Plasma Parameters at Upper/Down Stream Region near ECR Zone and Optimizing Microwave-launching on ECRIS

Division of Electrical, Electronic and Infocommunications Engineering,
Graduating School of Engeering, Osaka University

OSAKA UNIVERSITY

○ W. Kubo, S. Harsaki
I. Owada, K. Sato
K. Tsuda, and Y. Kato

ECRIS'20 presentation

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2 Background & Objective

Background

・In recent years, we have focused on waves propagation in ECR plasma. (Heating by the upper hybrid resonance [1, 2]/Installing the coaxial semi-dipole antenna [3])

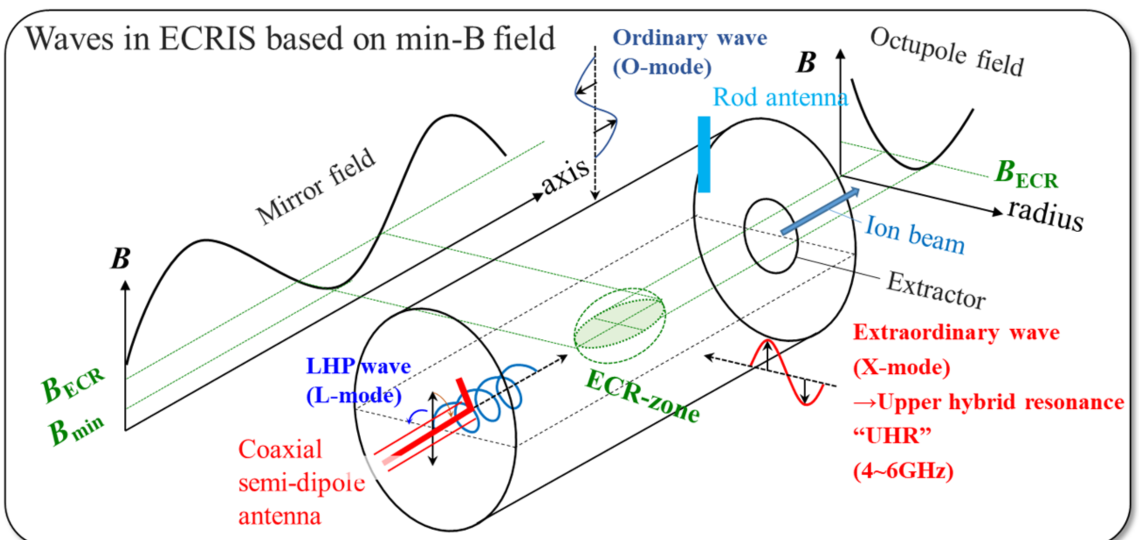
・For the excitation of right hand polarization (RHP) waves, there is still room for improvement in the position of microwave launching, which is empirically determined on conventional ECRIS.

Objective

・Optimization of ECR→We aim to improve the conventional microwave launching to more suitable one for RHP wave propagation in ECRIS.

・We conduct the simultaneous measurements by two Langmuir probes in the upperstream and downstream region with the respect to the ECR-zone.

→We have obtained results consistent with RHP wave propagation theory.



[1] Y. Kato, et al, Rev. Sci. Instrum. 87, 02A710 (2016)

[2] Y. Kato, et al, Rev. Sci. Instrum. 91, 013315 (2020)

[3] W. Kubo, et al, Rev. Sci. Instrum. 91, 023317 (2020)

2 *Background & Objective*

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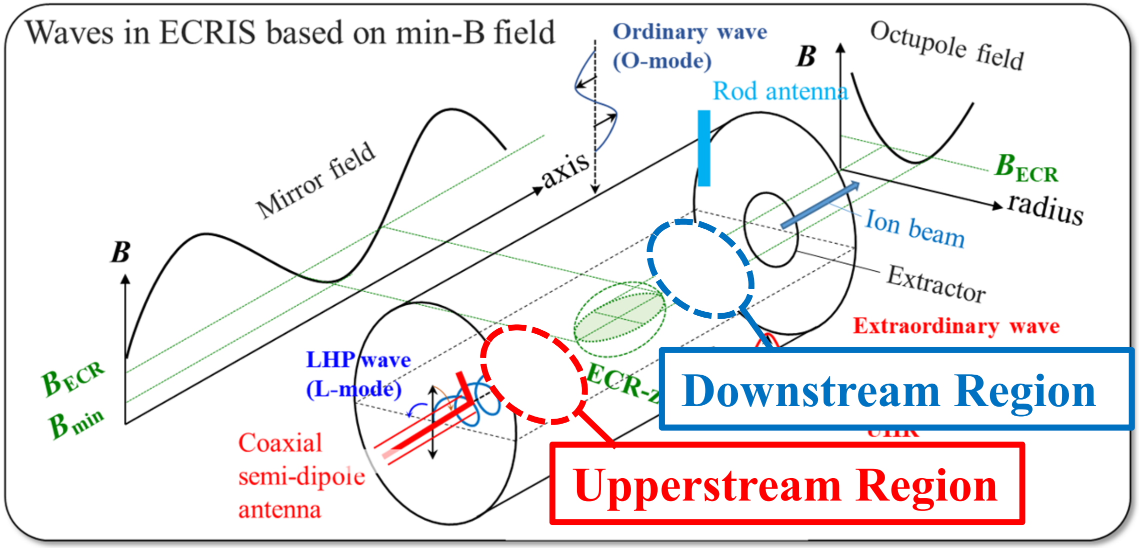

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The RHP Wave

RHP wave

- The wave which give rise to ECR
- Transverse electric (TE) mode
- The direction of the propagation is parallel to the magnetic field

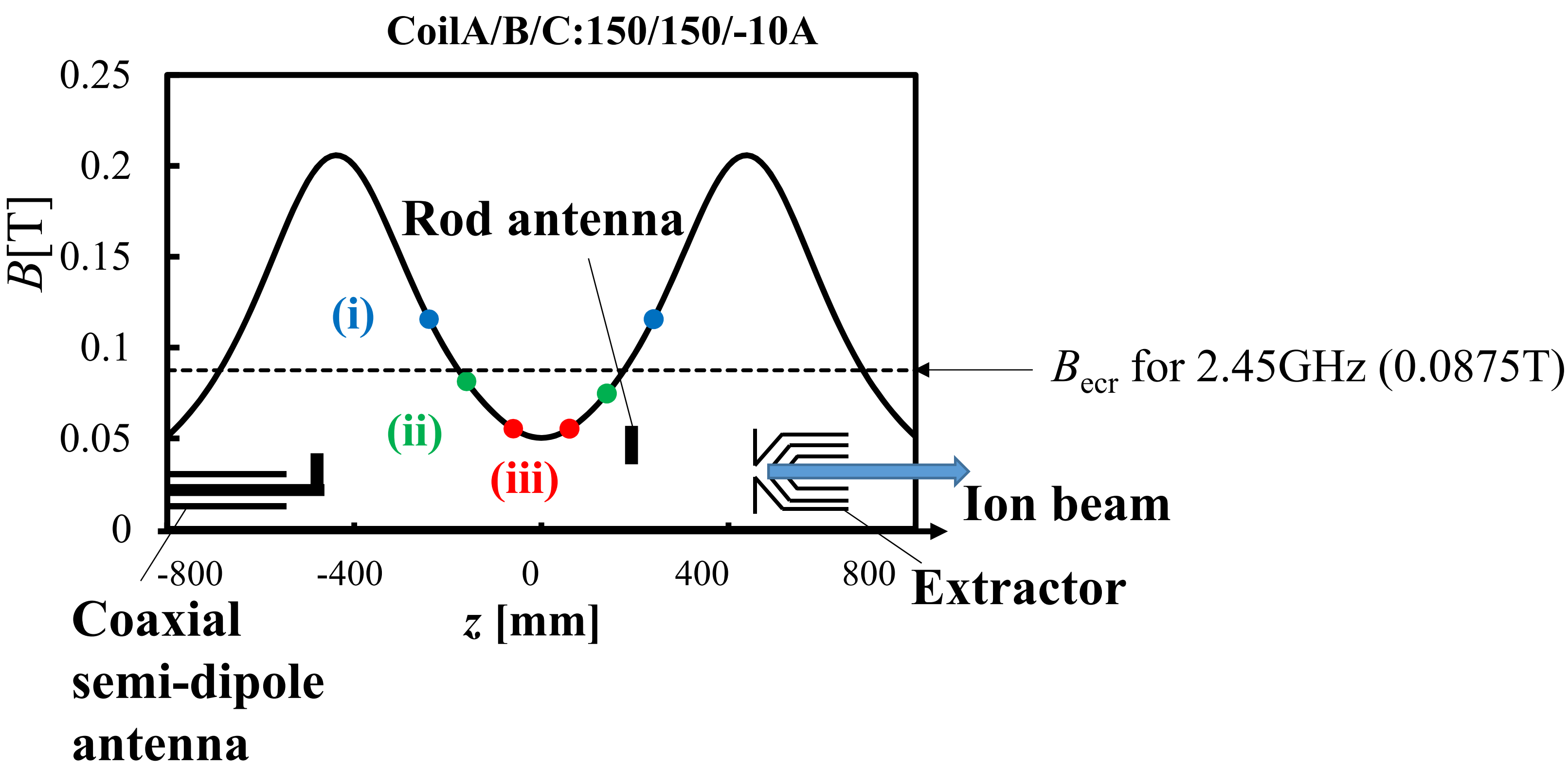
The dispersion relationship

$$N_r{}^2 = \left(v_\varphi{}^2/c^2\right)^{-1} = 1 - \frac{f_{\mathrm{pe}}{}^2}{f(f - f_{\mathrm{ce}})}$$

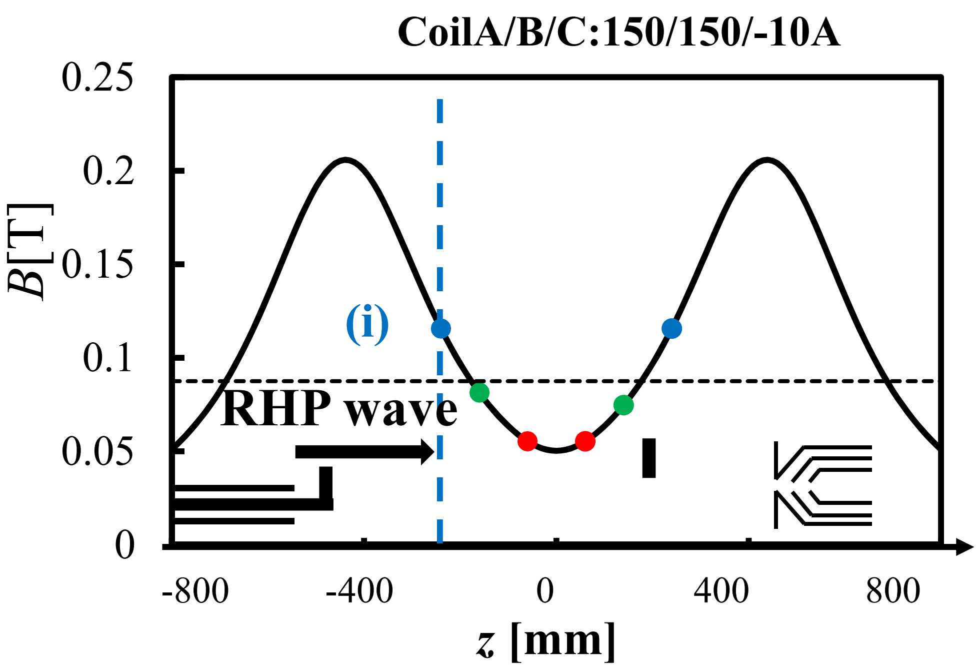
$$f = f_{\mathrm{r}} \Leftrightarrow N_r = 0,\ f = f_{\mathrm{ce}} \Leftrightarrow N_r = \infty$$

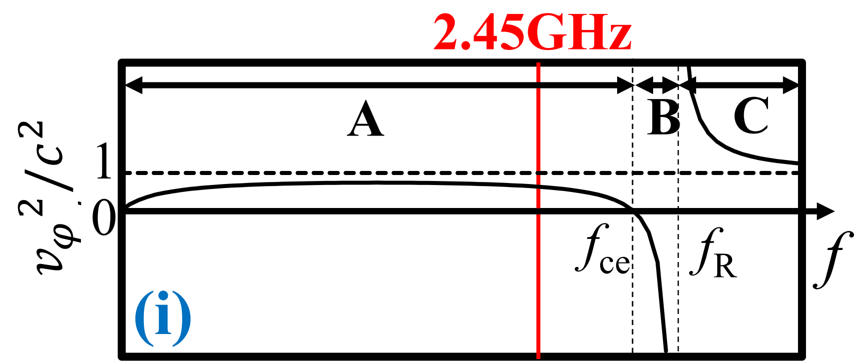
N_r:Refraction index of RHP wave,
v_φ:Phase velocity of RHP wave, f:Microwave frequency (fixed (at 2.45GHz))
f_{r}:R-cutoff frequency, f_{ce}:electron cyclotron frequency, f_{pe}: electron plasma frequency

Dispersion Relationships in Mirror Field



The dispersion relationship in the mirror field

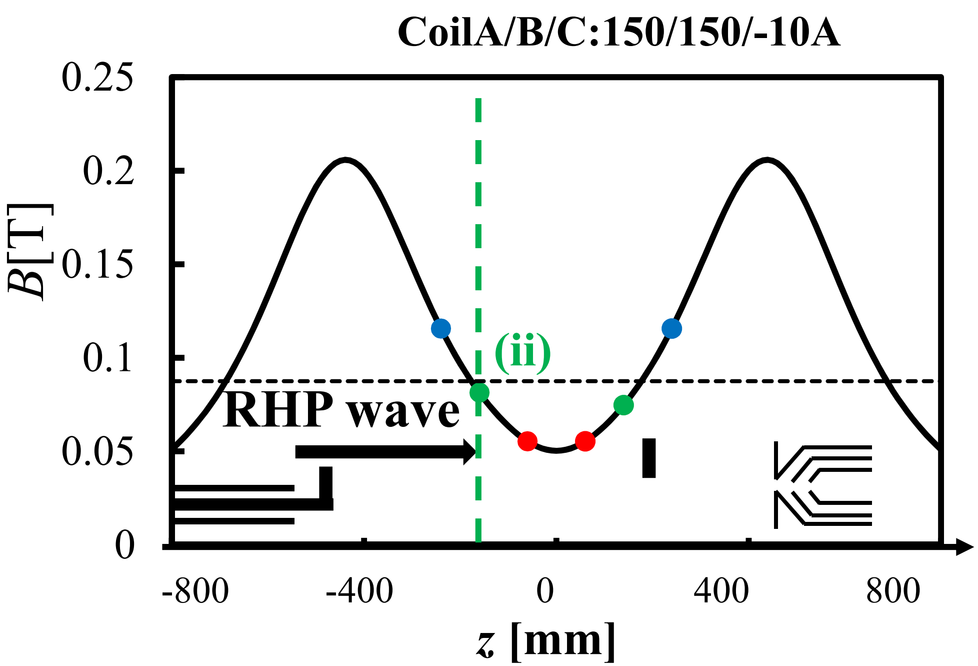


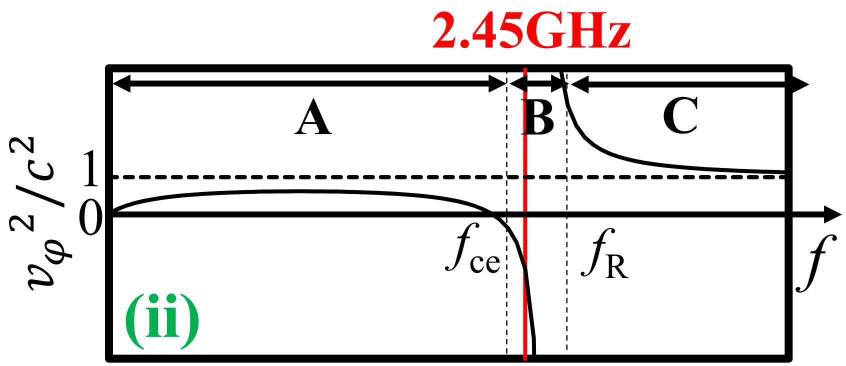


Three regions (A, B, and C) definition

A: $f < f_{ce} \rightarrow {v_\varphi}^2 > 0$ (Propagation region)

