16th US-Japan Workshop on Fusion Neutron Sources
for Nuclear Assay and Alternate Applications
Madison, Wisconsin
1st. Oct., 2014

The Parallel Running of Multiple IECF Devices

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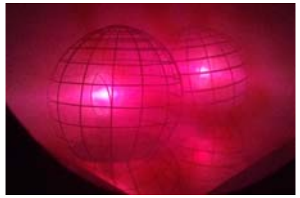
Outline

- Old IECF device at Kansai U.
- K-PIC simulation code
- Small IECF device
- Single operation
- Double operation (horizontal setting)
- Double operation (vertical setting)
- Conclusions



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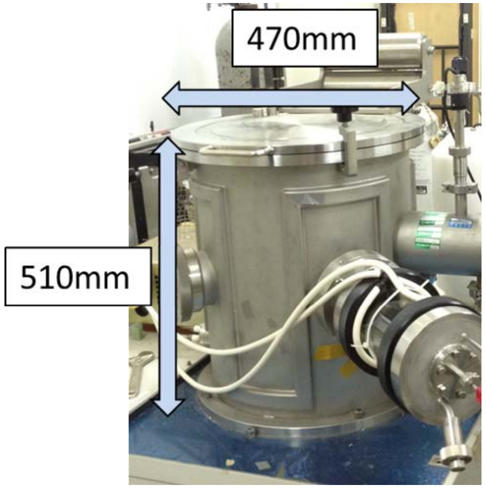
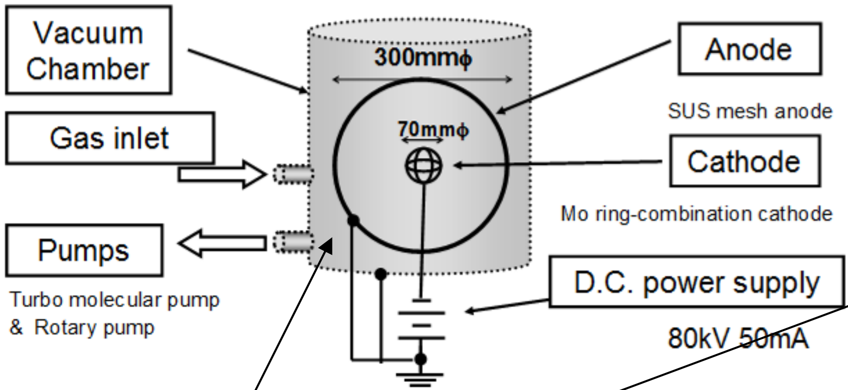
Set up for testing the small IECF device



appearance

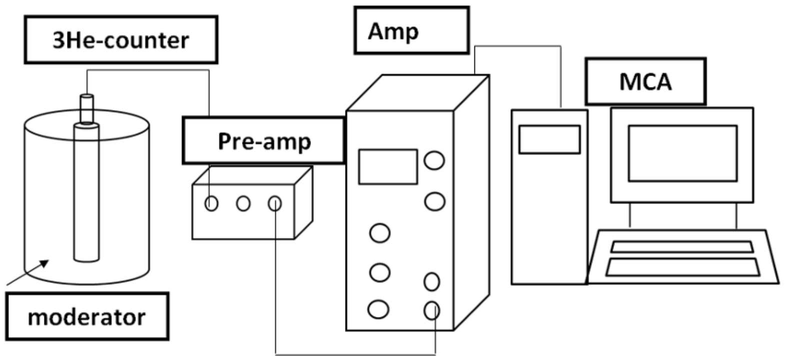
I = 50 mA (C.W.) V = 80 kV (C.W.)



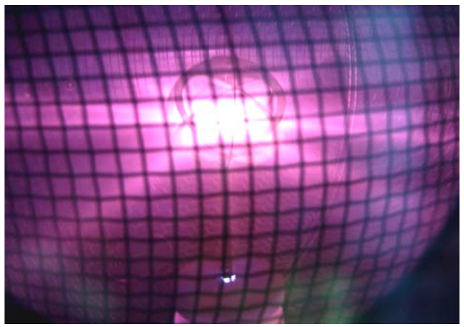
300mmΦanode

Spherical mesh is used as an anode.

Stainless mesh consist of stainless wire.



NPR is measured by 3He counter.



Discharge photo

Spot welding

PIC Simulation of IEC

Deuterium ions (D^+, D_2^+, D_3^+), fast neutrals (D^0, D_2^0) and electrons (e^-) are used as tracking particles. We use 1,000 particles of each ion species and 3,000 electrons distributed uniformly within the anode initially. We trace the trajectory of each particles by the Runge-Kutta method in 3-D space. They move in the 3-D vacuum potential calculated by the finite difference method with the 1 mm spatial 6,750,000 meshes. After pushing each particles, the atomic and molecular collisions and elastic collisions are taken into account by Monte Carlo method.

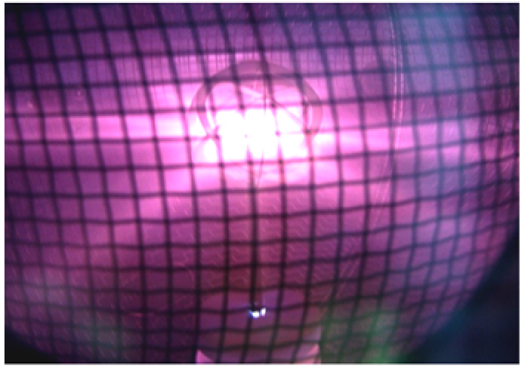
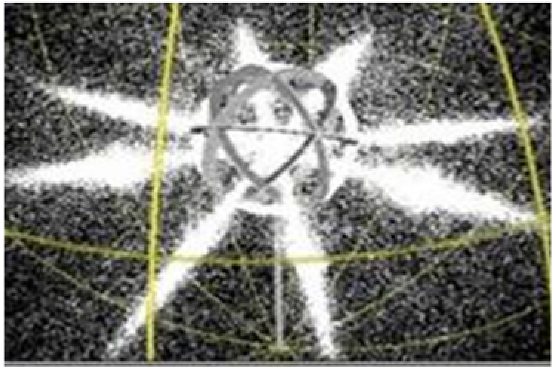
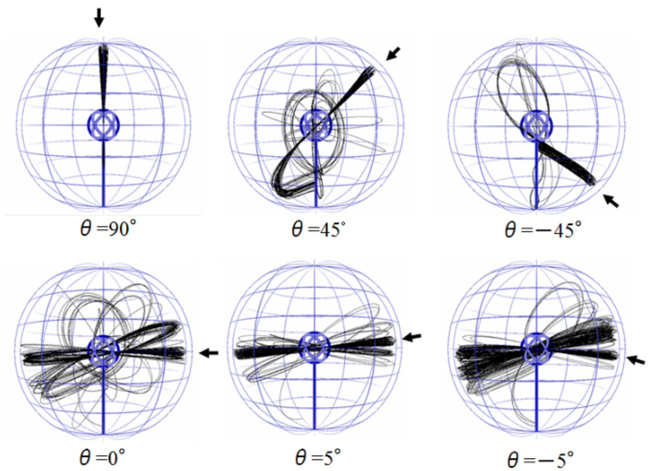


Photo of Star mode
(Experiment)



Electron Impact Ionization
(Simulation)

Horizontal ion trajectory is long.



