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Characteristics Measurement of ECR Ion Beam Obtained from Grid Extraction System

그리드 인출계를 이용한 ECR 이온빔 특성 연구

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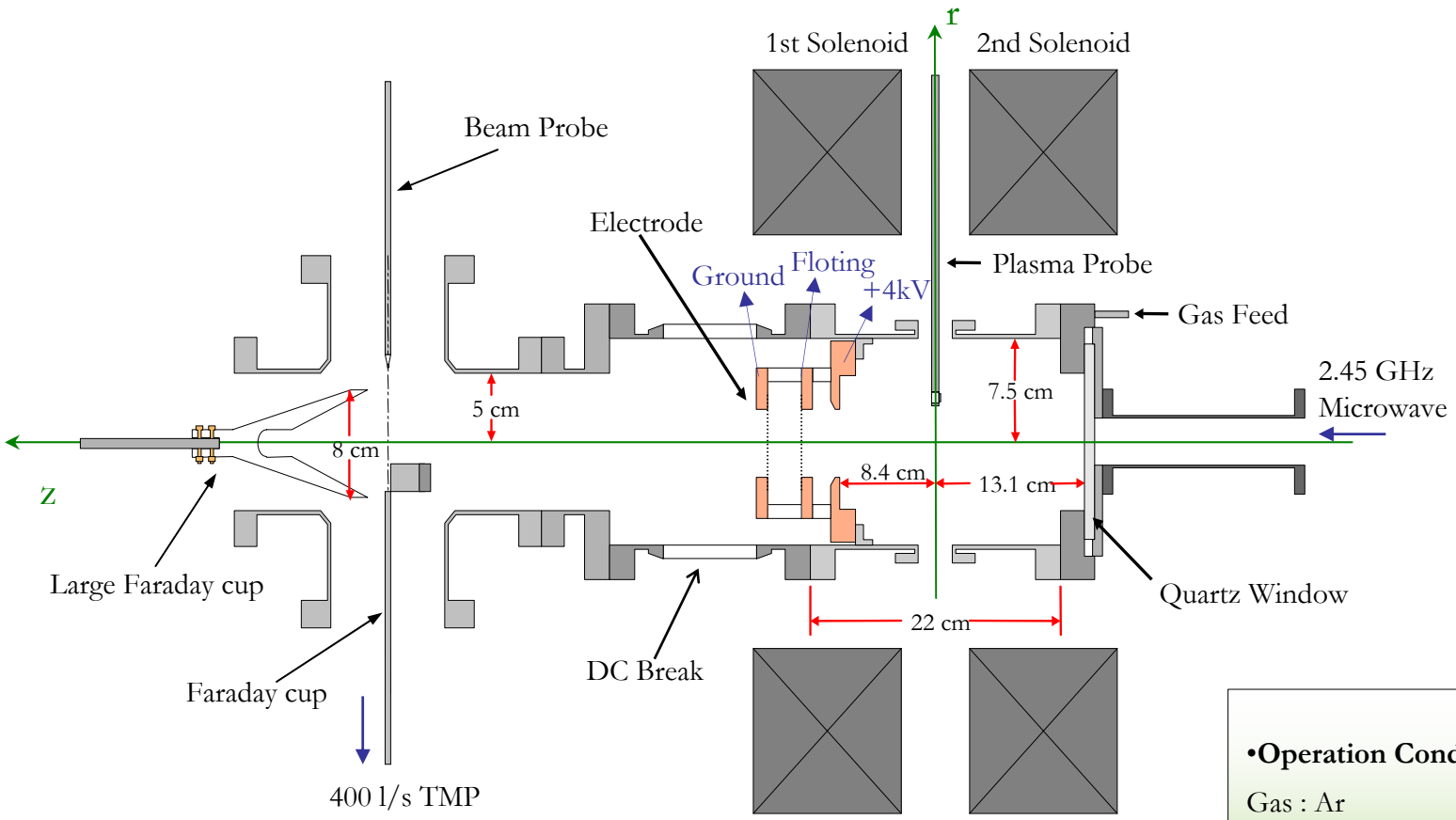
Abstract

- ECR plasma using a 2.45GHz magnetron and two solenoid magnets has been generated with Argon gas at 10^{-5} torr pressure range. The ion beam is extracted from the ECR plasma chamber by the gird extraction electrodes. The goal of our research is to find the relation between ion beam characteristics and grid structure. The open area ratio and hole shape of grids have an influence on the total current and formation of ion beam.
- For this work we measured the total ion beam current, density profiles and velocity profiles according to operation conditions by each grid electrodes. We have used cylindrical tungsten probe that directly measure the ion beam current. The results are in reasonable agreement with the Faraday cup measurement results. The results were compared with XOOPIC simulation results.
- *This work is partially supported by KSTAR project and MOST.

Schematic of Experimental Setup



•Operation Condition

Gas : Ar

P_{bass} : $1*10^{-7}$ Torr

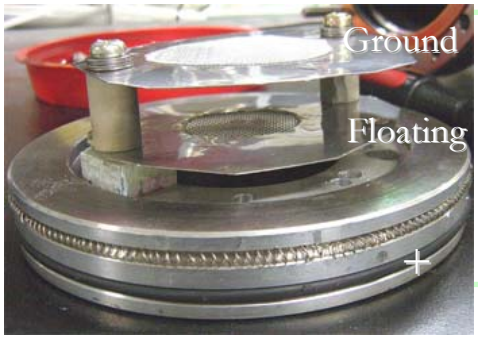
P_{Argon} : $2*10^{-5}$ Torr

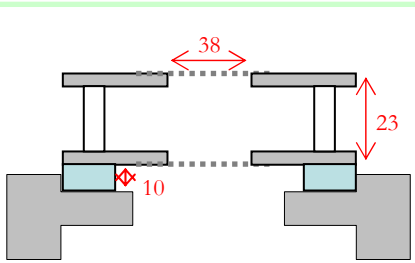
Microwave Power : 50 W

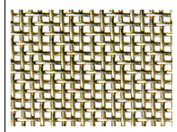
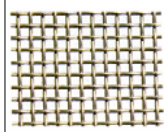
Solenoide Current : 94 A, 45 A

