Overview of Recent IEC Studies at Tokai University

13th US-Japan Workshop on Inertial Electrostatic Confinement Fusion

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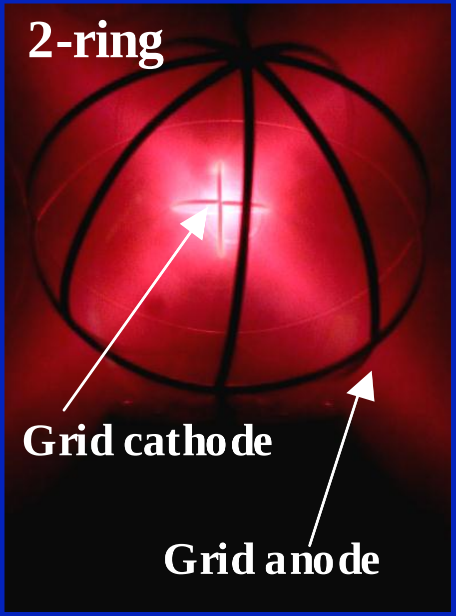
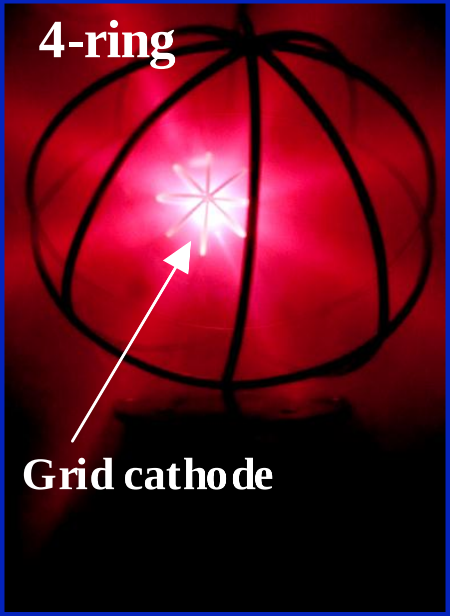
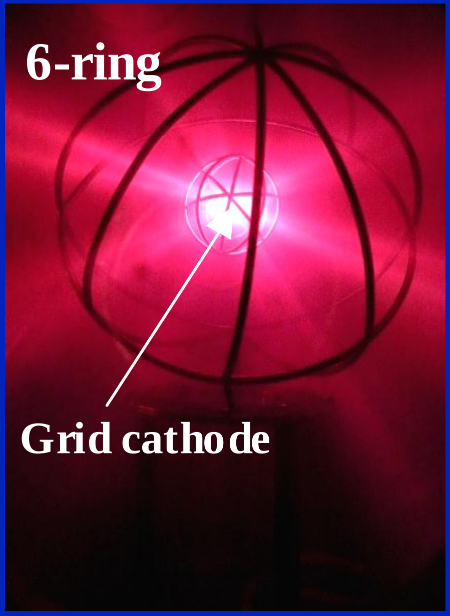
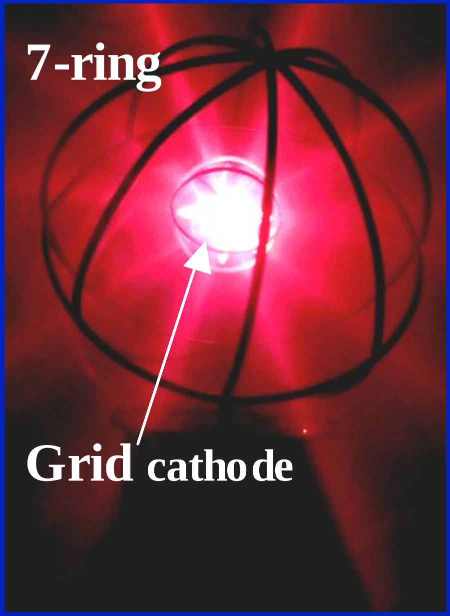
In 2005, we started to study neutron production with IEC. We studied that the effect of grid cathode structure on a low input power IEC device.

We prepared four types of cathodes where varied in geometric transparency.









The more rings increase the width of the spoke lights are sharp.

An increase in geometric transparency of the grid cathode by decreasing the number of wire rings is known to mean that recirculation ion current is increased.

We expected that this increase would contribute to an increase of the NPR.

However, our experimental results showed that the NPR in the low input power IECF device (V=10.0-30.0 kV, I=40.0 mA) increased by decreasing the transparency.

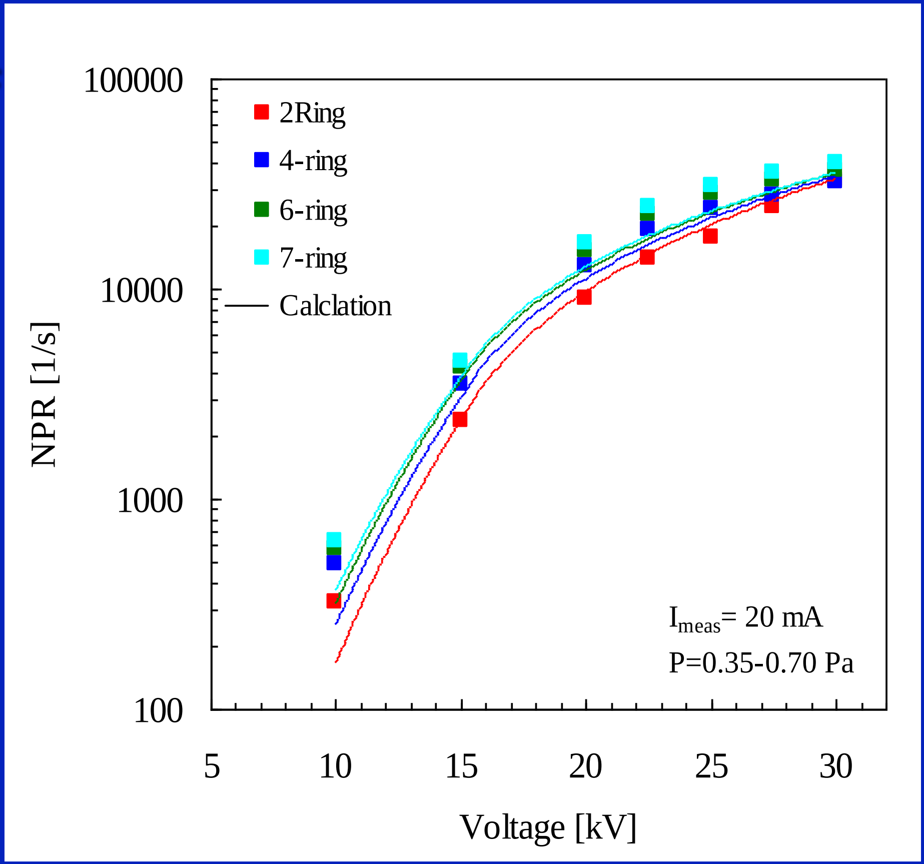
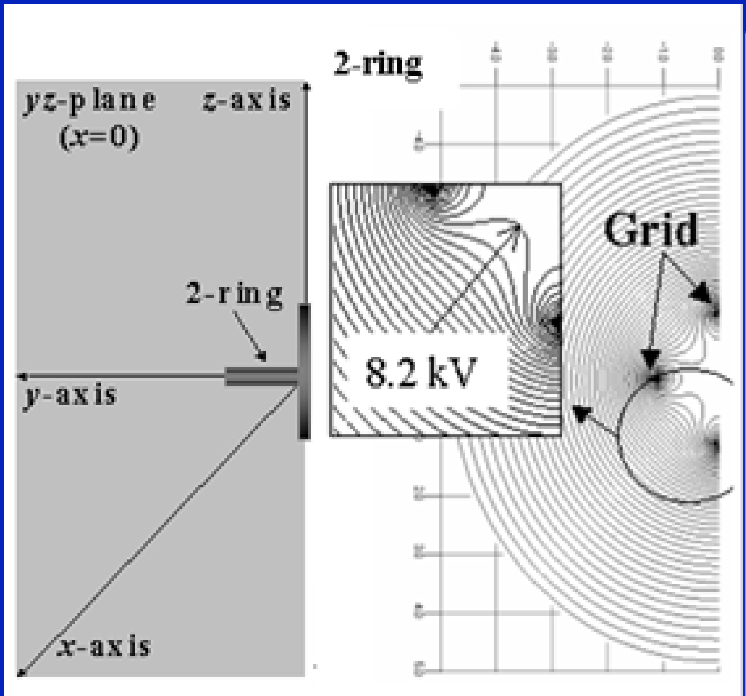
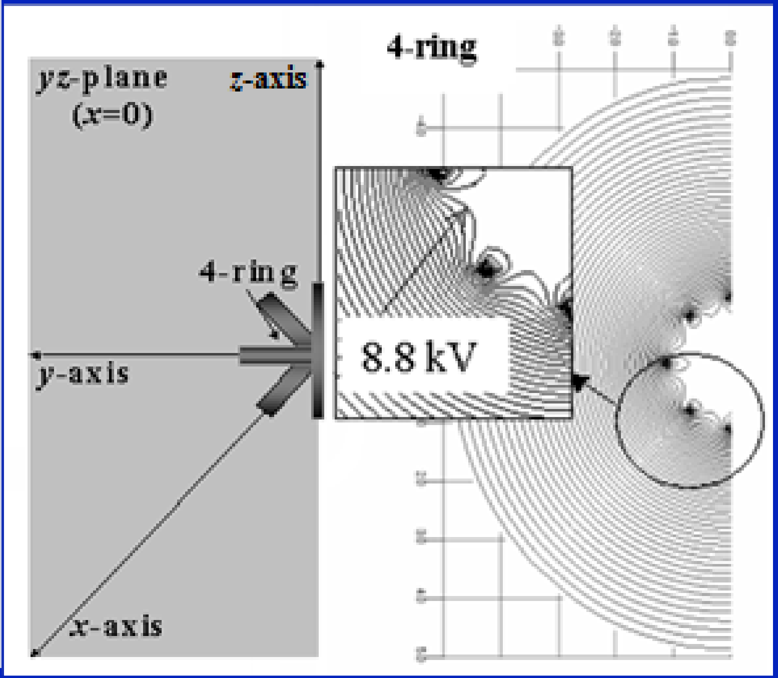