Ion trajectory from ion source

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K-PIC code
(Kansai)

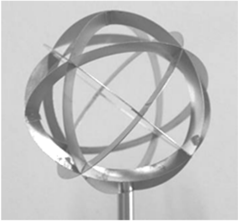
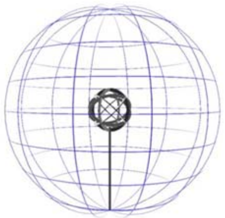
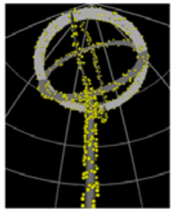

Photo(6ring cathode)

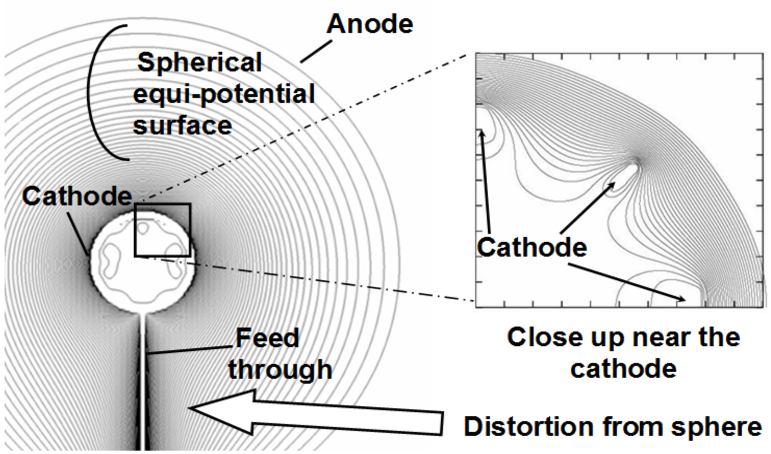

Photo (Anode)


Photo of glowing cathode
(Experiment)


FDM model cathode
(1mm cubic mesh)


Model of Anode


Ion Impact position
(Simulation)



The equi-potential surfaces are not spherical near the feed through. The effect of the cathode structure is not negligible. 3-D calculation is effective for complex field.

D^+

$$D^+(beam) + D_{2(back)} \rightarrow D^0(beam) + D_2^+(slow) \quad (1)$$
$$D^+(beam) + D_{2(back)} \rightarrow D_2^+(slow) + D^+(beam) + e^- \quad (2)$$
$$D^+(beam) + D_{2(back)} \rightarrow D^+(slow) + D^+(beam) + D^0(slow) + e^- \quad (3)$$

D_2^+

$$D_2^+(beam) + D_{2(back)} \rightarrow D_2^0(beam) + D_2^+(slow) \quad (4)$$
$$D_2^+(beam) + D_{2(back)} \rightarrow D_2^+(beam) + D_2^+(slow) + e^- \quad (5)$$
$$D_2^+(beam) + D_{2(back)} \rightarrow D^+(beam) + D^0(beam) + D_{2(back)} \quad (6)$$
$$D_2^+(beam) + D_{2(back)} \rightarrow D_3^+(slow) + D^0(beam) \quad (7)$$

D_3^+

$$D_3^+(beam) + D_{2(back)} \rightarrow D_2^0(beam) + D^+(beam) + D_{2(back)} \quad (8)$$
$$D_3^+(beam) + D_{2(back)} \rightarrow D^0(beam) + D_2^+(beam) + D_{2(back)} \quad (9)$$

D^0

$$D^0(beam) + D_{2(back)} \rightarrow D^+(beam) + D_{2(back)} + e^- \quad (10)$$
$$D^0(beam) + D_{2(back)} \rightarrow D^0(beam) + D_2^+(slow) + e^- \quad (11)$$
$$D^0(beam) + D_{2(back)} \rightarrow D^0(beam) + 2D^+(slow) + 2e^- \quad (12)$$
$$D^0(beam) + D_{2(back)} \rightarrow D^0(beam) + D^+(slow) + D^0(slow) + e^- \quad (13)$$

D_2^0

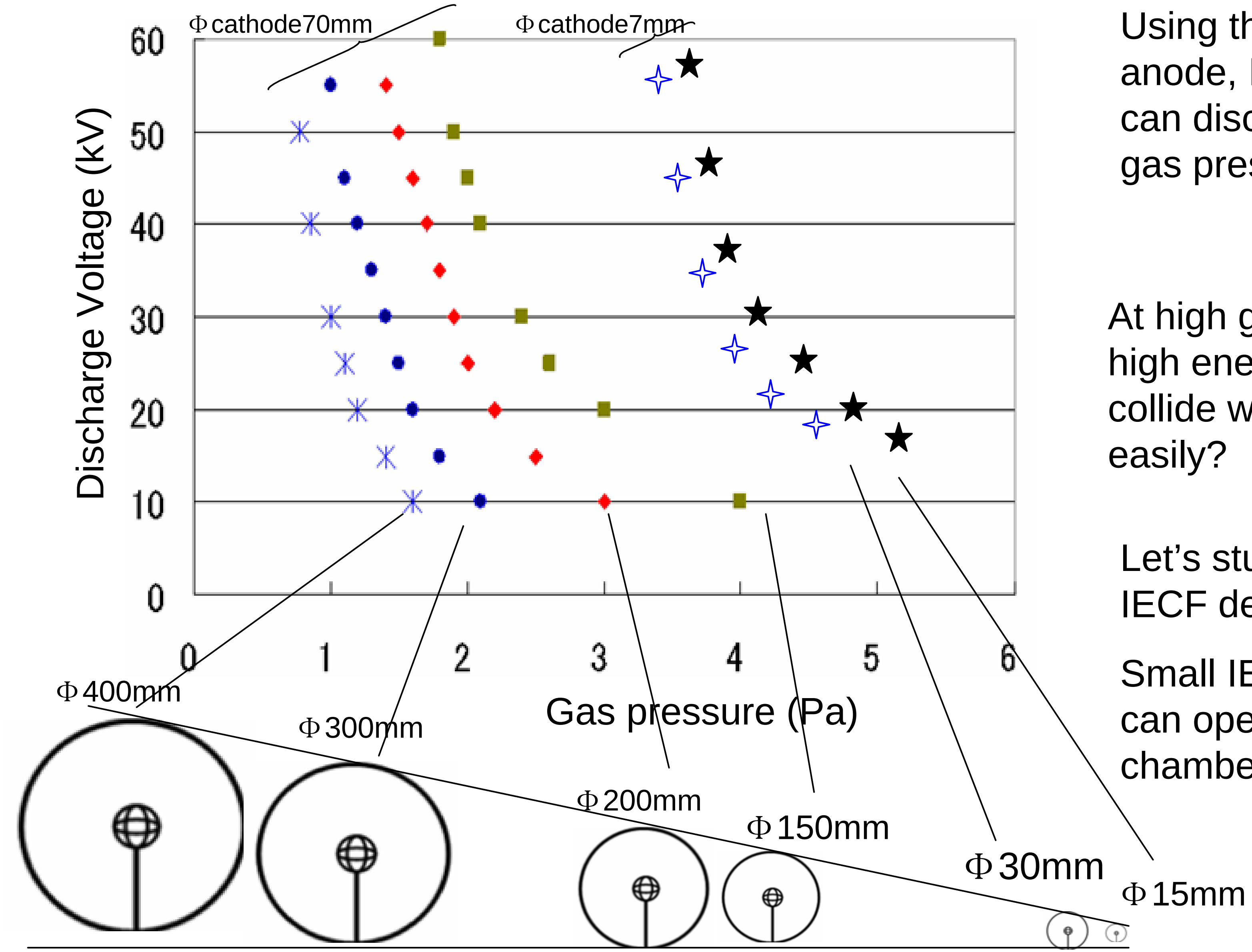
$$D_2^0(beam) + D_{2(back)} \rightarrow D_2^+(beam) + D_{2(back)} + e^- \quad (14)$$
$$D_2^0(beam) + D_{2(back)} \rightarrow 2D^+(beam) + D_{2(back)} + 2e^- \quad (15)$$

e^-

$$e^- + D_{2(back)} \rightarrow D_2^+(slow) + 2e^- \quad (16)$$
$$e^- + D_{2(back)} \rightarrow 2D^0(slow) + e^- \quad (17)$$
$$e^- + D_{2(back)} \rightarrow D^+(slow) + D^0(slow) + e^- \quad (18)$$

Elastic collisions (19)-(24)

