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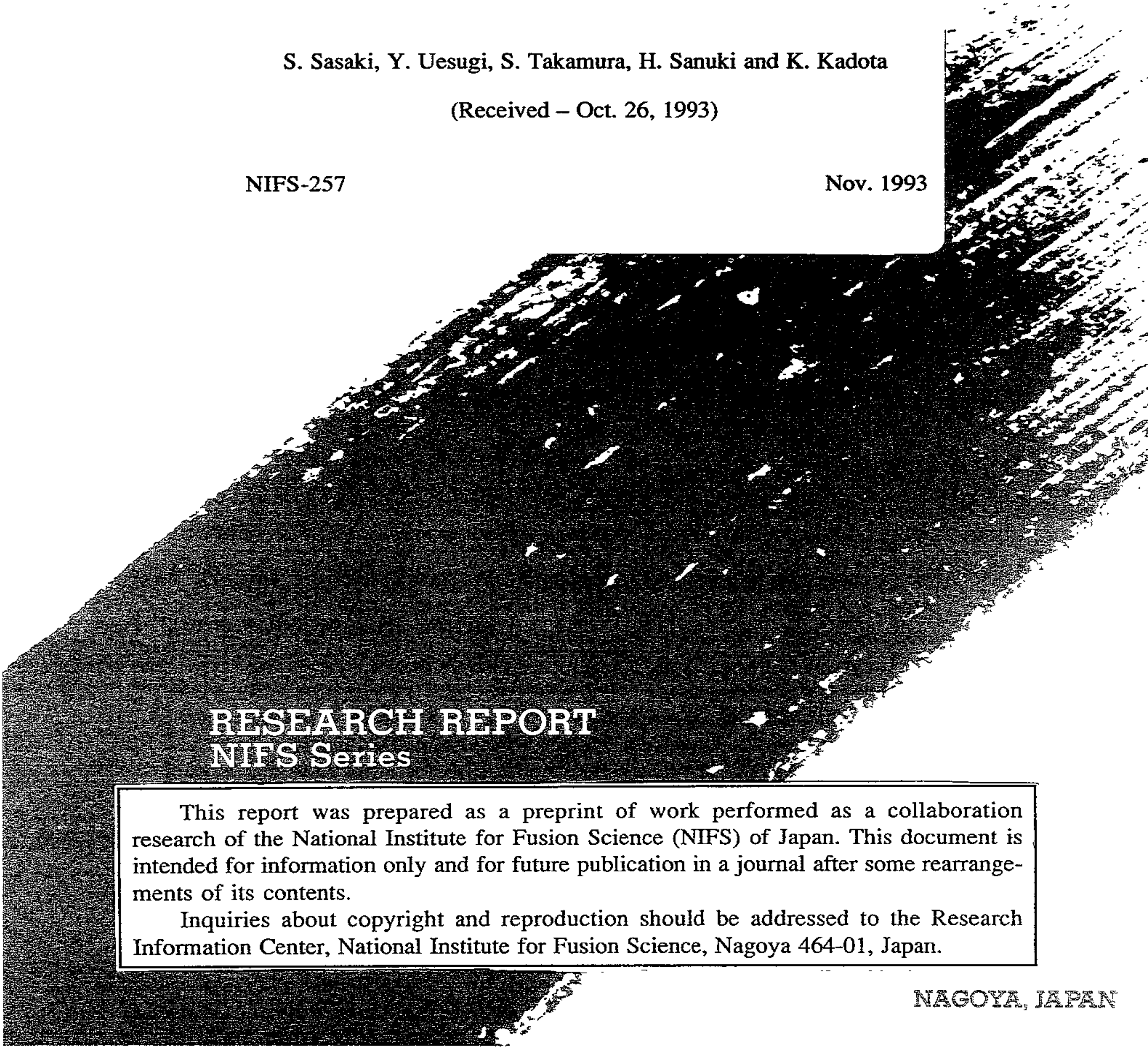

RESEARCH REPORT
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Temporal behavior of the electron density profile during limiter biasing in the HYBTOK-II tokamak

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ABSTRACT

A rapid change in the detailed edge electron density profile during positively biased limiter experiment is obtained with high temporal resolution of ~20 μs using a laser blow-off lithium beam probe technique in HYBTOK-II tokamak. The transient change in the electron density profile and the movement of the position where a steep density gradient is formed are experimentally observed. The temporal behavior of the electron density profile correlates well with reductions in the biasing current and Hα emission in the scrape-off layer, and the suppression of electrostatic fluctuations near the edge of the core region.

