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RESEARCH REPORT

NAGOYA, JAPAN

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Further communication about this report is to be sent to the Research Information Center, Institute of Plasma Physics, Nagoya University, Nagoya 464, Japan.

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Abstract

Optimization of discharge cleaning was studied by using 60 Hz AC and cw ECR discharges. Reduction rate of oxygen was investigated for variations of the wall temperature. It has been confirmed that, below 300° C, the reduction rate increases as the wall temperature is raised. A simple model is proposed for the cleaning process and H_2O pressure is calculated as a function of plasma density on the basis of this model. By comparing the calcurated results to an experimental observation, it has been found that it is essential to raise the electron density of the discharge-cleaning plasma high enough that the dissociation-loss rate of H_2O is as large as the sticking-loss rate in order to optimize the cleaning.

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1. Introduction

It is well known that titanium gettering is effective in obtaining high density and high temperature plasmas in tokamak devices [1]. In burning experiments, titanium getters may be unfavorable because of the necessity to manage a finite tritium inventory. One of the major roles of the getters is suppression of oxygen efflux from the first wall. As far as oxygen reduction is concerned, getters may not be necessary if it is possible to reduce oxygen contamination to a sufficiently low level by discharge cleaning techniques. It has been reported in PLT experiments [1], however, that discharge cleaning is inferior to gettering in the reduction of oxygen. Optimization of the discharge cleaning is necessary to obtain high temperature and high density plasmas without titanium gettering. In this paper, we present some data obtained in the discharge cleaning of the JIPP T-II device, and discuss optimization of this technique.

2. Characteristics of AC discharge cleaning

By feeding the OH primary coil from 60 Hz commercial lines, we have obtained low power repetitive discharges of 60 or 120 Hz. Hydrogen is used as the working gas and the pressure P_2 is set between 0.5 and 1.0 x 10^{-2} Pa. A 500 W ECR-DC source [2] is superposed in order to minimize misfiring of the discharge.

The electron density of the plasma has been measured with a 4 mm microwave interferometer and is 5.6 x 10^{11} cm^{-3} for the primary voltage U_0 of 1600 V r. m. s. Assuming that the energy balance of the electrons is similar to that in a positive column of a glow discharge, we have tried to estimate the electron temperature using E/P_2 [3], where E is the field strength. The estimated temperature is around 8 eV for U_0 = 600 - 1600 V.

The partial pressure of the water vapor P_{18} is observed by a quadrapole mass analyzer. Long time variations of P_{18} are plotted in Fig. 1. A remarkable feature is that, for all variations of the wall temperature, the decay time of P_{18} changes at a time when P_{18} reaches a certain value. Except the later phase of the 250°C case, the decay becomes faster as the wall temperature is raised. The relation between P_{18} and the bellows temperature T_w is shown in Fig. 2 at a time during the later phase. The results are consistent with those of the glow-discharge cleaning obtained by Waelbroeck et al. [4]. These data indicate that, at least below 300°C, the oxygen-reduction rate is improved by raising the wall temperature.

3. Evaluation of the wall condition

In the JIPP T-II, ohmic plasmas have been used to characterize the wall condition according to the following determinations: i) wave forms of loop-voltage etc. (see Fig. 8 in ref. 2), ii) dependence of O II (4414.9 Å) intensity I_{ox} on $\bar{n}_e$, iii) Z_{eff} estimated from electric conductivity.

We show Z_{eff} values obtained after 65 h of AC + ECR-DC with T_w = 200° C preceded by 2 day of 350 C baking. In Fig. 3 a),

Z_{eff} is plotted against $\overline{n_e}$. Included are 210 data points from 106 shots for which operation was identical except for variations in the gas-puffing. A histogram of the data in Fig. 3 a) is shown in Fig. 3 b). It is found from these data that Z_{eff} nearly equals 1.0 for $\overline{n_e} > 5.0 \times 10^{13}$ cm^{-3}.