Discharge characteristics of small IECF device by K-PIC code



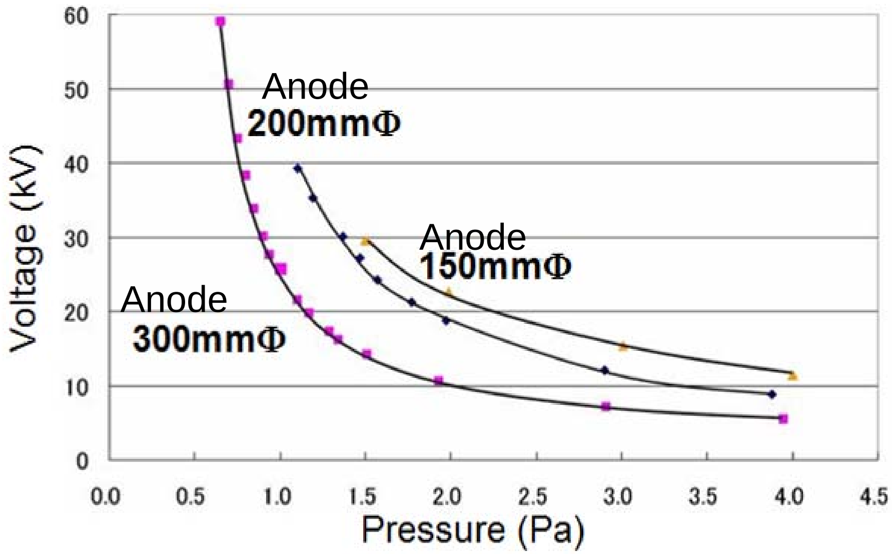
Using the smaller anode, IECF device can discharge at higher gas pressure.

At high gas pressure, high energized ion can collide with neutral easily?

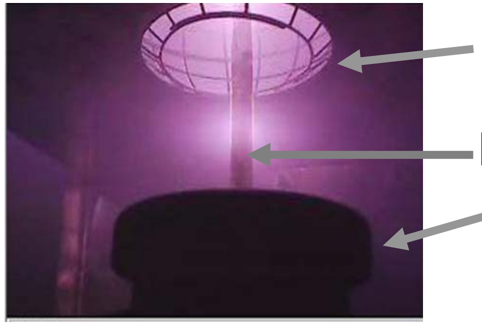
Let's study about small IECF devices.

Small IECF devices can operate in vacuum chamber at parallel.

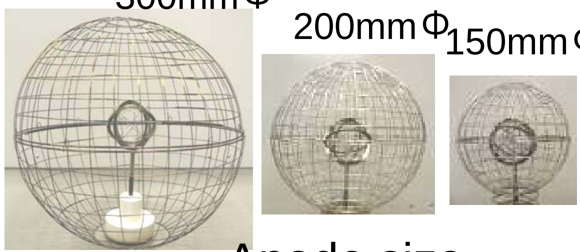
Comparison of anode diameter (old-experiment)



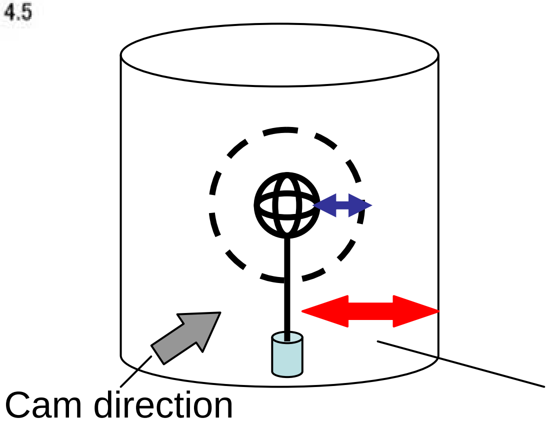
Pressure – discharge voltage characteristics



Inside photo



Anode size

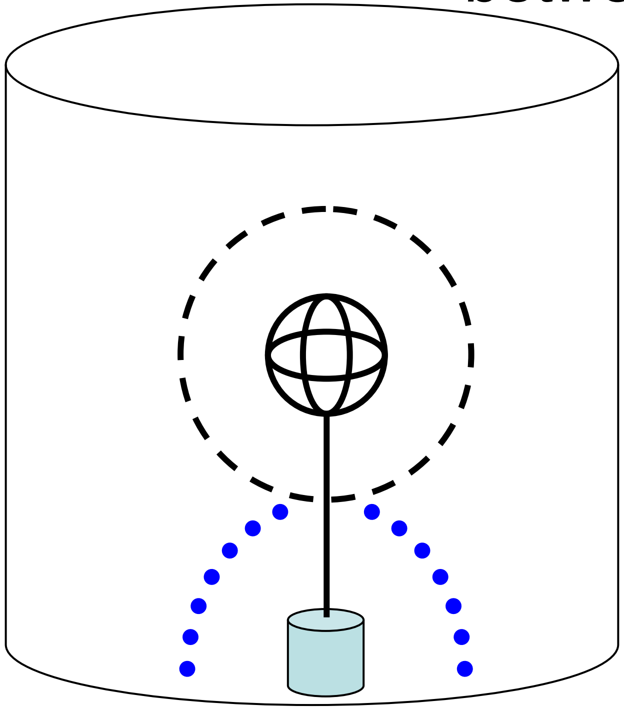


Discharge is mainly occurred at longest path.

Using the large anode, IECF device can discharge at stable HV & lower gas pressure.

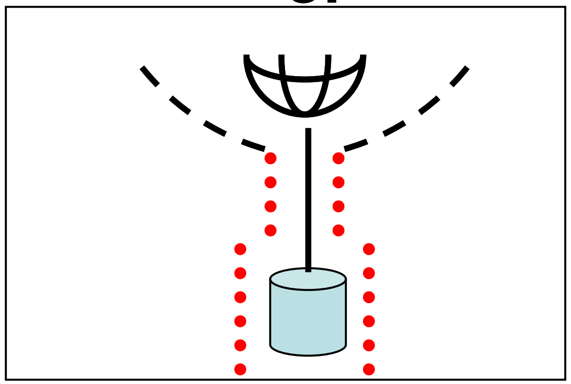
With the smaller anode, the discharge is getting unstable, the higher voltage can't be applied.

Guard fence for preventing the discharge between anode and feed-through



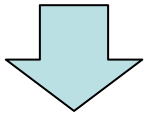
Anode & hemispherical guard fence

or



Cylindrical guard fence

Using this guard fence, the path between anode and cathode becomes longest.



Discharge of small anode becomes stable, the high voltage can be applied.