Experimental Setup

- **Tri-electrode**



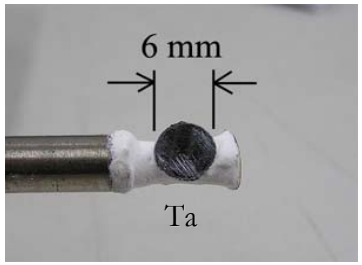


	mesh A	mesh B	mesh C
			
Open Area Ratio	67.4 %	41.9 %	61.6 %
Specification	0.35 t 0.4 w 1.8 sw 3.0 lw	0.18 Φ 0.33 open	0.229 Φ 0.83 open

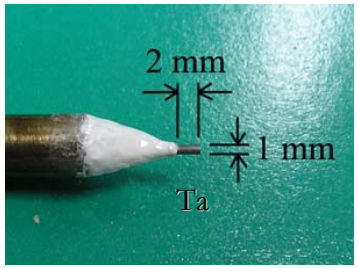
Electrode 1
Floating Mesh : mesh A
Ground Mesh : mesh B

Electrode 2
Floating Mesh : mesh A
Ground Mesh : mesh C

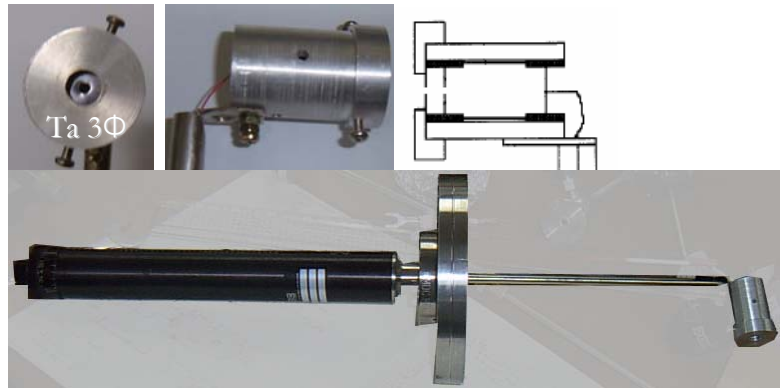
- **Plasma probe**



- **Beam probe**



- **Faraday cup**

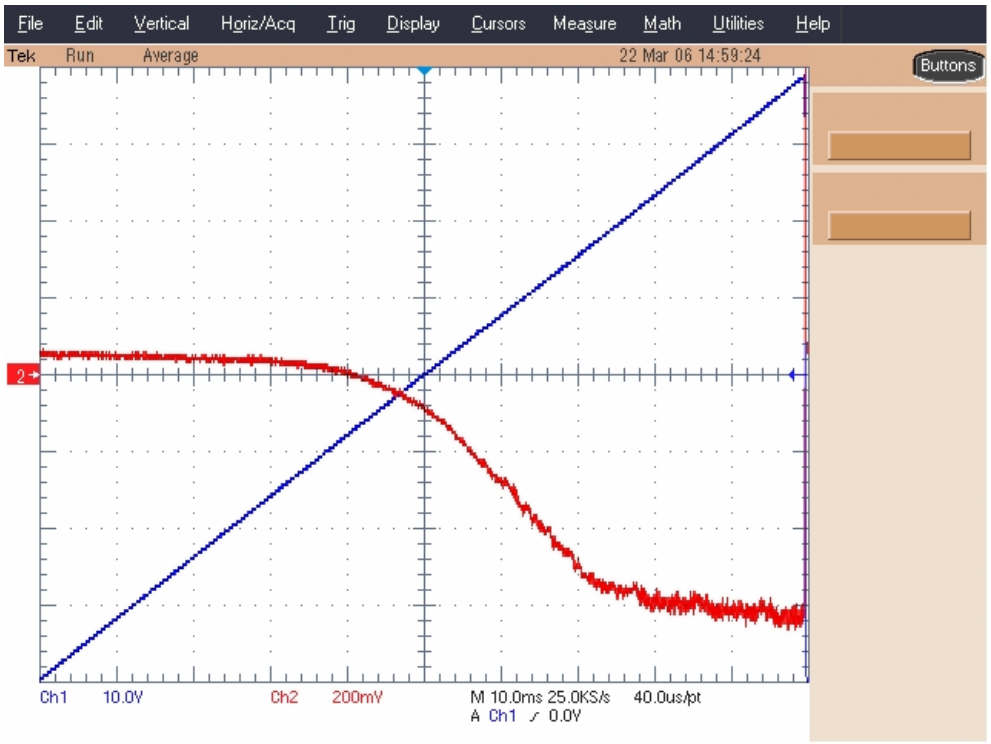


ECR Plasma

Langmuir Probe Measurement

$$I_e = I_e^* \exp\left[\frac{e(V_b - V_p)}{T_e}\right] \quad (V_b \le V_p) \quad \Rightarrow \quad T_e = \frac{e(V_b - V_p)}{\ln(I_e) - \ln(I_e^*)}$$

$$I_e = I_e^* = Sn_e e\sqrt{\frac{T_e}{2\pi m_e}} \quad (V_b > V_p) \quad \Rightarrow \quad n_e = \frac{I_e^*}{eS}\sqrt{\frac{2\pi m_e}{T_e}}$$



- **Plasma Condition**
  (r=0, z=0)