Key Words:
limiter biasing, tokamak, plasma confinement, transient phenomena,
laser blow-off lithium beam probing.

Space- and time-resolved measurements of plasma edge parameters are desired for investigations on improved plasma confinement, such as the H-mode, in tokamak plasmas. Recently, limiter and divertor biasing have been considered as an effective means for improving plasma confinement through the control of the edge electric field. Several theoretical [1,2] and experimental [3,4] studies indicate that the radial electric field and associated shear poloidal flow at the plasma edge play an important role in improved confinement. In CCT [5] and TEXTOR [6], it was found that a radial current triggers the H-mode like transition and improves the particle confinement. So far, however, a limited amount of information from the plasma edge prevented detailed analysis. Neutral lithium beam probing [7-8] is a powerful techniques for obtaining the edge electron density profile well inside the last closed flux surface, where a strong electric field is formed by electrical biasing. In the present work, the temporal evolution of the edge electron density profile has been measured with high temporal (~20 μs) and spatial (~3 mm) resolutions using laser blow-off lithium beam probing. Dynamic changes in the biasing current, H_α emission, electrostatic fluctuations and MHD activities are discussed in relation to the transient behaviors of the electron density profile and improved confinement. The experimental results of positive limiter biasing are briefly summarized in this article. Details of negative biasing and electron beam injection experiments performed in HYBTOK-II are described elsewhere [9,10].

The experimental set-up is schematically shown in Fig. 1. HYBTOK-II is a small research tokamak with a major radius R of 40 cm, a vacuum vessel radius b of 12.8 cm, and the limiter radius a of 11 cm. The toroidal magnetic field B_t and the plasma current I_p are operated at 0.5 T and 10 kA. The biasing voltage is applied between two circular poloidal limiters (molybdenum) and the vacuum vessel (SUS). In the positive biasing case, an outward electric field is formed in the edge region. Two limiters installed at the opposite sections on the torus are simultaneously powered by a charged capacitor for the period of ~1.5 ms. The disturbance length of each limiter is shorter than the connection length of the magnetic field line between the limiters because of relatively large cross-field diffusion in the SOL. Hence these limiters are considered to work independently. Electron density profiles are numerically reconstructed from the Li I emission profile along the neutral lithium beam. Details of the lithium beam probing technique have been reported elsewhere [7,8]. The temporal resolution, estimated as ~20 μs, is determined by the shutter period of ~14 μs, considering the transit time through the beam path. The electron temperature T_e, space potential V_s, floating potential V_f, and ion saturation current I_s are measured by single probes. The temporal resolutions for V_s and T_e are 500 μs, determined by the voltage scan time for the Langmuir probe. MHD oscillations are observed by a Mirnov probe, indicating the time derivative of the poloidal magnetic field, $\dot{B}_\theta$.

Experimental results of the temporal and spatial behaviors in the positively biased tokamak discharge are shown in Figs. 2 and 3, respectively. In Fig. 2, two time axes are used; i.e. one is the time in the discharge sequence t_d, and the other is the time after the biasing trigger t_b [μs]. A biasing voltage V_{Lim} of 60 V is applied during t_d = 2500-4100 μs. The limiter voltage rise time is 30 μs, which mainly comes from the finite internal resistance of the biasing power supply. The plasma potential changes very rapidly within only several micro seconds after the rise of V_{Lim}. First, quasi steady-state characteristics in the period from 500 μs to 1000 μs after biasing are described. The electron density profile is modified by biasing as shown in Fig. 3(a). The edge electron density decreases, while that of core region increases at t_b = 1000 μs. A steep density gradient is formed at minor radius $r \approx$ 6.5-7.5 cm as shown in Fig. 3(c). The transient behavior of the electron density profile is shown in Fig. 3(b), where the density is normalized to that without biasing. Figure 3 (d) show the bias modified potential profile. The temporal change in V_s during biasing is so small that it is within the size of the data point. In the SOL ($r \geq$ 11 cm), T_e is 15-20 eV and T_e in the region near the core (r = 8-9 cm) is 20-25 eV. No apparent changes in T_e due to biasing were seen.