Under the conditions where the oxygen contribution to Z_{eff} was small, we evaluate relative cleanliness of the wall by the method of ii). Examples are shown in Fig. 4. These data were obtained from several shots of 2.5 T, 100 kA discharges. The case I data were taken just after the discharge cleaning and case II after the vessel had been left evacuated without plasma for one night. From these data, we infer that the surface once cleaned is recontaminated due to gases evolved from the sections where discharge cleaning is ineffective. Case III is unusual in that the base pressure had temporally risen by an order of magnitude due to troubles in the pumping system. The distributions of Z_{eff} values are equivalent to that in Fig. 3 and one cannot find any difference in those three situations, that is, Z_{eff} 1.0 in all of the three cases. The solid lines in the figure were obtained from an empirical equation,

$$I_{ox} = a \; [\; 1 - \exp(-\overline{n}_e/n_c) \;] + b\overline{n}_e^{\,3} \qquad ,$$

where a. b, n_c are parameters used in fitting the data. A discussion of this equation will be given elsewhere. It is worth noting that the correlation between Z_{eff} and $\overline{n_e}$ is opposite to that between I_{ox} and $\overline{n}_e$. This suggests that, even in low density discharges, oxygen contribution to Z_{eff} is negligible and that some metal impurities raise Z_{eff} values. It has been observed that titanium from TiC coated limiters and/or iron from the wall are dominant metal impurities in these discharges and that the amount of influxes are independent of $\bar{n}_e$. If the density of these impurities is around 2×10^{10} cm^{-3}, the absolute values of Z_{eff} and $Z_{eff} - \bar{n}_e$ correlation in Fig. 3 are understandable.

By optimizing AC + ECR DC, we have found that a 40 h of discharge cleaning with $T_w = 220^\circ$ C is sufficient to obtain cleanliness equivalent to that of case II in Fig. 4.

4. Optimization of the plasma density for cleaning

In this section, we discuss on the relation of the oxygen-reduction rate to the plasma density using a simple model in order to study what is the essential point in the optimization of n_e for discharge cleanings.

The reduction of oxygen consists of the following three processes: i) generation of an atomic hydrogen fluxe in the plasma, ii) production of water vapor by chemical reactions at the wall surface, iii) evacuation of the water vapor by the pumping system. In this model, we have taken into account H_2O molecules which are lost due to sticking to the wall and H_2O dissociation by electron impact. This model is similar to the one proposed by Waelbroeck et al. [4] except that the atomic hydrogen is considered to mainly contribute to H_2O production. On the basis of this model, we obtain the following relation in the steady state,

$$P_{18}/P_2 = n_{18}/n_2 = A / (1 + B n_e^{-1}) \qquad (1),$$

where $A = (k_2/k_{18})s_{18}n_w$, $B = [(1/4)p_{st}v_{18}A_w + S] / k_{18}V_p$, n_{18} is the density of H_2O in the plasma, n_2 the hydrogen-molecular density, k_2 the production rate of hydrogen atoms by electron impact, k_{18} the dissociation rate of H_2O by electron impact, s_{18} the cross section of H_2O production, n_w the surface density of oxygen, p_{st} the sticking probability of H_2O, v_{18} the thermal velocity of H_2O, S the pumping speed for H_2O, A_w the surface area of the wall and V_p the plasma volume. This relation indicates that, for sufficiently high electron densities, n_{18}/n_2 approaches $(k_2/k_{18})s_{18}n_w$ asymptotically and saturates. This saturation should be seen in the densities higher than B. This implies that one can improve the cleaning time by raising n_e up to around B. Since p_{st} is larger than 0.1 for clean surfaces, S ($\sim 10^6$ cm^3/s) is much smaller than $(1/4)p_{st}V_{18}A_w$ (> 10^8 cm^3/s) and can be neglected in estimating the value of B. Using the dissociation cross sections of ref. [5], we have calculated k_{18} and obtained 4.9×10^{-9} cm^3/s for an electron temperature of 8 eV (see Sec. 2.), which results in $B \sim 2.2 \times 10^{11}$ cm^{-3}. The solid line in Fig.5 shows the relation (1) with this value of B. The $P_{18} - n_e$ relations experimentarily obtained are also shown with closed circles in the figure. The agreement between calculated and experimental results is fairly close.

