# Discharge Simulation on Miniaturization of IECF Device


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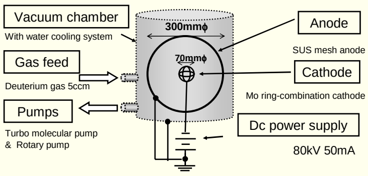
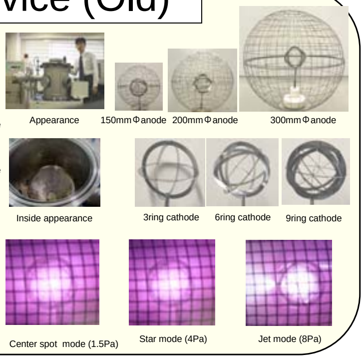
## Motivation

IECF researchers have been studied to get more neutron production rate, using more expensive and powerful power supply and larger vacuum chamber. However, the cross section of D-D reaction is gradually saturated at high energy, The larger anode operation results in decrease of the gas pressure and less neutron production rate. The research of downsizing about IECF device has not been studied. It is though that the glow discharge of small IEC is easy to transfer the arc discharge. However, the smaller anode operation will achieve the high gas pressure discharge and more neutron rate. The discharge characteristic of minimized IECF device is investigated by the particle in cell simulations.

## Setup of IECF device (Old)

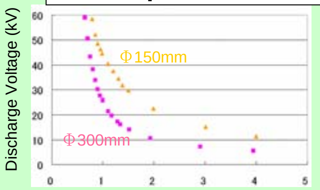
Old Device (no ion source model, glow discharge)
I = 50 mA (C.W.) V = 80 kV (C.W.)



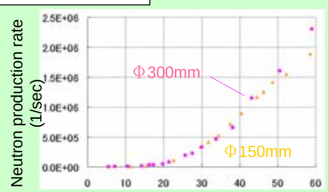




The old device is designed for the operation by the glow discharge. The power supply (80kV,50mA) is relatively cheaper than high power supply(100kV, 100A,pulse) of ion source driven IEC device.

## Experimental Data




Experimental discharge characteristics of 150mm anode and 300mm anode (Ic=40mA)

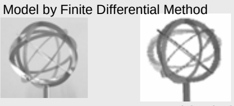



Neutron production rate vs. applied voltage with 150mm anode and 300mm anode (Ic=40mA)

From the results, the larger anode of IEC can be operated at lower gas pressure.
The neutron production rate of 300mm and 150mm of anode is almost same.

## Simulation Model

Cathode Model by Finite Differential Method



Photo(6ring cathode) FDM model cathode (1mm cubic mesh)

Example results of Star Discharge by Discharge Simulation

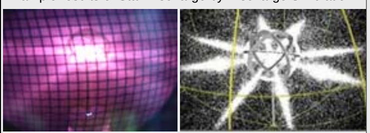


Photo of Star mode (Experiment) Electron Impact Ionization (Simulation)

Star Mode Discharge (1.5Pa, 20kV)at 300mm Anode

Calculating Area and Size of Electrode

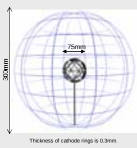
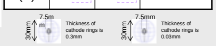


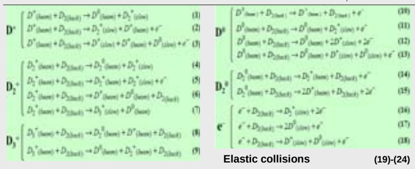

Table of Electrode Size

| Model | Anode Diameter Φa(mm) | Cathode Diameter Φc(mm) | Thickness of Cathode Ring Tc(mm) |
|---|---|---|---|
| (A) | 300 | 75.0 | 0.3 |
| (B) | 30 | 7.5 | 0.3 |
| (C) | 30 | 7.5 | 0.03 |

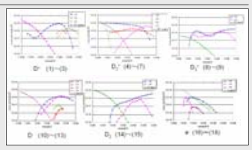



Model (A) Model (B) Model (C)

Three type of electrodes are simulated by the PIC code. The scale of Model (A) is same size of old IEC device at Kansai U.. Model (B) is 1/10 scale of anode and cathode which thickness is same as original one. Model (C) is completely 1/10 scale model.