Secondly, the dynamic behavior of the plasma parameters and their correlation with the electron density profile is described. The most striking changes are a sudden reduction of I_{Lim} from t_b = 350 μs and a gradual decrease of H_α emissions both in the SOL and the core region about 200-300 μs after biasing. The former may come from the suppression of particle transport in the edge resulting in a high cross-field impedance [6], and the latter from the reduction of the recycling because of the decreased ion flux to the wall. Biasing also affects the amplitude and frequency of MHD activities. The amplitude of $\dot{B}_\theta$ decreases to about half the level compared to that without biasing as shown in Fig. 2(e). Fourier analysis of $\dot{B}_\theta$ indicates that the average oscillation frequency of 21.3 kHz decreases to 16.5 kHz with biasing. It is known from mode analysis that MHD activity has toroidal and poloidal mode numbers of 2 and 1, respectively. The suppression appears at a relatively early stage in the biasing, $t_b \leq 200$ μs. On the other hand, electrostatic fluctuations, $\dot{V}_f$ as well as $\tilde{V}_f$ (see Fig. 2(e) and Fig. 3(e)), at $r = 8$ cm are suppressed after the reductions of I_{Lim} and H_α emissions. They are compared to those without biasing in Fig. 3 (e). In the inner region ($r \approx 8$ cm), the fluctuations decrease to half the value without biasing. The power spectrum of $\dot{V}_f$ indicates a suppression of a large peak around 15-30 kHz. On the other hand, fluctuations with a frequency around 10-20 kHz in the edge ($r \geq 12$ cm) are enhanced. No significant change in the fluctuation of the ion saturation current I_s is seen. The transient behavior of the electron density profile is well correlated with the dynamic behavior of the biased plasma. Temporal changes are characterized by the following four phases, i. e., (1) $t_b \approx$ 0-200 μs, (2) $t_b \approx$ 200-500 μs, (3) $t_b \approx$ 500-1000 μs, and (4) $t_b \geq 1000$ μs:

(1) The plasma potential profile is modified very rapidly within ≈ 30 μs. The edge electron density initially decreases with a time scale of ≈ 80 μs, while that of core region ($r \leq 8$ cm) does not change as shown in Fig. 3(a). The edge electron density decreases, especially in the region $r \geq 10$ cm, until $t_b \approx 200$ μs. As a result, the density profile has a steep gradient at $r \approx$ 9-10 cm, suggesting that cross-field particle transport is locally suppressed. MHD activity is suppressed in this phase.

(2) The electron density at $r \approx$ 9-10 cm, where a steep gradient emerges at $t_b \approx$ 200μs, increases again until $t_b \approx 300$ μs. As a result, the position of the steep density gradient moves to $r \approx$ 10-11 cm. H_α emissions in the SOL begins to decrease gradually during $t_b \approx$ 200-400 μs. A sudden reduction of I_{Lim} occurs at $t_b \approx 350$ μs.

The edge electron density decreases while the density gradient peak remains at the same position during $t_b \approx 300\text{-}500\ \mu s$ as shown in Fig. 3 (b-1).

(3) The core electron density ($r \leq 8$ cm) continuously increases while the edge density slightly decreases in this phase. Hence, the density profile becomes more peaky and the position of the steep density gradient moves inward with a propagation velocity of ≈ 8000 cm/s, which is estimated from Figs. 2 (f) and 3 (c). Electrostatic fluctuations in the inner region ($r \approx 8$ cm) are suppressed during this phase.

(4) Strong MHD oscillations occur from $t_b \approx 900\ \mu s$. The enhancement of MHD activity can be considered to be the result of current profile modifications. The density in the core ($r \leq 8$ cm) decreases and the edge density ($r \geq 10$ cm) begins to increase again from $t_b \sim 1000\ \mu s$. With the enhancement of MHD activity, the biasing current I_{Lim} and H_α emission begin to increase again.