From the above considerations, we can conclude that it is essential to raise the electron density so high that the value of $n_e n_{18} k_{18} V_p$(dissociation-loss rate) is as large as $P_{st}(n_{18}/4) v_{18} A_w$ (sticking-loss rate) in order to optimize discharge cleaning.

Summary

It has been observed that, during AC + ECR-DC, the H_2O pressure decays faster as the wall temperature is raised. The decay time changes at a point where the pressure reaches a certain level. This suggests that the mechanisms which dominate the cleaning in the later phase are different from those in the earlier phase. By optimizing AC + ECR-DC, we have found that 40 h of discharge cleaning with the wall temperature of 220°C is sufficient to obtain high density tokamak discharges having $Z_{eff} \sim 1.0$. A simple model is proposed to analyze the discharge-cleaning process. By comparing a calculated result with this model to the experimental results, we have found that, for optimization, it is essential to raise the electron density of the discharge-cleaning plasma high enough that the dissociation-loss rate of H_2O is as large as the sticking-loss rate.

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Figure Captions

Fig. 1 Long time variations of P_{18}.

Fig. 2 Relation between P_{18} and the bellows temperature.

Fig. 3 Z_{eff} estimated from conductivity for tokamak discharges.

Fig. 4 O II (4414.9 Å) intensity in tokamak discharges.

Fig. 5 Relation between P_{18}/P_2 and the density of discharge-cleaning plasmas.

