ISSN 0915-633X

INTERNATIONAL ATOMIC ENERGY AGENCY

THIRTEENTH INTERNATIONAL CONFERENCE ON
PLASMA PHYSICS AND CONTROLLED NUCLEAR FUSION RESEARCH

Washington, DC, United States of America, 1–6 October 1990

IAEA-CN-53/A-4-4

NATIONAL INSTITUTE FOR FUSION SCIENCE

Study of Limiter *H*- and *IOC*- Modes by Control of Edge Magnetic Shear and Gas Puffing in the JIPP T-IIU Tokamak

K. Toi, Y. Hamada, K. Kawahata, T. Watari, A. Ando, K. Ida, S. Morita,
R. Kumazawa, Y. Oka, K. Masai, M. Sakamoto, K. Adati, R. Akiyama, S. Hidekuma,
S. Hirokura, O. Kaneko, A. Karita, T. Kawamoto, Y. Kawasumi, M. Kojima,
T. Kuroda, K. Narihara, Y. Ogawa, K. Ohkubo, S. Okajima, T. Ozaki, M. Sasao,
K. Sato, K.N. Sato, T. Seki, F. Shimpo, H. Takahashi, S. Tanahashi, Y. Taniguchi
and T. Tsuzuki

(Received – Aug. 28, 1990)

NIFS-40 Sep. 1990

RESEARCH REPORT
NIFS Series

NAGOYA, JAPAN

INTERNATIONAL ATOMIC ENERGY AGENCY

THIRTEENTH INTERNATIONAL CONFERENCE ON
PLASMA PHYSICS AND CONTROLLED NUCLEAR FUSION RESEARCH

Washington, DC, United States of America, 1–6 October 1990

IAEA-CN-53/A-4-4

STUDY OF LIMITER *H*- AND *IOC*- MODES BY CONTROL OF EDGE MAGNETIC SHEAR AND GAS PUFFING IN THE JIPP T-IIU TOKAMAK

K. TOI, Y. HAMADA, K. KAWAHATA, T. WATARI, A. ANDO,
K.IDA, S. MORITA, R. KUMAZAWA, Y. OKA, K. MASAI, M. SAKAMOTO,
K. ADATI, R. AKIYAMA, S. HIDEKUMA, S. HIROKURA, O. KANEKO,
A. KARITA, T.KAWAMOTO, Y. KAWASUMI, M. KOJIMA, T. KURODA,
K. NARIHARA, Y. OGAWA, K. OHKUBO, S. OKAJIMA*), T. OZAKI,
M. SASAO, K. SATO, K.N. SATO, T. SEKI, F. SHIMPO,
H. TAKAHASHI, S. TANAHASHI, Y. TANIGUCHI, T. TSUZUKI

National Institute for Fusion Science, Nagoya 464-01,Japan

*)Department of Applied Physics, Chubu University, Kasugai 487,Japan

13th International Conference on Plasma Physics and
Controlled Nuclear Fusion Research, Washington,DC,
United States of America, 1-6 October 1990

IAEA-CN-53/A-4-4

STUDY OF LIMITER *H*- AND *IOC*- MODES BY CONTROL OF EDGE MAGNETIC SHEAR AND GAS PUFFING IN THE JIPP T-IIU TOKAMAK

Abstract

Two types of improved confinement regimes, H-mode and IOC(improved ohmic confinement)-mode, are studied in circular-limiter plasmas on JIPP T-IIU. When the rapid ramp-down of plasma current (CRD) is employed during auxiliary heating, the threshold heating power required for the L-H transition is reduced by 30-50 %, compared with that in the case without CRD. This is interpreted to be due to enhancement of the global magnetic shear near the plasma edge by CRD. This model based on edge magnetic shear is also applicable to the limiter H-mode obtained without CRD by high heating power. In the limiter configuration, improved confinement regime, IOC-mode, is obtained in ohmically heated high density plasmas by gas puff control. This improvement may be attributed to reduction of anomalous transport, since radiation loss has only minor effect.