Fig. 4.10. Comparison of the calculated NPR with experimental data.





We clarified this tendency by analyzing the equi-potential lines near the grid. As a result, we found that the distortion of these lines near the grid was lessened by decreasing the transparency. Lessening the distortion of these lines, rather than the increase in recirculation ion current, was effective in increasing the NPR in the low input power IECF device.

Recently, we investigate two themes.

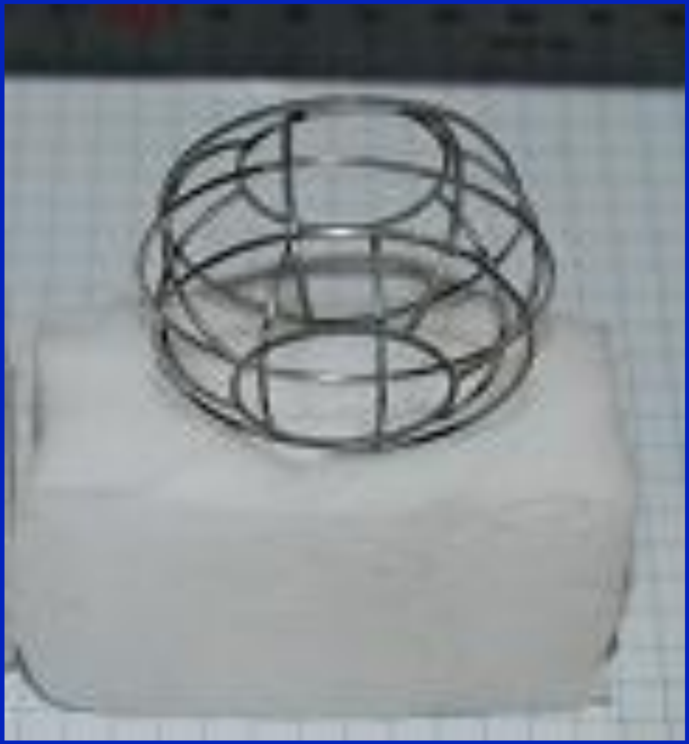
1. Research for neutron production region.

   We are interested in the beam use of neutron. So we measured NPR at two direction with two 3He counters simultaneously.

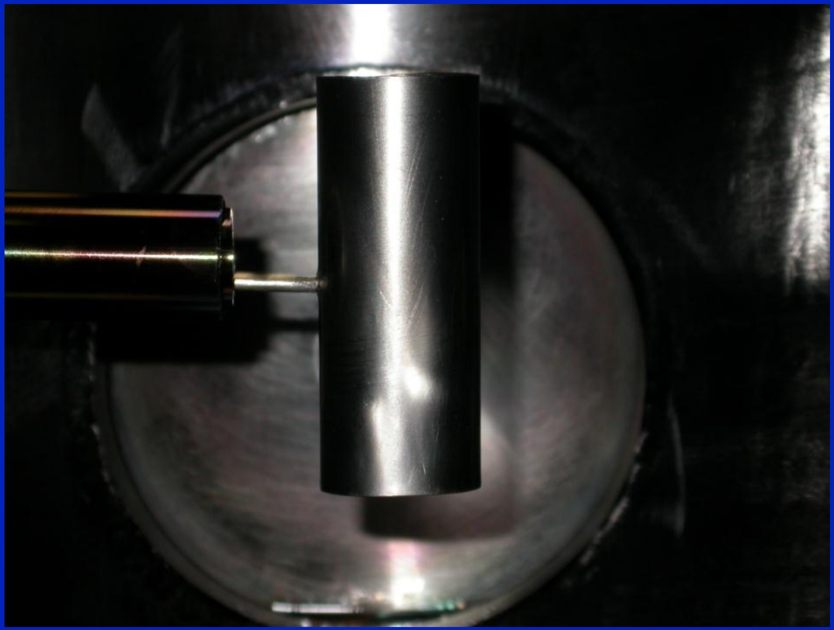
2. Determine the plasma parameters in the central core of the cathode.

   Potential well measurement has already done by Onishi et.al. by stark effect. It may not be worth while to do now. We measured it by simple and direct method.