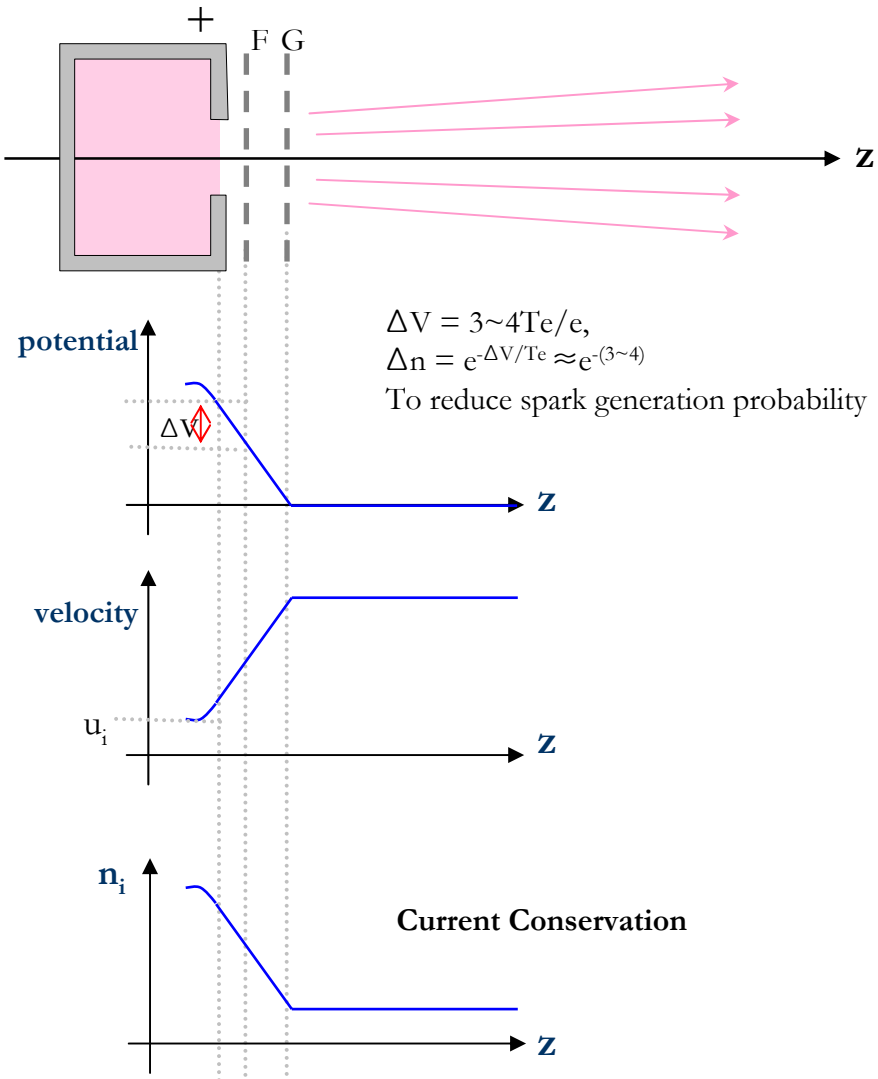
Te : 10eV

Ne : $2*10^9$ #/cm^3

Vp : 16 V

Vf : -6 V

Calculated Beam Current Density



$\Delta V = 3\sim4Te/e$,
$\Delta n = e^{-\Delta V/Te} \approx e^{-(3\sim4)}$
To reduce spark generation probability

Current Conservation

$$C_s = \sqrt{\frac{kT_e}{M}} = \sqrt{\frac{10eV}{1830 \times 0.511eV/c^2 \times 40}} \cong \frac{c}{60000} \cong 5 \times 10^2 m/s$$

$J = q*C_s*n$

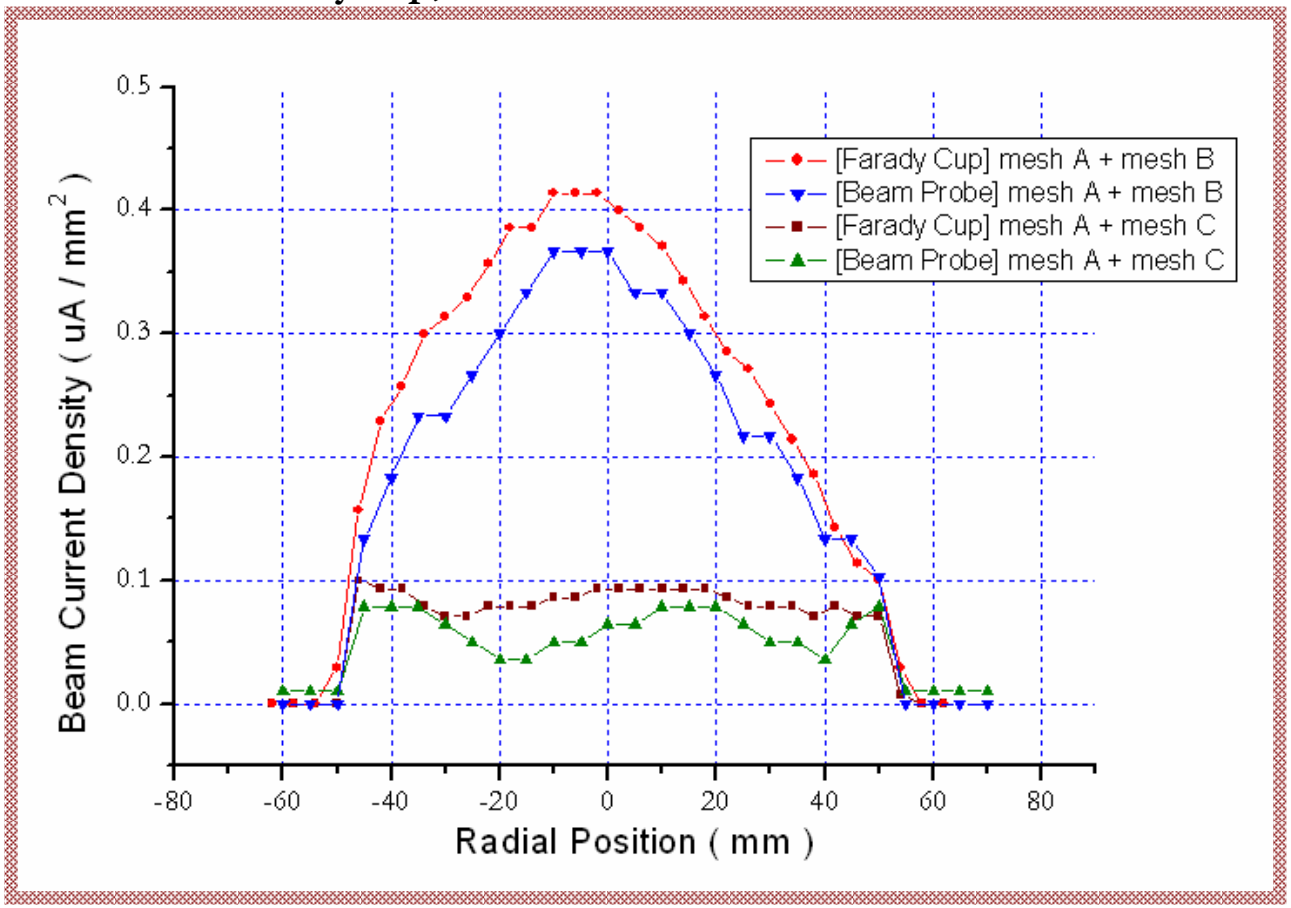
$J = (+1.6*10^{-19}\ C)*(5*10^4\ cm/s)*(2*10^9\ \#/cm^3)$
$= 1.6*10^{-5}\ A/cm^2 = 0.16uA/mm^2$