Keywords: Limiter H-Mode, L-H Transition, Edge Magnetic Shear, Edge Toroidal Current Density, Edge Localized Modes, Limiter IOC-Mode, Gas Puff Control, Density Fluctuations

1. LIMITER *H*-MODE

Trigger mechanism of the L-H transition is still unclear, while many tokamaks have obtained the H-mode in divertor and limiter configurations since its discovery in ASDEX [1]. Recently, transition models based on the change in edge radial electric field [2,3] are developed. They seems to partly explain the data of edge radial electric field obtained experimentally [4,5] and dramatic suppression of edge fluctuations in high-frequency and short-wavelength region at the transition [6]. The models, however, might not explain the experimental observation in ASDEX [7]: coherent magnetic fluctuations with low mode numbers (m=3 or 4, n=1), which are localized near the plasma edge and are excited during L-phase, are suppressed just prior to the transition. In ref.7, a new transition model is proposed that the transition is governed by the change in a toroidal current density (j_ϕ) near the edge. We test the new model in the limiter tokamak JIPP T-IIU (R≅91 cm, a≅23 cm, B_t≅2.8-3.0 T), modifying the edge current density by the rapid ramp-down in plasma current (CRD) [8]. The limiter configuration is advantageous for studying the effect of magnetic shear on the transition, because the magnetic shear can be simply changed by modifying the current density profile with the same external magnetic configuration.

Figure 1 shows the effect of CRD on the L-H transition, where heating power is set below the threshold in the case without CRD [9]. The transition does not always correlate with high edge electron temperature (T_{eb}) just prior to the transition. The dependence of the heating power (RF or RF+NBI) on plasma current (I_p) at the transition is investigated for H-modes with and without CRD. The threshold power in the case with CRD is lower by 30-50 % than that in the case without CRD for the same I_p [8]. It is concluded that the transition is determined not by the decreased I_p, but by the modification of the edge j_ϕ-profile.

Figure 2(a) shows the H-mode with CRD, where the transition is initiated without any sawtooth event and without any rise in T_{eb} prior to the transition. The magnetic shear near the edge $\hat{s}_{mb}$ (at r/a=0.8, where the transport barrier determined experimentally is located at r/a=0.8-0.9 [8]) calculated by a magnetic diffusion equation is appreciably increased by CRD. When it increases up to a certain value $\hat{s}_{mb}$=1.8-2.0, the transition readily occurs. The increase in $\hat{s}_{mb}$ up to the value means that a current channel is almost detached from the limiter, as shown in Fig.2(b). On the other hand, rapid ramp-up of I_p easily quenches the H-mode obtained at very high heating power (P_{RF}+ P_{NI} $\cong$ 2.6 MW). This is interpreted that $\hat{s}_{mb}$ is appreciably reduced by the ramp-up.

We now consider whether the H-mode without CRD, obtained with high heating power, is governed by the same mechanism, i.e., edge magnetic shear or edge j_ϕ-profile. When strong electron heating occurs or when an appreciable amount of bootstrap current is generated in the plasma volume by high power heating, the plasma current I_p tends to increase on a time scale shorter than the resistive diffusion time of the plasma. Then, a reversed toroidal electric field near the edge may be induced to conserve poloidal magnetic flux. This field may detach the current channel from the limiter, keeping I_p constant, as shown in Fig.3(b). This change in j_ϕ-profile is inferred from time evolution of low mode number magnetic fluctuations driven by ∇j_ϕ, as observed in ASDEX [7]. If the rational surface of the mode locates within the detached region ($j_\phi \cong 0$), it may be easily stabilized, because of reduced ∇j_ϕ and enhanced $\hat{s}_{mb}$($\cong$2) there. Figure 3(a) shows time evolution of m/n=3/1 mode observed in H-mode without CRD, where the rational surface locates near the edge around r/a=0.8-0.9. Suppression of the mode can be explained by the above discussion. Note that, as shown in Fig.3(a), the m/n=3/1 mode can be most unstable in the course of the transition (L-to-H, or H-to-L, or ELM) between L-type j_ϕ-profile and H-type one, accompanying ELM(-like) spike in the H_α/D_α-emission.

