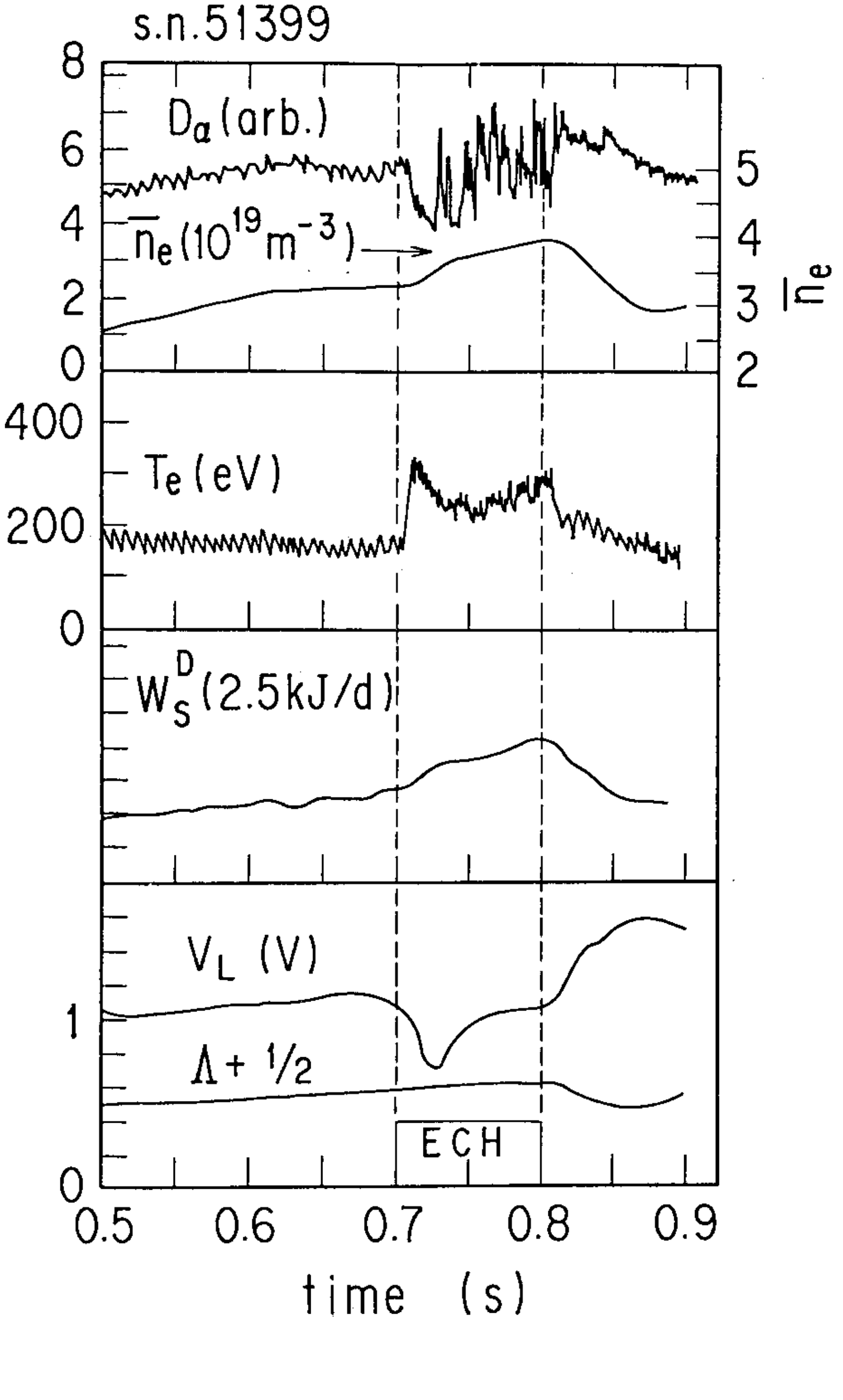

Fig. 2 Time evolutions of the intensity of the deuterium Balmer line D_α, edge electron temperature at the radius 0.88a measured by ECE T_e (0.88a), stored energy measured by diamagnetism W_S^D, loop voltage V_L, and Shafranov lambda Λ. B_{t0} = 1.23 T. I_p = 201 kA. r_0/a = 0.85.