- mesh A + mesh B
$0.16\ mA/mm^2 * 0.674 * 0.419 = 0.045\ uA/mm^2$
- mesh A + mesh C
$0.16\ uA/mm^2 * 0.674 * 0.616 = 0.066\ uA/mm^2$
- mesh A + mesh A
$0.16\ uA/mm^2 * 0.674 * 0.616 = 0.073\ uA/mm^2$

Experimental Results -1

- Extraction Voltage : 4.0kV
- +Electrode current : 30.8mA
- Ground Electrode current : 6.4mA

◆ **Small Faraday cup, Beam Probe**



Experimental Results -2

- Extraction Voltage : 4.0kV
- +Electrode current : 30.8mA
- Ground Electrode current : 6.4mA

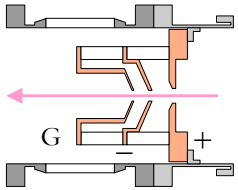
◆ **Large Faraday cup (5026mm^2, diameter=80mm)**

mash A + mesh B
Total Current = 235uA
235/5026 = 0.047uA/mm2

mash A + mesh C
Total Current = 757uA
757/5026 = 0.151uA/mm2

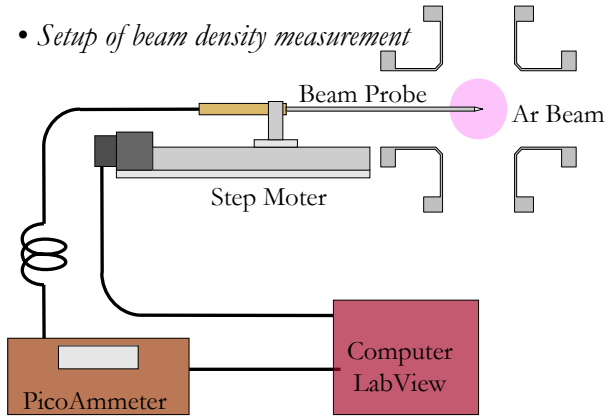
Optical Transparency Ratio	1.47 : 1
Maximum Beam Current Density Ratio	4 : 1
Average Beam Current Density Ratio	3.2 : 1

Beam Density Profile Measurement



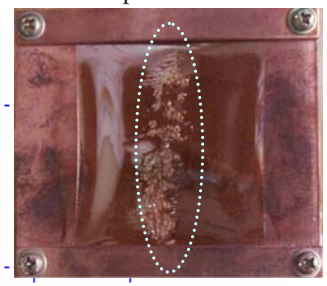
Base Pressure : $7*10^{-7}$ Torr
Ar Pressure : $2*10^{-5}$ Torr
Coil Current : 60 A, 60 A
MW Power : 90 W
V+ = 20 kV, V- = - 3 kV