Above experimental evidence of JIPP T-IIU suggests that the transition between L-phase and H-one is governed by edge current density or the related magnetic shear rather than edge radial electric field or its shear.

2. Limiter *IOC*-Mode

Improved confinement mode in ohmically heated high density plasmas, IOC-mode, was discovered in divertor configuration of ASDEX by gas puff control [10]. In JIPP T-IIU, IOC-mode has been obtained in the limiter configuration by the same technique [11]. The transition is triggered by sudden reduction of gas puff rate in ohmically heated high density plasmas at high $q(a) \cong 6$(Fig.4(a)). After the transition, electron density profile starts to peak, and electron and ion temperatures increase obviously. Then, plasma confinement is improved considerably. The improvement may be attributed to reduction of anomalous transport, since radiation power loss has only minor effect on this ohmically heated plasma. However, density fluctuations related to electron and ion modes, measured by FIR-laser scattering [12], exhibit only small change, as shown in Fig.4(b). We need further study on fluctuations of density and plasma potential, and other plasma parameters in this limiter IOC-mode.

Acknowledgments

One of the authors(K.T.) wishes to acknowledge Drs. K. Itoh, S.-I. Itoh, H. Sanuki, and K.C. Shaing for useful discussions. The authors also wish to thank Drs. A. Iiyoshi and M. Fujiwara for continued support and encouragement.

References

[1] WAGNER, F., et al., Phys. Rev. Lett. **49** (1982) 1408.

[2] ITOH, S.I. and ITOH., K., Phys. Rev. Lett **60** (1988) 2276. and Research Report of National Institute for Fusion Science NIFS-4(1990).

[3] SHAING, K.C. and CRUME, E.C.,Jr., Phys. Rev. Lett **63** (1989) 2369.

[4] GROEBNER, R.J., et al., Phys. Rev. Lett. **64** (1990) 3015

[5] IDA, K., et al., Research Report of National Institute for Fusion Science NIFS-26(1990)(to be published in Phys. Rev. Lett.).

[6] BURRELL, K.H., et al., Contr. Fusion and Plasma Phys. **31** (1989) 1649.

[7] TOI, K., et al., Phys. Rev. Lett. **62** (1989) 430.

[8] TOI, K., et al., Phys. Rev. Lett. **64** (1990) 1895.

[9] WATARI, T., et al., Nucl. Fusion **30** (1990) 1197.

[10]SÖLDNER, F.X., et al., Phys. Rev. Lett. **61** (1988) 1105.

[11]HAMADA, Y., et al., Proc. of 17th Europ. Conf. on Contr. Fus. and Plasma Heating, Amsterdam, 1990, Vol.1, p.34.

[12]KAWAHATA, K., et al., Plasma Phys. and Contr. Nucl. Fus. Res.(Proc. 12th Int. Conf.,Nice, 1988) **1** (1989) 287.