1. In order to estimate the neutron production region. Two cathode were used.

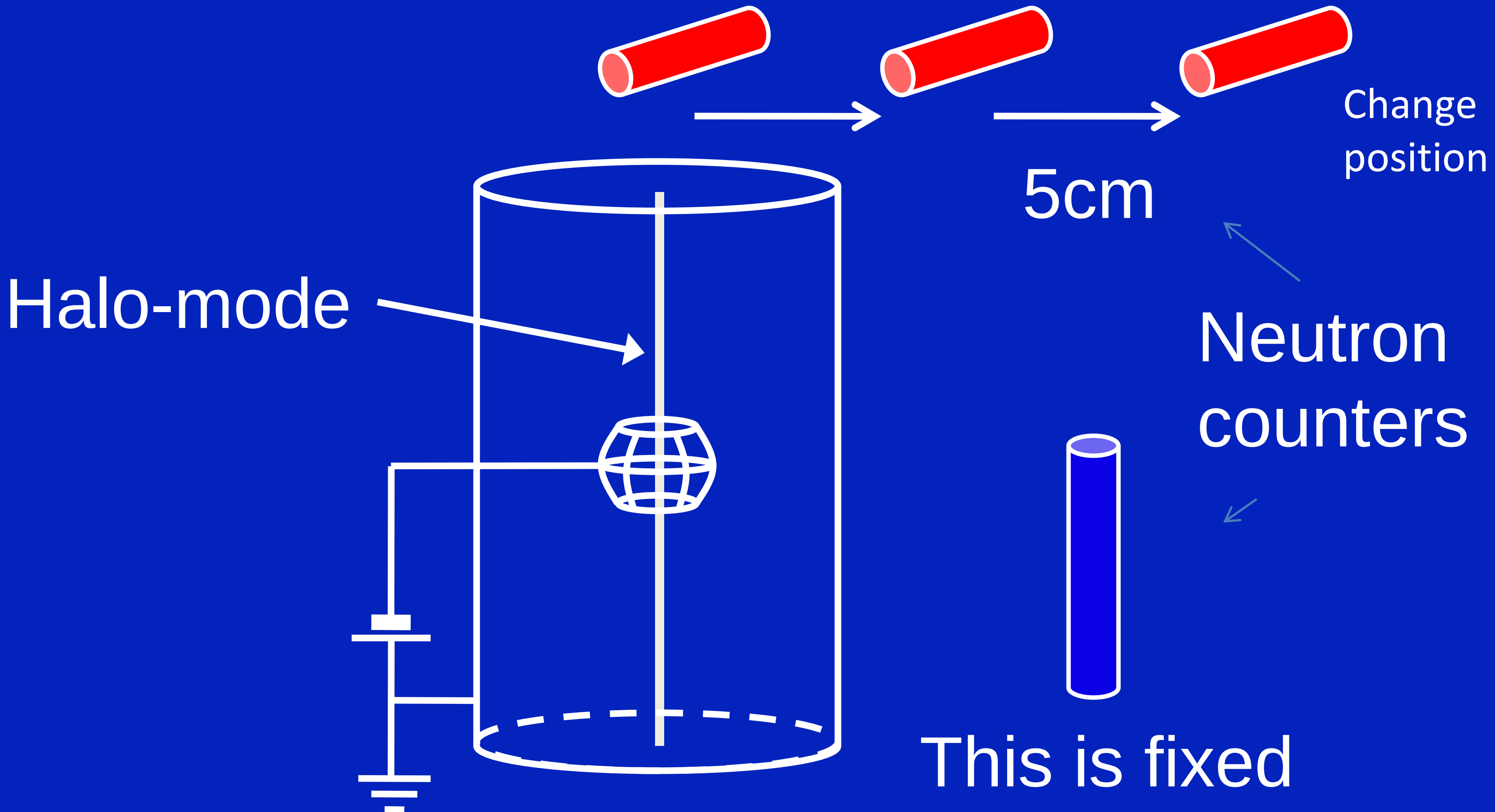


mesh type for halo mode



cylinder type for single jet

Define r that the ratio the counts above detector to the side detector counts.

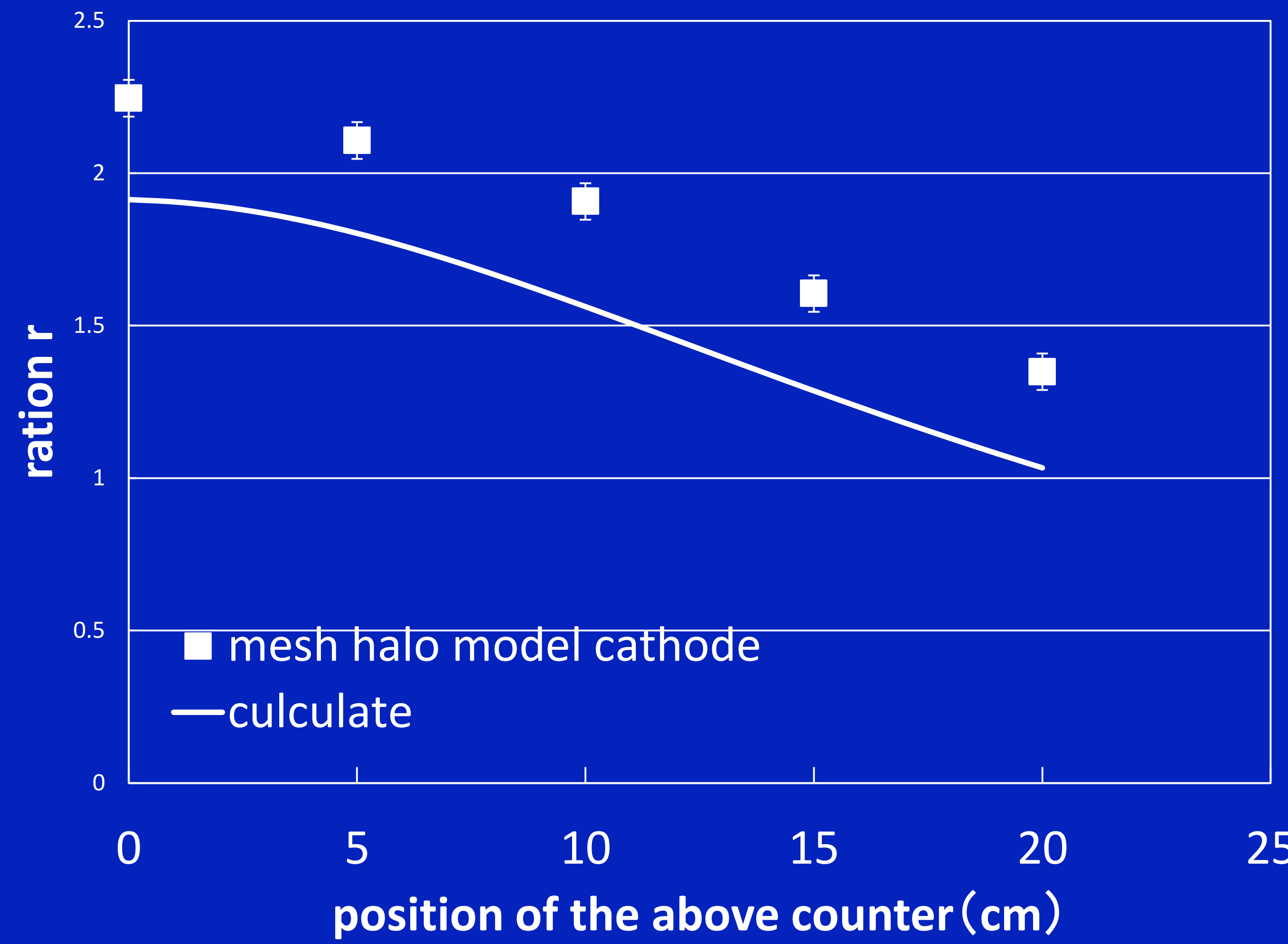


The ratios were compared with calculations values.

Calculation value was estimated by numerical integration. It assumes that neutrons generated region forms a line shape and neutrons were emitted isotropically.

Result for mesh cathode(halo mode)