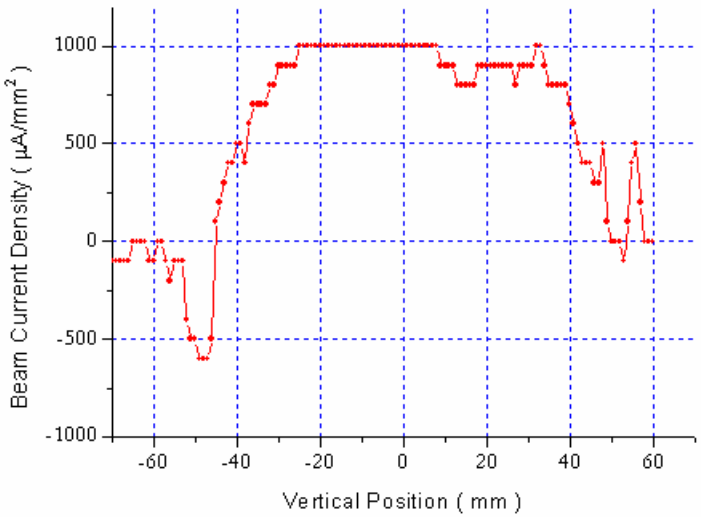
• *Setup of beam density measurement*



◆ **Rectangular hole electrode**

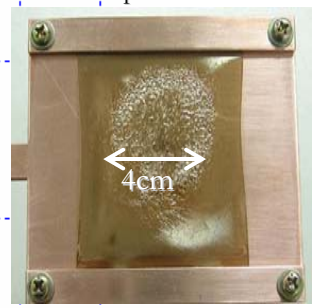
Ar beam implanted PET film

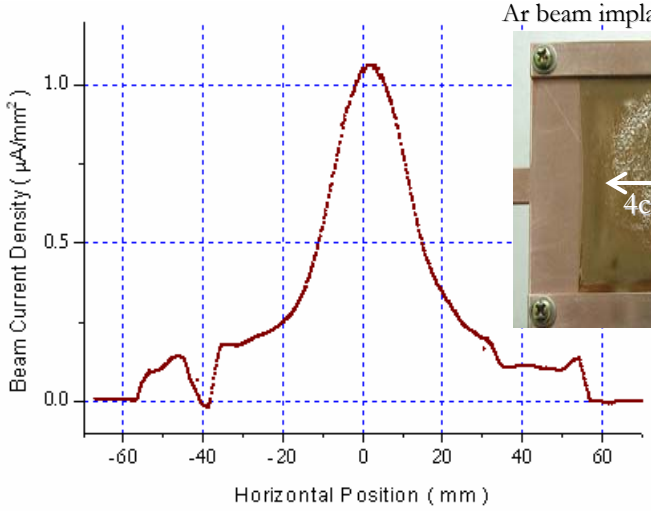




◆ **Circular hole electrode**

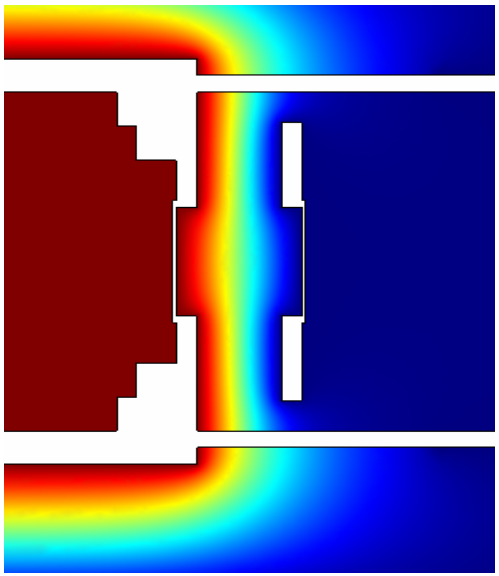
Ar beam implanted PET film



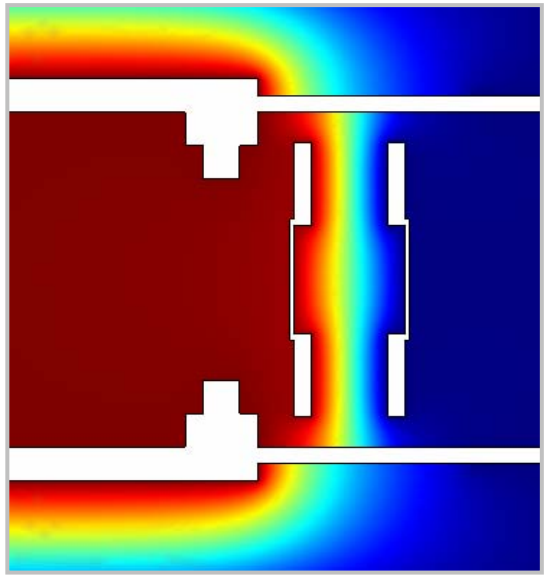


Equipotential

• Diode - 4000 : 0



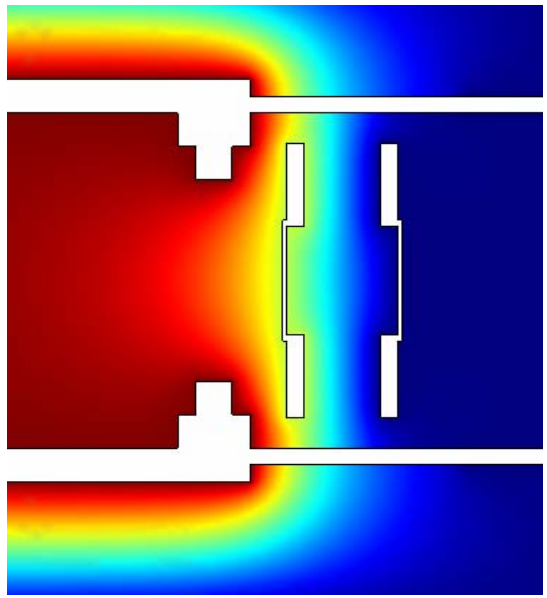
• Triode - 4000 : 3900 : 0



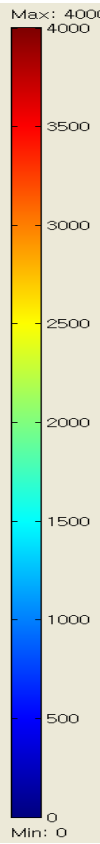
Plasma

(2250)

• Triode - 4000 : Floating : 0



No plasma

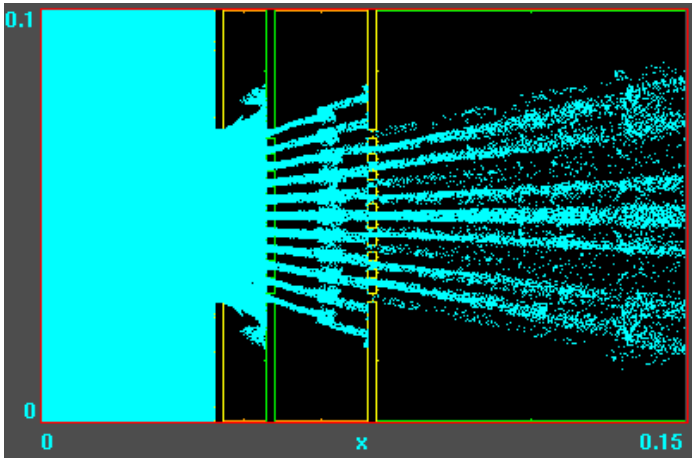


(by COMSOL Multiphysics)