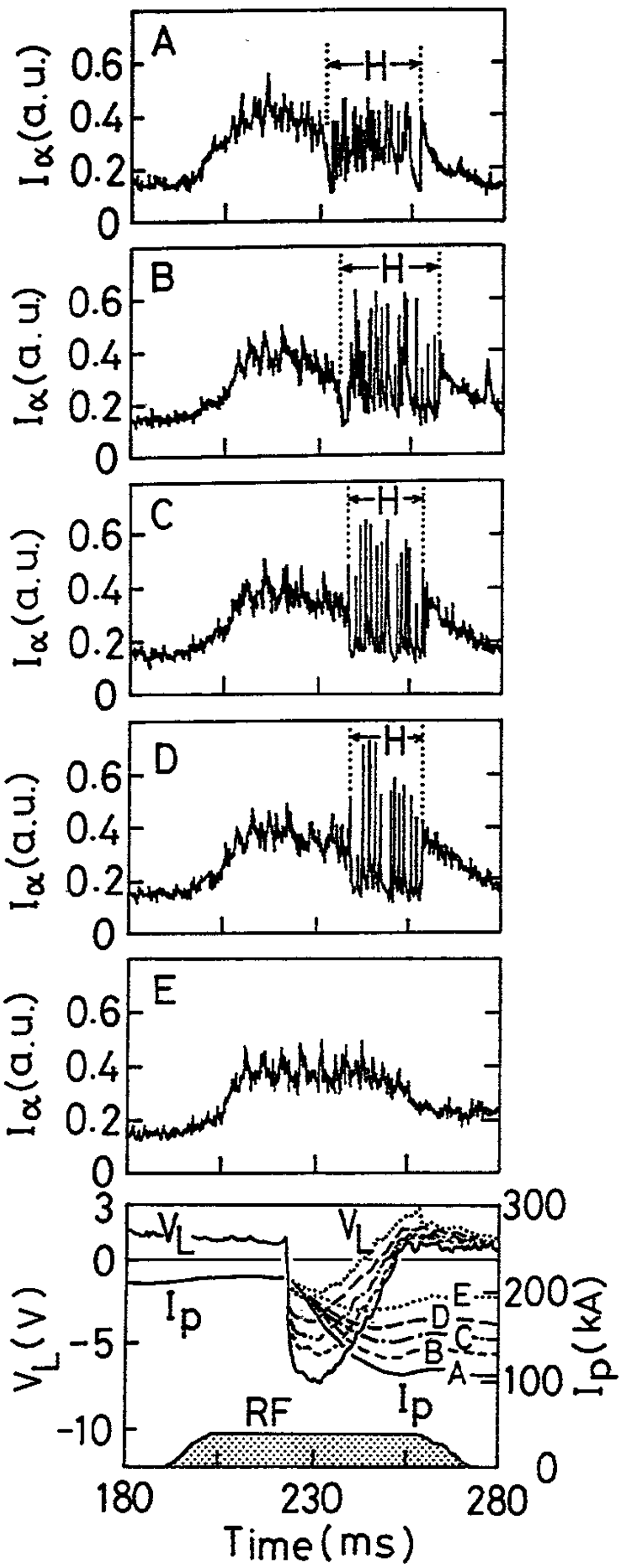
Figure Captions

Fig.1 The effect of rapid current ramp-down on the L-H transition in ICRF heated deuterium plasmas with about 10 % hydrogen minority, where $P_{RF}\cong1.2$ MW and $B_t\cong2.8$ T. I_α denotes the H_α/D_α-emission.

Fig.2 (a) H-mode triggered by CRD without any sawtooth event and without any T_{eb}-rise prior to the transition, where $P_{RF}\cong1.3$ MW and $P_{NI}\cong0.6$ MW. $\hat{s}_{mb}$ is the magnetic shear at r/a=0.8 calculated for the Z_{eff}-value from visible bremsstrahlung. (b) Model profiles of j_ϕ, q(safety factor) and $\hat{s}_m$ (global magnetic shear) for H-mode initiated by CRD.