The transient characteristics of improved confinement in the biased limiter experiment are obtained in detail by using laser blow-off lithium beam probing. The improvement of the plasma particle confinement in the edge can be seen from the fact that the electron density in the core increases although the plasma source due to the recycled hydrogen is reduced. The suppression of particle transport in the edge starts just after the decrease of the edge density about 200 μs after biasing. After a sudden decrease of the biasing current and gradual decrease of the H_α emission which occur from 300-400 μs after biasing, the position of the steep density gradient moves inward with a velocity of ≈ 8000 cm/s. MHD oscillations with toroidal and poloidal mode numbers of 2 and 1 are suppressed by biasing. Detailed studies on this dynamic behavior of the electron density profile might provide the experimental data base associated with the transport barrier formation and propagation. The plasma confinement is finally deteriorated by strong MHD activity caused by modification of the current profile, which would come from the peaked density profile. Electrostatic fluctuations in the inner region ($r \approx 8$ cm) are suppressed, while those in the SOL are enhanced. It seems that the electrostatic fluctuations are correlated with the modified radial electric field profile. Several theoretical analyses suggest the effects of the electric field on the growth of instabilities [11-13]. Further investigation is, however, necessary for a detailed discussion of the physical mechanism of the locally improved confinement and propagation of the steep density gradient position.

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FIGURE CAPTIONS

Fig. 1 Experimental set-up for biased limiter experiment on HYBTOK-II.

Fig. 2 Temporal behavior of the discharge and plasma parameters. (a) Loop voltage V_{Loop} and plasma current I_p. (b) Limiter voltage V_{Lim} and biasing current I_{Lim}. (c) H_α emissions observed by the chord passing through the SOL and the center. (d) Floating potential V_f and ion saturation current I_s at $r \approx 8$ cm. (e) Time derivative of the floating potential, $\dot{V}_f$, and poloidal magnetic field $\dot{B}_\theta$. Time intervals for the suppression of fluctuations are shown by horizontal bars. (f) The steep density gradient position.

Fig. 3 (a) Change in the electron density profile. (b-1,2) Temporal evolution of electron density profile. (c) Space derivative of the electron density profile. (d) Modification of the space potential V_s. (e) Relative change in the amplitude of electrostatic fluctuations.

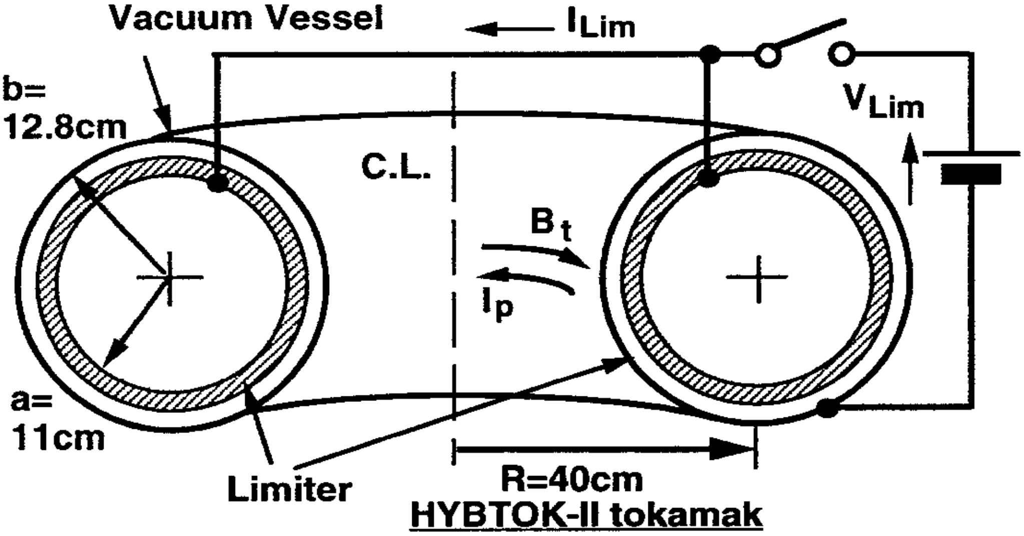
Vacuum Vessel
I_{Lim}
b=
12.8cm
V_{Lim}
C.L.
B t
I p
a=
11cm
Limiter
R=40cm
HYBTOK-II tokamak

