Overview of IEC Research at Tokyo Tech.

Eiki Hotta,
Ngamdee Wantapon, Keita Nobe, Kazuki Nanjo,
Hiroki Imaji, and Masato Watanabe
IEC Devices at Tokyo Tech.

Spherical IEC

Cylindrical IEC

Coaxial double cylindrical IEC

Cylindrical: Magnetic-assisted IEC

$B = 50 \text{ mT}, V = -15 \text{ kV}$
Recent IEC Research

◆ Double cylindrical IEC Device

✓ Uniform irradiation of neutron
  ✓ High quality semiconductor by NTD: Neutron Transmutation Doping
✓ High current pulsed operation
✓ Increase of NPR
✓ Long operation time

◆ Cylindrical IEC Device

✓ High current pulsed operation

✓ Magnetic field assistance
  ✓ Electron confinement, Ion source

Cusp or axial magnetic field
Coaxial Double Cylindrical IEC Device

- **Objectives:** High quality semiconductor production by Neutron Transmutation Doping (NTD)

  \[ ^{30}\text{Si} + n \rightarrow ^{31}\text{Si} \rightarrow ^{31}\text{P} + \beta \]

  (Neutron capture) (\(\beta^-\) decay)

- **Improvement of performance**
  - Uniform irradiation area
  - Stable long time operation
  - Increase of NPR

[Image of Coaxial Double Cylindrical IEC Device]

Neutron Transmutation Doping

http://sangaku.jaea.go.jp/3-facility/02-field/index-16.html
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**Coaxial Double Cylindrical IEC**

- Uniform neutron irradiation aiming at NTD: $^{30}\text{Si} \,(n, \beta)\,^{31}\text{P}$

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**Vacuum Chamber**

- **Anode (Inner cylinder)**
- **Cathode grid**
- **Anode (Outer cylinder)**

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**Irradiation Region**

- **85 cm**
- **79 cm**
- **37 cm**

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**Moderator (Water)**

**Reflector (Water)**
Measurement of NPR, Uniformity of Irradiation

Polyethylen (PE) block (Moderator)

Uniform irradiation area:
Neutron flux density within ±5%

Experimental condition
- D-D fusion, DC power supply, -30 kV, 60 mA
- Coolant temperature: 17°C - 8.3°C

1 mm Plate Cathode

Depth: 1 mm
Width: 5 mm
Diameter: 1.6 mm

<1mm Plate electrode>
Width: 1 mm
Depth: 5 mm

<5mm Plate electrode>
Width: 5 mm
Depth: 1 mm

<Rod electrode>
Diameter: 1.6 mm
Max. NPR $1.5 \times 10^6$ n/s

(Rod electrode, with cooling, -45 kV, 60 mA)
Waveforms in Pulsed Operation

charging current

rise time

delay time
current peak (100%)

(90%)

(10%)

\[ p = 4 \text{ mTorr} \]
NPR in Pulsed Operation

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NPR averaged over a pulse

Ngamdee Wantapon will introduce the detailed results in poster session

15th US–Japan Workshop on IEC at Kyoto University
Cylindrical IEC Device

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Cathode: φ1.6-mm Stainless Steel Rod x16
Anode: φ1.2-mm Stainless Steel Rod x32

Vacuum Chamber (393 mm Diameter, 340 mm High)

Anode Grid (200 mm Diameter, 320 mm High)

Cathode Grid (40 mm Diameter, 380 mm High)

H₂ or D₂ (1–10 mTorr)

0–100 kV

Grid electrodes

Cathode
Anode

Anode Bias

0–1 kV
Cylindrical IEC Device

Whole system

Vacuum Chamber

Feedthru

Anode Rod x32

Cathode Rod x16

40 mm

Side view of discharge

Bottom view of discharge
Cusp Magnetic Field + Anode Bias

Grid anode (Bias < -1 kV)

Grid cathode (DC, -100 kV, 60mA)

Chamber (GND)

Ferrite magnet (0.36 T)

Cusp magnetic field

Ion source Magnetron discharge

Axial cusp magnetic field for electron confinement and ion production:
Magnetron discharge
Effect of cusp magnetic field on NPR

Max. NPR
$1.1 \times 10^6 \text{ n/s}$
(30 kV, 50 mA)

With cusp magnetic field
$\sim 1.5$ times higher NPR,
although NPR $\propto I$ does not change
Anode Bias

Biased with anode resistor and DC power supply
...ions are extracted by bias voltage towards the center efficiently
Effect of Bias Voltage on NPR

NPR increases with increasing the bias voltage, then saturates.

Number of generated ions is limited.
Region of Stable DC Discharge

Periodic discharge occurs with cusp magnetic field

10 mA, 15 kV, no bias

Stable region shifts to higher current, lower voltage

High neutron yield is available in PULSED operation with an adequate power supply
The pulsed power supply was developed for landmine detection system.

Electric circuit

Practical waveform of pulsed operation (40 kV, bias 50 kΩ, 8.08 mTorr)
The biased anode is also effective in pulsed operation.

The maximum neutron production rate of $6.8 \times 10^9$ n/s was obtained at a pulsed discharge of $-70$ kV, 10 A with bias voltage of $-1.0$ kV.
Cusp Magnetic Field: From axial to azimuthal

Axial cusp magnetic field

Electrons move in axial direction by ExB drift
→ Electron confinement is not good enough

Azimuthal cusp magnetic field

Electrons drift in azimuthal direction
→ Better electron confinement
IEC Device with Azimuthal Cusp Magnetic Field

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Cathode grid
(ϕ 40 mm, h 380 mm)

Anode grid
(ϕ 200 mm, h 320 mm)

Electro magnet
(100 turns)

Vacuum chamber
(ϕ 393 mm, h 340 mm)

Deuterium gas
(~ 1 Pa)

0–100 kV

0–1 kV
Magnetic Field Distribution

When $E=20$ kV/10 cm and $B=10$ mT, Larmor radius of electron is 1.2 cm.
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NPR Dependence on Discharge Current

- With cusp magnetic field low pressure operation is realized
- NPR is slightly increased
- This means cusp magnetic field acts as an ion source

\[
\begin{align*}
\text{Neutron Production Rate [n/s]} \times 10^5
\end{align*}
\]

- with Cusp (4coils)
- w/o Cusp

- 7.7mTorr~ , 300K~
- 8.7mTorr~ , 300K~

\[ V_c = 20\text{kV} \]
Voltage - Current Characteristics

DC : Normal glow
Pulsed : Abnormal glow

Empirical formula of discharge voltage obtained by Aston
\[ V = K_1 + K_2 \, j^{1/2} \]

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1 A: 7.2 mA/cm²
The boundary between the normal and the abnormal glow depends on the cathode material and filling gas species. Transition from abnormal glow to arc depends on the cathode temperature.
Summary

◼ Several types of IEC devices: DC and pulsed operation

◼ Spherical device: Point source
  – fundamental research

◼ Cylindrical device: Line source
  – Line magnetic cusp field was tested
    ● Pulsed operation: Max. NPR $7.4 \times 10^9$ n/s at 80 kV, 15 A, 20 $\mu$s
    – D-$^3$He reaction was demonstrated to get high energy proton (14.7 MeV)

◼ Coaxial double cylindrical device: Cylindrical source
  – Uniform neutron irradiation area
  – For high quality semiconductor production by NTD

◼ Recent research: Effect of magnetic field

◼ Azimuthal cusp magnetic field
IEC Laboratories in the World

Dr. Smruti R. Mohanty
Centre of Plasma Physics
(Assam, India)
Thank you for your attention