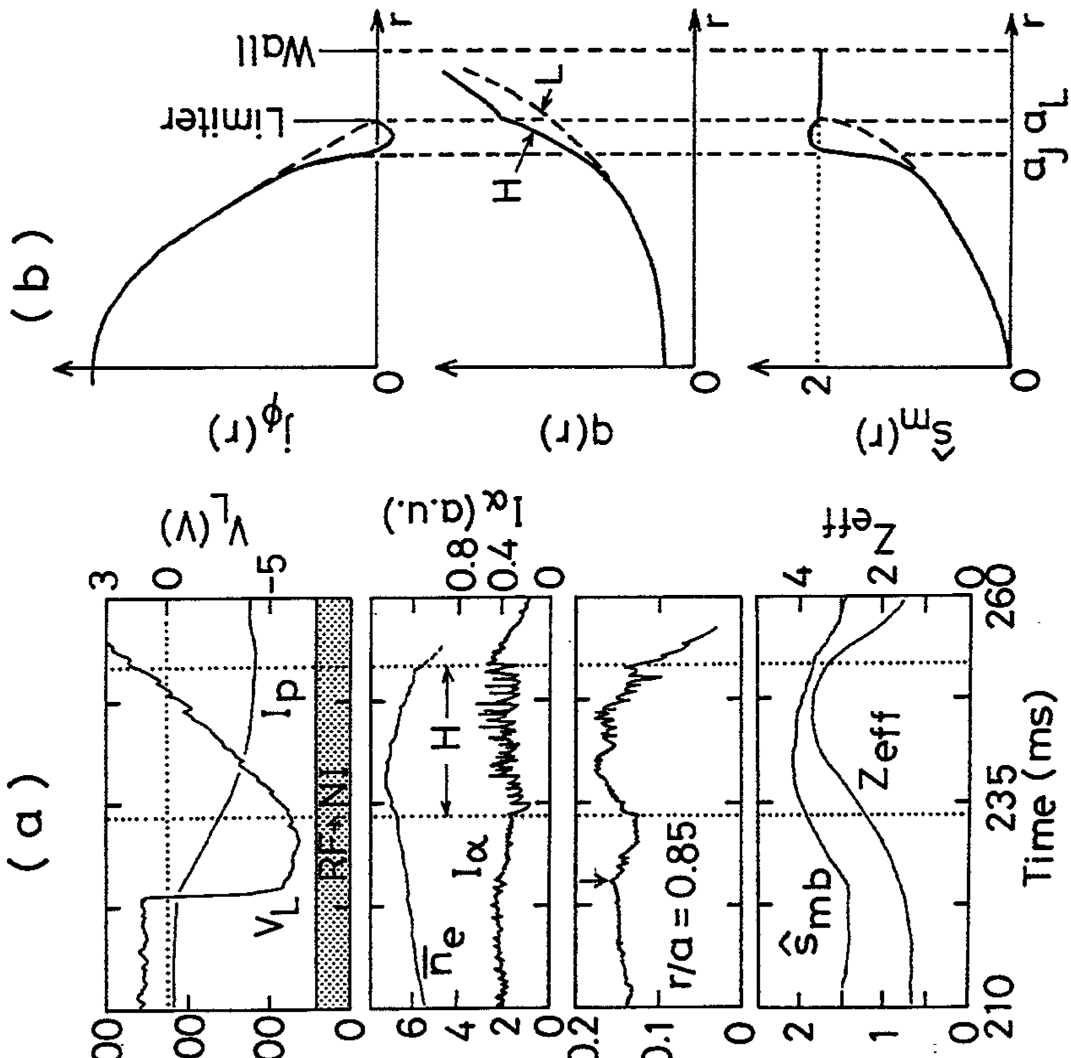
Fig.3 (a) Power spectrum calculated from Mirnov probe signal $\dot{B}_\theta^{IN}$ from t=225 ms to 230 ms in the H-mode without CRD, where $P_{RF}\cong1.1$ MW and $P_{NI}\cong0.75$ MW. Spectral peak C corresponds to m/n=3/1 unstable mode whose rational surface locates near the edge. Time evolution of the m/n=3/1 mode filtered from signals of Mirnov probes on the inner and outer midplane ($15\leq f\leq35$ kHz), edge and central electron temperatures, and H_α/D_α-emission measured by a detector viewing outer edge. (b) Model profiles for H-mode obtained without CRD.

Fig.4 (a) Temporal evolution of limiter IOC-discharge, where a vertical dotted line indicates the IOC-transition. (b) Time variation of electron density fluctuations obtained by FIR-laser scattering with heterodyne detection in the other IOC-shot.



A
B
C
D
E
H
Iα(a.u.)
0.6
0.4
0.2
0
3
0
-5
-10
VL
Ip
VL(V)
Ip(kA)
300
200
100
0
RF
180
230
280
Time(ms)

Fig.1



(a)
(b)
I_p (kA)
V_L (V)
RF+NI
$\bar{n}_e(10^{13}cm^{-3})$
I_α (a.u.)
T_{eb}(keV)
r/a = 0.85
$\hat{s}_{mb}$
Z_{eff}
H
Time (ms)
210
235
260
$j_\phi(r)$
q(r)
$\hat{s}_m(r)$
Limiter
Wall
L
a_J a_L
r