Fig. 1

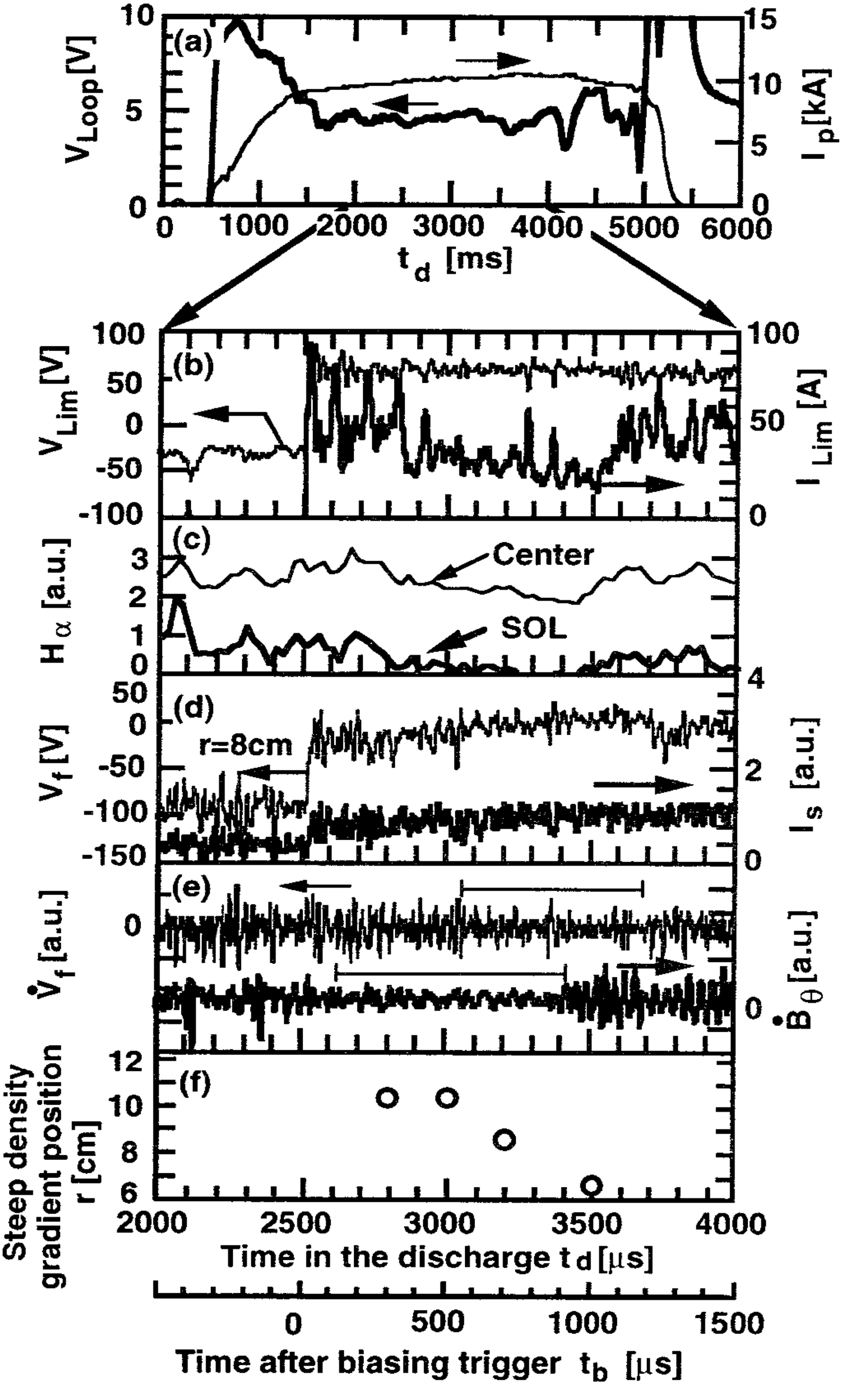
(a)
V_Loop[V]
I_p[kA]
t_d [ms]
0
1000
2000
3000
4000
5000
6000
(b)
V_Lim[V]
I_Lim [A]
(c)
Hα [a.u.]
Center
SOL
(d)
r=8cm
V_f [V]
I_s [a.u.]
(e)
V̇_f [a.u.]
Ḃ_θ [a.u.]
(f)
Steep density gradient position r [cm]
Time in the discharge t_d [μs]
2000
2500
3000
3500
4000
Time after biasing trigger t_b [μs]
0
500
1000
1500