The dispersion relationship in the mirror field

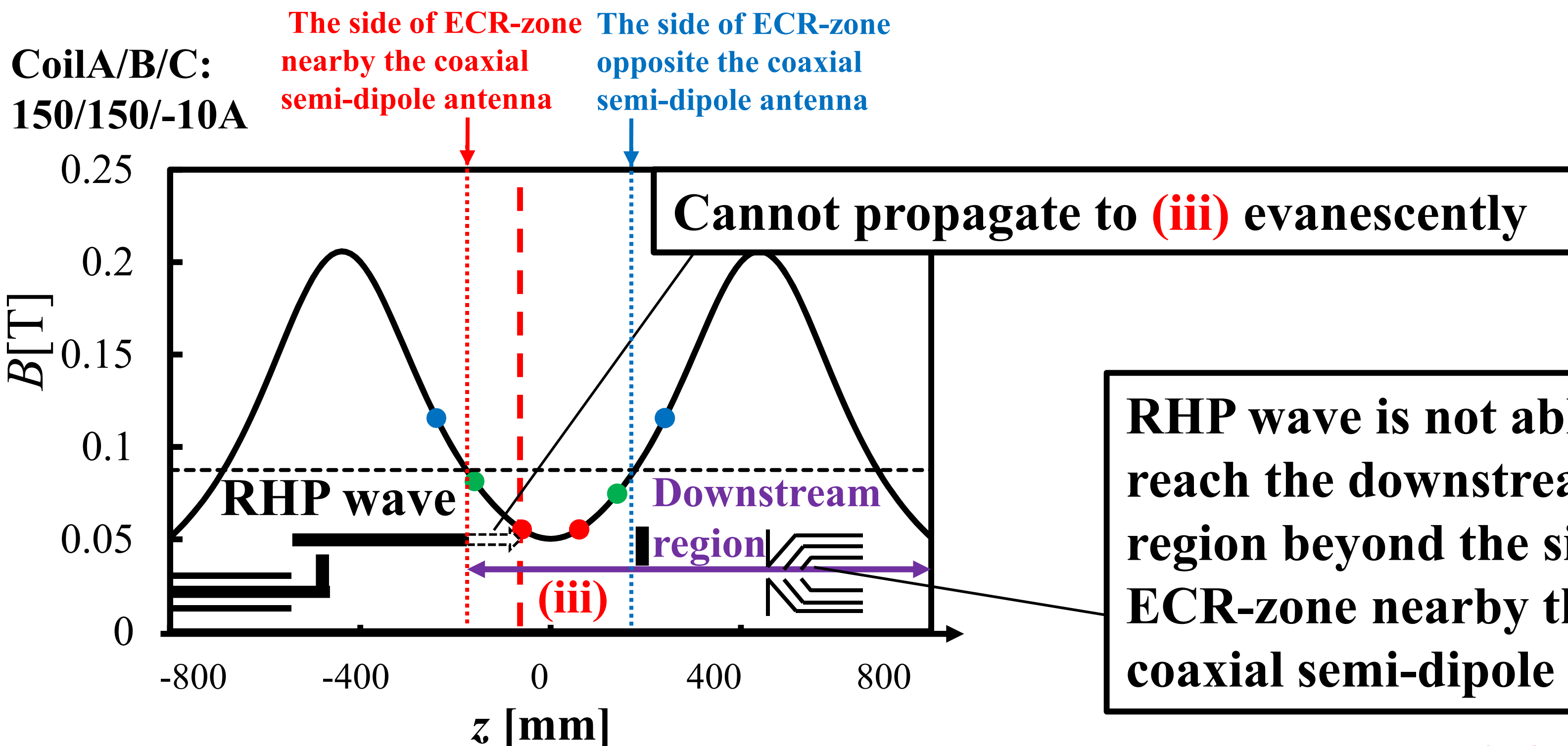




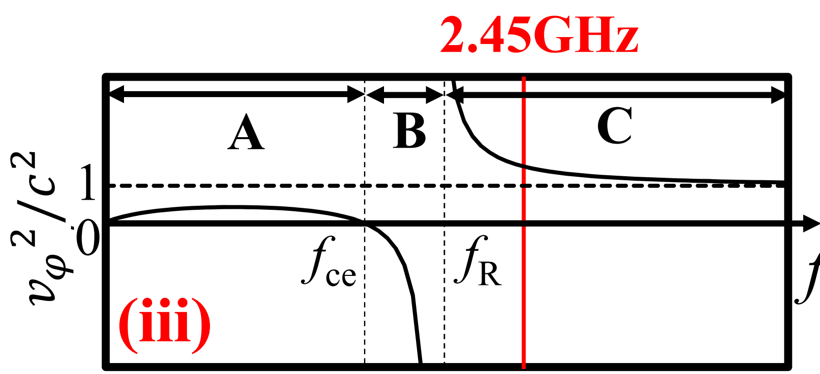
Three regions definition

B: $f_{ce} < f < f_R \rightarrow v_\varphi{}^2 < 0$ (**Non-propagation region**)

The dispersion relationship in the mirror field



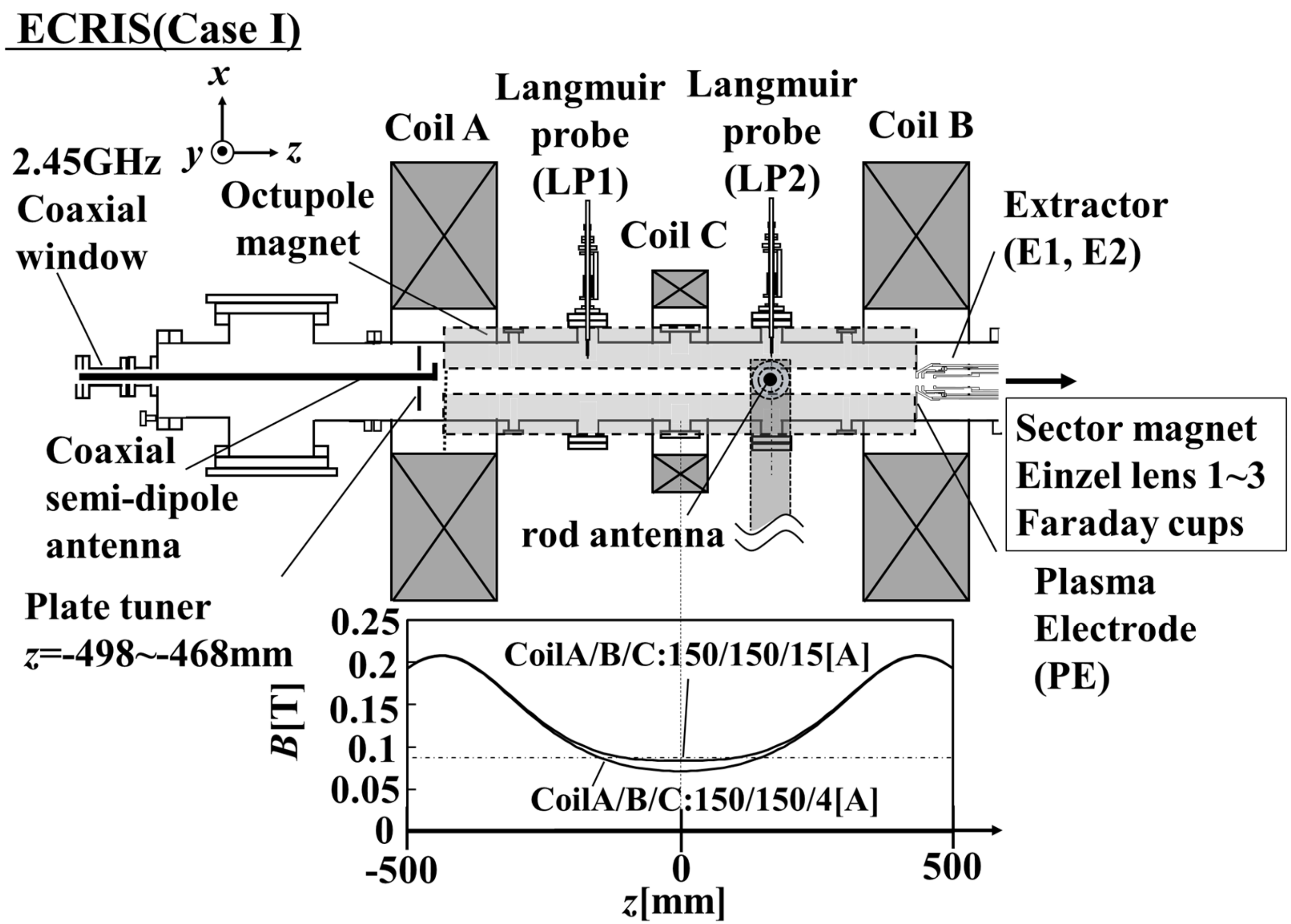
RHP wave is not able to reach the downstream region beyond the side of ECR-zone nearby the coaxial semi-dipole antenna.



Three regions definition

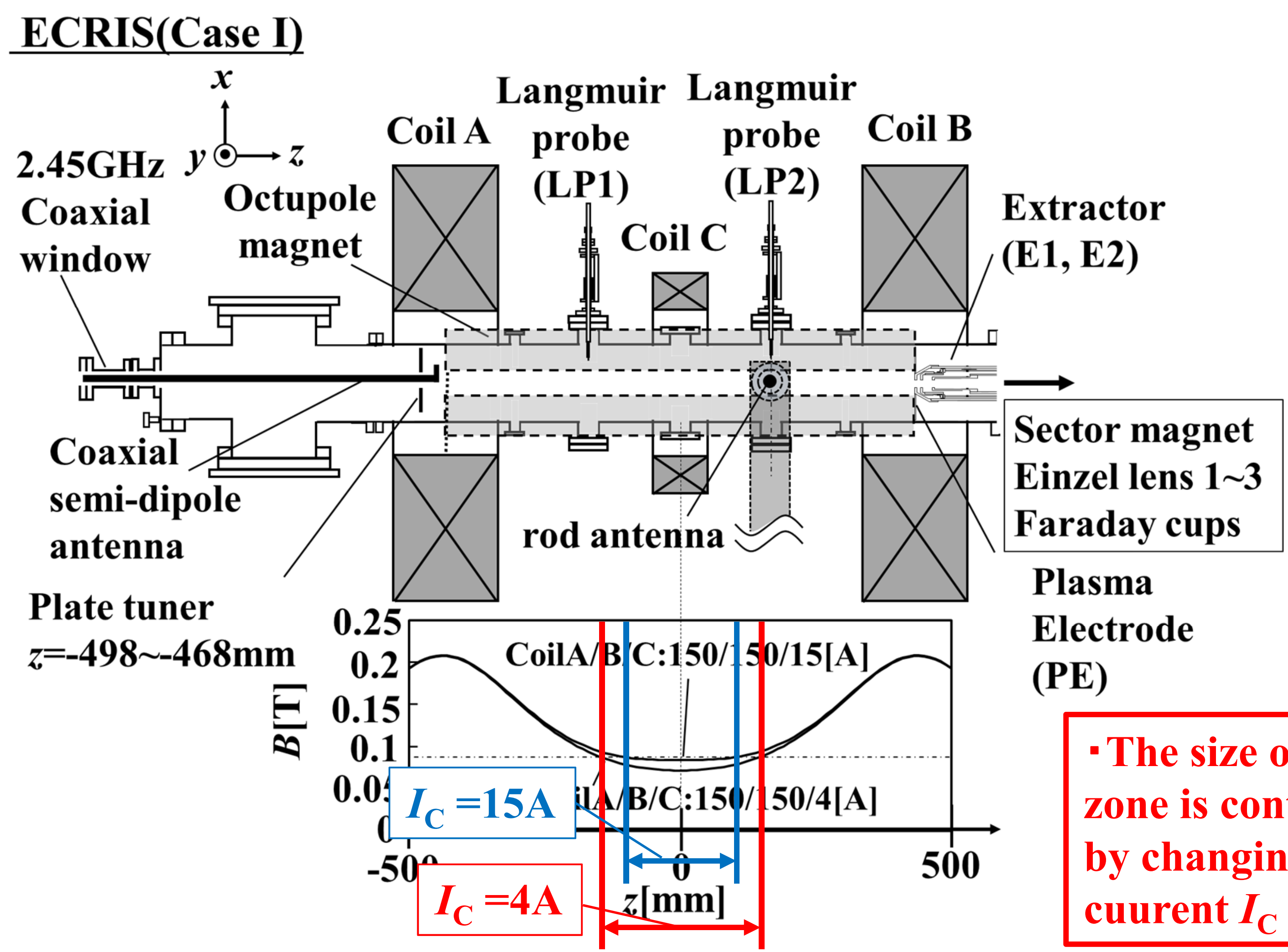
C: $f_R < f \rightarrow v_\varphi^2 > 0$ (Propagation region)

ECRIS (Case I)



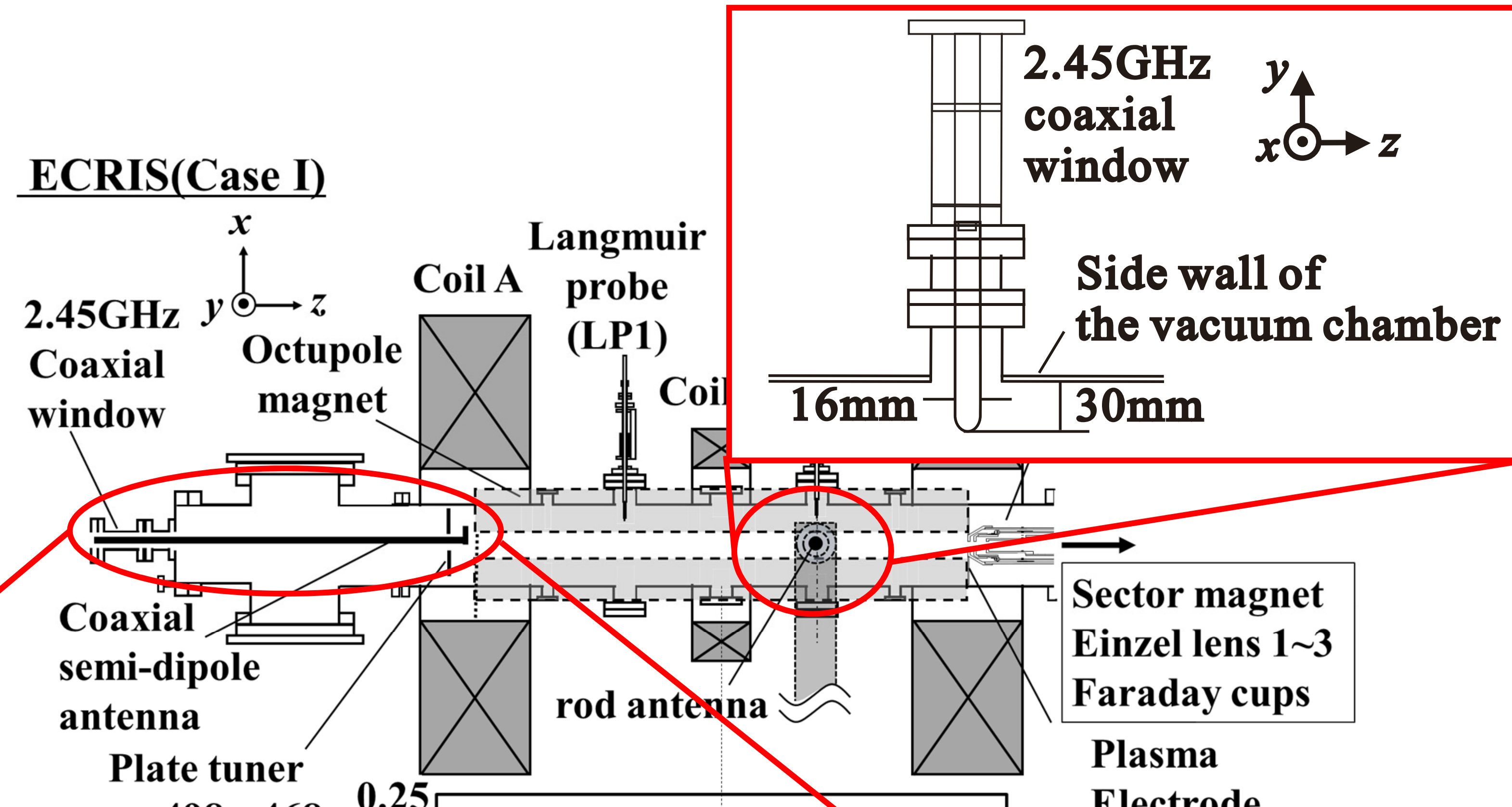
ECRIS(Case I)
x
y
z
2.45GHz
Coaxial
window
Octupole
magnet
Coil A
Langmuir
probe
(LP1)
Langmuir
probe
(LP2)
Coil C
Coil B
Extractor
(E1, E2)
Sector magnet
Einzel lens 1~3
Faraday cups
Coaxial
semi-dipole
antenna
rod antenna
Plate tuner
z=-498~-468mm
Plasma
Electrode
(PE)
CoilA/B/C:150/150/15[A]
CoilA/B/C:150/150/4[A]
B[T]
0.25
0.2
0.15
0.1
0.05
0
-500
0
500
z[mm]