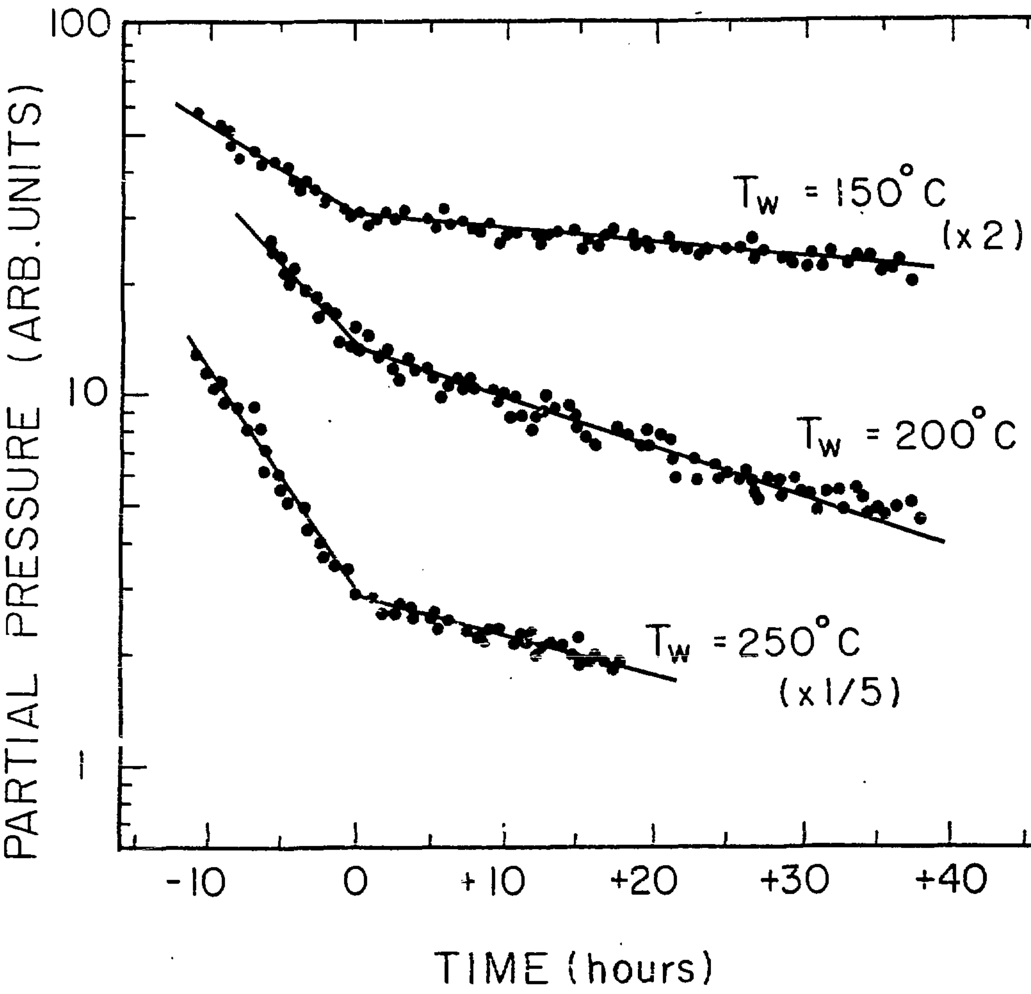
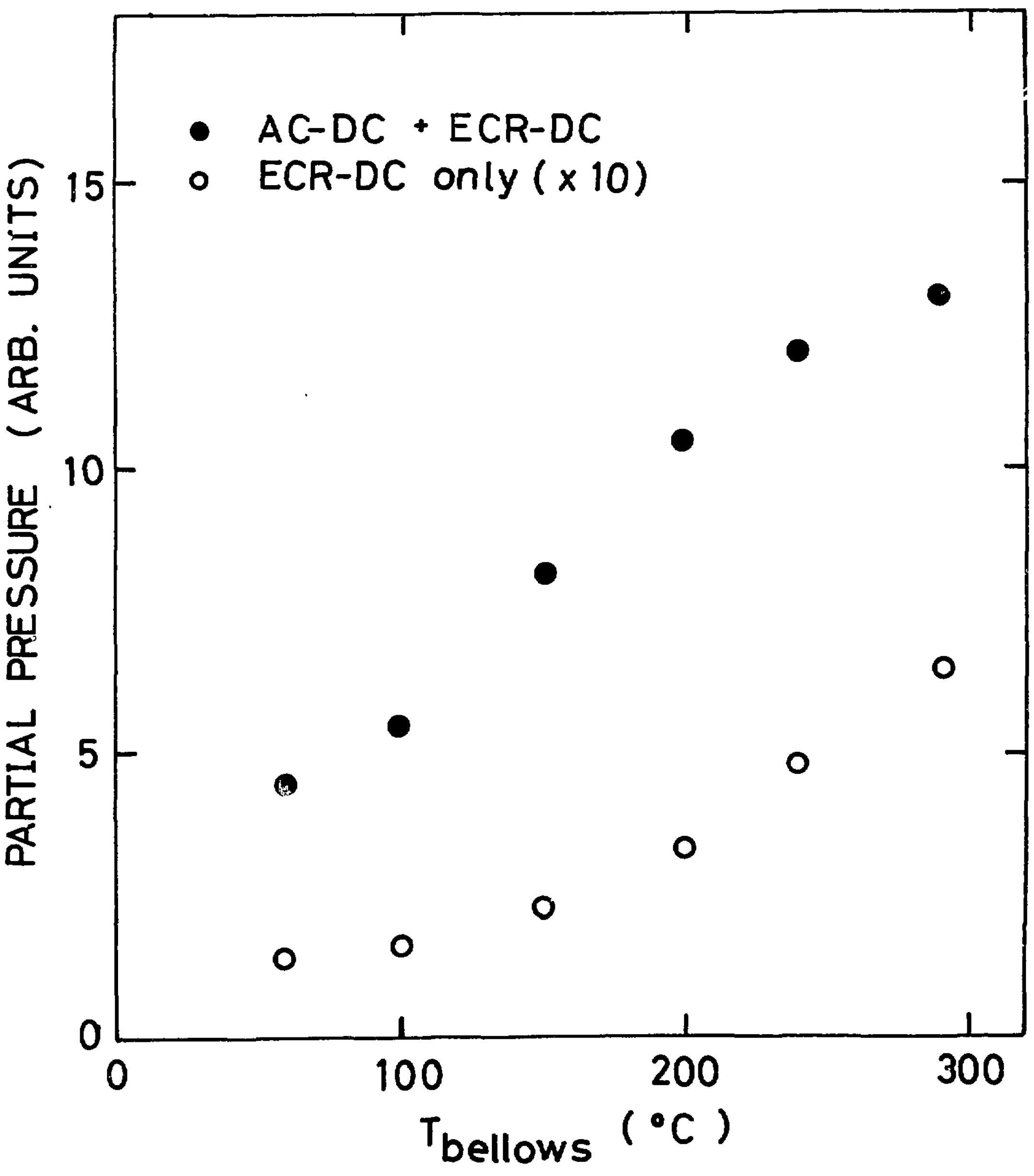