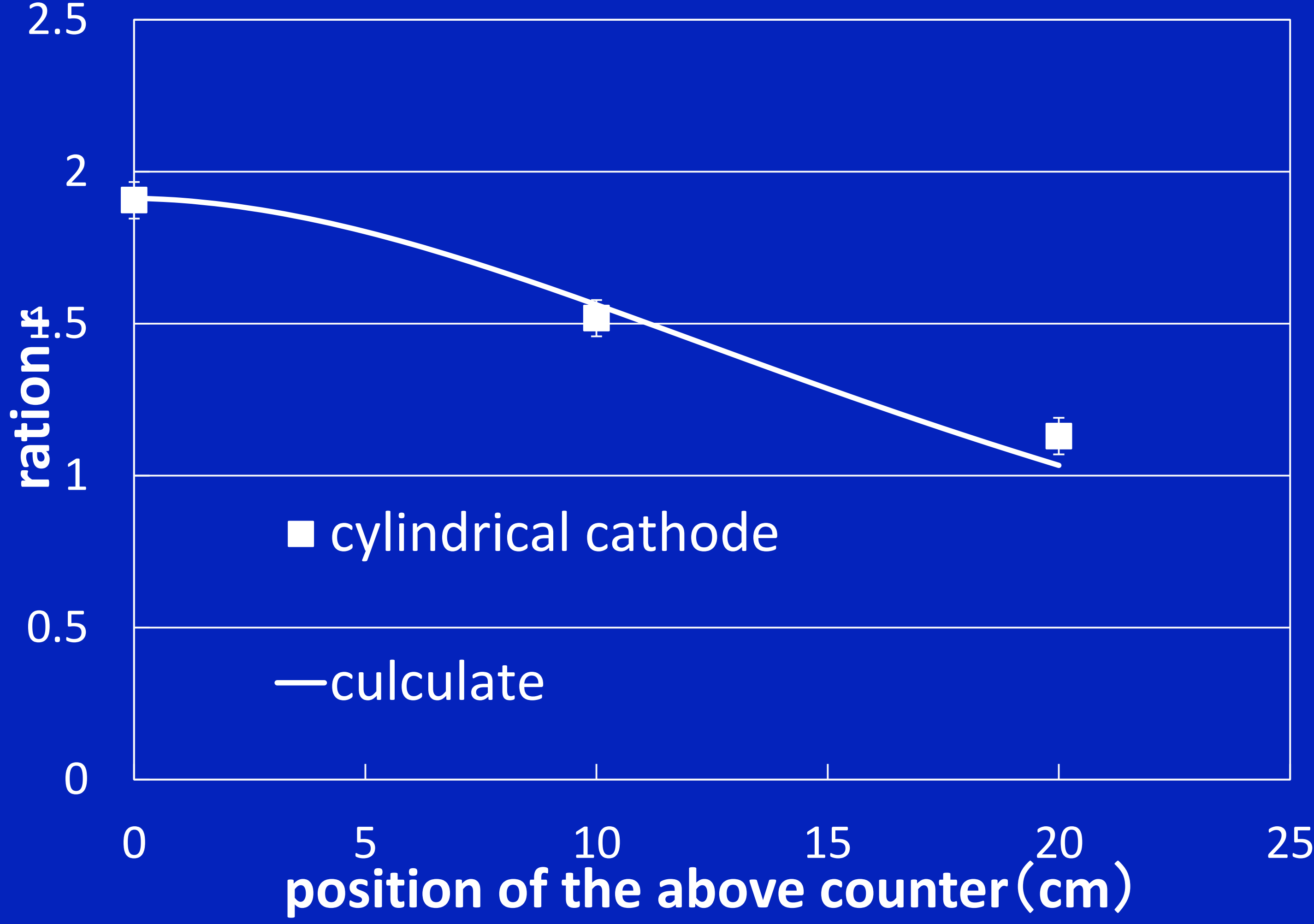
conditions
- 20kV
- 5mA
- 0.14Pa



Not line shape source (halo mode) ?

Result for cylindrical cathode

condition
- 20kV
- 5mA
- 0.15Pa



line shape source (cylindrical cathode) ?

2. Determine the plasma parameters

Change the distance r

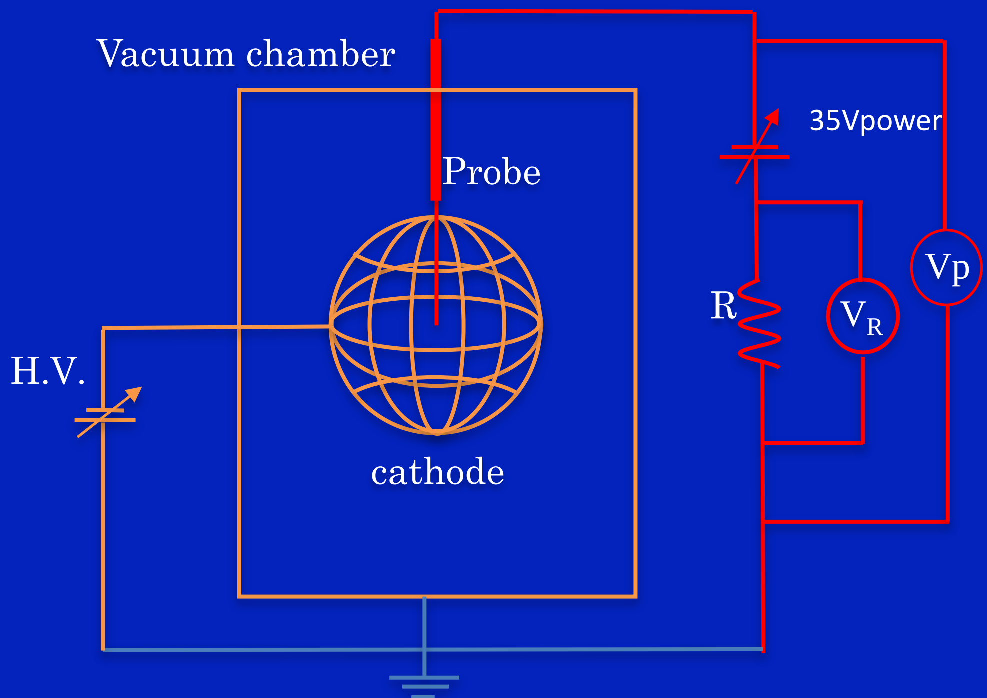
- ✓Insert the probe directly into the cathode
- ✓Change the distance r from the center of the cathode
- ✓The distance r = 0, 1, 2, 3 cm

Control the IECF device

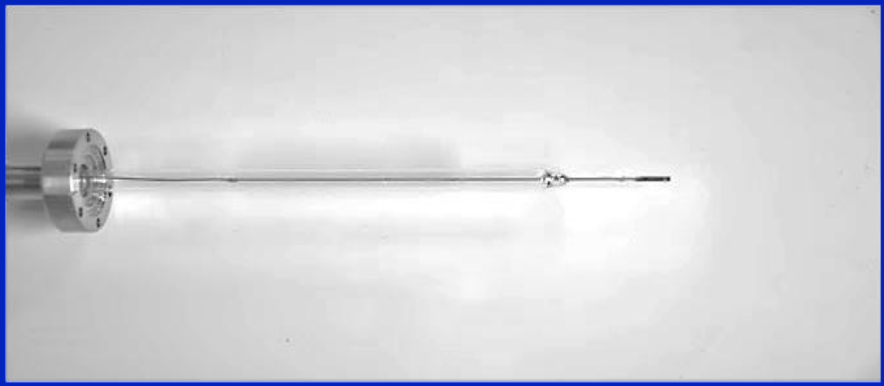
- ✓Cathode: 10 cm
- ✓Input Gas: H_2
- ✓Supply Voltage: -300V~-800V
- ✓Current-Supply: 10, 20, 30, 40mA
- ✓Pressure: 2 Pa, 3Pa, 4Pa

Control the probe

- ✓35V DC Power Supply
- ✓R=1.10281Ω
- ✓Record data: Digital Multi-Meter and Computer

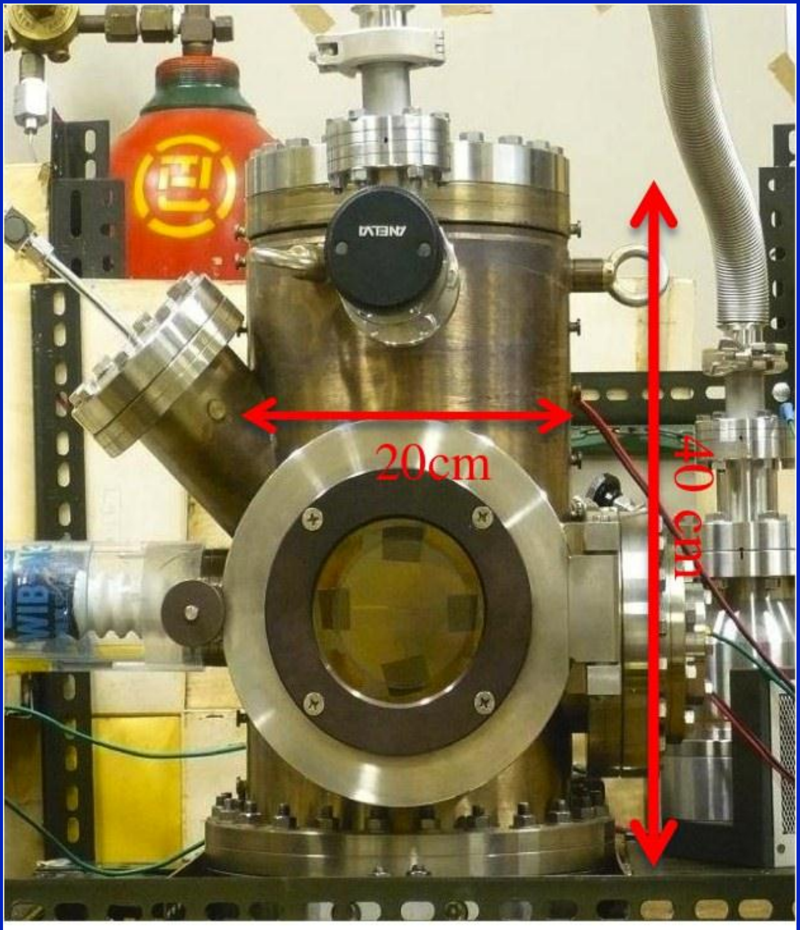


Setup the experiment

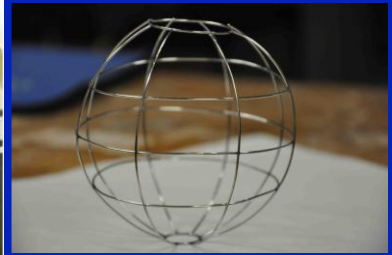


Single Probe (W, diameter: 1mm)