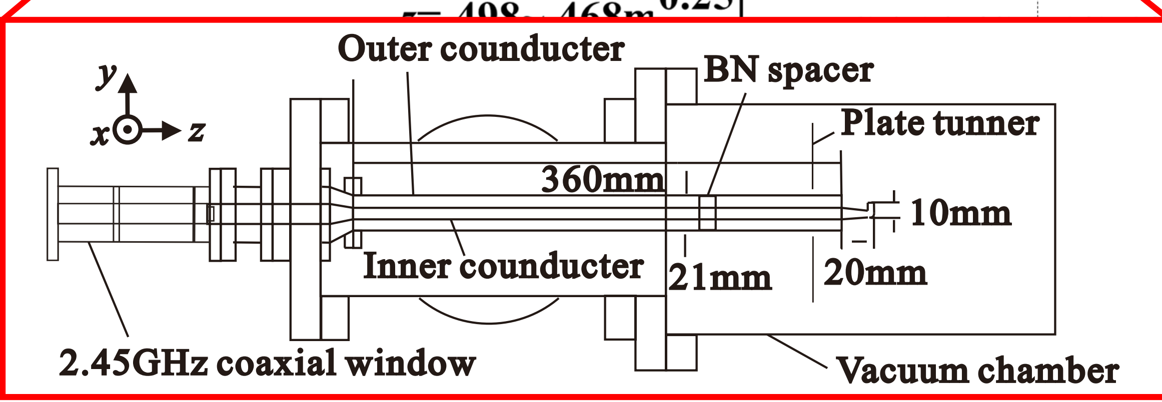
ECRIS (Case I)



・The size of ECR-zone is controllable by changing coil C cuurent I_C

5 ECRIS (Case I)



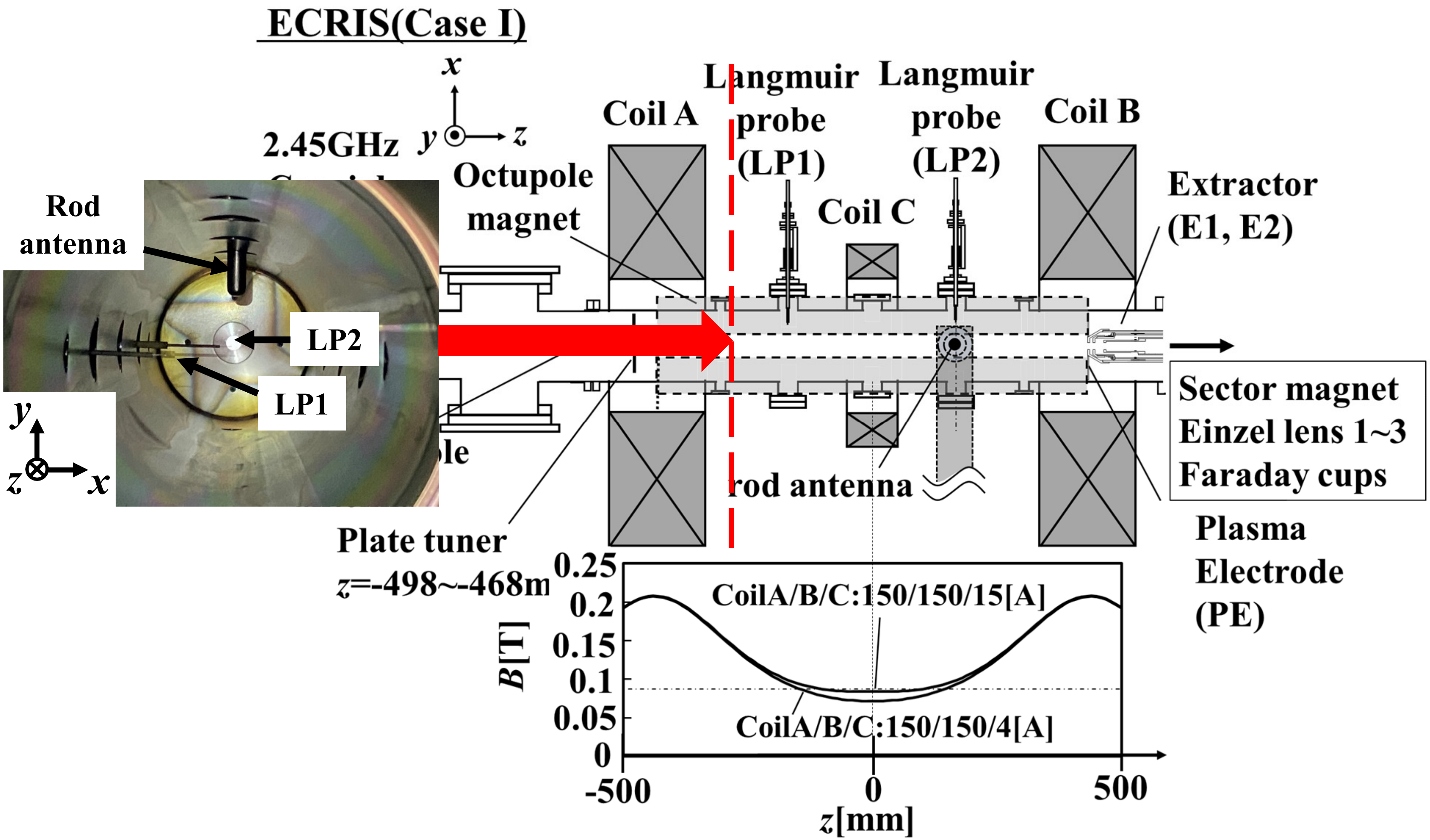


・It is able to insert to small space by tapered shape whose ratios of inner/outer diameter are constant.[3]
(No cut-off for fundamental mode in coaxial waveguide)

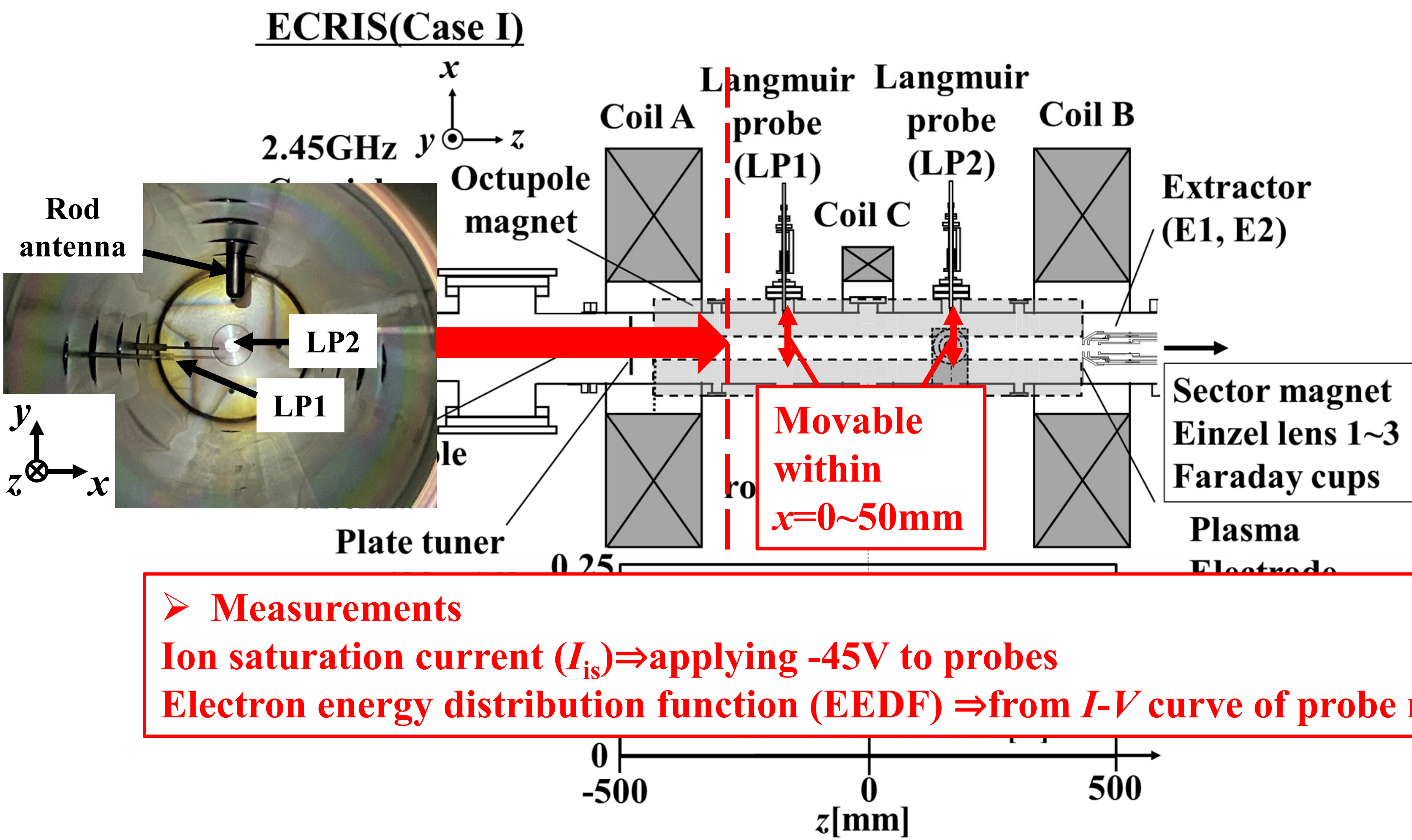
・ We aim to excite TE modes by the L-shape tip[3].

[3] W. Kubo, et al., Rev. Sci. Instrum. 91, 023317 (2020)

5 ECRIS (Case I)



ECRIS (Case I)

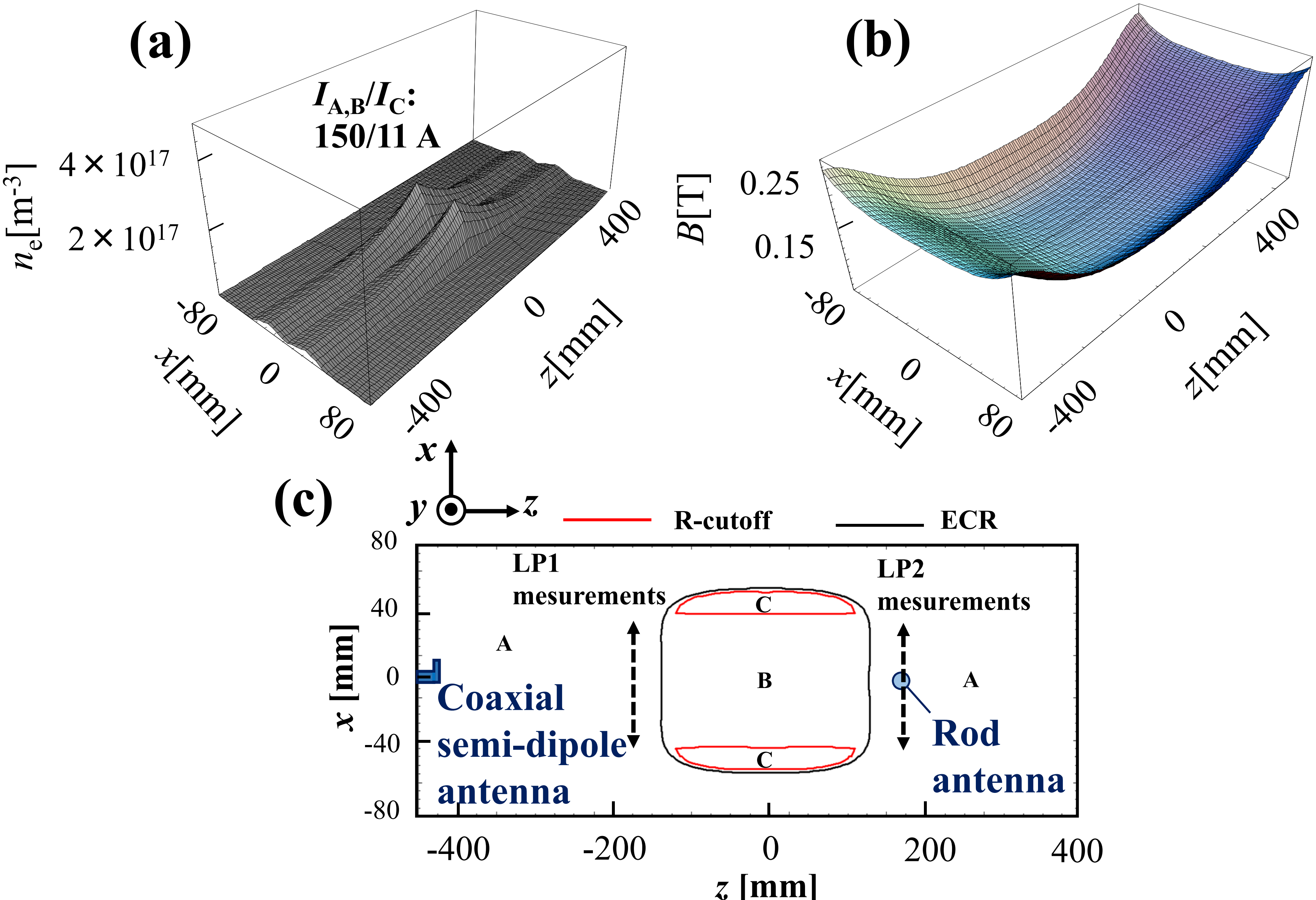


➢ **Measurements**

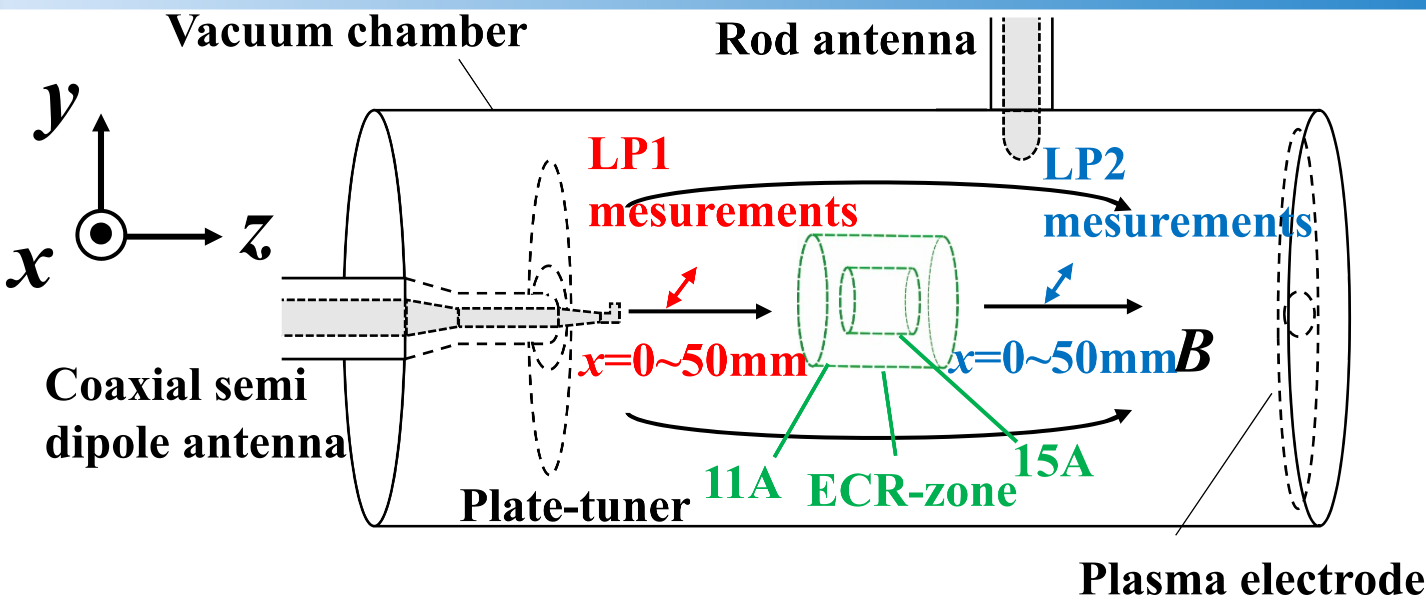
Ion saturation current (I_{is})⇒applying -45V to probes