Fig.2

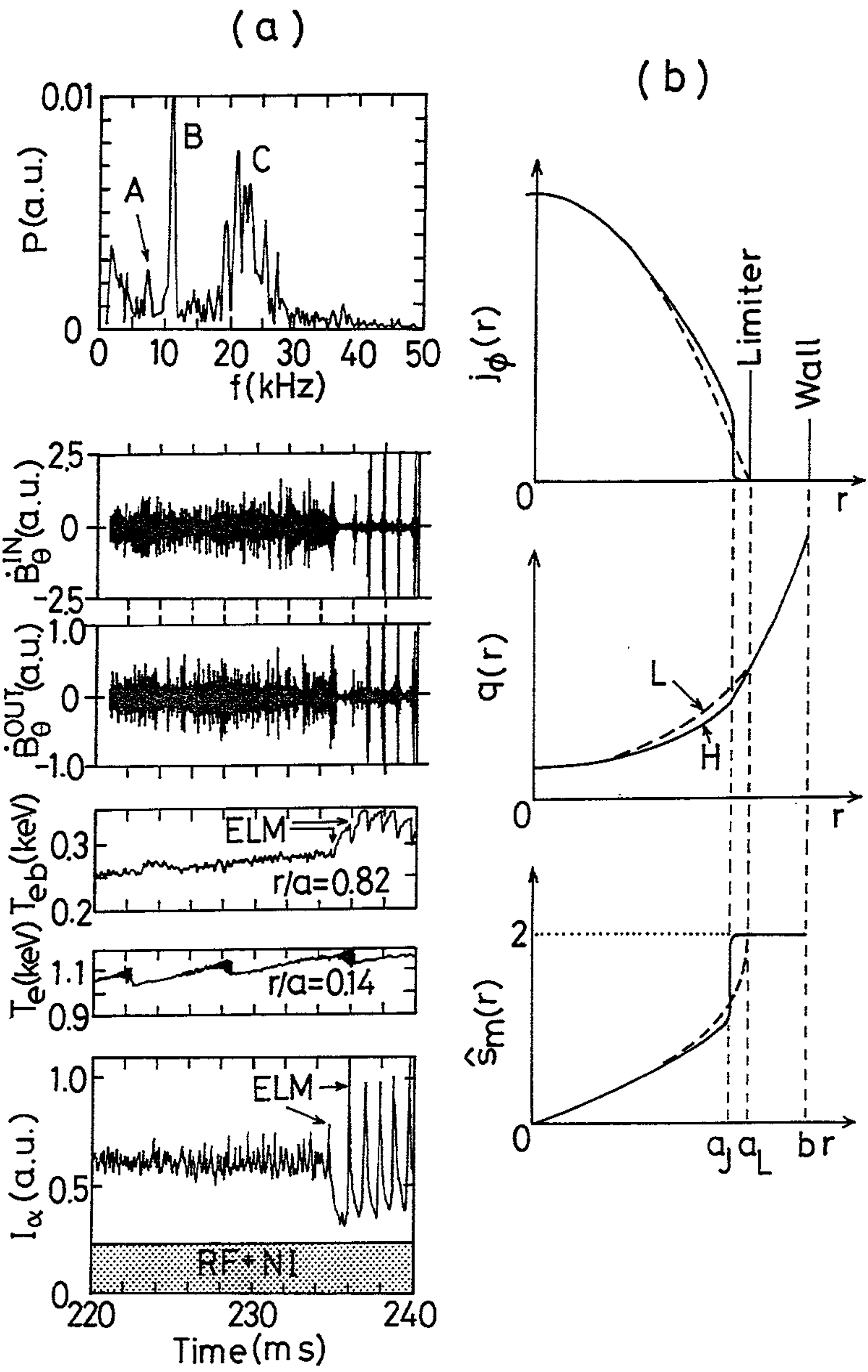

(a)
0.01
P(a.u.)
A
B
C
0
0 10 20 30 40 50
f(kHz)
2.5
0
-2.5
1.0
0
-1.0
ELM
r/a=0.82
0.3
0.2
Teb(keV)
Te(keV)
1.1
0.9
r/a=0.14
1.0
0.5
0
ELM
RF+NI
220 230 240
Time(ms)
(b)
jϕ(r)
Limiter
Wall
0
r
q(r)
L
H
0
r
2
ŝm(r)
0
aJ aL b r