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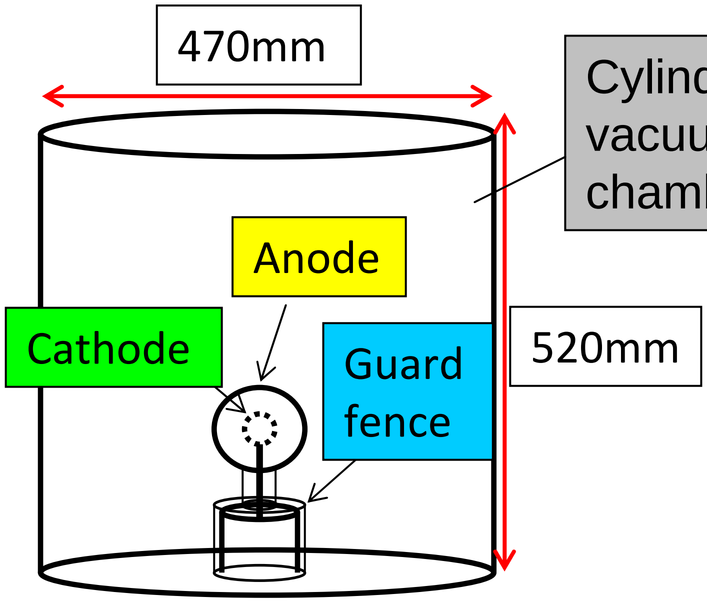
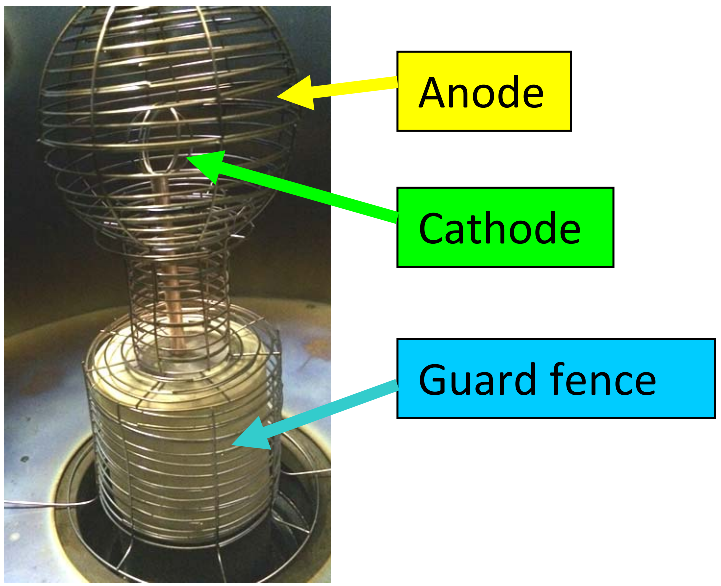
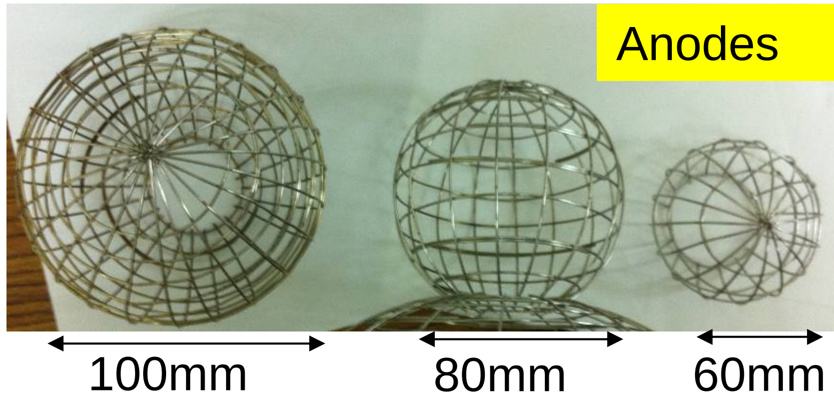
Setup of small IECF device





appearance

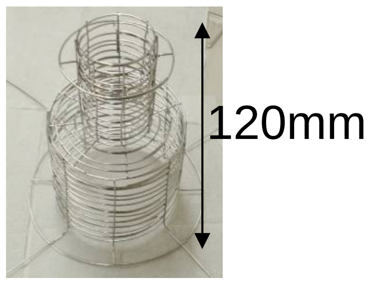
Anodes



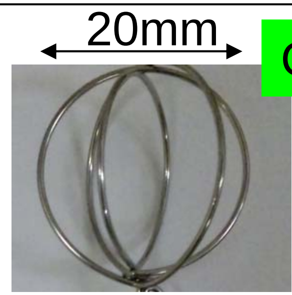

Winding wire around
spherical foamed polystyrene


Remove by acetone

Guard fence



Cathode



Wire cathode (Mo)

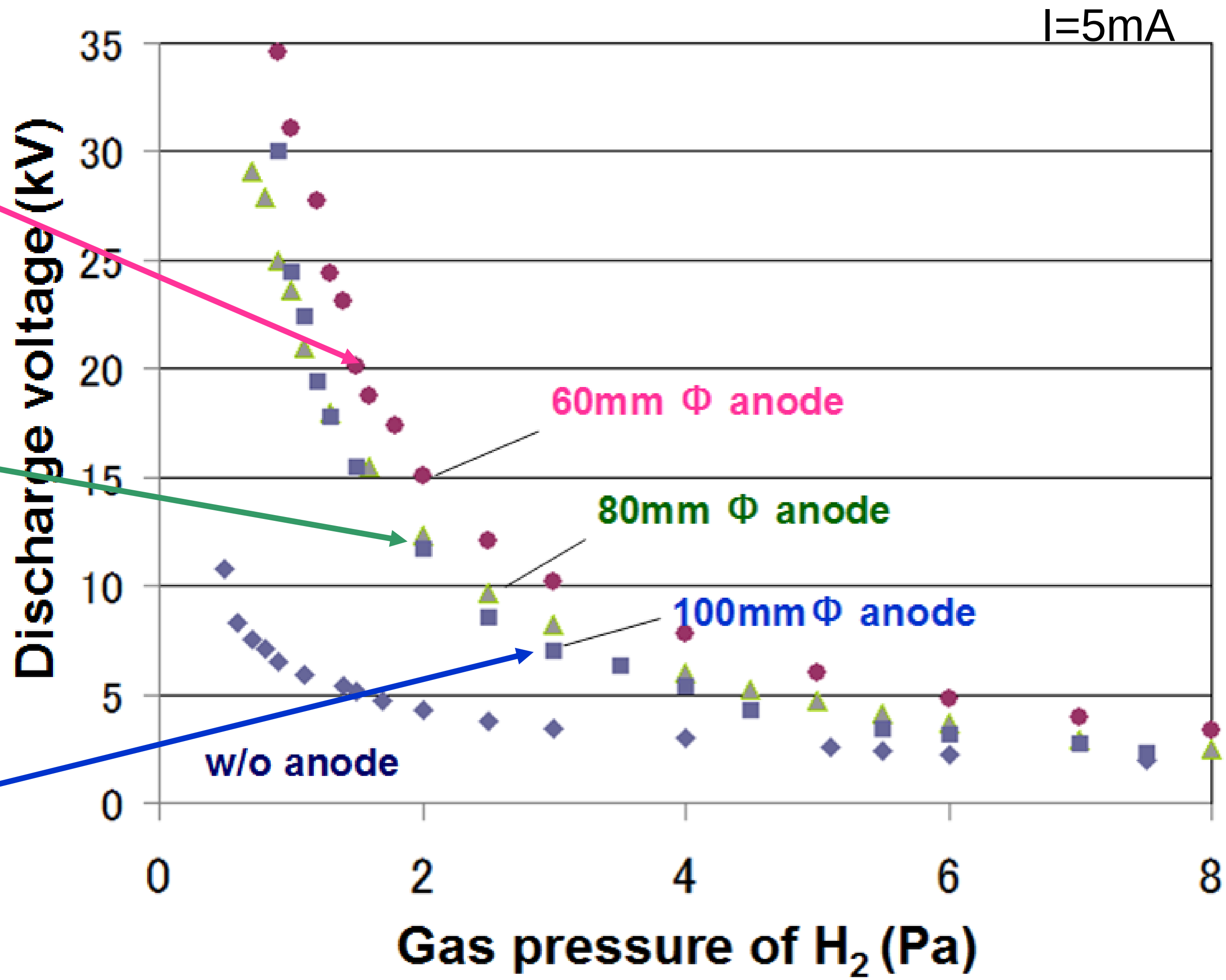
(wire diameter is 1mm)