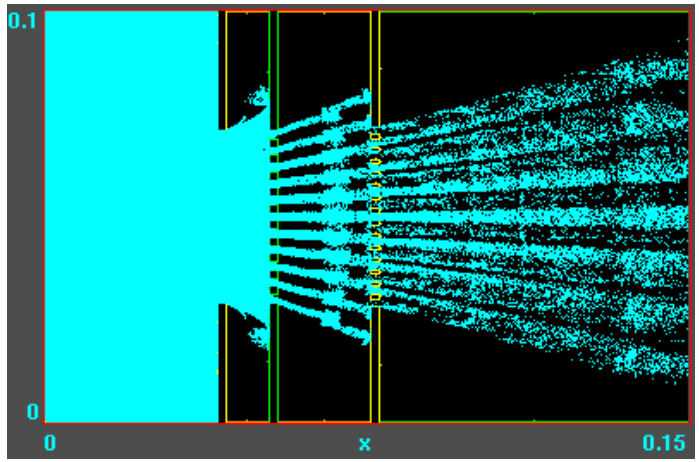
XOOPIC Simulation -1

◆ x-y space for argon

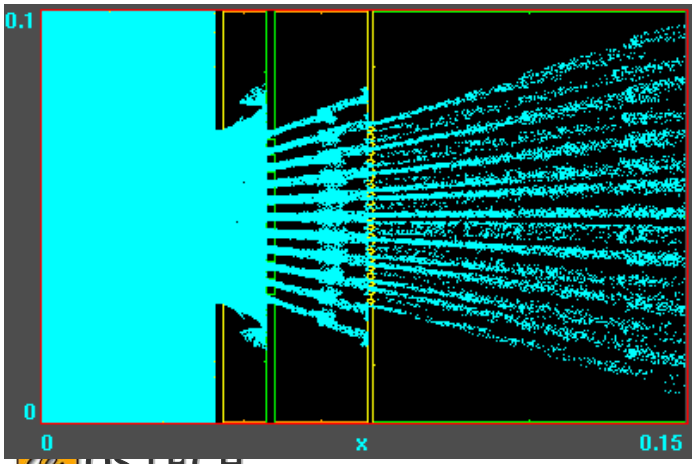
① Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **2**mm, Hole distance **2**mm



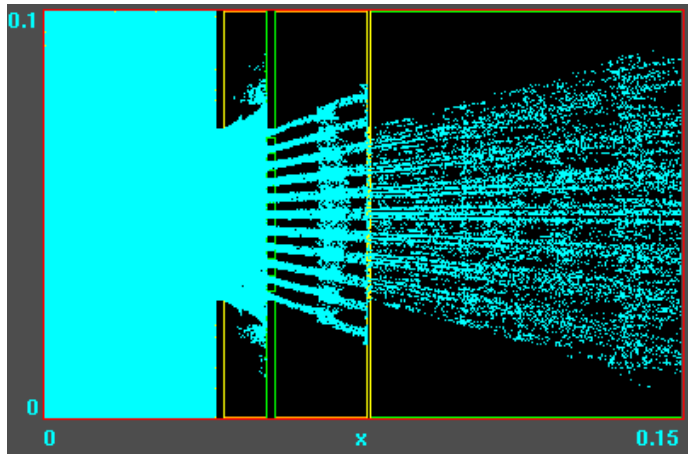
② Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **1.5**mm, Hole distance **1.5**mm



③ Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **1**mm, Hole distance **1**mm

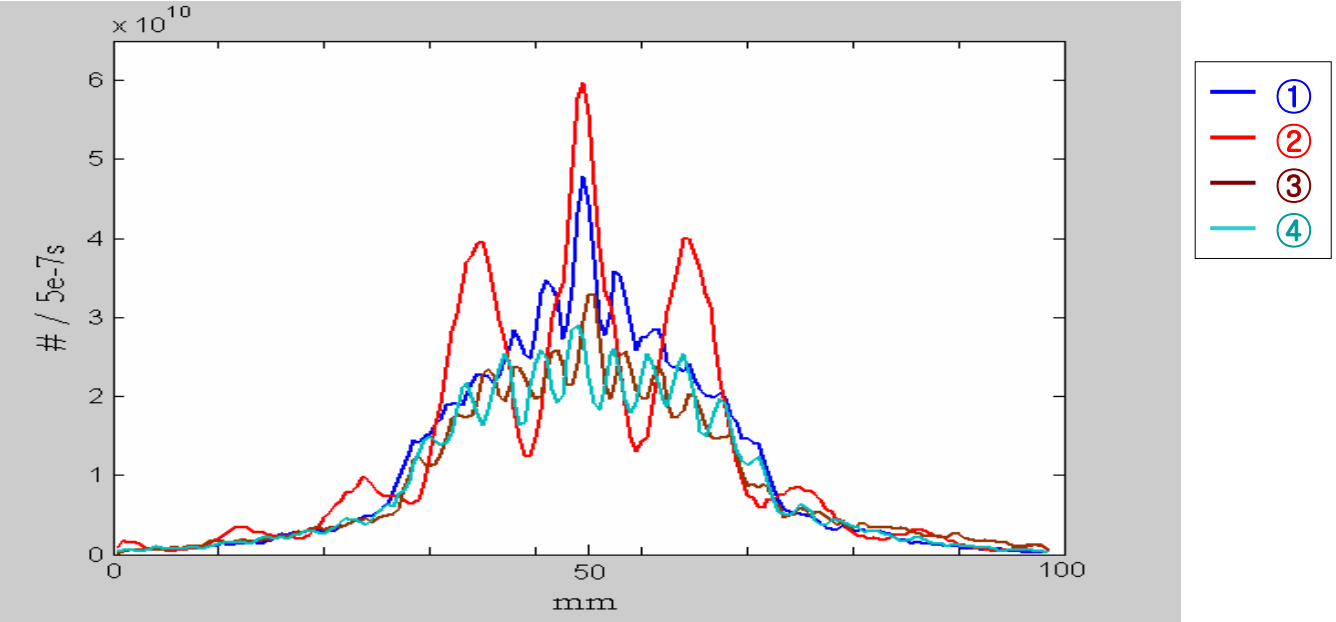


④ Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **0.5**mm, Hole distance **0.5**mm



XOOPIC Simulation -2

- Number of reached particles on the Boundary Downstream Chamber

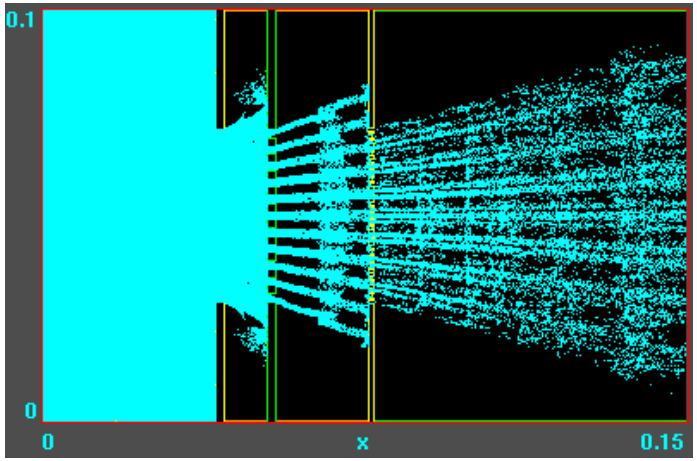


Optical Transparency	50%
Average Beam Current Density Ratio	1 : 1.1 :0.83 : 0.82
Hole Size Ratio	1: 0.75 : 0.5 : 0.25
Maximum Beam Current Density Ratio	1 : 1.25 : 0.91 : 0.61