Equipments

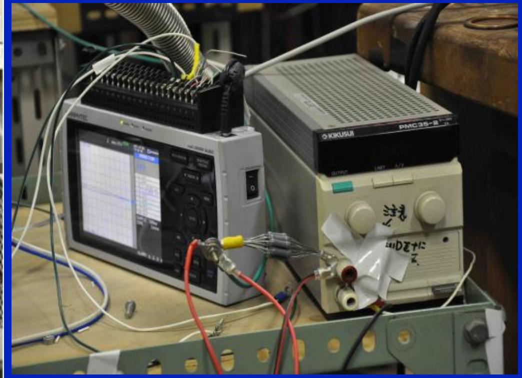


IECF device

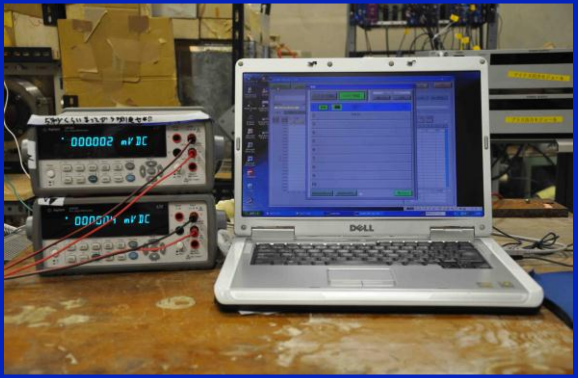


Grid-Cathode(10cm)SUS-304

Power supply(-20kV, 40mA)



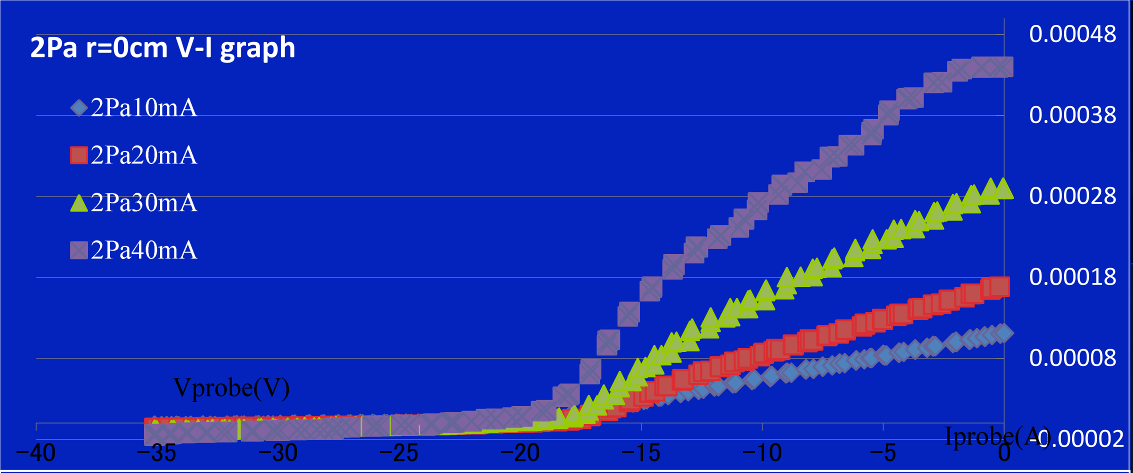
Data-logger and 35V-DC

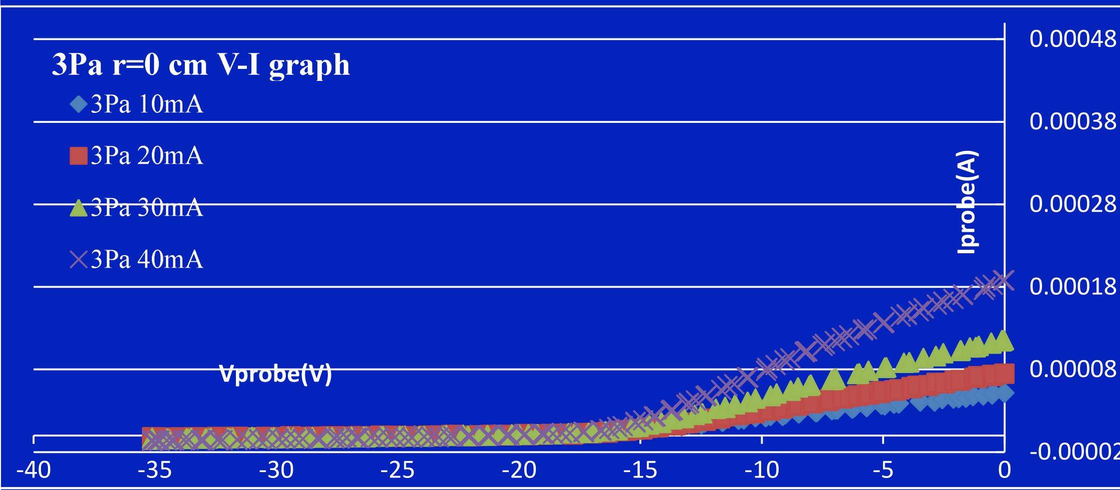


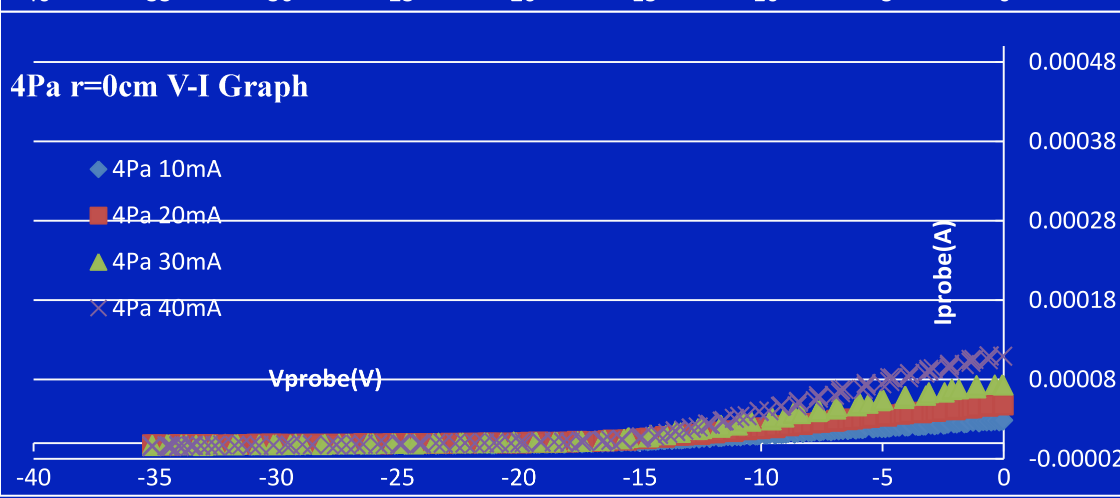
Digital Multi-Meter and PC

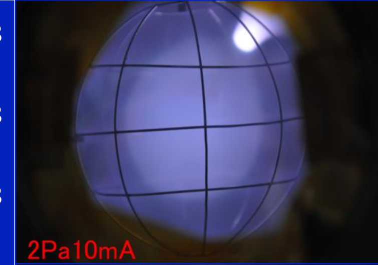
RESULTS(preliminary)

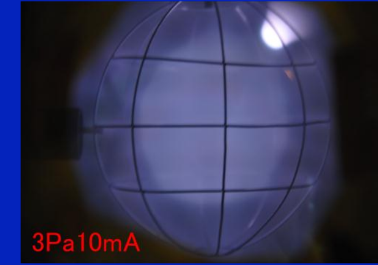
1. V-I Characteristic
2. Electron Temperature T_e
3. Plasma potential V_s
4. Electron density n_e

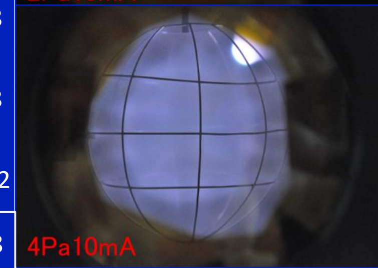












At r= 0, changing the current-supply and pressure, we measure the relation between probe voltage and probe current. From 3 Graphs, with the same current supply: $\mathbf{Ip_{2Pa} > Ip_{3Pa} > Ip_{4Pa}}$. Reason is the influence of "**Sheath**".