Discharge characteristics of small anodes

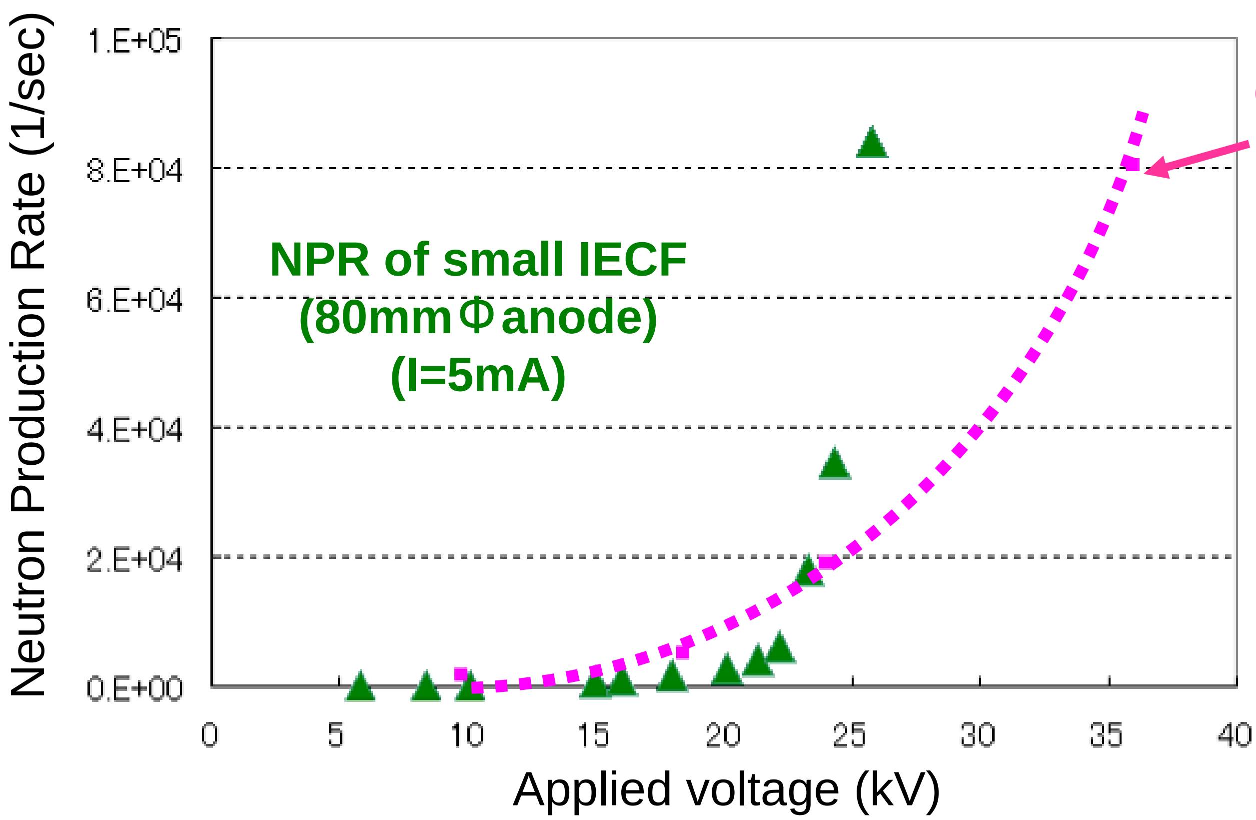
60mm

80mm

100mm



Neutron Production Rate of small IECF device （single）



The cathode is shinling
by over heating

80mmΦ anode
at 1Pa, 31kV, 10mA

NPR of a small IECF device (80mmΦ) is
greater than original IECF device (300mmΦ)

The operational current is limited within 5mA
by the over heating of ion collide on small cathode.

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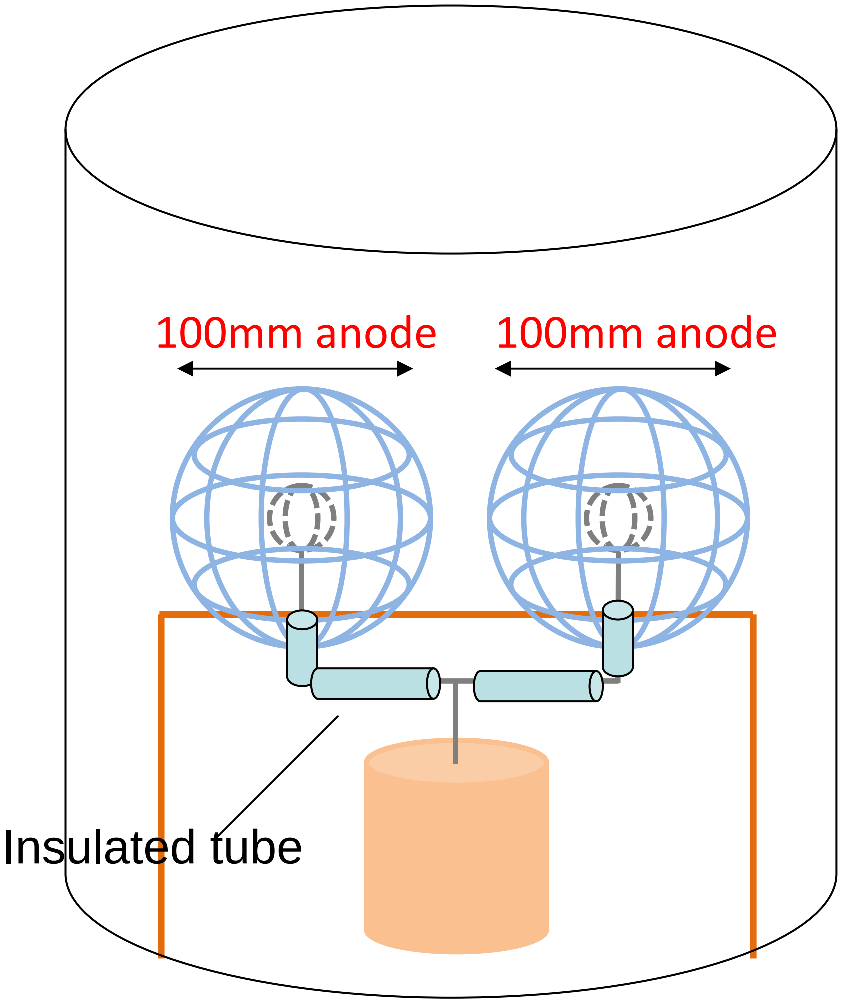
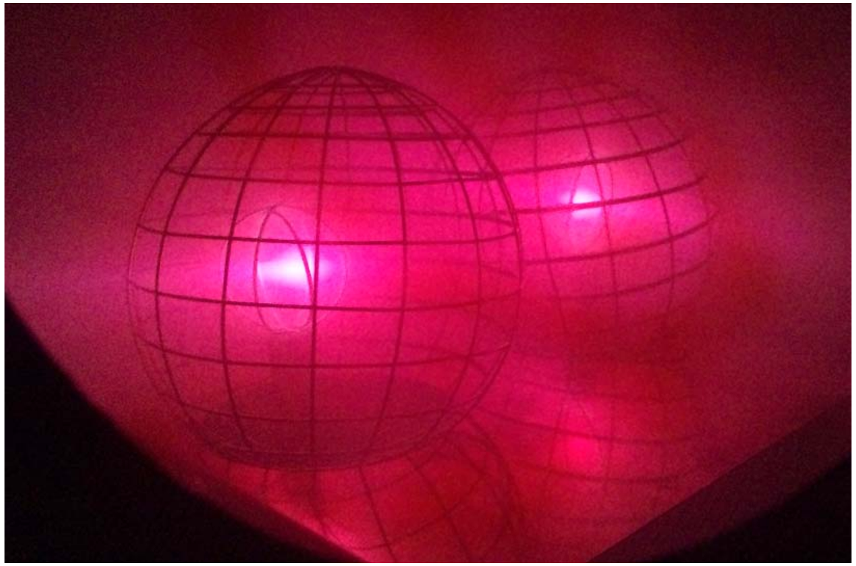
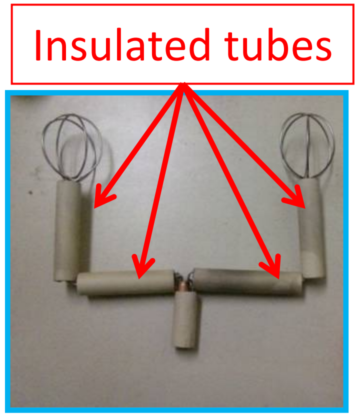
Parallel operation of Double IEC device (horizontal setting)



Two 100mm Anodes setting
(side by side)