Electron energy distribution function (EEDF) ⇒from *I-V* curve of probe measure

Accessibility Condition

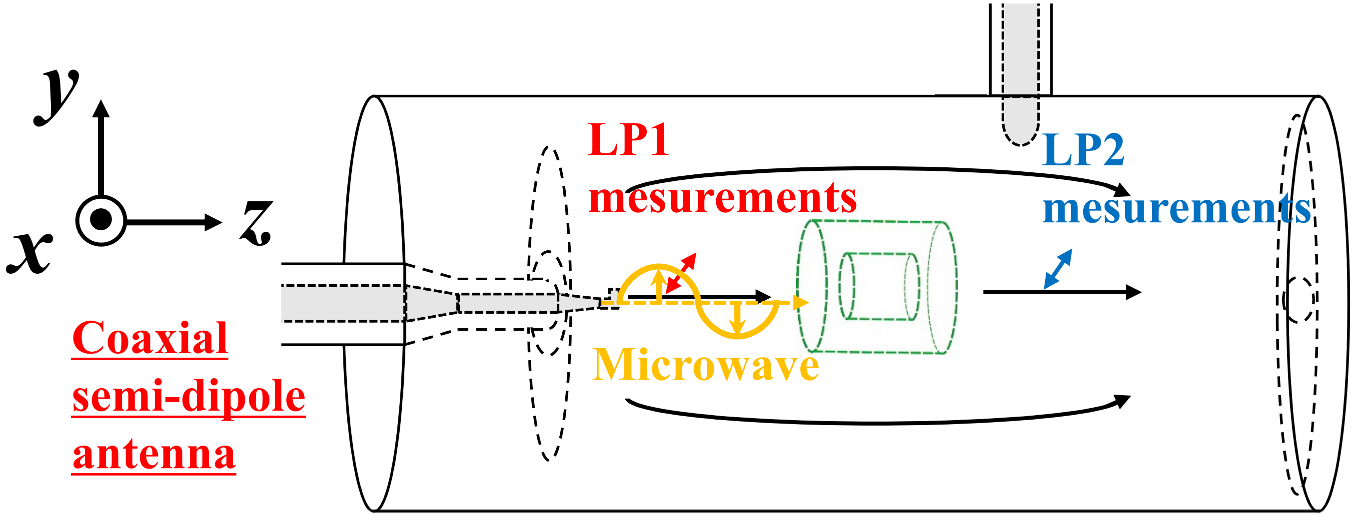


Case I Experimental Results (1)

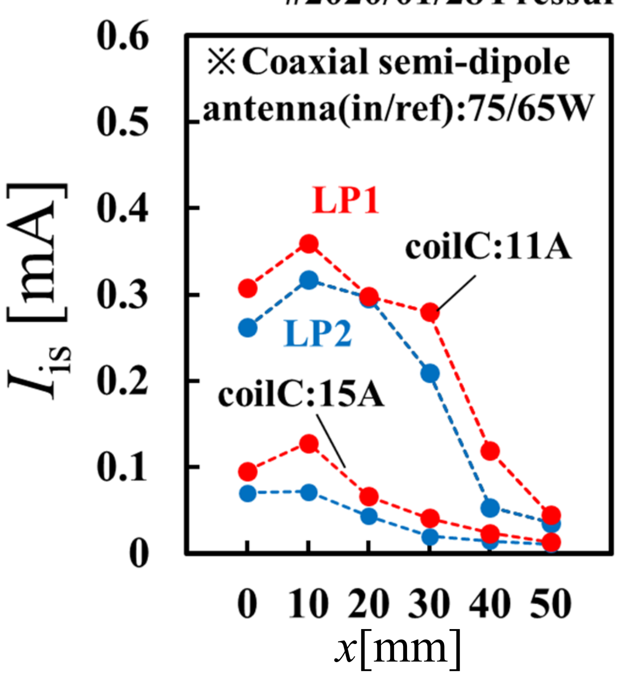


- Measurement position: x=0~50mm
- CoilC current I_C : 11, 15A

Case I Experimental Results (1)

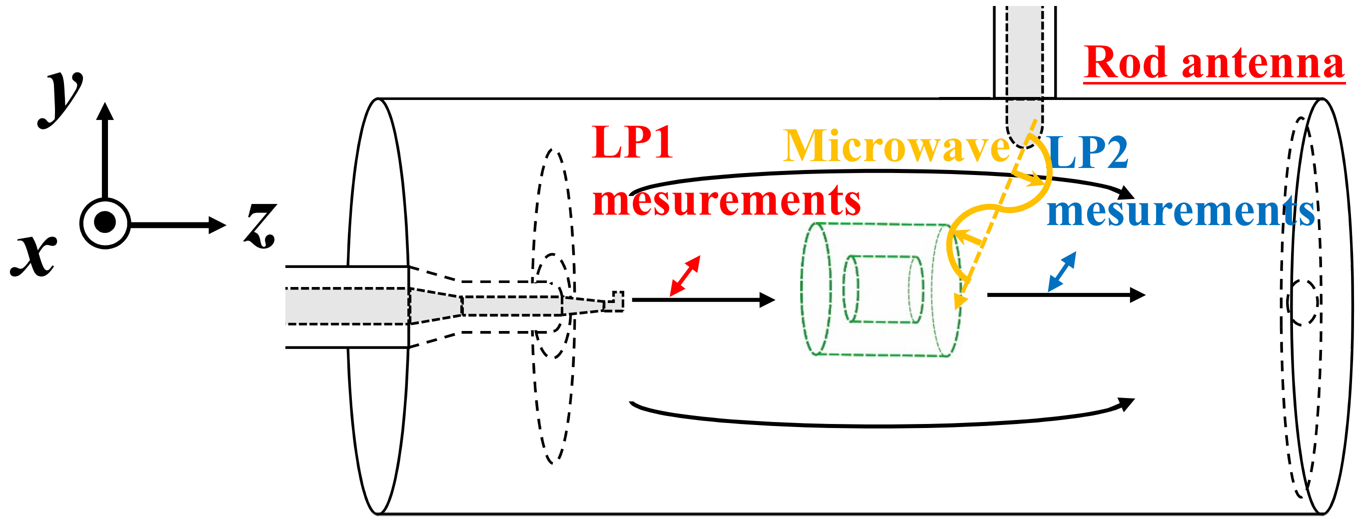


#2020/01/28 Pressure:5.1-6.6 × 10^{-4}Pa, $I_{A,B}$:150A



I_{is}'s measured by LP1 are higher than those by LP2 in the case of the coaxial semi-dipole antenna

7 *Case I Experimental Results (1)*



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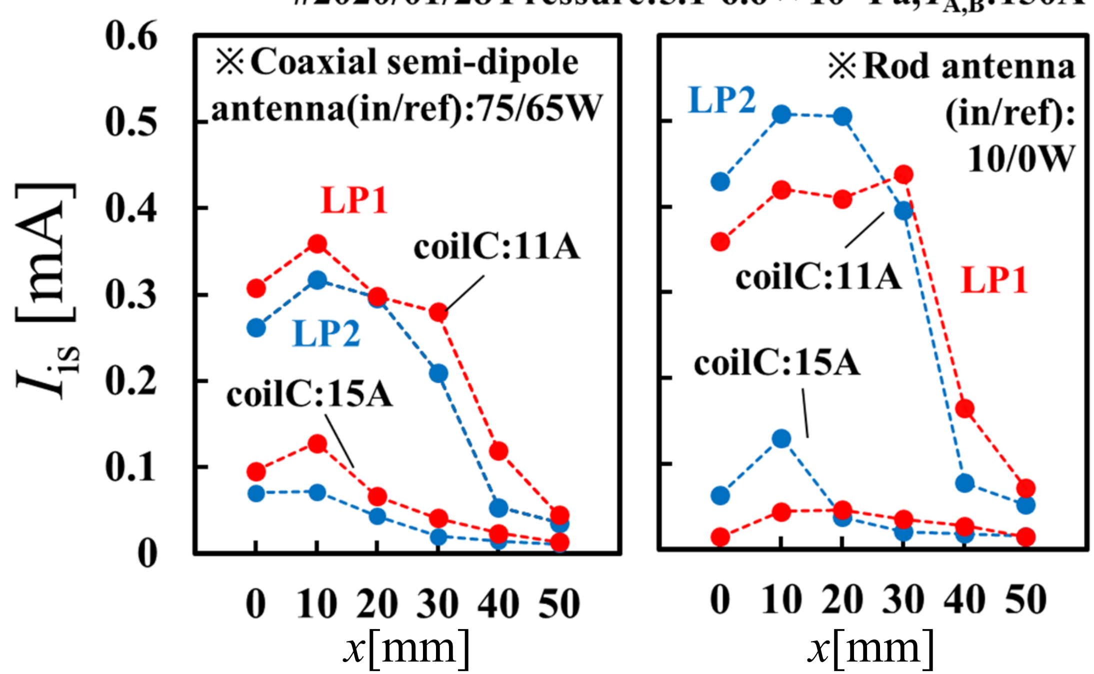
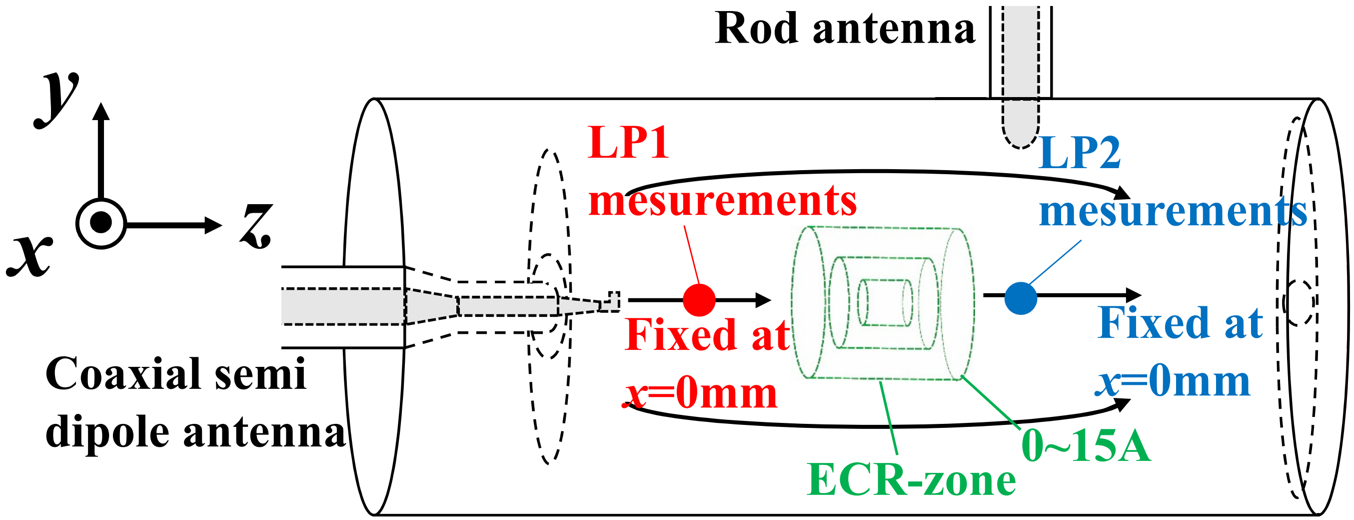


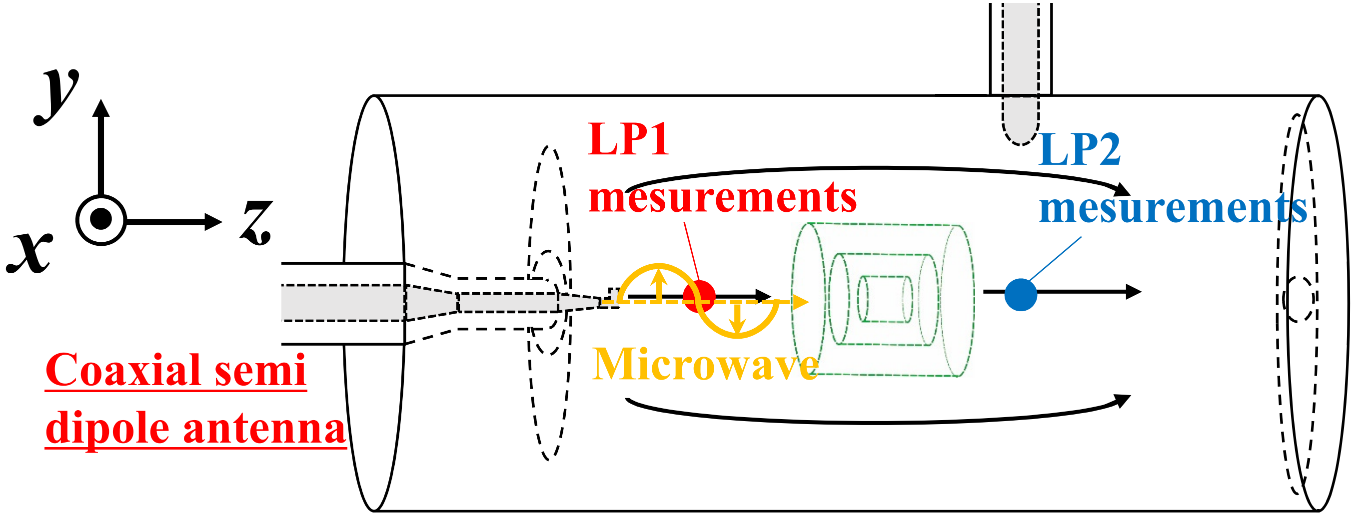
On the contrary, I_{is}'s measured by LP2 are higher than those by LP1 in the case of the rod antenna

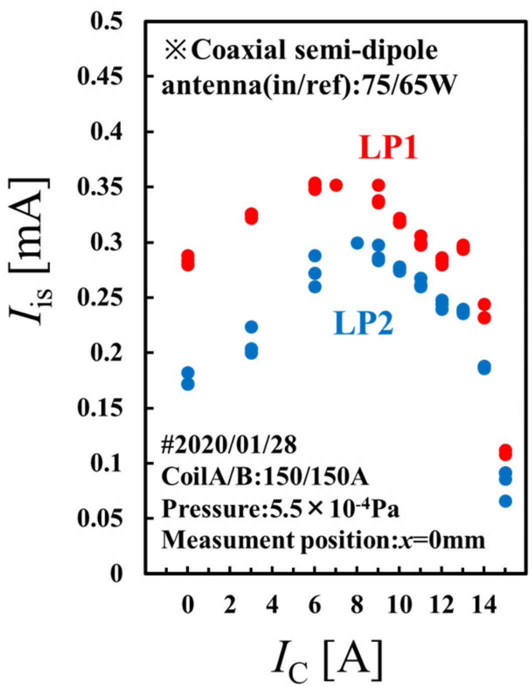
Case I Experimental Results (2)



- Measurement position: Fixed at x=0mm
- Changing I_C (0~15A)