3 pictures above expressed the length of sheath. "Sheath" layer is a region surround the cathode with has density of ion higher than density of electron.

Sheath layer of 2Pa is higher than 3 Pa, 4Pa. So, the core of plasma (2Pa) became smaller → current became bigger.

- With the same procedure: change the distance, the gas-pressure, the current-supply, the relations between probe-voltage and probe-current were determined
- At the same conditions, different gas-pressure: $\mathbf{Ip_{2Pa} > Ip_{3Pa} > Ip_{4Pa}}$
- Because of the influence of “Sheath layer”, we can not do experiments when $r > 3cm$

Electron temperature T_e, plasma potential V_s and electron-saturation current I_{es}

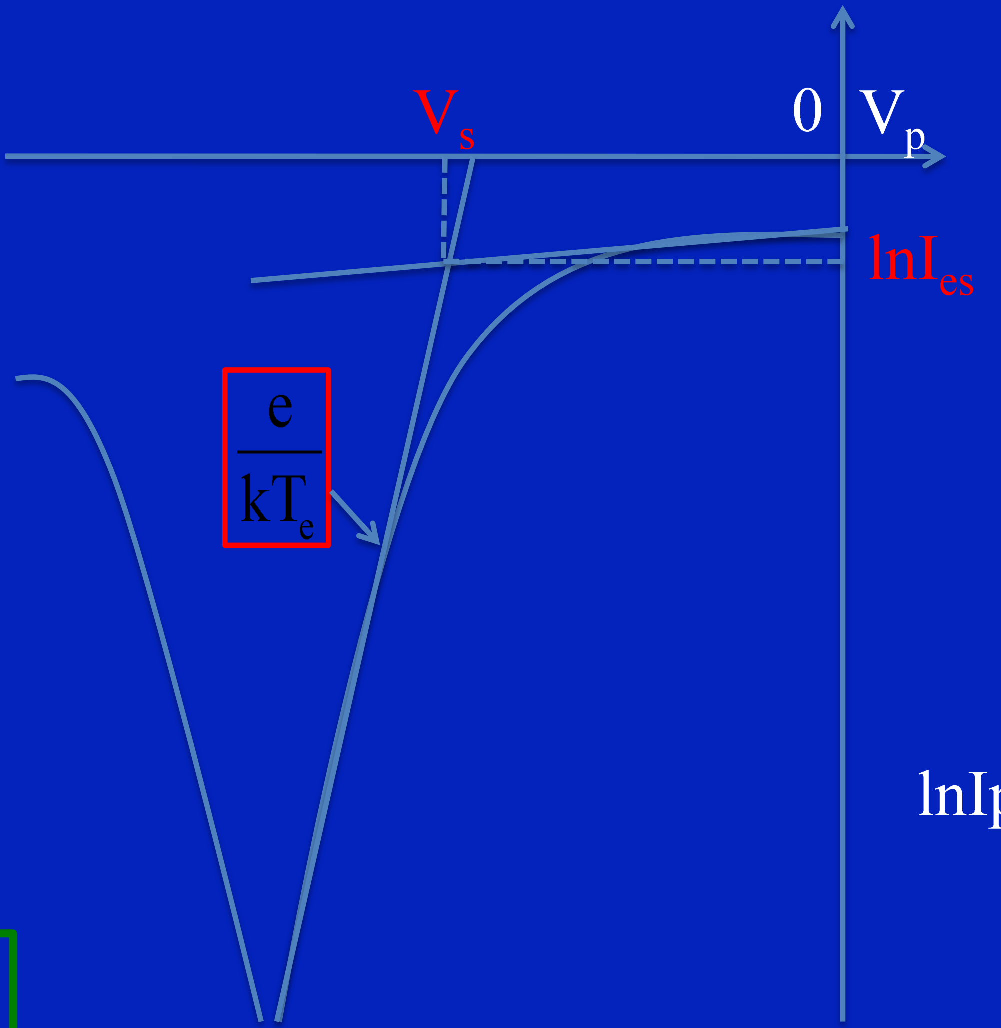
The electron-current has the form

$$I_p = I_{es}\exp[-e(V_s - V_p)/kT_e]$$

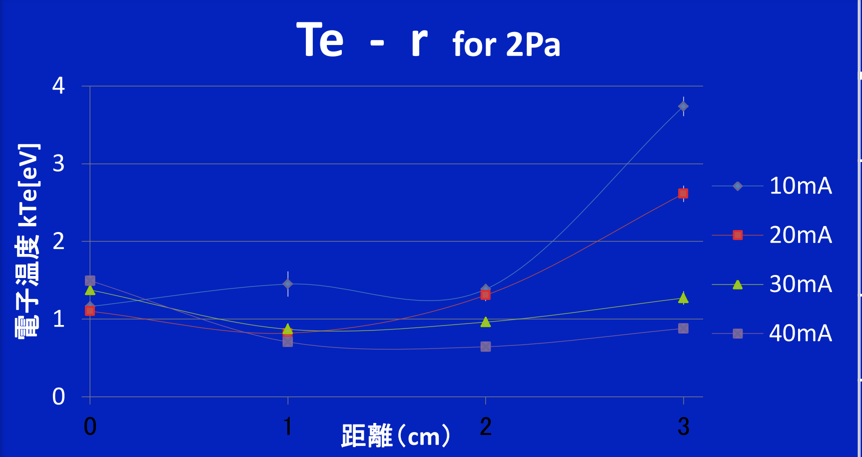
Taking natural logarithm of the above equation, we obtain

$$\ln I_p = \ln I_{es} - \frac{eV_s}{kT_e} + \frac{eV_p}{kT_e}$$

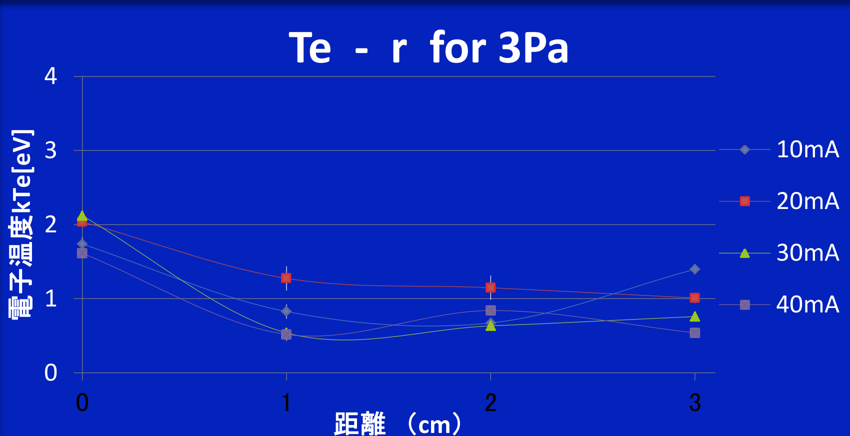
From Graph.3, we can determine T_e, plasma potential V_s and electron-saturation current I_{es}