Discharge photo (H_2 **5Pa, 3.4kV, total 10mA)**



Branched Cathode

Setting appearance

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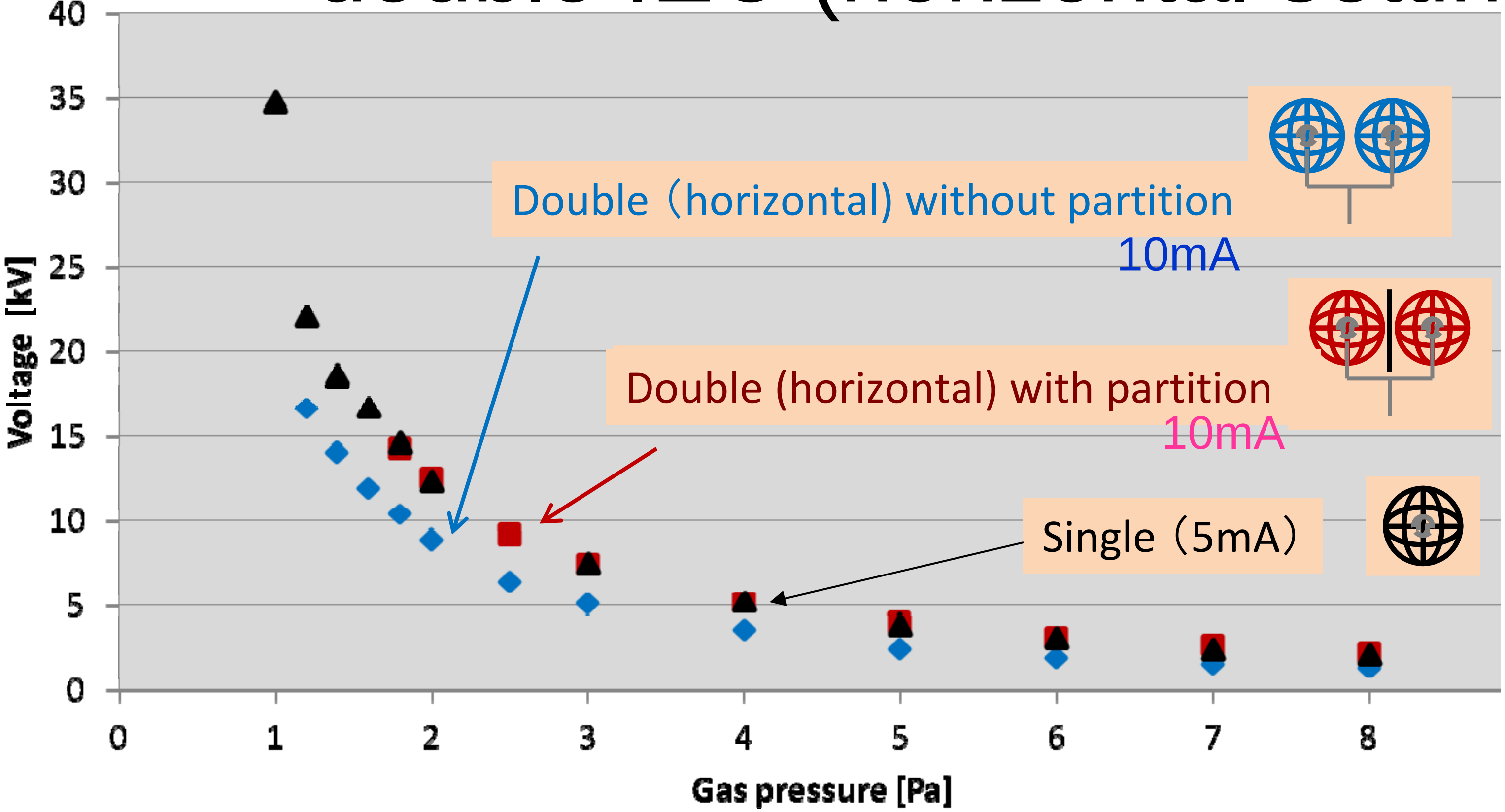
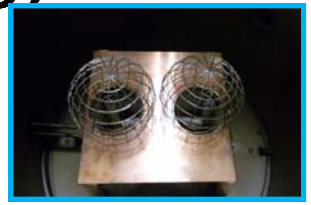
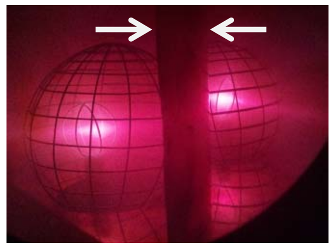
Discharge characteristics of double IEC (horizontal setting)





Comparison of each discharge curves



（H_2, 5Pa, 5.7kV, with partition）

Double IEC with a partition, P-V curve is just same as single.

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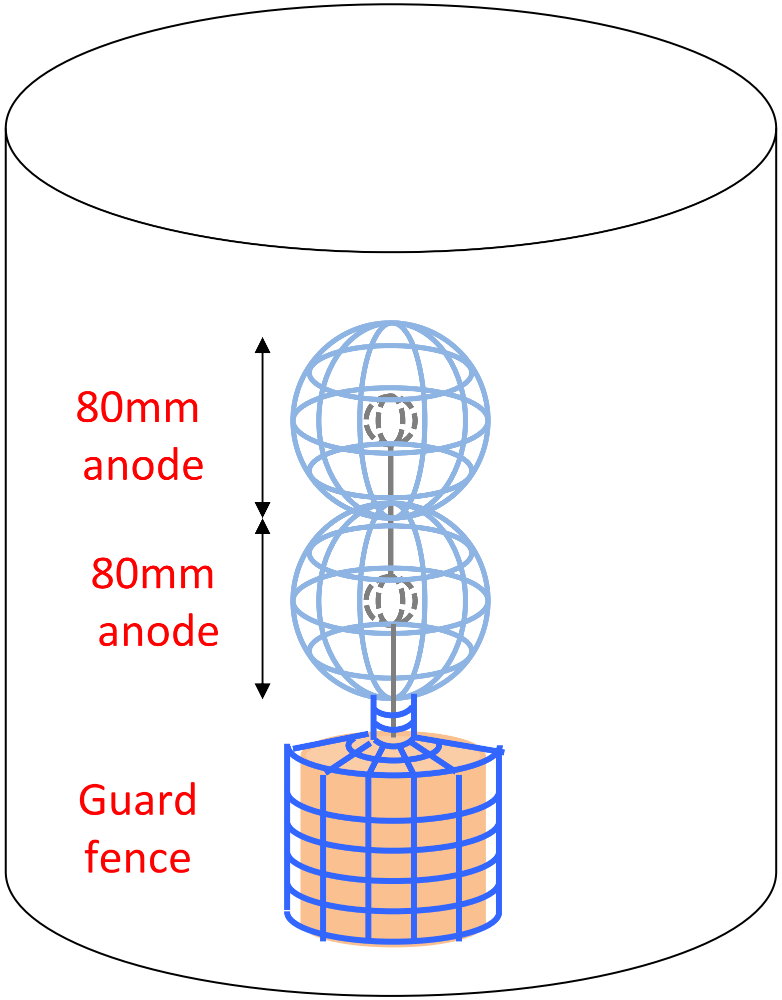
Parallel operation of double IEC devices (vertical type)



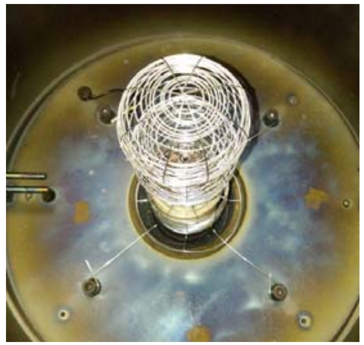
Two 100mm Anodes setting
(vertically)