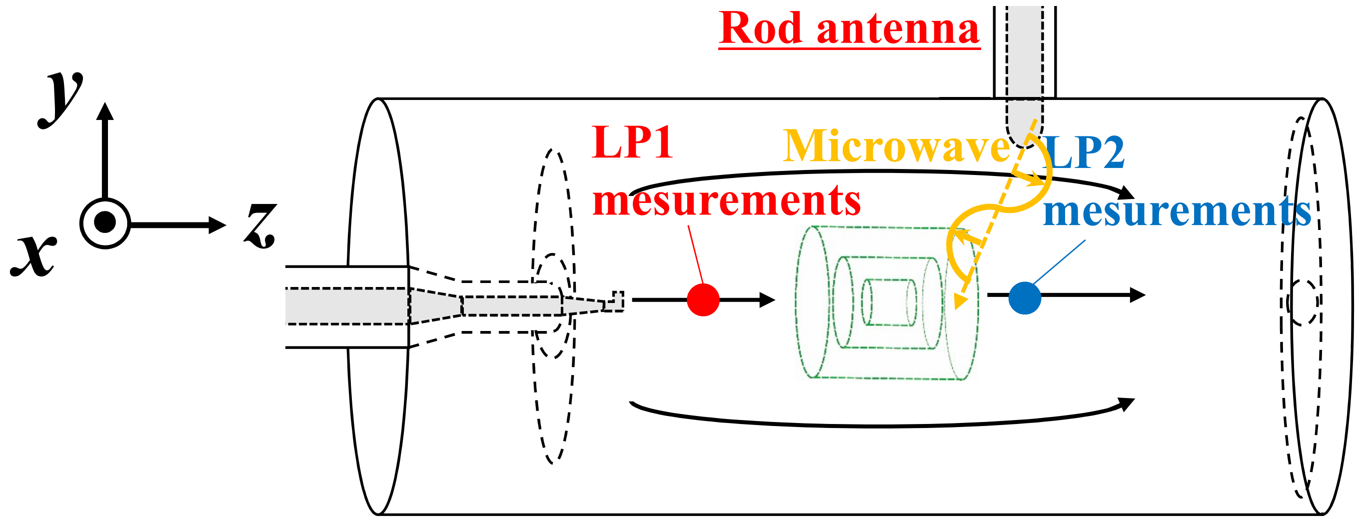
Case I Experimental Results (2)

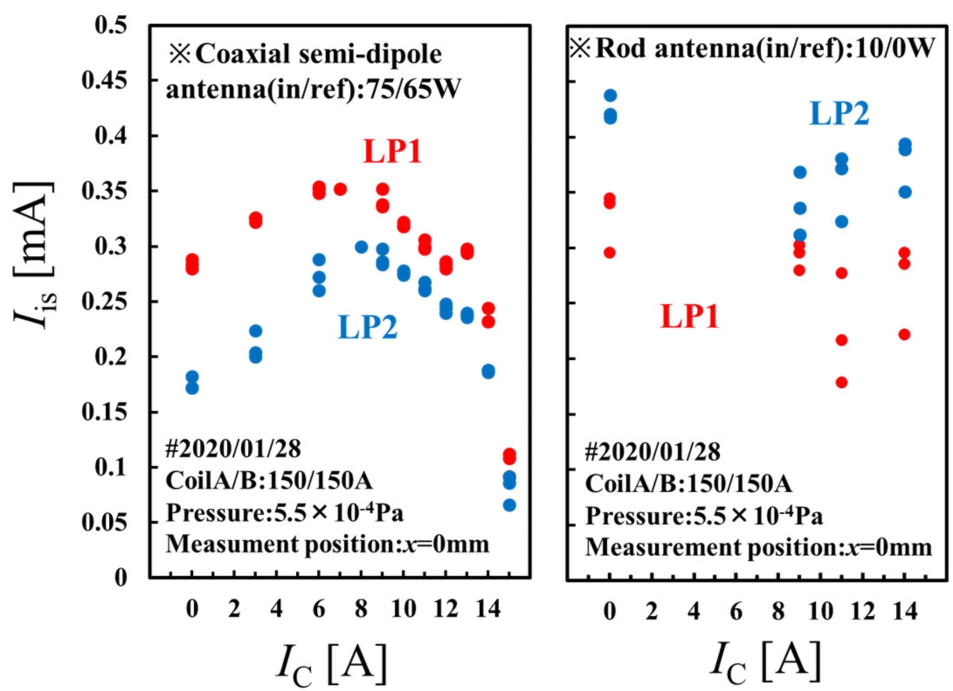




I_{is}'s measured by LP1 are higher than those by LP2 when I_C's are 0~15A in the case of the coaxial semi-dipole antenna

Case I Experimental Results (2)

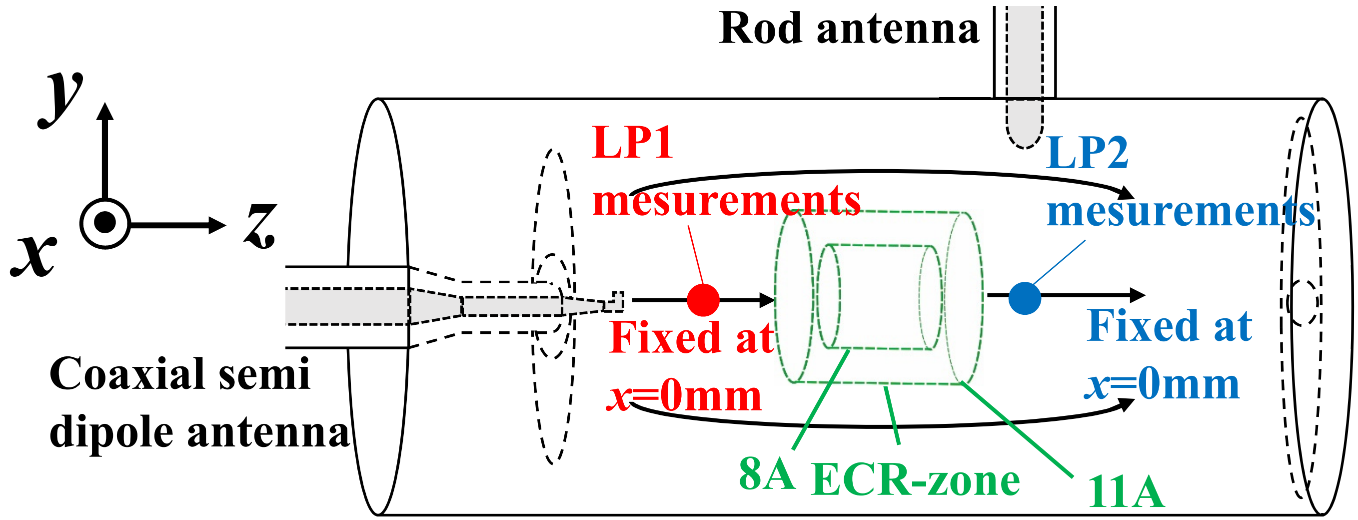




On the contrary, I_{is}'s measured by LP2 are higher than those by LP1 when I_C's are 0~15A in the case of the rod antenna

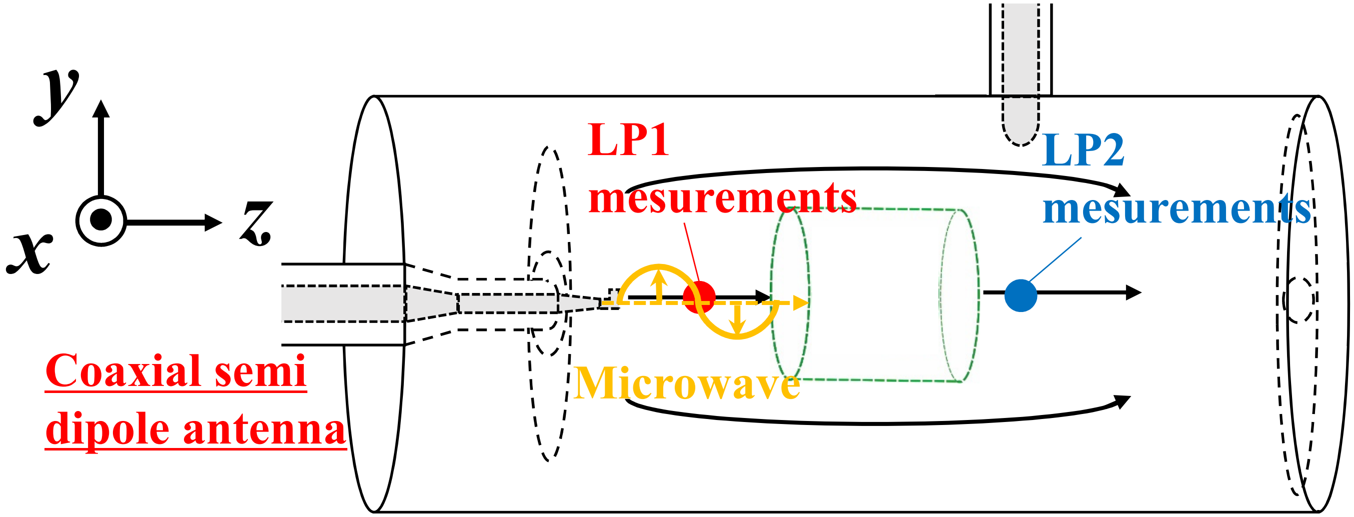
Measurement results (1), (2) of I_{is} suggest that the RHP wave cannot pass through the ECR-zone

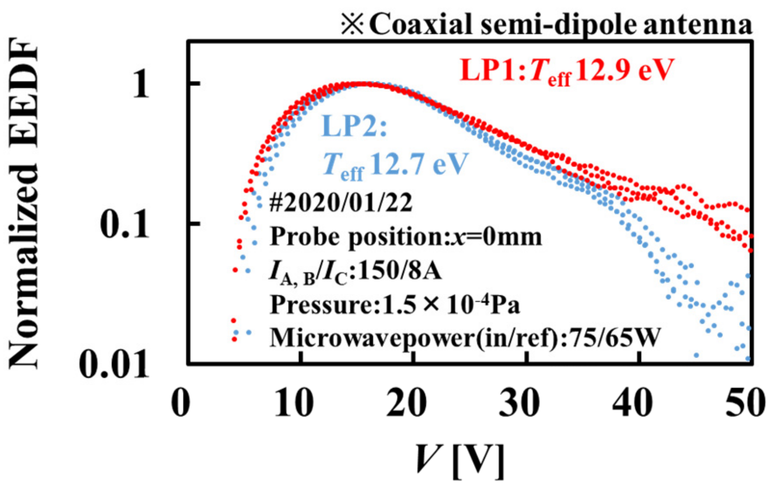
Case I Experimental Results (3)



- Measurement position: x=0mm
- I_C =8A (the coaxial semi-dipole antenna), and 11A (the rod antenna)

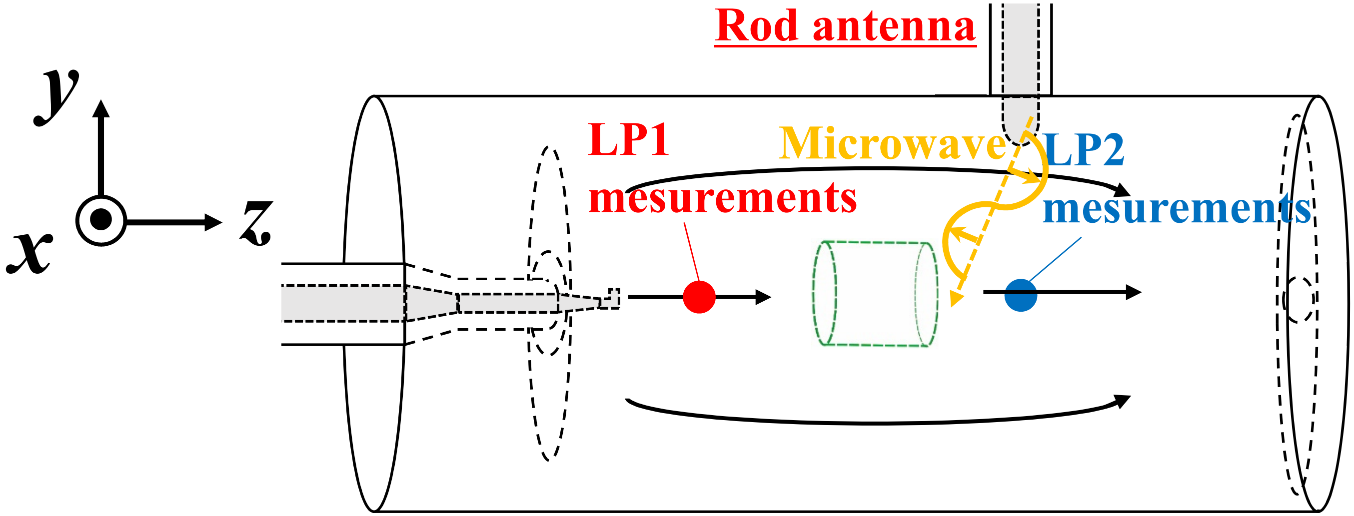
Case I Experimental Results (3)



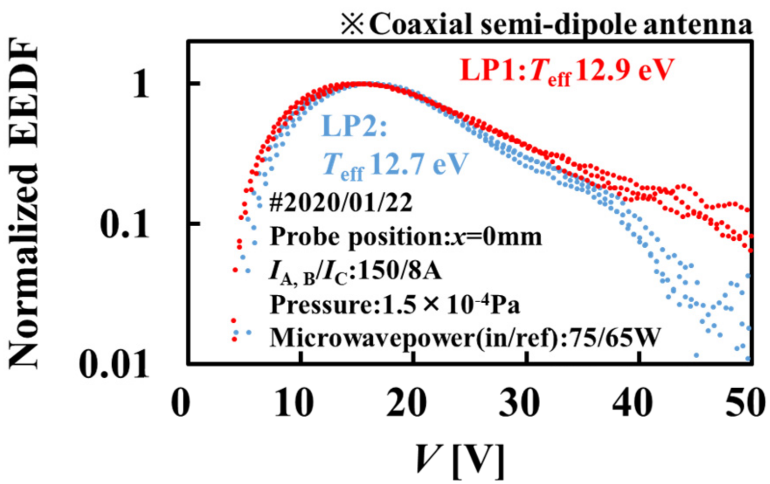


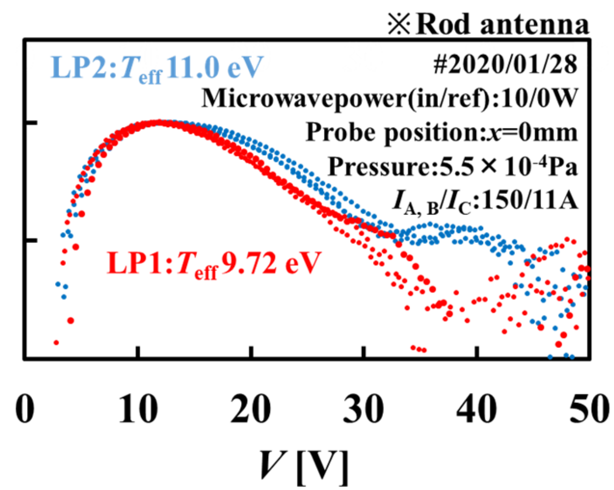
EEDF measured by LP1 has higher tail than that by LP2 in the case of the coaxial semi-dipole antenna

Case I Experimental Results (3)