Elastic collisions (19)-(24)



Data of Cross Sections

Atomic Processes in Particle simulation

Discharge Simulation Method

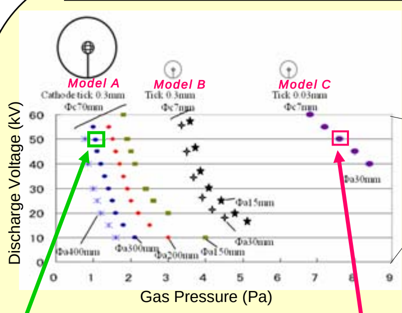
The three-dimensional Monte Carlo particle in cell code [1] including the atomic processes is used for investigation of the discharge. The full three dimensional potential are calculated containing the potential effect of the feed-through and the spatial structure of the cathode. The finite difference method with the 1 mm spatial mesh is used for the calculation. Deuterium ions ($D^+$, $D_2^+$, $D_3^+$), fast neutrals ($D^0$, $D_2^0$) and electrons ($e^-$) are taken as tracking particles. The initially 1000 particles of each kind of ion species and 3000 electrons are distributed uniformly between the space of the anode and the cathode. The trajectory of each particle is followed by the Runge-Kutta method. The time step is $10^{-12}$ sec. After pushing each particle, the atomic and molecular collisions and the elastic collisions are taken into account by Monte Carlo method. When the total number of ions becomes more than 60000, it is recognized that 'discharge' is occurred in this discharge simulation.


[1] H. Osawa, T. Tabata, M. Ohnishi: Fusion Sci. Technol.**47**(2005) p.1270-1273

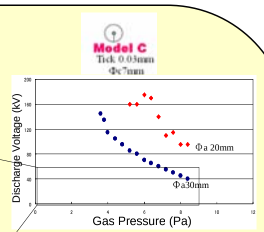

## Conclusions

The particle simulations show that the minimized IECF device (30mm anode) has possibility to discharge at 7.7 Pa, 50 kV and that high gas pressure operation has instability of discharge characteristics. The preventing transfer to arc discharge is achieved with real small IEC device, the neutron production rate will be very larger than that of low-gas pressure operation with expensive power supply. The parallel running of many small IECF devices is easy to make high NPR at low price.

## Simulation Results




'Discharge' characteristics of different sized anode and cathode (model A, B and C)




Instability Discharge of Small IEC (Model C, Φa20mm)

Too many secondary electron is produced at Model C of over 20mm Φa. It caused the instability of discharge voltage.

### Examples of Detailed Data

**Model A at 1.2Pa, 50kV (Φa=300mm,Φc=75mm,Tc=0.03mm at 3usec)**

Neutron production rate 13.4 (Arbitrary Unit)
0.5 by $D^+$
8.4 by $D_2^+$
4.5 by $D^0$ & $D_2^0$

| Number of particles | | |
|---|---|---|
| | $e$ | 64 |
| | $D^+$ | 274 |
| | $D_2^+$ | 4863 |
| | $D_3^+$ | 0 |
| Fast neutrals (over 10keV) | $D^0$ | 1552 |
| | $D_2^0$ | 3078 |

**Model C at 7.7Pa, 50kV (Φa=300mm,Φc=75mm,Tc=0.03mm at 3usec)**

Neutron production rate 211 (Arbitrary Unit)
6 by $D^+$
151 by $D_2^+$
53 by $D^0$ & $D_2^0$

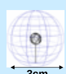
| Number of particles | | |
|---|---|---|
| | $e$ | 256 |
| | $D^+$ | 1858 |
| | $D_2^+$ | 49986 |
| | $D_3^+$ | 0 |
| Fast neutrals (over 10keV) | $D^0$ | 11875 |
| | $D_2^0$ | 25385 |

1/10 sized IEC device (Model B&C) can discharge in the simulation.
The thickness of cathode (Transparency of cathode) plays an important role of discharge (From comparing Model B with C).
At higher gas pressure, the $D_2^+$ ion is easy to increase themselves and product more neutrons.
If the mass of $D_2^+$ ions hit on the cathode surface, very large number of secondary electrons are produced and they lead to the arc discharge.

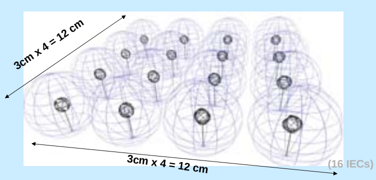
## Future Plan

The small IEC should be examined experimentally. If the one small IEC (3cm) can be discharged at higher gas pressure, the measurement of neutron production rate with this small IEC will be most important study of IEC. Small IEC devices are easy to gather in same vacuum chamber and may operated with one power supply. If the many IECs can be parallel-operated, the neutron production rate must be proportional to the number of IECs.

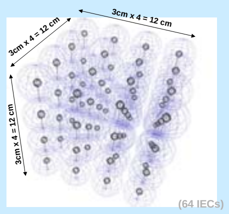
The plane or cube arrangement of IECs will have good performance of discharge. The electrons escaped through the mesh anode may be captured with neighbor IEC's potential.




Real scale of small IEC (3cm)




**Planar arrangement of IECs (4 x 4)**




**Cubic array of IECs** (4 x 4 x 4)