PARTIAL PRESSURE (ARB.UNITS)
100
10
1
-10
0
+10
+20
+30
+40
TIME (hours)
T_W = 150°C
(x 2)
T_W = 200°C
T_W = 250°C
(x 1/5)

Fig. 1


● AC-DC + ECR-DC
○ ECR-DC only (x 10)
PARTIAL PRESSURE (ARB. UNITS)
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5
10
15
0
100
200
300
$T_{bellows}$ (°C)

Fig. 2

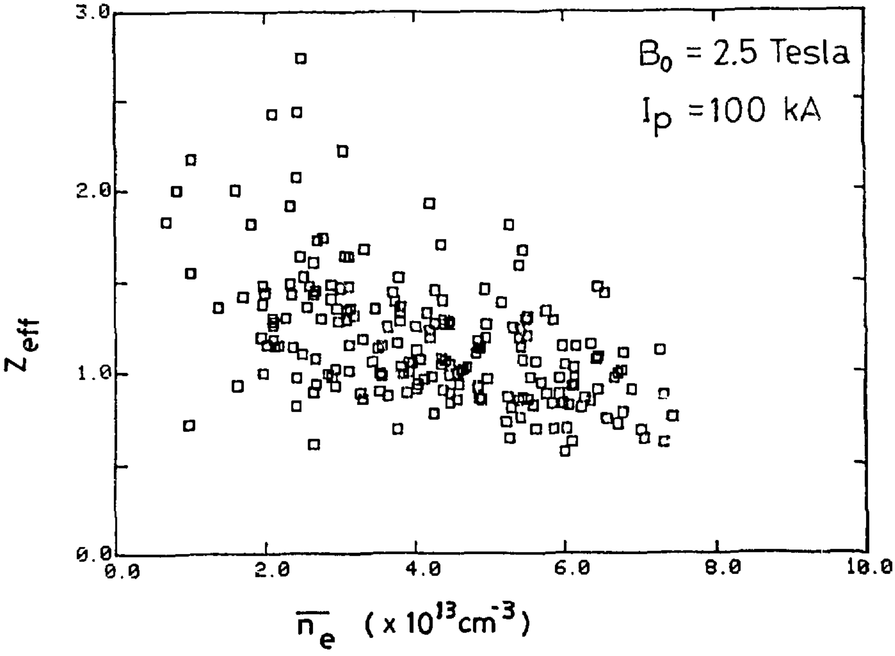
B_0 = 2.5 Tesla
I_p =100 kA
3.0
2.0
1.0
0.0
Z_{eff}
0.0
2.0
4.0
6.0
8.0
10.0
$\overline{n_e}$ (x 10^{13} cm^{-3})

Fig. 3 a)