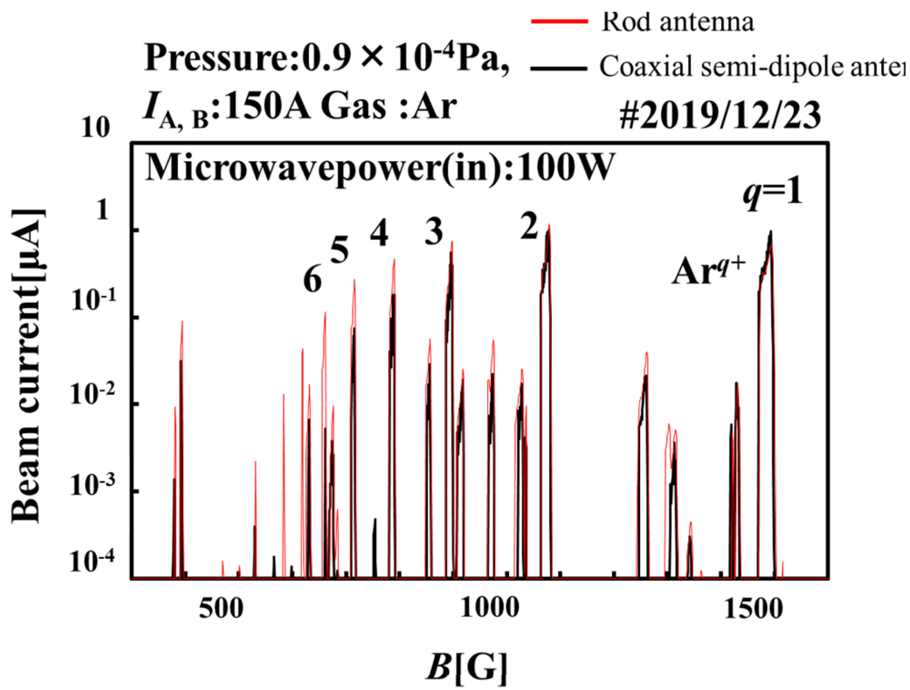


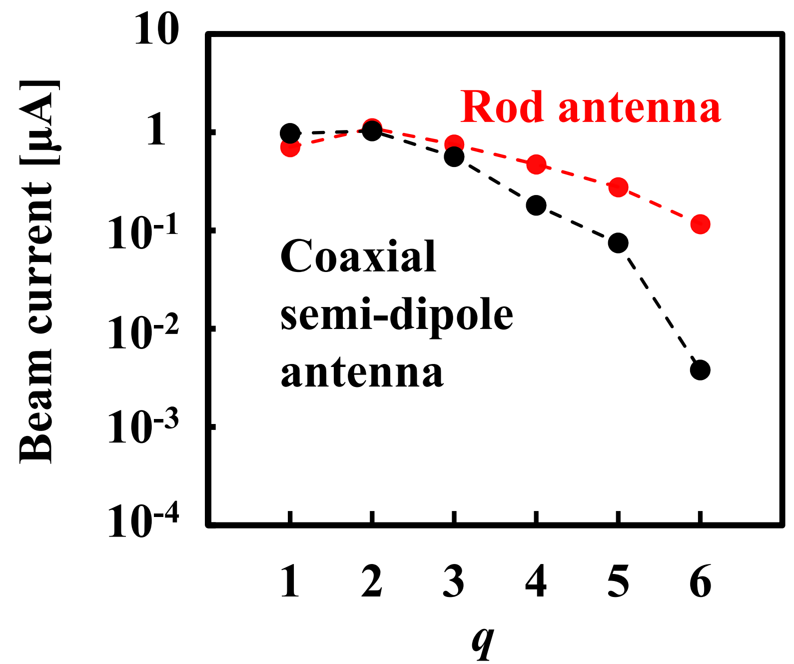
EEDF measured by LP2 has higher tail than that by LP1 in the case of rod antenna

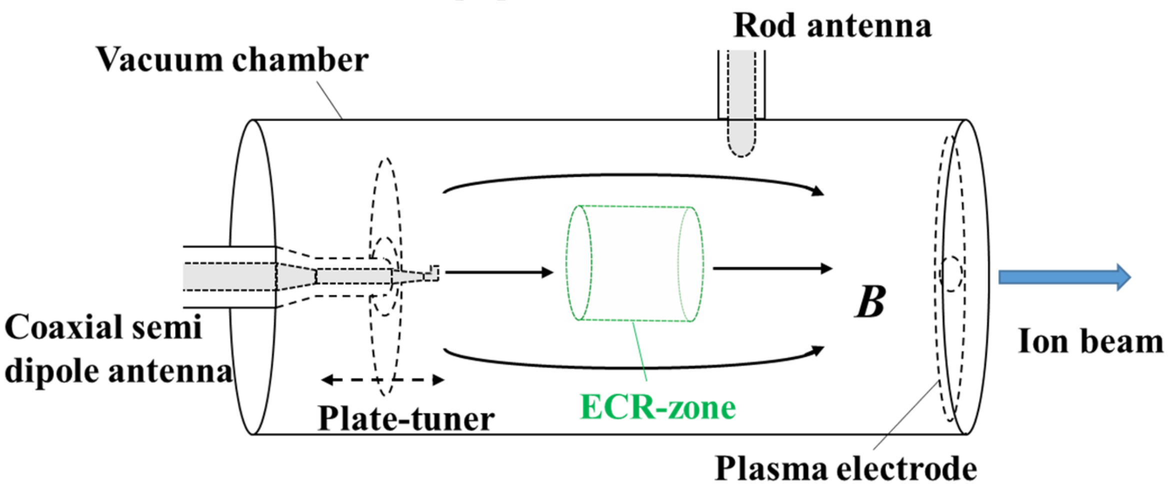




Case I Experimental Results (4)

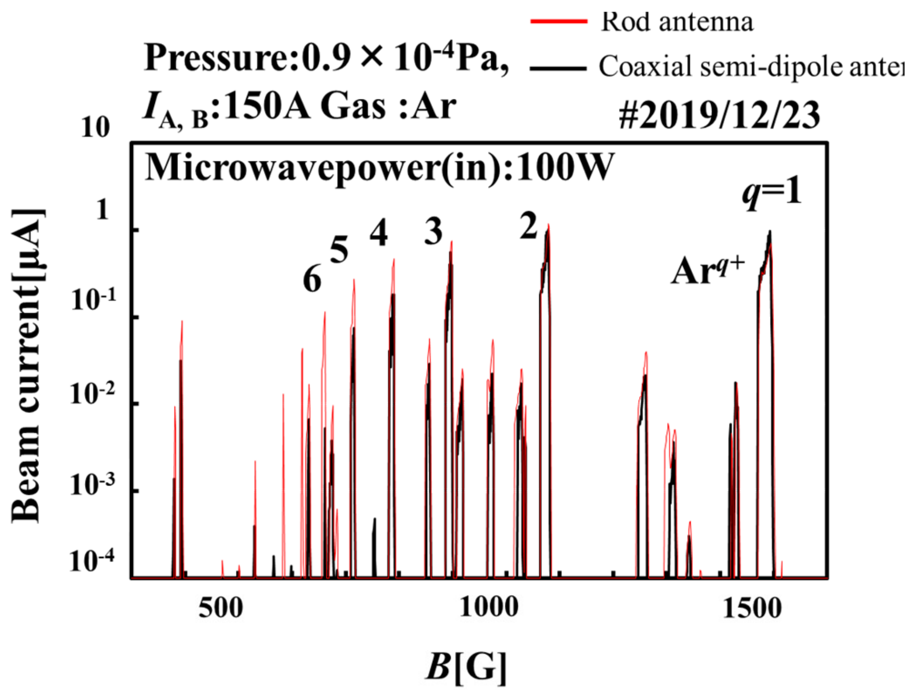


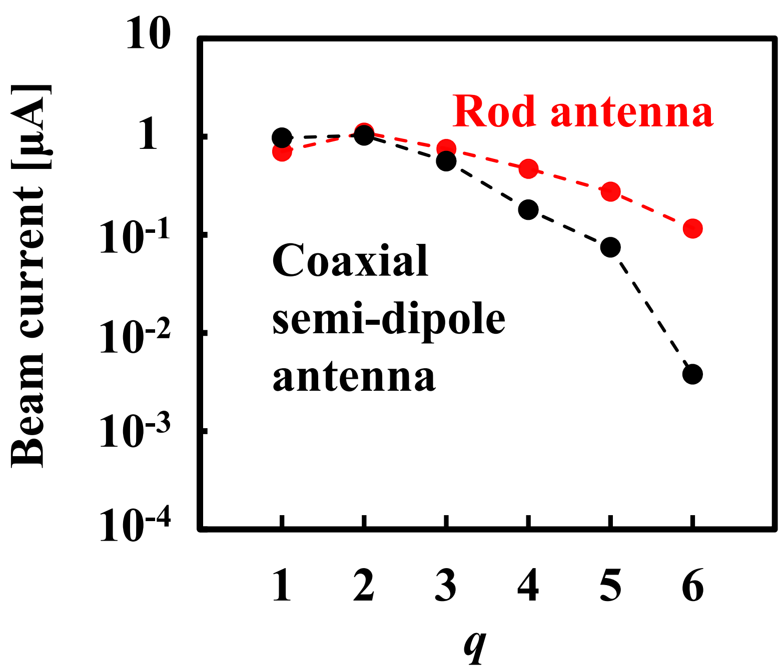


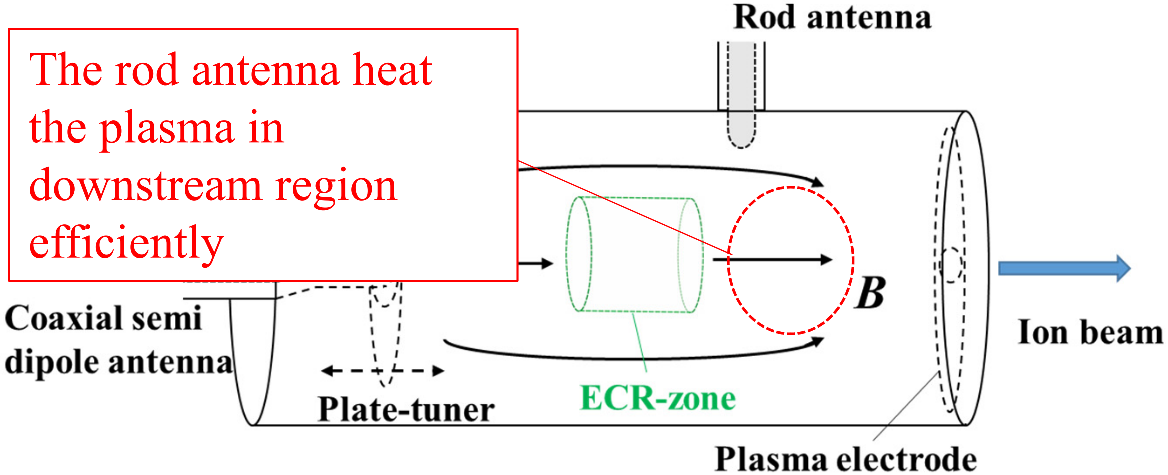


- At incident microwavepower 100W, multicharged Ar ion beams ($Ar^{3+\sim6+}$) in the case of the rod antenna are higher than those in the case of the coaxial semi-dipole antenna.
- It is considered that this is because the rod antenna in downstream region heat the plasma on the side closer to ion beam extractor efficiently.

Case I Experimental Results (4)

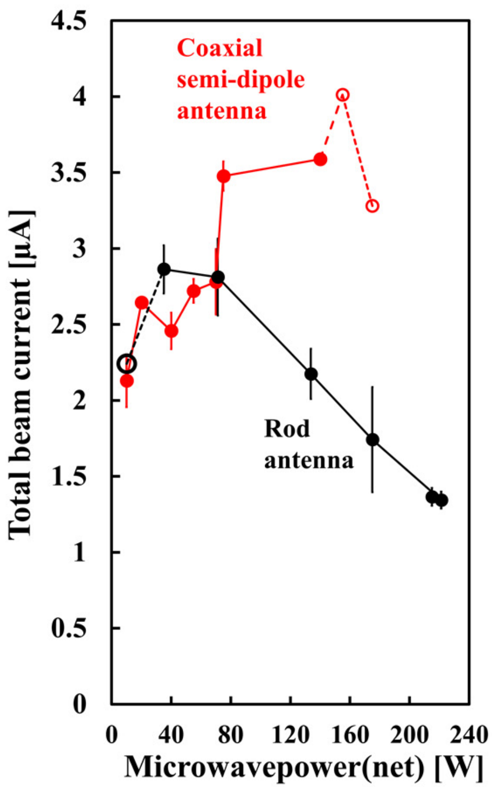


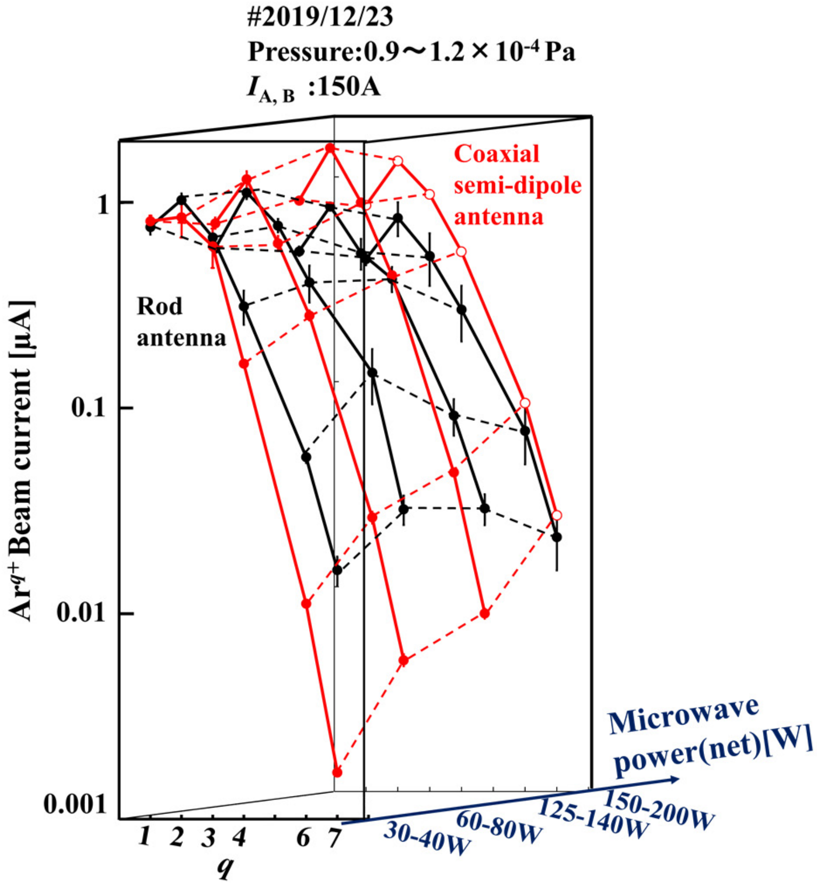




- At low incident microwavepower 100W, multicharged Ar ion beams ($Ar^{3+\sim6+}$) in the case of the rod antenna are higher than those in the case of the coaxial semi-dipole antenna.
- It is considered that this is because the rod antenna in downstream region heat the plasma on the side closer to ion beam extractor efficiently.