Discharge photo of H_2

10mA 1.6Pa 38.7kV

Anodes

cathodes



Setting
appearance

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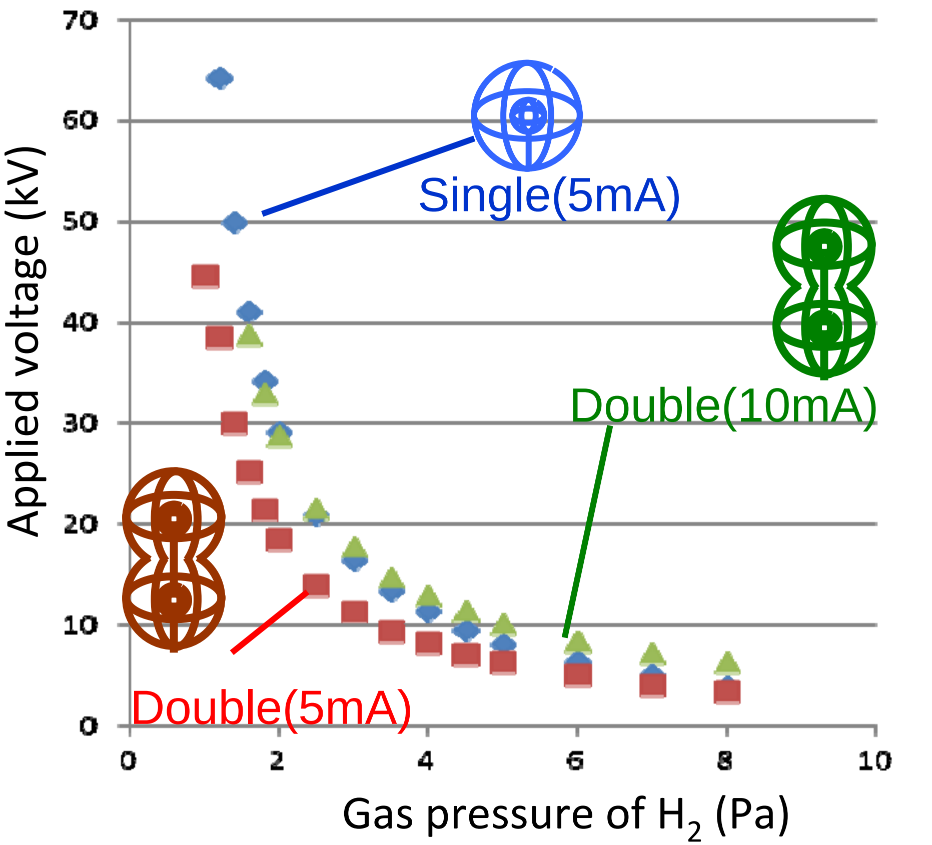
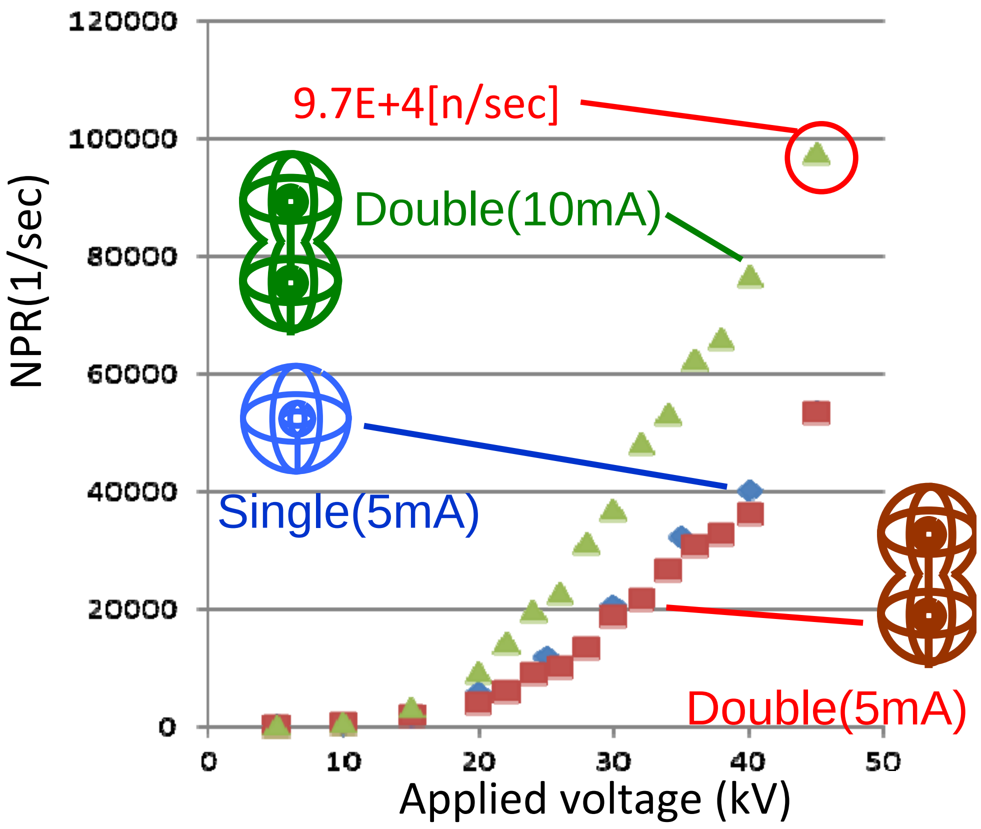
Experimental Results of double IECF device (vertical type)

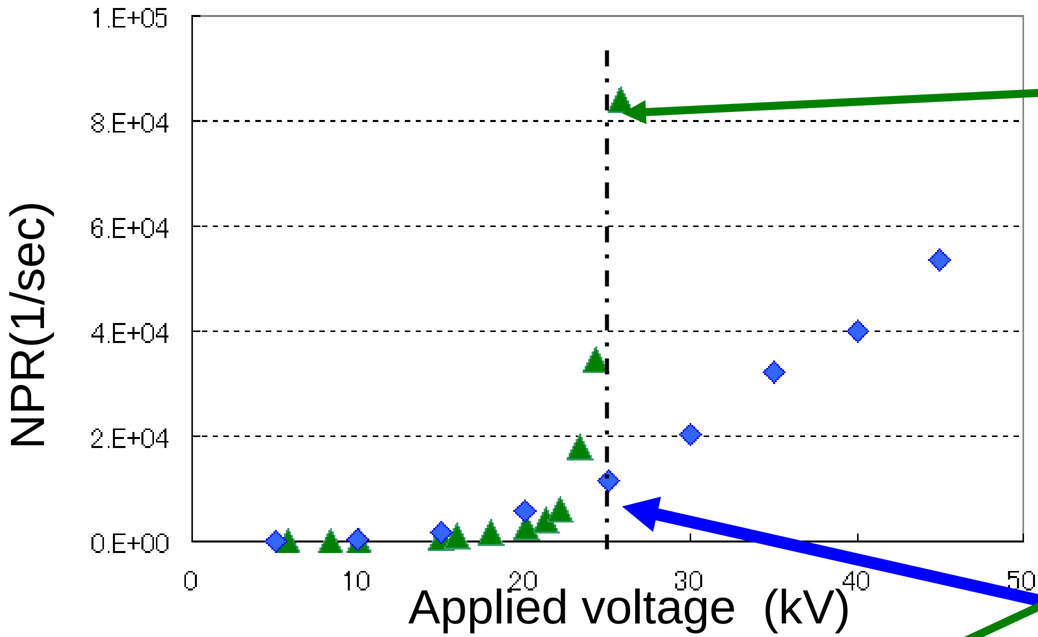


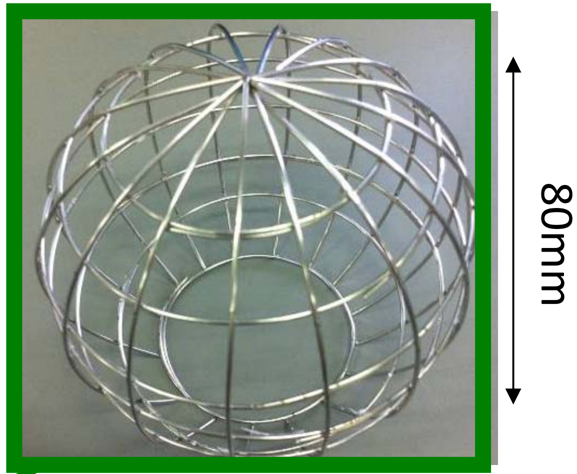


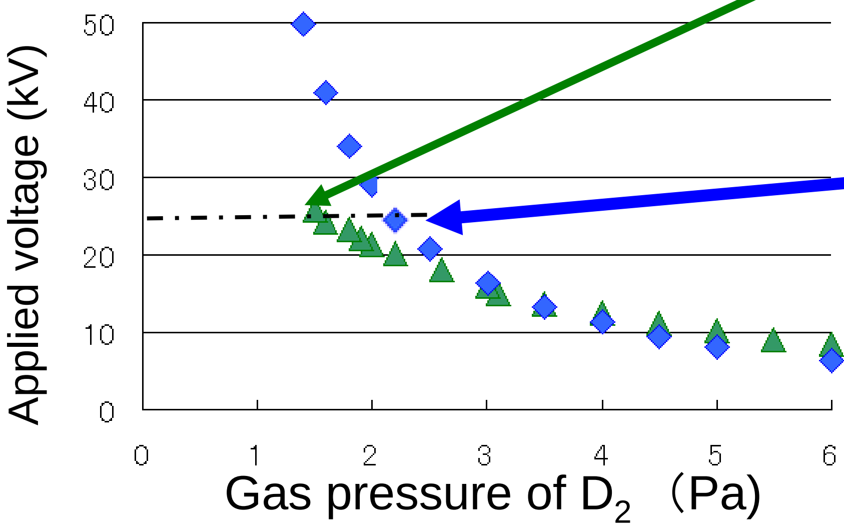
NPR of double (at 10mA) is almost twice of NPR of single (at 5mA).