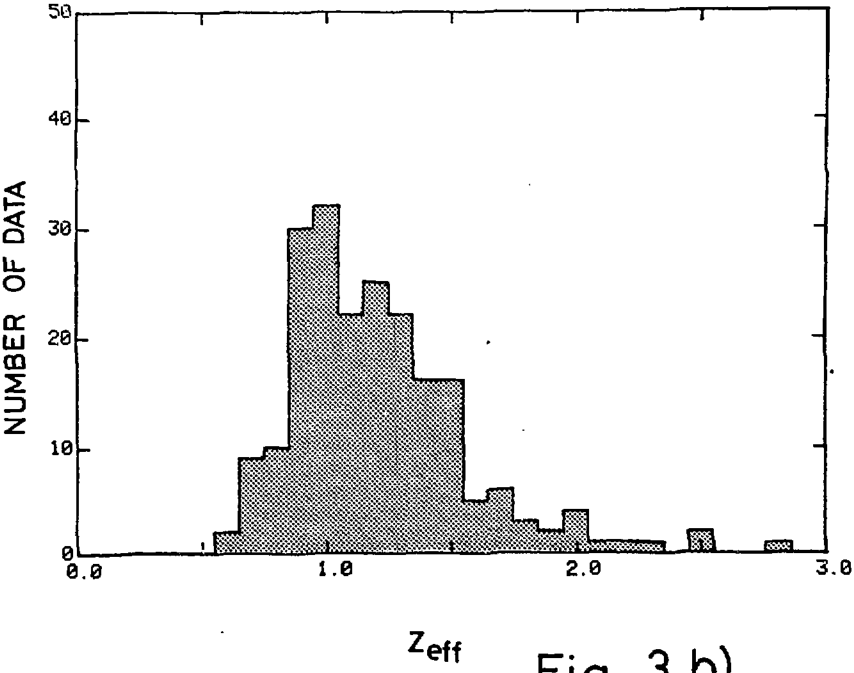
50
40
30
20
10
0
NUMBER OF DATA
0.0
1.0
2.0
3.0
Z_{eff}

Fig. 3 b)

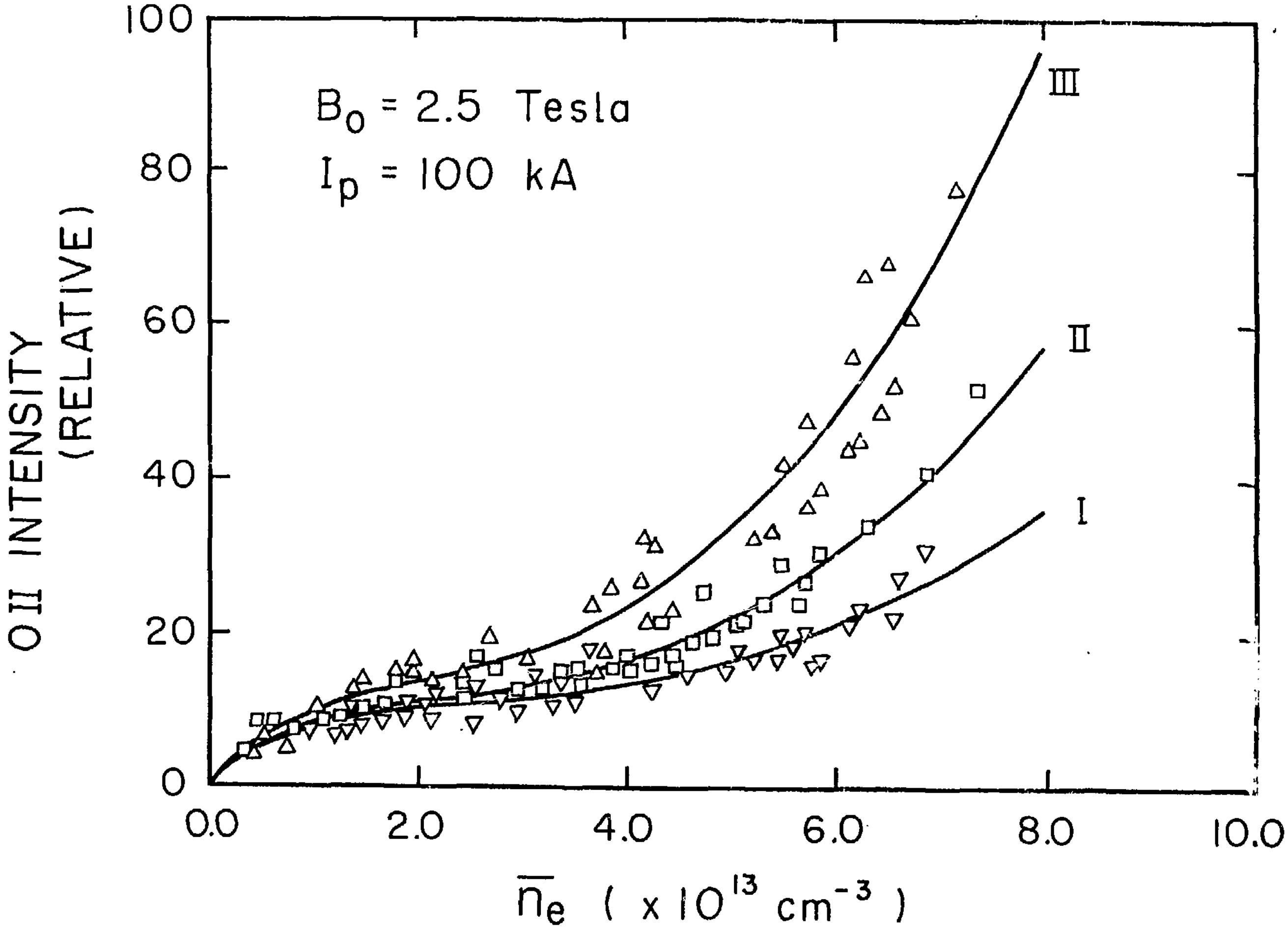
100
80
60
40
20
0
OII INTENSITY (RELATIVE)
$B_0 = 2.5$ Tesla
$I_p = 100$ kA
III
II
I
0.0
2.0
4.0
6.0
8.0
10.0
$\overline{n}_e$ (x 10^{13} cm^{-3})