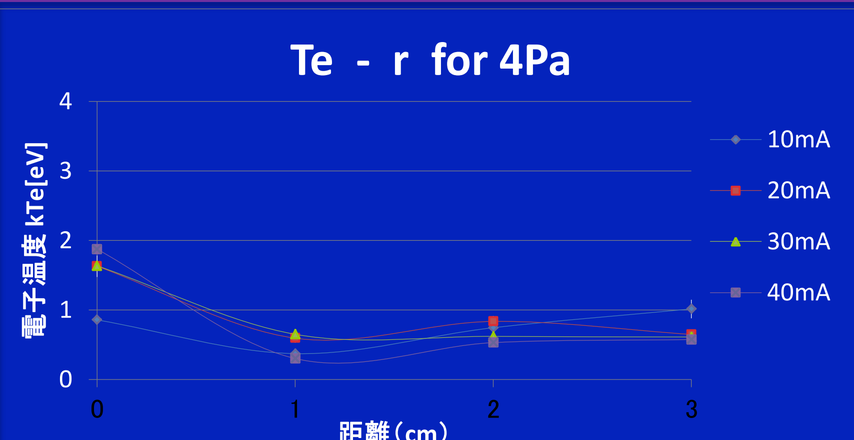
Graph.3 V-lnI characteristic



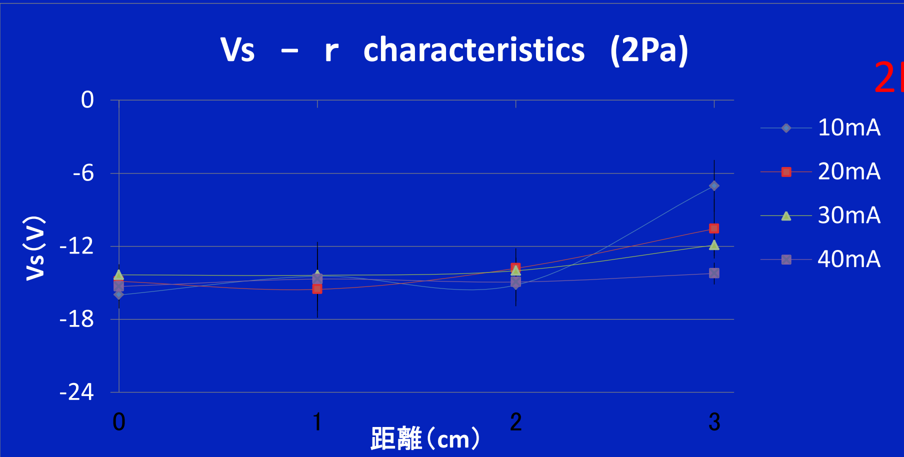
r(cm)	10mA	20mA	30mA	40mA
0	1.16±0.04	1.10±0.04	1.38±0.04	1.49±0.03
1	1.50±0.20	0.82±0.08	1.20±0.10	0.70±0.03
2	1.39±0.06	1.31±0.08	0.96±0.04	0.65±0.05
3	3.70±0.10	2.60±0.10	1.27±0.09	0.88±0.03



r(cm)	10mA	20mA	30mA	40mA
0	1.74±0.09	2.04±0.06	2.12±0.04	1.61±0.03
1	0.80±0.10	1.30±0.10	0.54±0.06	0.52±0.09
2	0.67±0.05	1.10±0.20	0.63±0.02	0.84±0.05
3	1.40±0.07	1.01±0.07	0.76±0.04	0.54±0.05

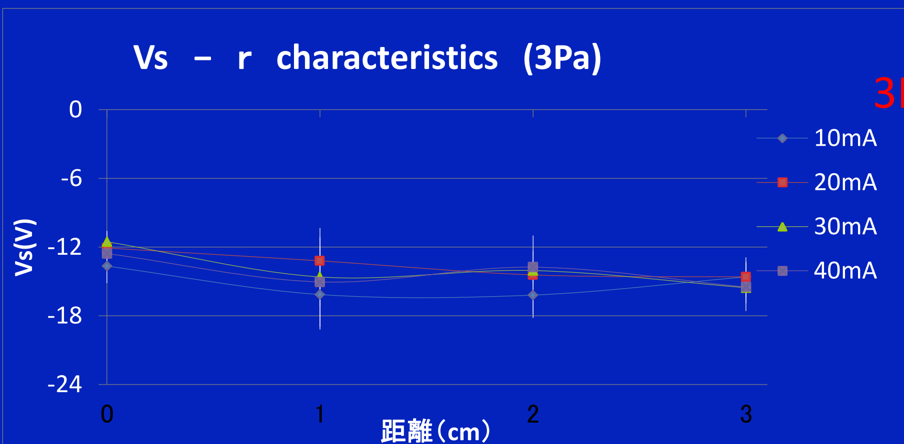


r(cm)	10mA	20mA	30mA	40mA
0	0.86±0.07	1.60±0.2	1.63±0.07	1.87±0.06
1	0.37±0.06	0.59±0.06	0.65±0.08	0.30±0.05
2	0.74±0.06	0.83±0.08	0.62±0.05	0.53±0.03
3	1.70±0.10	0.65±0.05	0.61±0.05	0.57±0.03



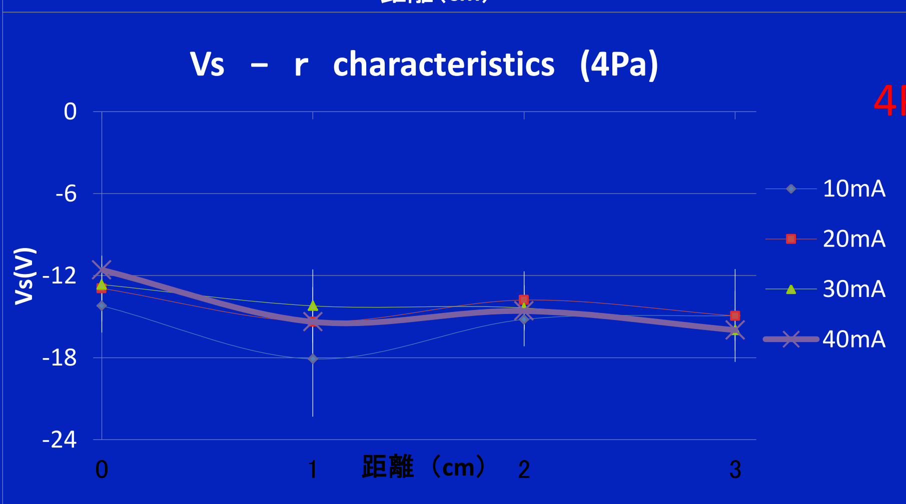
2Pa

r(cm)	10mA	20mA	30mA	40mA
0	-16.0±1.0	-15.0±1.0	-14.3±0.9	-15.0±1.0
1	-14.0±3.0	-16.0±2.0	-14.0±2.0	-15.0±1.0
2	-15.0±1.0	-14.0±2.0	-14.0±1.0	-15.0±2.0
3	-7.0±2.0	-11.0±2.0	-11.9±0.9	-14.2±0.9



3Pa

r(cm)	10mA	20mA	30mA	40mA
0	-14.0±1.0	-12.0±1.0	-12.0±1.0	-12.6±0.7
1	-16.0±3.0	-13.0±3.0	-15.0±2.0	-15.0±4.0
2	-16.0±2.0	-14.0±3.0	-14.1±0.9	-14.0±1.0
3	-15.0±1.0	-15.0±2.0	-16.0±1.0	-15.0±2.0