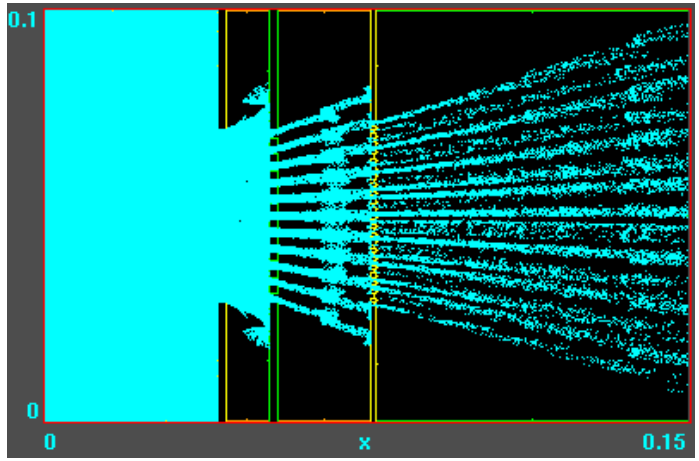
XOOPIC Simulation -3

◆ **x-y space for argon**

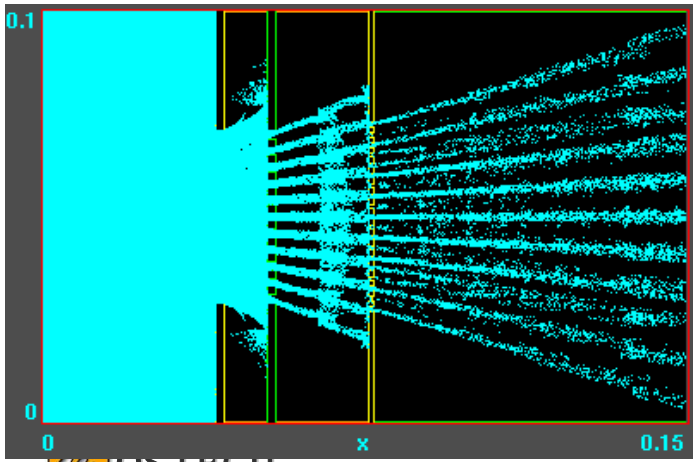
① Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **1**mm, Hole distance **0.5**mm (67%)



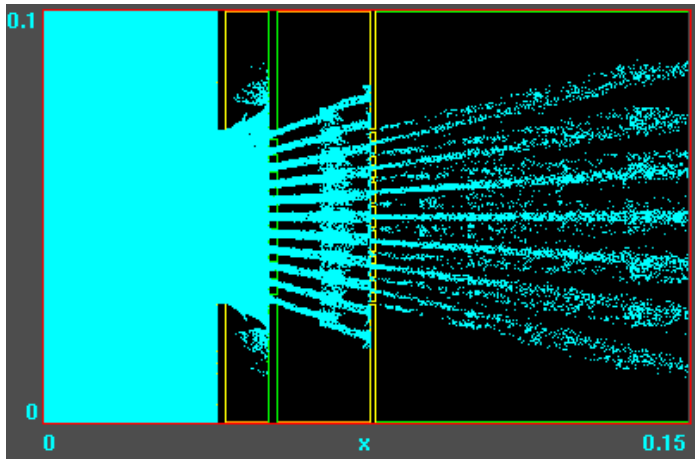
② Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **1**mm, Hole distance **1**mm (50%)



③ Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **1**mm, Hole distance **1.5**mm (40%)

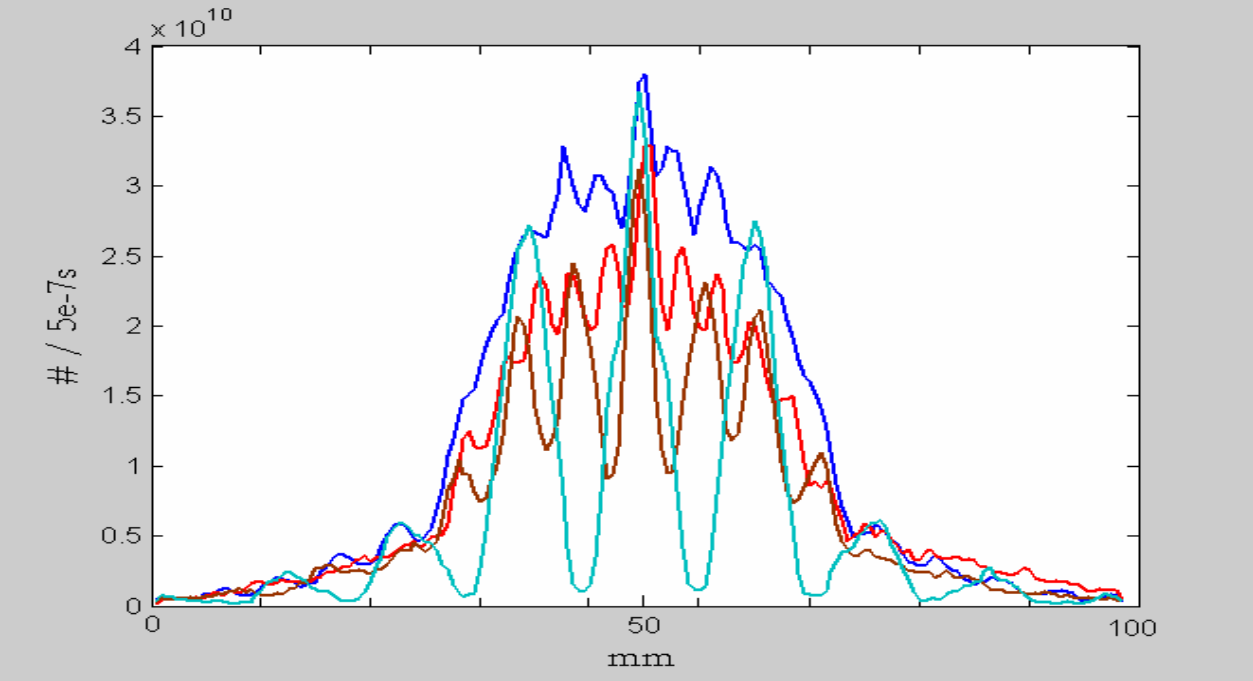


④ Hole diameter **2**mm, Hole distance **2**mm
+ Hole diameter **1**mm, Hole distance **2**mm (33%)