Fig. 4

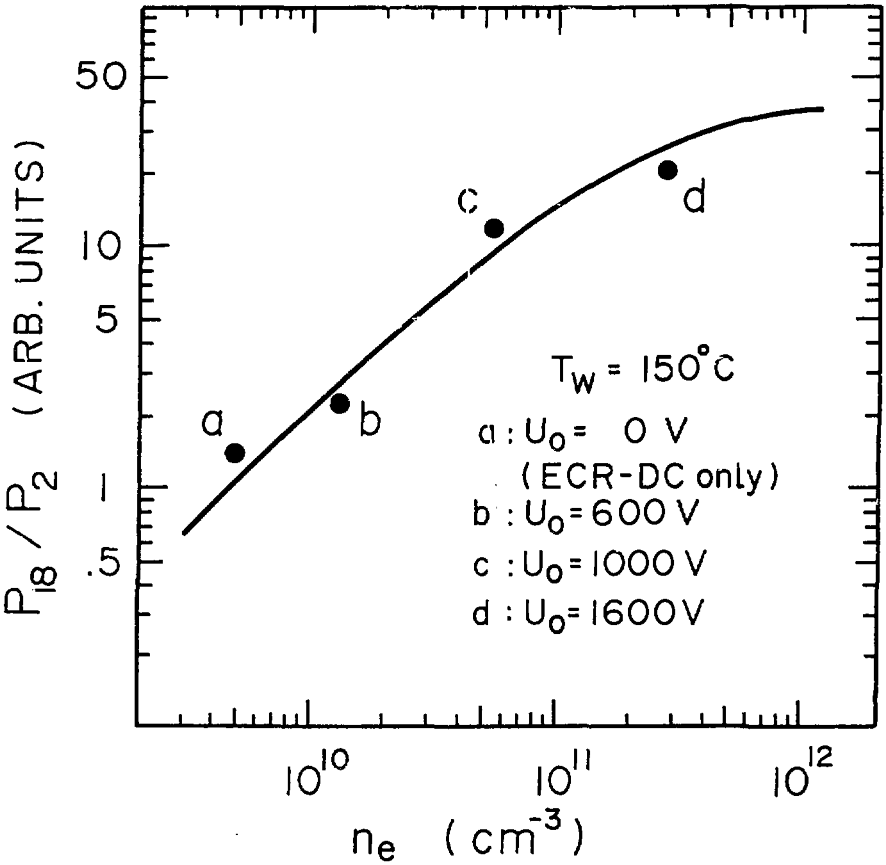
50
10
5
1
.5
P_{18}/P_2 (ARB. UNITS)
a
b
c
d
T_W = 150°C
a : U_0 = 0 V
(ECR-DC only)
b : U_0 = 600 V
c : U_0 = 1000 V
d : U_0 = 1600 V
10^{10}
10^{11}
10^{12}
n_e (cm^{-3})

Fig. 5