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
Set up for testing the small IECF device

Spherical mesh is used as an anode.

Stainless mesh consists of stainless wire.

NPR is measured by 3He counter.
PIC Simulation of IEC

Deuterium ions (D⁺, D₂⁺, D₃⁺), fast neutrals (D⁰, D₂⁰) 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.

Horizontal ion trajectory is long.
K-PIC code

\[ D^+(\text{beam}) + D_2^+(\text{back}) \rightarrow D_2^0(\text{beam}) + D_2^+(\text{slow}) \]  (1)
\[ D^+(\text{beam}) + D_2^+(\text{back}) \rightarrow D_2^+ + D^+(\text{beam}) + e^- \]  (2)
\[ D^+(\text{beam}) + D_2(\text{back}) \rightarrow D^+(\text{slow}) + D^+(\text{beam}) + D^0(\text{slow}) + e^- \]  (3)
\[ D_2^+ + D_2^+ + D_2(\text{back}) \rightarrow D_2^0 + D_2^+(\text{beam}) + D_2^+(\text{slow}) \]  (4)
\[ D_2^+ + D_2(\text{back}) \rightarrow D_2^+(\text{beam}) + D_2^+(\text{slow}) + e^- \]  (5)
\[ D_2^+ + D_2(\text{back}) \rightarrow D_2^+(\text{beam}) + D_2^0(\text{beam}) + D_2^+(\text{slow}) + D_2^+(\text{back}) \]  (6)
\[ D_2^+(\text{beam}) + D_2(\text{back}) \rightarrow D_2^0 + D_2^0 + D_2^0(\text{beam}) + D_2^0(\text{slow}) + e^- \]  (7)
\[ D_3^+ + D_2(\text{back}) \rightarrow D_2^0 + D_3^0 + D_2^0(\text{beam}) + D_2(\text{back}) \]  (8)
\[ D_3^+ + D_2(\text{back}) \rightarrow D_2^0 + D_3^0 + D_2^0(\text{beam}) + D_2^0(\text{back}) \]  (9)
\[ D_2^0(\text{beam}) + D_2(\text{back}) \rightarrow D_2^0 + D_2^0(\text{beam}) + D_2(\text{back}) + e^- \]  (10)
\[ D_2^0(\text{beam}) + D_2(\text{back}) \rightarrow D_2^0(\text{beam}) + D_2^0(\text{back}) + e^- \]  (11)
\[ D_2^0(\text{beam}) + D_2(\text{back}) \rightarrow D_2^0(\text{beam}) + 2D_2^0(\text{beam}) + 2e^- \]  (12)
\[ D_2^0 + D_2(\text{back}) \rightarrow D_2^0 + D_2^0 + D_2^0(\text{beam}) + D_2^0(\text{slow}) + e^- \]  (13)
\[ D_2^0 + D_2(\text{back}) \rightarrow D_2^0 + D_2^0 + D_2^0(\text{beam}) + D_2^0(\text{slow}) + 2e^- \]  (14)
\[ D_2^0 + D_2(\text{back}) \rightarrow 2D_2^0 + D_2(\text{back}) + 2e^- \]  (15)
\[ e^- + D_2(\text{back}) \rightarrow D_2^0 + e^- \]  (16)
\[ e^- + D_2(\text{back}) \rightarrow 2D_2^0 + e^- \]  (17)
\[ e^- + D_2(\text{back}) \rightarrow D_2^0 + D_2^0(\text{slow}) + e^- \]  (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)

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

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

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

Cylindrical vacuum chamber

Anodes

Winding wire around spherical foamed polystyrene

Remove by acetone

Guard fence

Wire cathode (Mo)
(wire diameter is 1mm)
Discharge characteristics of small anodes

![Discharge voltage (kV) vs. Gas pressure of H₂ (Pa) for different anode sizes: 60mm, 80mm, 100mm, and w/o anode. Each data point represents a different parameter set. The graph shows a clear trend where discharge voltage decreases with increasing gas pressure.]
Neutron Production Rate of small IECF device (single)

Fitting curve of NPR by original anode (300mm $\Phi$, I=5mA)

NPR of a small IECF device (80mm $\Phi$) is greater than original IECF device (300mm $\Phi$)

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

NPR of small IECF (80mm $\Phi$ anode) (I=5mA)

The cathode is shinling by over heating

80mm $\Phi$ anode at 1Pa, 31kV, 10mA
Parallel operation of Double IEC device (horizontal setting)

Two 100mm Anodes setting (side by side)

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

Setting appearance

Branched Cathode
Discharge characteristics of double IEC (horizontal setting)

Comparison of each discharge curves

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

(H₂, 5Pa, 5.7kV, with partition)
Parallel operation of double IEC devices (vertical type)

Two 100mm Anodes setting (vertically)

Discharge photo of H₂
10mA 1.6Pa 38.7kV
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.

Applied voltage (kV)

Gas pressure of $D_2$ (Pa)

NPR (1/sec)

The density of anode wires is different.
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 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

Now, the triple IECs are tested.

At next workshop, the tritium experiment will be finished