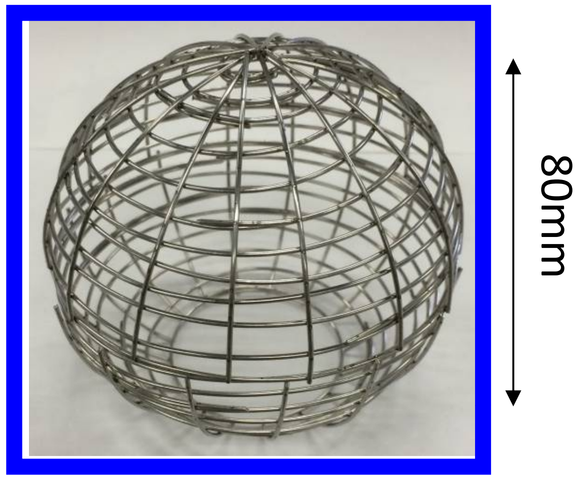
However, the amount of NPR is quite small. ⇨ Why?

Comparison of NPR & anode structure (single)









The density of anode wires is different.

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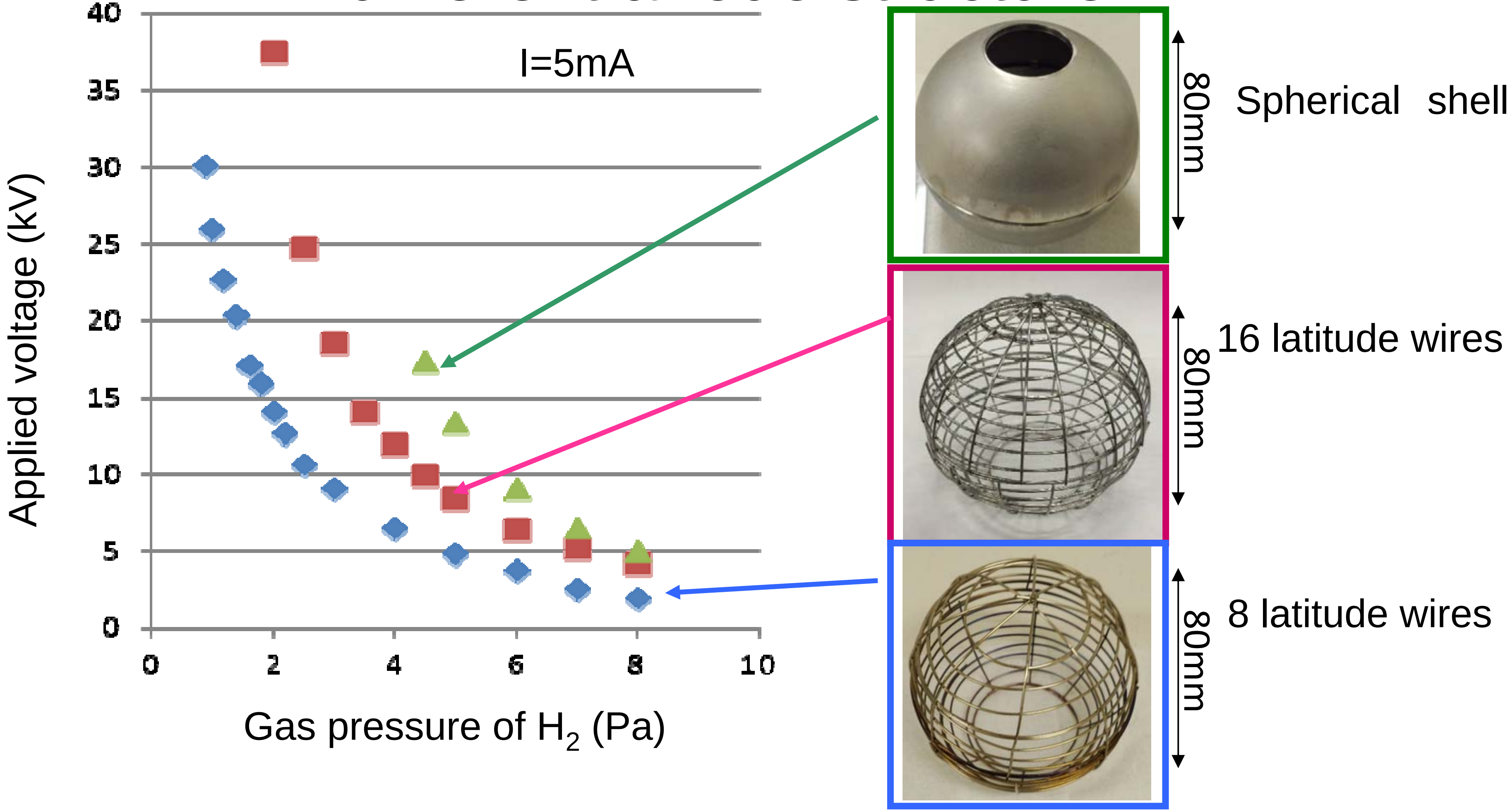
Discharge characteristics of different anode structure



The density of anode structure is very important factor in discharge.

Conclusions

･parallel operation

Double IEC devices at horizontal setting help the their discharge each other.

Double IEC devices at vertical setting don't affect each other.

Increasing parallel running-IECs, total NPR will be increased proportionally.

･P-V curve & NPR

With smaller anode, the discharge is occurred at higher gas pressure.

Using the anode with smaller network of wire, the discharge is occurred at higher gas pressure.

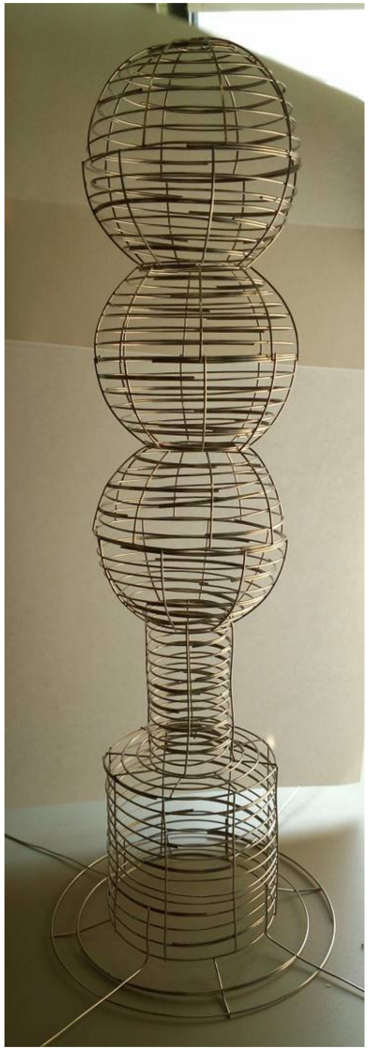
⇒The operational discharge characteristic curve can be controlled by changing anode diameter and structure.

Operational gas pressure is very important factor for NPR.

⇒At suitable gas pressure, NPR will be improved.

Future Plan

Triple IECs



Triple anodes

Now, the triple IECs are tested.

At next workshop, the tritium experiment will be finished