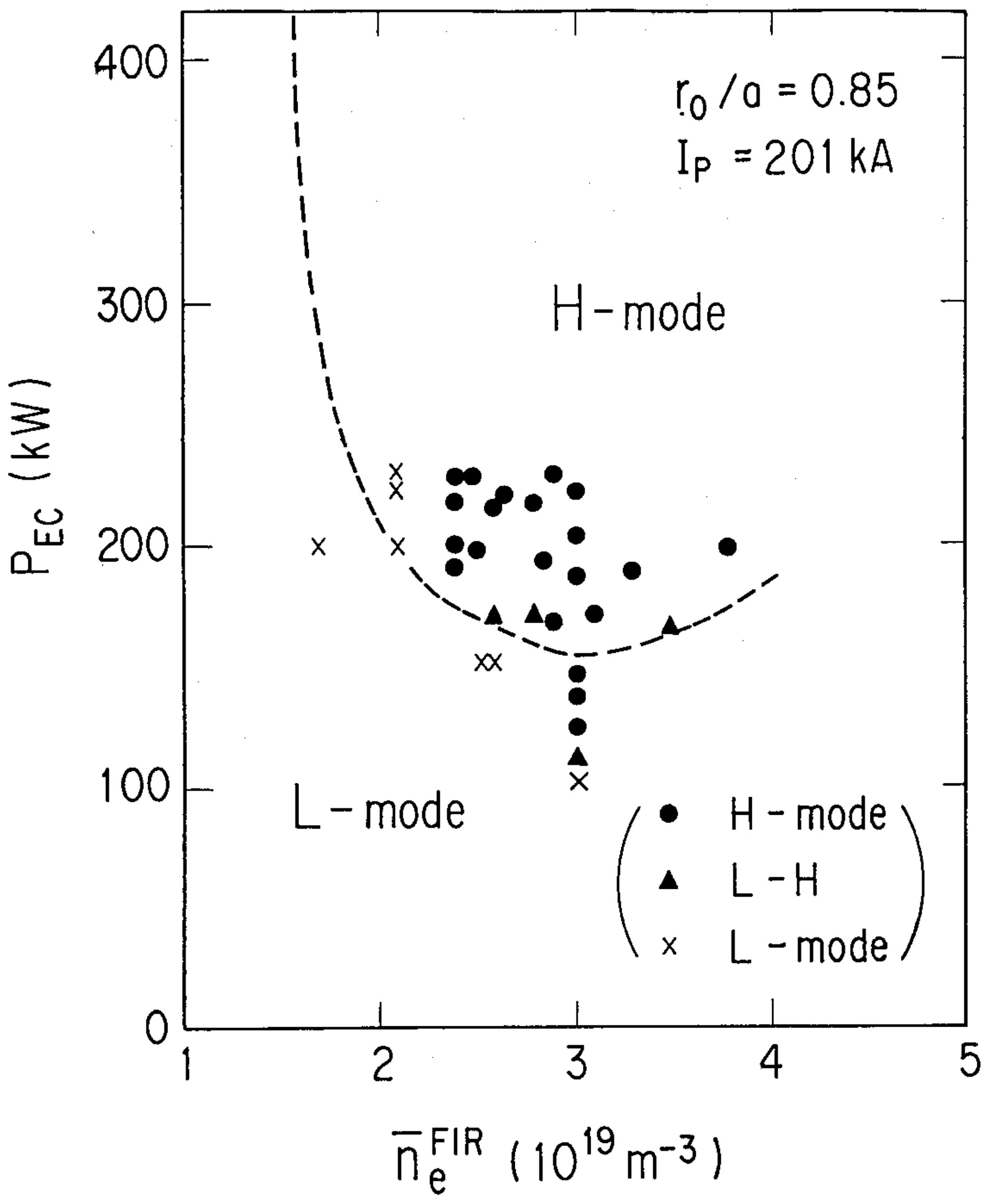

Fig. 3 Density and ECH power plot which shows the parameter region in which H-mode was obtained. The triangle shows the boundary between H-mode and L-mode in the parameter space. Broken line shows the threshold power for the H-mode transition by NBH.