Case I Experimental Results (5)



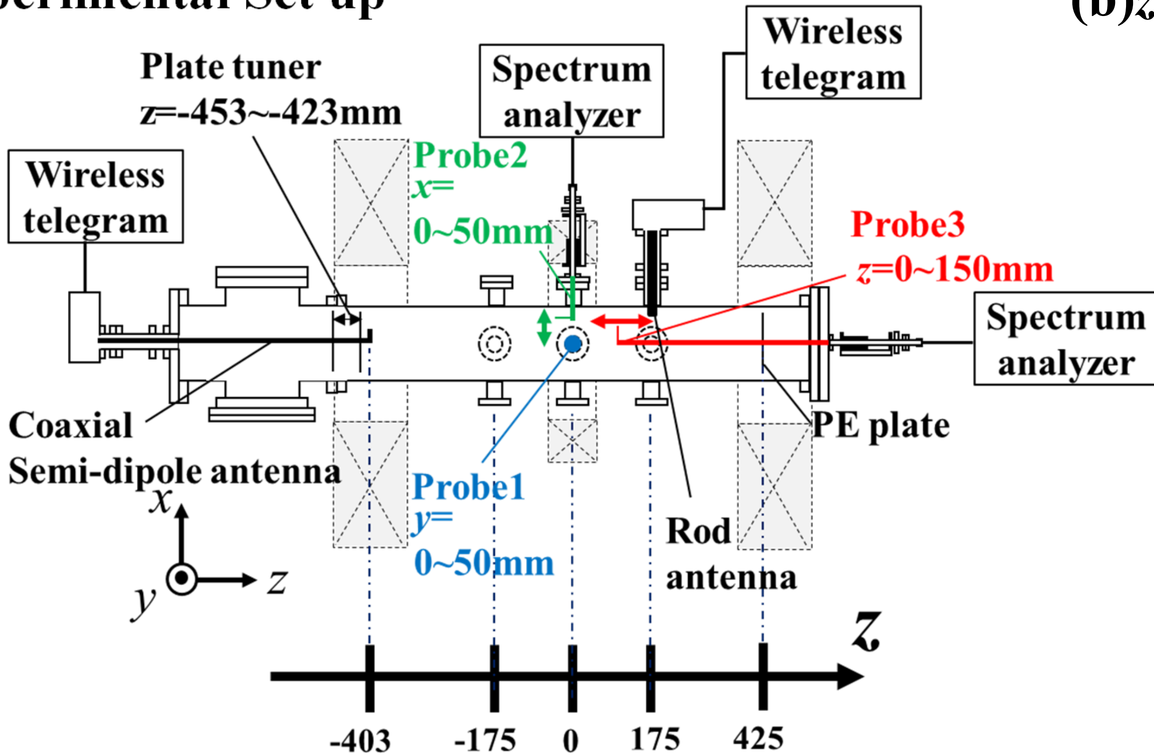


- At microwavepowers higher than net 80W, total ion beam current and CSD's tend to become unstable and change to decrease in the case of the rod antenna.
- On the other hand, they continue to increase stably in the case of the coaxial semi-dipole antenna.
- It is considered that this is because installing the antenna on the z-axis is better for the waves propagation in high electron density than inserting it from the side port[3].

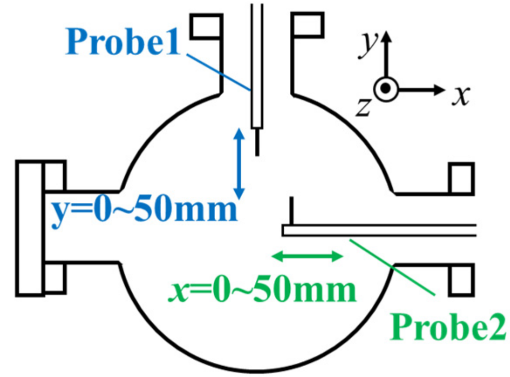
[3] W. Kubo, et al., Rev. Sci. Instrum. 91, 023317 (2020)

Preparation for optimizing microwave-launching

(a)Experimental Set up



(b)z=0 cross section

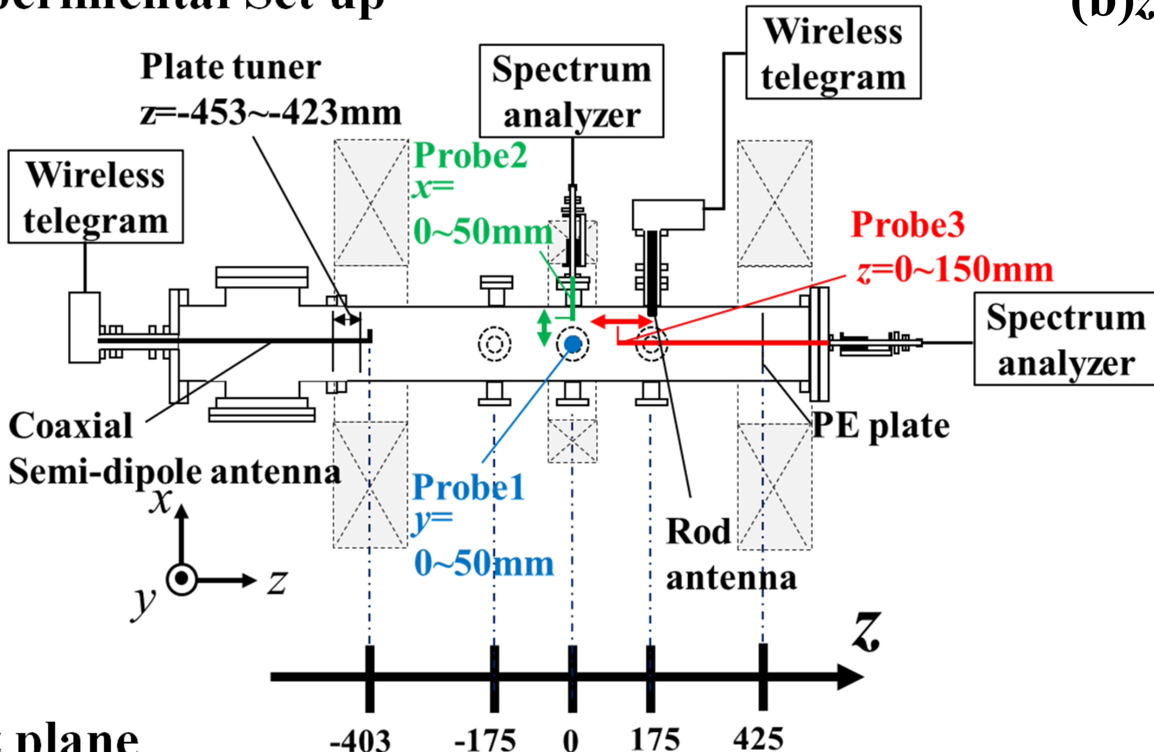


z=0 cross section

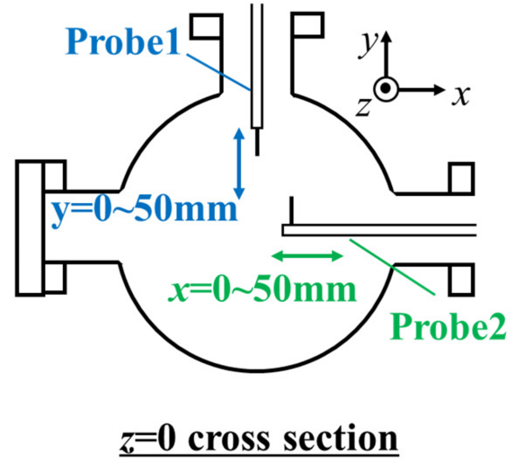
- We are going to install the coaxial dipole antenna and the rod antenna on the test chamber.
- We are going to generate the microwave by the wireless telegram and launch them from the two antennas.
- We measure the electric field strength in y direction by 3 probes and spectrum analyzer (probe 1, 2, and 3)
- We plan to improve two antennas to suitable ones for 2.45GHz microwave-launching.

Preparation for optimizing microwave-launching

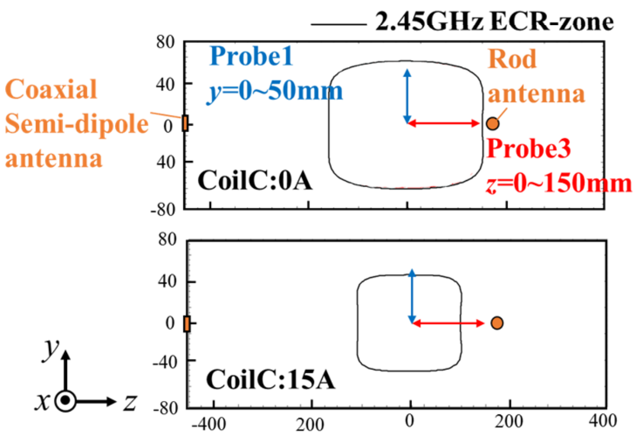
(a)Experimental Set up



(b)z=0 cross section



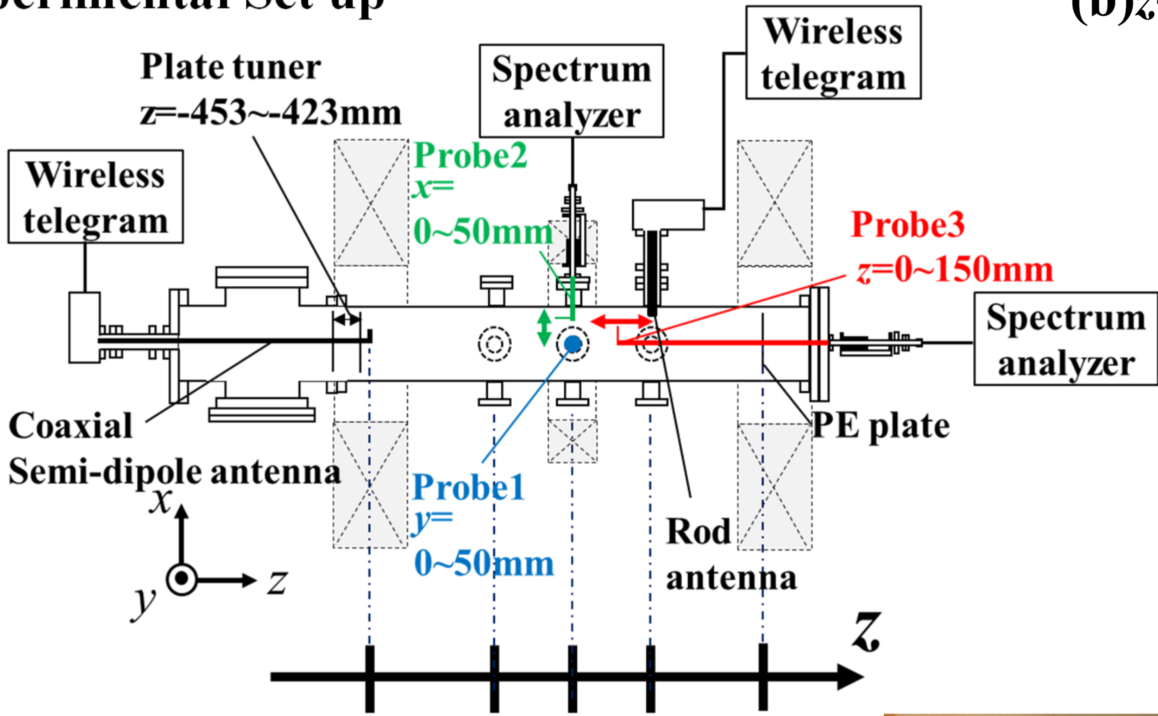
(c)y-z plane



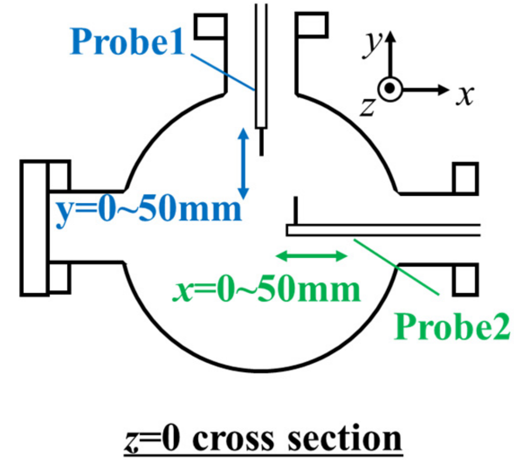
- We are going to conduct the measurements near ECR-zones.
- We aim to maximize the electric field strengths near ECR-zone by improving antennas.

Preparation for optimizing microwave-launching

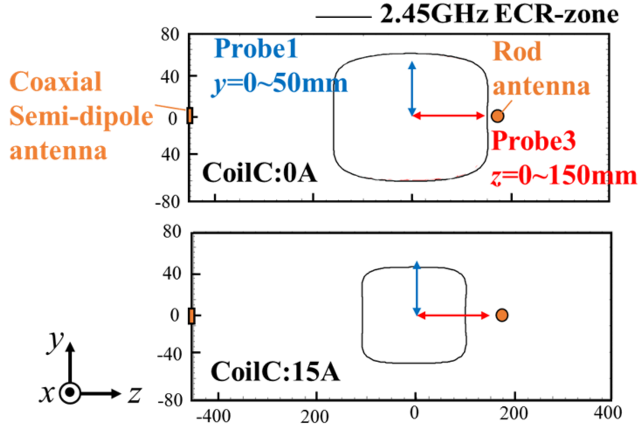
(a)Experimental Set up



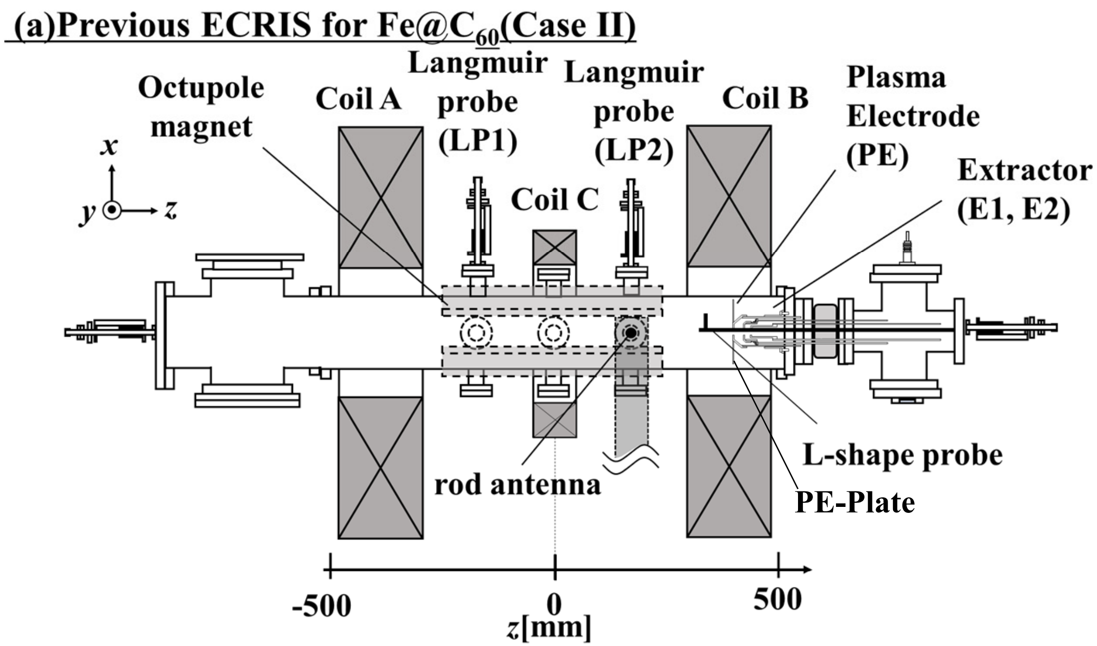
(b)z=0 cross section



(c)y-z plane

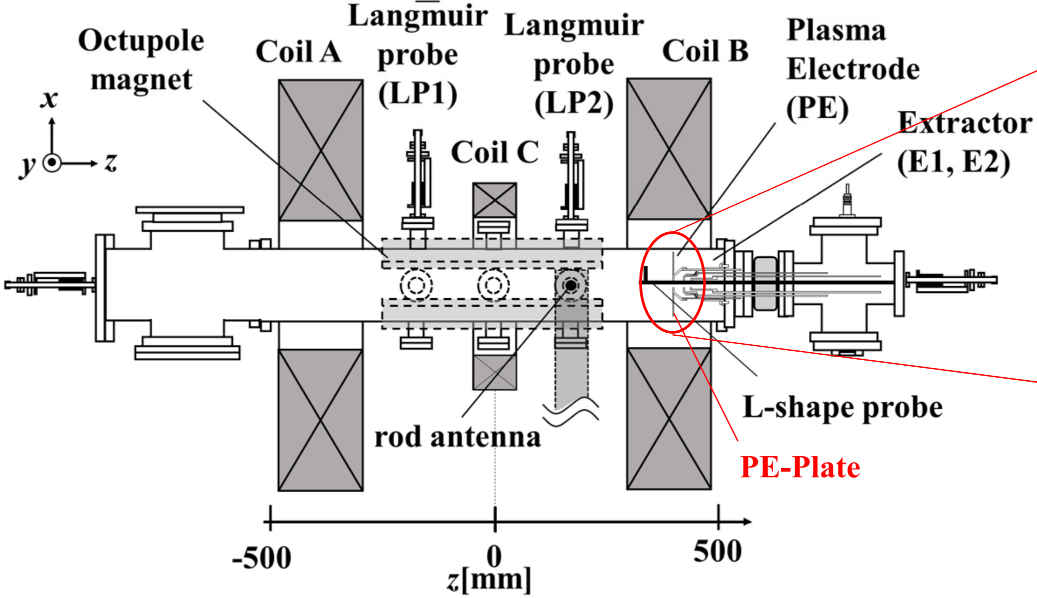


13 *Previous ECRIS for Fe@C_{60} (Case II)*

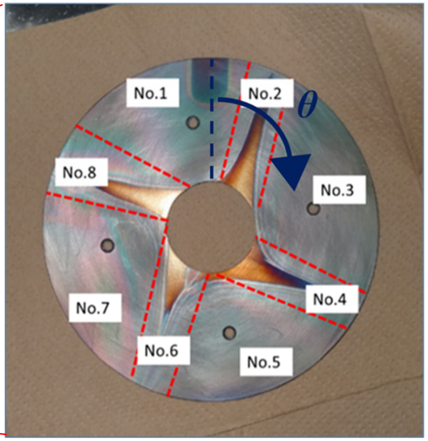


Previous ECRIS for $Fe@C_{60}$ (Case II)