Fig. 2

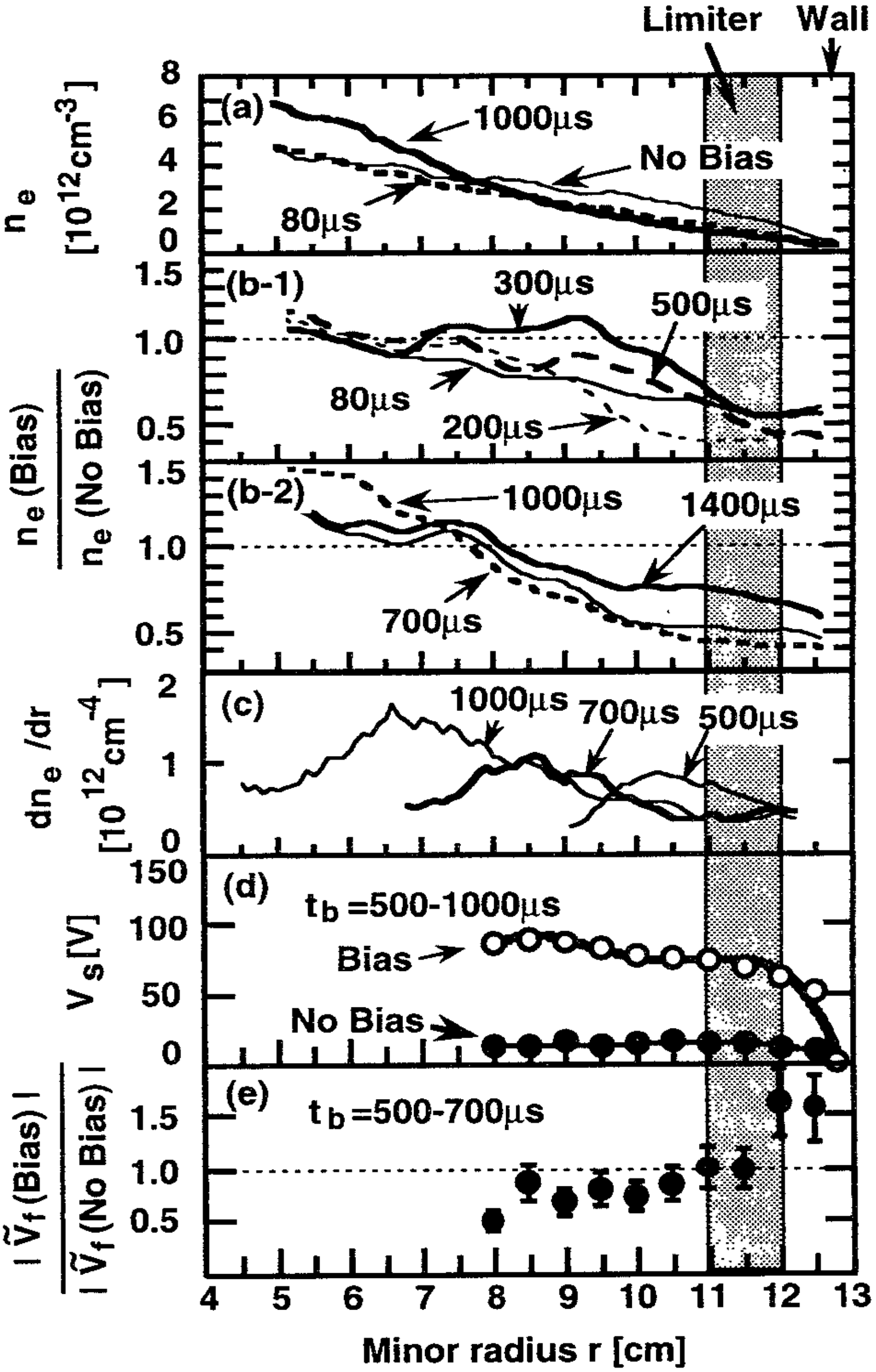
Limiter
Wall
(a)
1000μs
No Bias
80μs
n_e [10^{12}cm^{-3}]
8
6
4
2
0
(b-1)
300μs
500μs
80μs
200μs
1.5
1.0
0.5
n_e(Bias) / n_e(No Bias)
(b-2)
1000μs
1400μs
700μs
1.5
1.0
0.5
(c)
1000μs
700μs
500μs
dn_e/dr [10^{12}cm^{-4}]
2
1
0
(d)
t_b=500-1000μs
Bias
No Bias
V_s[V]
150
100
50
0
(e)
t_b=500-700μs
$|\tilde{V}_f$(Bias)$|$ / $|\tilde{V}_f$(No Bias)$|$
1.5
1.0
0.5
4
5
6
7
8
9
10
11
12
13
Minor radius r [cm]

Fig. 3

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