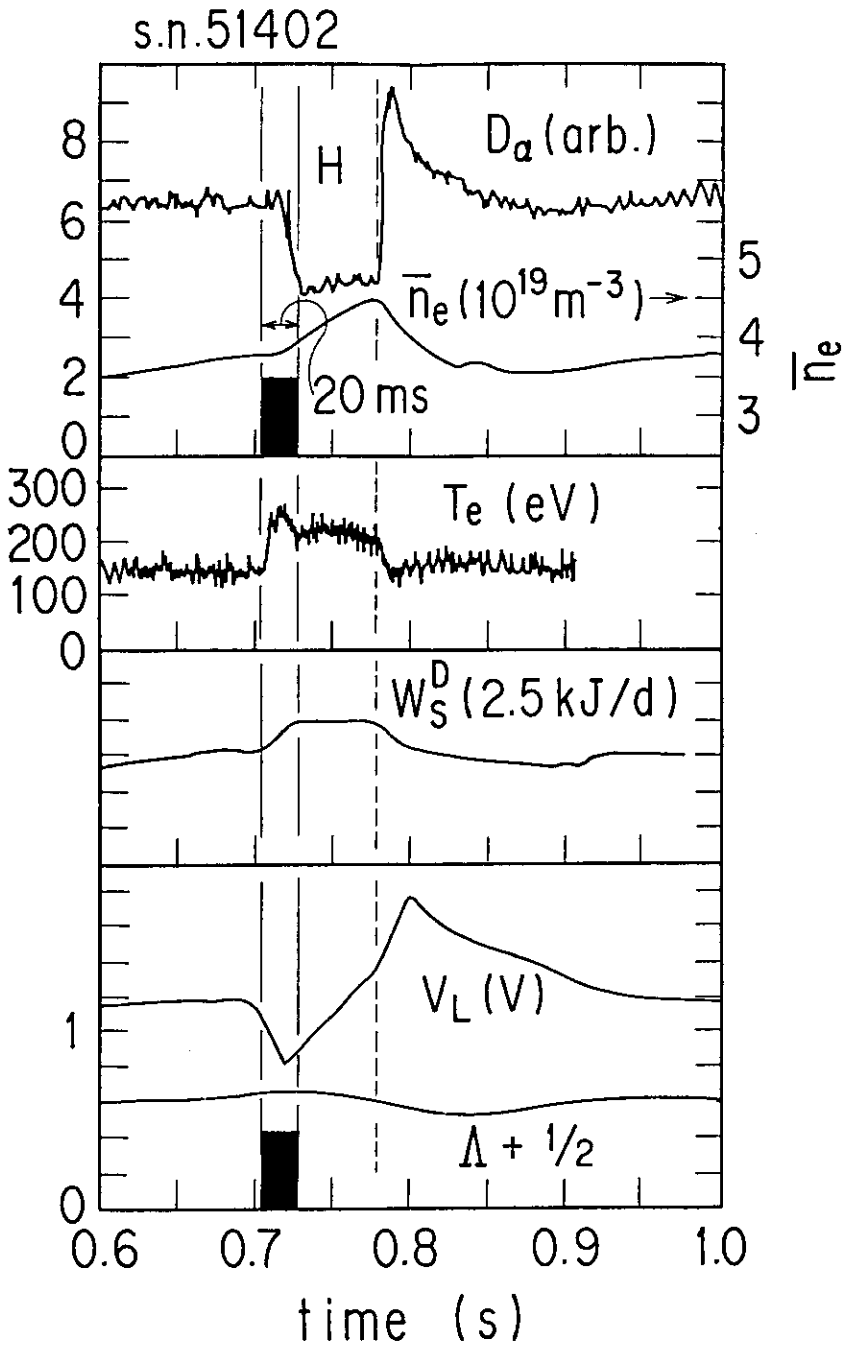

Fig. 4 Time evolutions of the H-mode shot by a short (20 ms) ECH pulse. H-mode lasts for 50 ms after the off of the ECH pulse. B_{t0} = 1.23 T. I_p = 201 kA.