(a)Previous ECRIS for $Fe@C_{60}$(Case II)

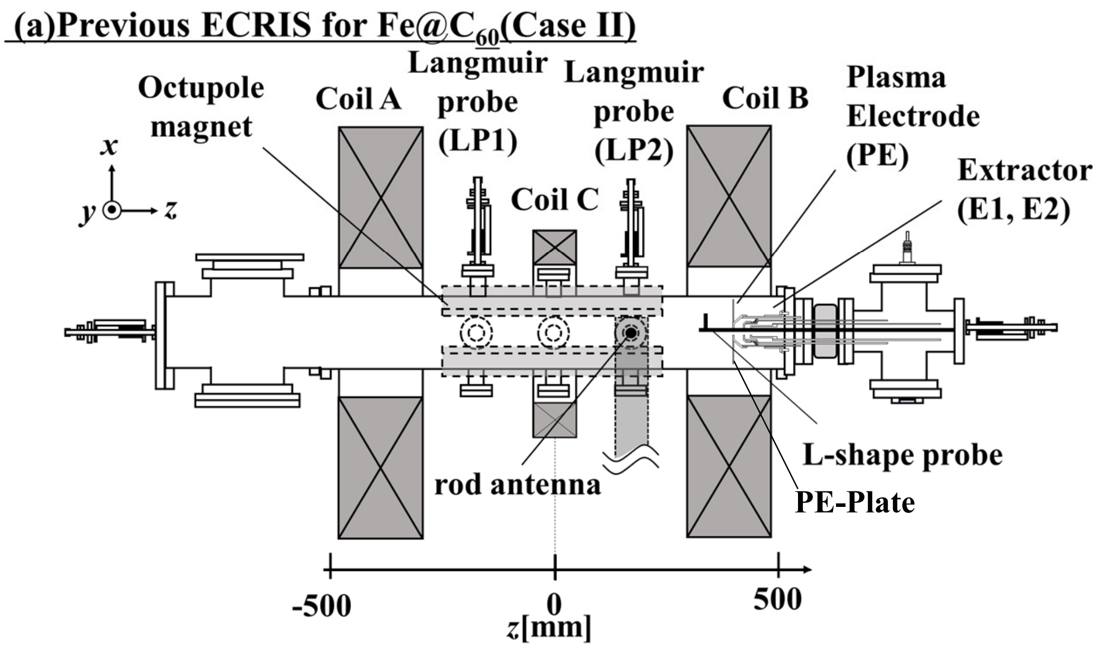


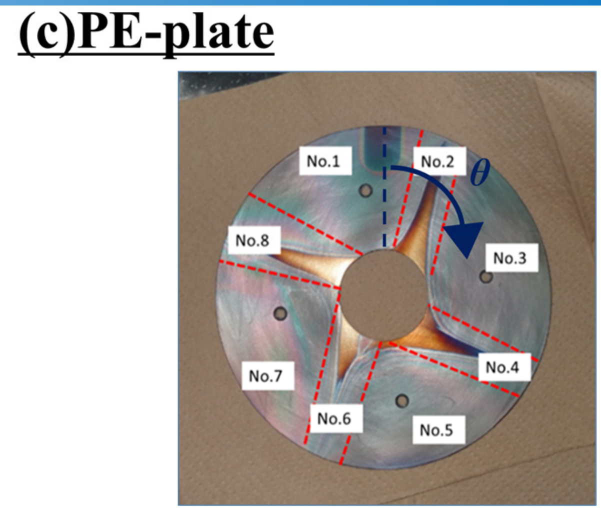
(c)PE-plate

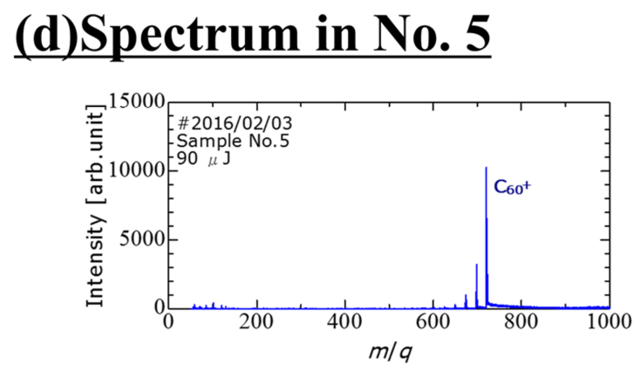


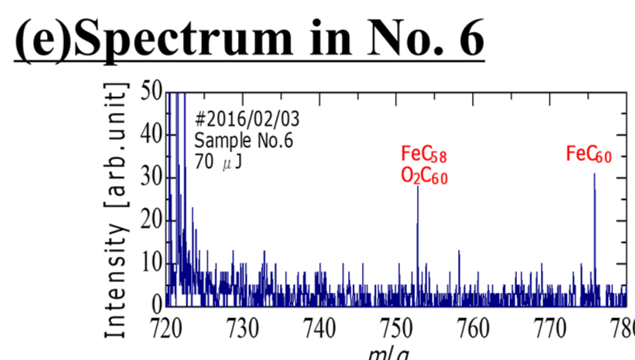
After a series of synthesizing $Fe@C_{60}$ experiments, We confirm the plasma pattern on PE-plate.
⇒We try to dissolve samples deposited on No. 5 and No. 6 region and analyze them by TOFMS.

Previous ECRIS for Fe@C_{60} (Case II)









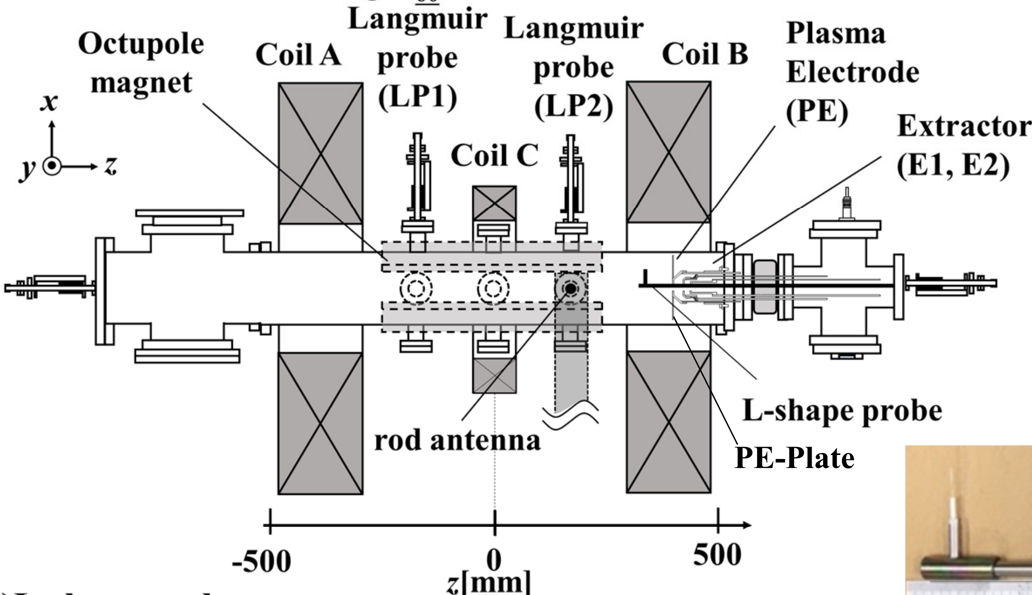
✓ **Results of TOFMS analysis[4]**

- **No. 5⇒C_{60} spectrum is confirmed**
- **No. 6⇒Productions of Fe@C_{58} and Fe@C_{60} are suggested**

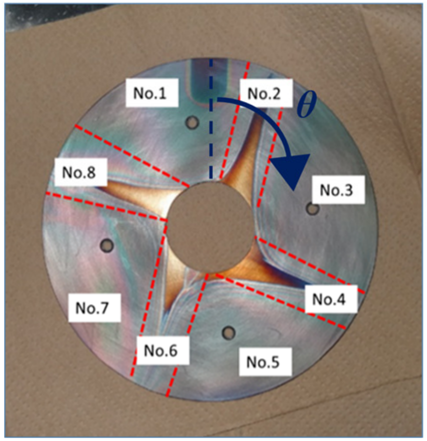
[4] Y. Kato, et al., IIT2018, IEEE Conf. Publ., 2019, pp172-175.

Previous ECRIS for Fe@C_{60} (Case II)

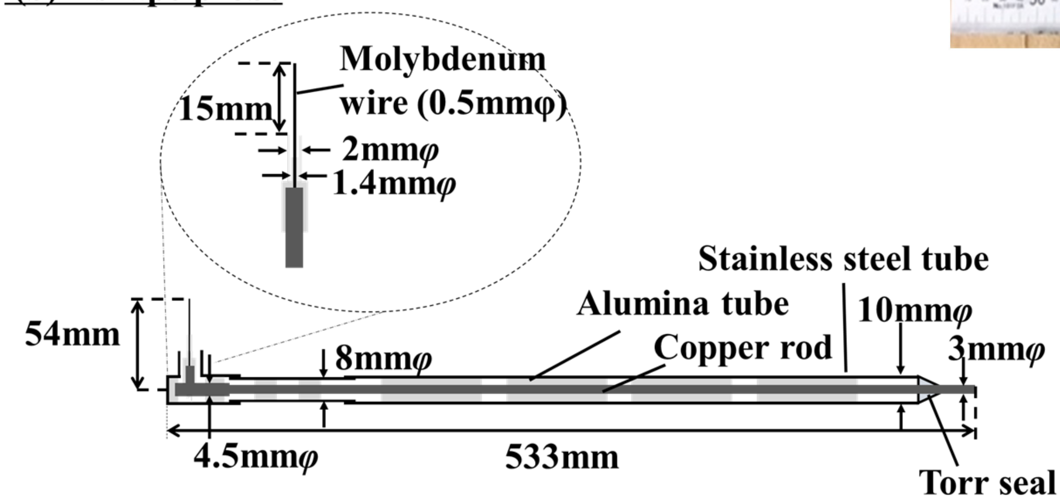
(a)Previous ECRIS for Fe@C_{60}(Case II)



(c)PE-plate



(b)L-shape probe



・Our ECRIS was damaged by the earthquake in Osaka on June 18, 2018.

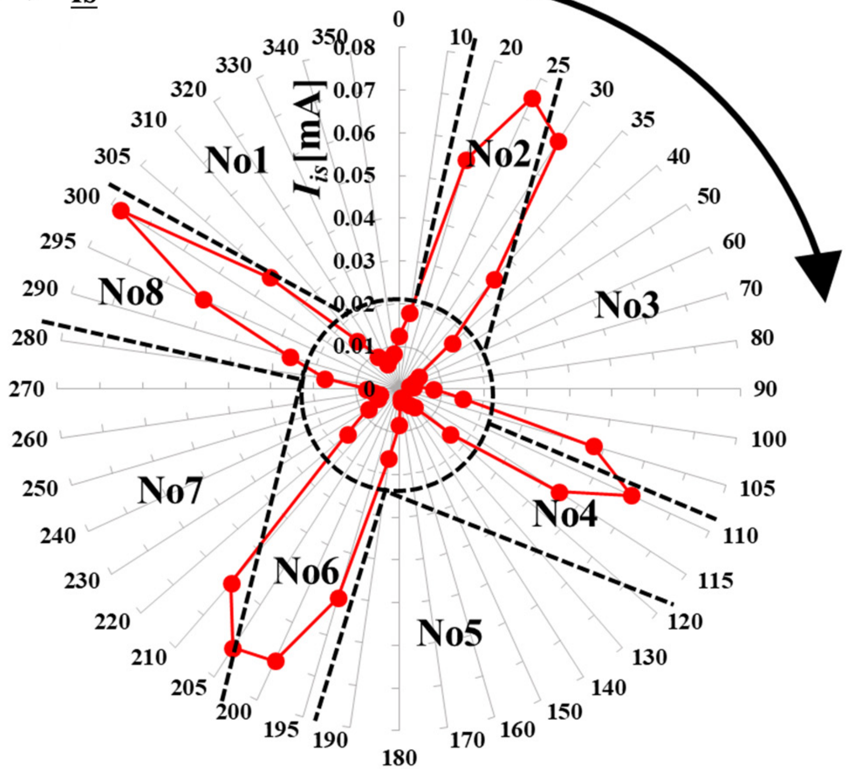
・The damaged extractor was removed when we reconstruct and improve the ECRIS[5].

⇒There was the opportunity to insert the L-shape probe to the vacuum chamber from the extractor.

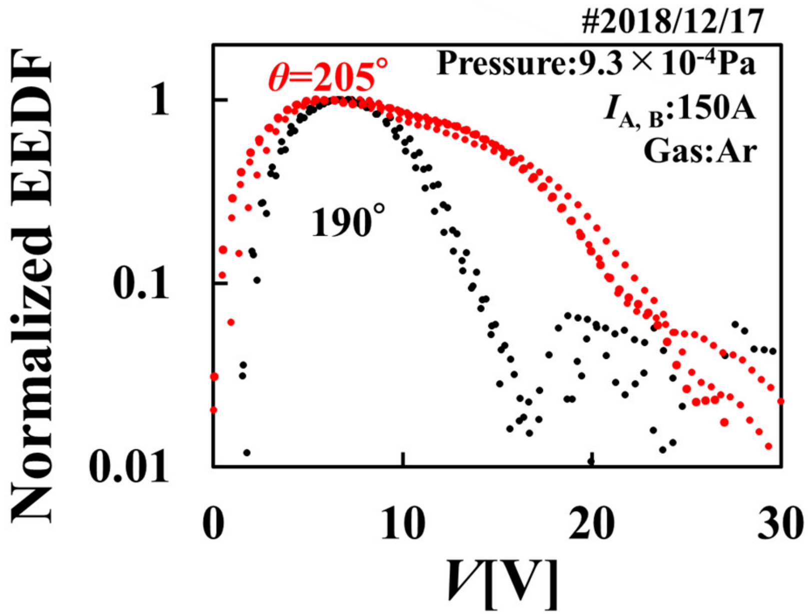
[5] S. Harisaki, et al, Rev. Sci. Instrum. 91, 013308 (2020)

Case II Experimental Results

(a)I_{is}



(b)EEDF at θ=190° and 205°



- The I_{is} peaks are observed in even number regions (No. 2, 4, 6, 8).
- EEDF at θ=205° which is in the No.6 has the higher tail than that at θ=190° which is in the boundary region of No.5 and No. 6.

Summary & Future Plans

Summary

・We measure plasma parameters in upper/down stream regions.
⇒We confirm differences of plasma parameters in upper/down stream regions consistent with the RHP wave propagation theory by comparing them.
・We compare the extracted ion beams in the case of antennas in upper/down stream regions.
・We measure plasma parameters near the extractor for Fe@C_{60} experiments and observe high energy electrons in the region where Fe@C60 production are suggested.

Future plan

・We optimize microwave-launching for 2.45GHz (ECR) and 4~6GHz (UHR)
・We conduct the dual ECR heating experiments by the optimized microwave launching.
・We conduct UHR experiments under the condition that ECR is optimized.

Thank you for listening!!

For any question or comment,
please contact w.kubo@nf.eie.eng.osaka-u.ac.jp