XOOPIC Simulation -4

- Number of reached particles on the Boundary Downstream Chamber



Optical Transparency Ratio	1 : 0.76 : 0.6 : 0.5
Average Beam Current Density Ratio (30mm~70mm)	1 : 0.73 : 0.55 : 0.48
Maximum Beam Current Density Ratio	1 : 0.89 : 0.85 : 0.97

Beam Optics

***Shape of electrode*, Plasma density, Electrode Potential ..→ Plasma meniscus**

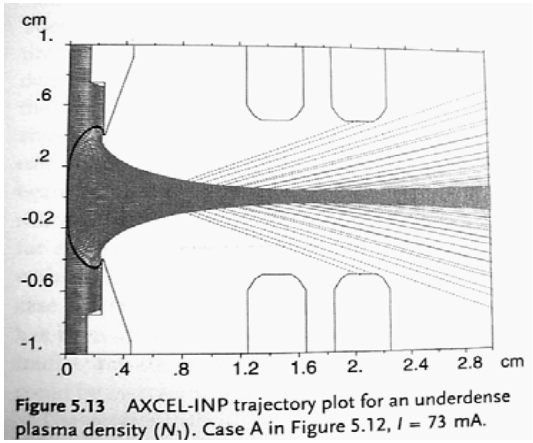


Figure 5.13 AXCEL-INP trajectory plot for an underdense plasma density (N_1). Case A in Figure 5.12, I = 73 mA.

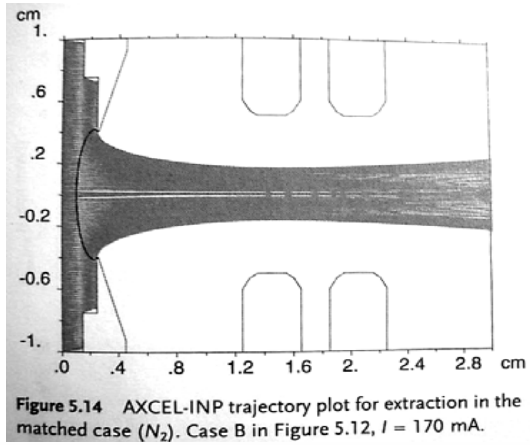


Figure 5.14 AXCEL-INP trajectory plot for extraction in the matched case (N_2). Case B in Figure 5.12, I = 170 mA.

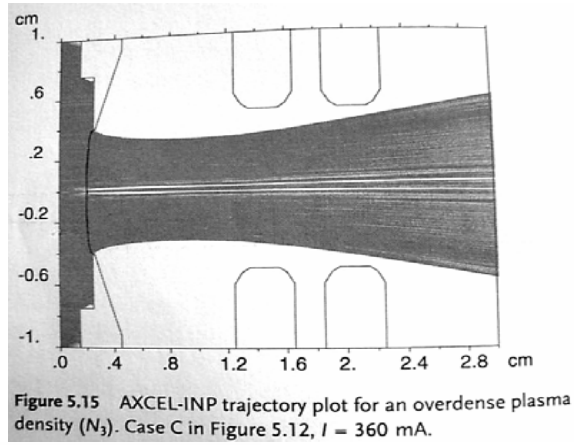
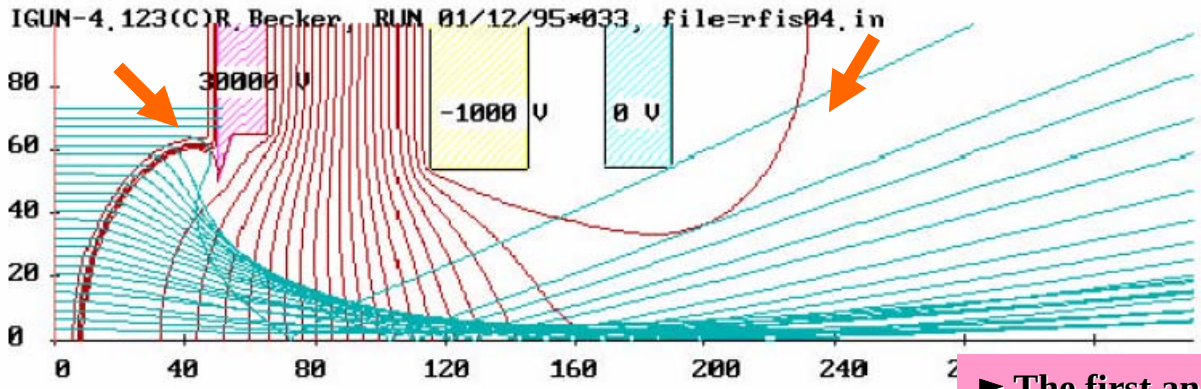


Figure 5.15 AXCEL-INP trajectory plot for an overdense plasma density (N_3). Case C in Figure 5.12, I = 360 mA. [1]



► **The first and second grids behave like lends.**

[1] G. Brown, "The Physics and Technology of Ion Sources" 2/E, 2004, WILEY-VCH

Summary

- The goal of our research is to find the relation between ion beam characteristics and grid structure. The ion beam is extracted from the ECR plasma chamber by the gird extraction electrodes.
- The current density ratio of ion beam is three or four times larger than the opening area ratio.
- The ion density profiles are different from each other in shape.
- The probe measurement results are in reasonable agreement with the Faraday cup measurement results.
- In XOOPIC condition that produce reasonable result,
  we have expected ion current density ratio with respect to grid opening ratio.
- As a result of XOOPIC simulation, both hole-size and optical-transparency affect the beam current density.

- The effect of grid shape must be investigated further.