Fig.3

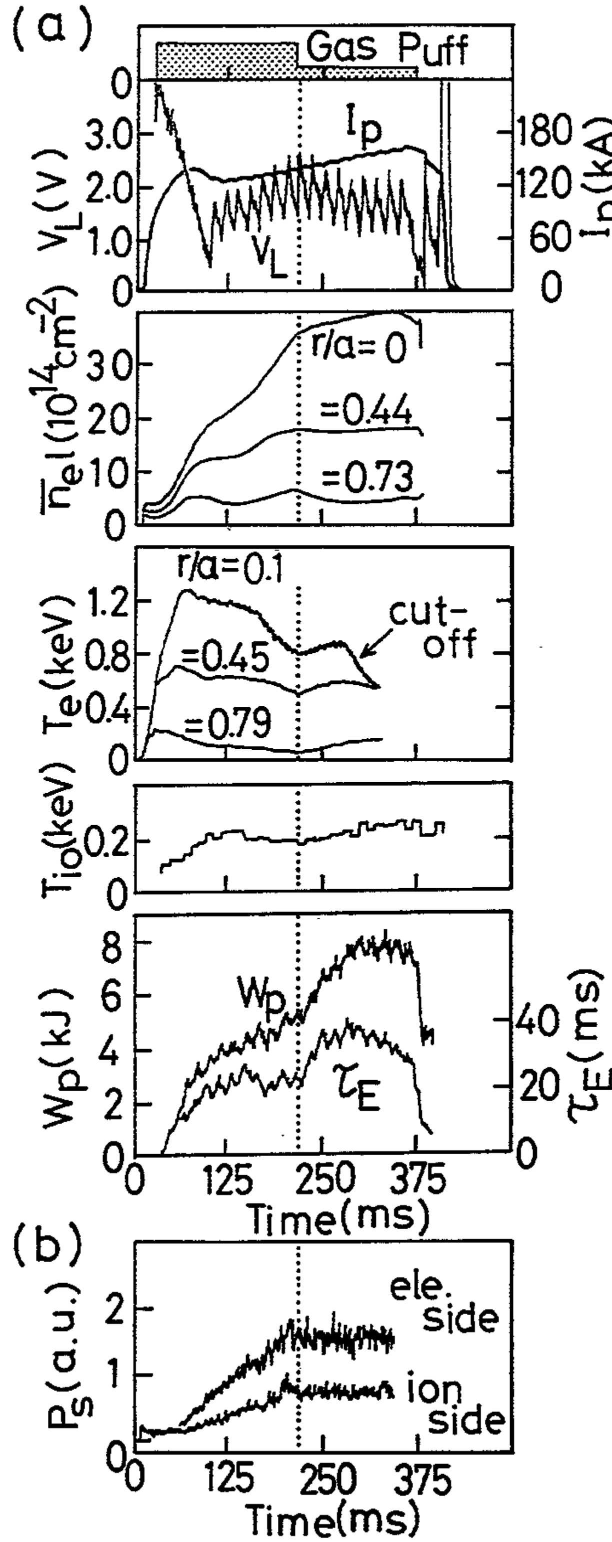

(a)
Gas Puff
0
3.0
2.0
1.0
0
V_L(V)
I_p
V_L
180
120
60
0
I_p(kA)
$\bar{n}_e l$ (10^{14}cm^{-2})
30
20
10
0
r/a= 0
=0.44
=0.73
r/a=0.1
1.2
0.8
0.4
0
T_e(keV)
=0.45
=0.79
cut-off
T_{io}(keV)
0.2
0
8
6
4
2
0
W_p(kJ)
W_p
τ_E
40
20
0
τ_E(ms)
0
125
250
375
Time(ms)
(b)
P_s(a.u.)
2
1
0
ele. side
ion side
0
125
250
375
Time(ms)

Fig.4