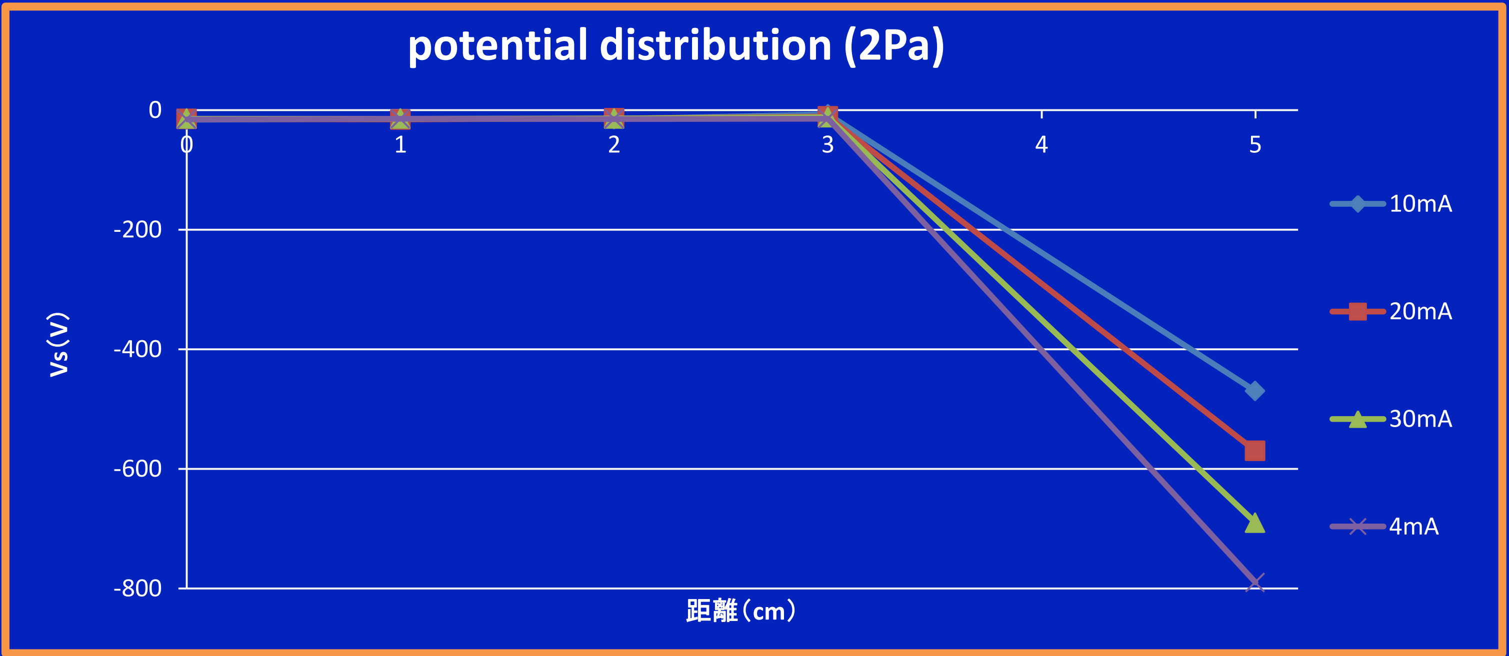


4Pa

r(cm)	10mA	20mA	30mA	40mA
0	-14.0±2.0	-13.0±2.0	-13.0±1.0	-12.0±1.0
1	-18.0±4.0	-15.0±3.0	-14.0±3.0	-15.0±3.0
2	-15.0±2.0	-14.0±2.0	-14.0±2.0	-15.0±1.0
3	-15.0±3.0	-15.0±2.0	-16.0±2.0	-16.0±2.0

From the graph of plasma potentials :

- The values of V_s were not affected so much by the distance.
- The values of V_s did not change when we changed the pressure and also the current supply.
- The values of V_s were about -14V~-16V



Inside the cathode, the virtual anode exists

Calculation of electron density

The electron-current's formula has the form

$$I_e(V_p) = I_{es} \exp\left(-e\frac{V_s - V_p}{kT_e}\right) \qquad (1)$$

Where I_{es} is the electron-saturation current. I_{es} has the form

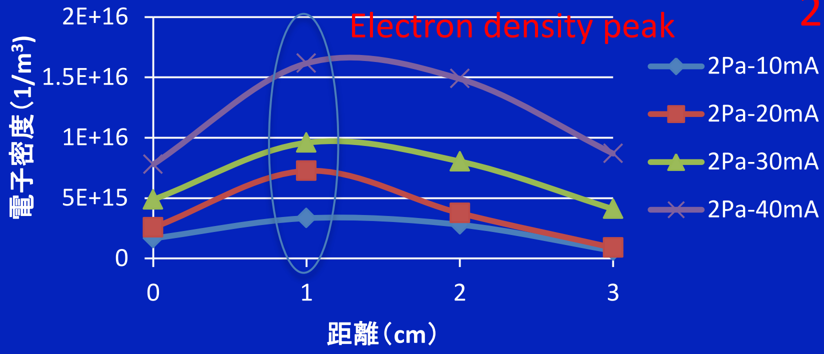
$$I_{es} = \frac{1}{4} e n_e \bar{v} A \qquad (2)$$

Where $\bar{v}$ is the average velocity of electron and has the form: $\bar{v} = \sqrt{\frac{8kT_e}{\pi m_e}}$ (3)

A: Probe's surface area & n_e: electron density

$$n_e = \frac{4 I_{es}}{eA\bar{v}} \qquad (4)$$

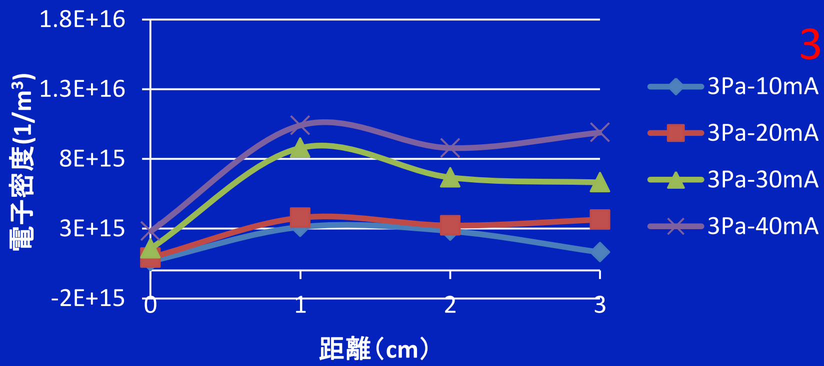
2Paにおける電子密度ー距離特性



2Pa

r(cm)	10mA	20mA	30mA	40mA
0	(1.67±0.03)E+15	(2.56±0.04)E+15	(4.88±0.07)E+15	(7.79±0.09)E+15
1	(3.30±0.10)E+15	(7.30±0.30)E+15	(9.60±0.50)E+15	(1.60±0.30)E+15
2	(2.80±0.06)E+15	(3.70±0.10)E+15	(8.00±0.20)E+15	(1.50±0.60)E+15
3	(6.40±0.01)E+15	(8.90±0.02)E+15	(4.10±0.10)E+15	(8.70±0.10)E+15

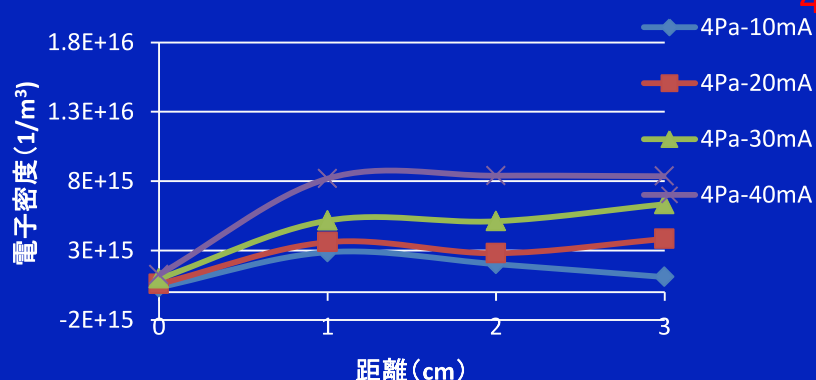
3Paにおける電子密度–距離特性



3Pa

r(cm)	10mA	20mA	30mA	40mA
0	(6.60±0.20)E+14	(9.19±0.01)E+14	(1.56±0.02)E+15	(2.80±0.02)E+15
1	(3.10±0.20)E+15	(3.80±0.20)E+15	(8.80±0.50)E+15	(1.04±0.04)E+16
2	(2.80±0.10)E+15	(3.20±0.20)E+15	(6.70±0.10)E+15	(8.80±0.30)E+15
3	(1.30±0.03)E+15	(3.60±0.10)E+15	(6.30±0.20)E+15	(9.90±0.40)E+15

4Paにおける電子密度–距離特性



4Pa

r(cm)	10mA	20mA	30mA	40mA
0	(3.51±0.06)E+14	(5.90±0.20)E+14	(9.80±0.20)E+14	(1.27±0.02)E+15
1	(2.90±0.20)E+15	(3.60±0.20)E+15	(5.20±0.30)E+15	(8.20±0.50)E+15
2	(2.02±0.08)E+15	(2.80±0.10)E+15	(5.10±0.20)E+15	(8.40±0.30)E+15
3	(1.09±0.03)E+15	(3.80±0.10)E+15	(6.30±0.30)E+15	(8.40±0.20)E+15

From the electron-density graph

- ✧ $n_{e2Pa} > n_{e3Pa} > n_{e\ 4Pa}$ because the affect of sheath layer. It made the plasma core in 2Pa is smaller than 3Pa, 4Pa → the electron-density of 2Pa was increased.
- ✧ 3Pa, 4Pa: have the same graph forms.
- ✧ 2Pa, at r = 1cm, the densities got the highest values.
- ✧ The electron density was about 10^{15}~10^{16}($1/m^3$)

Summary

- ✓ neutron production region was investigated.
- ✓ Halo mode : not line shape
- ✓ Cylindrical cathode use : line shape
- ✓ This time, some plasma parameters were measured
- ✓ Inside the cathode
  - Electron temperature: 0.4eV ~ 4eV
  - Plasma potential:-14V~-16V
  - Electron density: 10^{15}~10^{16} (1/m^3)
- ✓ Inside the cathode (r< 3cm), virtual anode was determined
- ✓ However, the existence of virtual cathode could not be determined