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Duoplasmatron type molecular carbon ion source

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DuoPlasmatron ion source

NUCLEAR INSTRUMENTS AND METHODS **15** (1962) 193–196
NORTH-HOLLAND PUBLISHING CO.

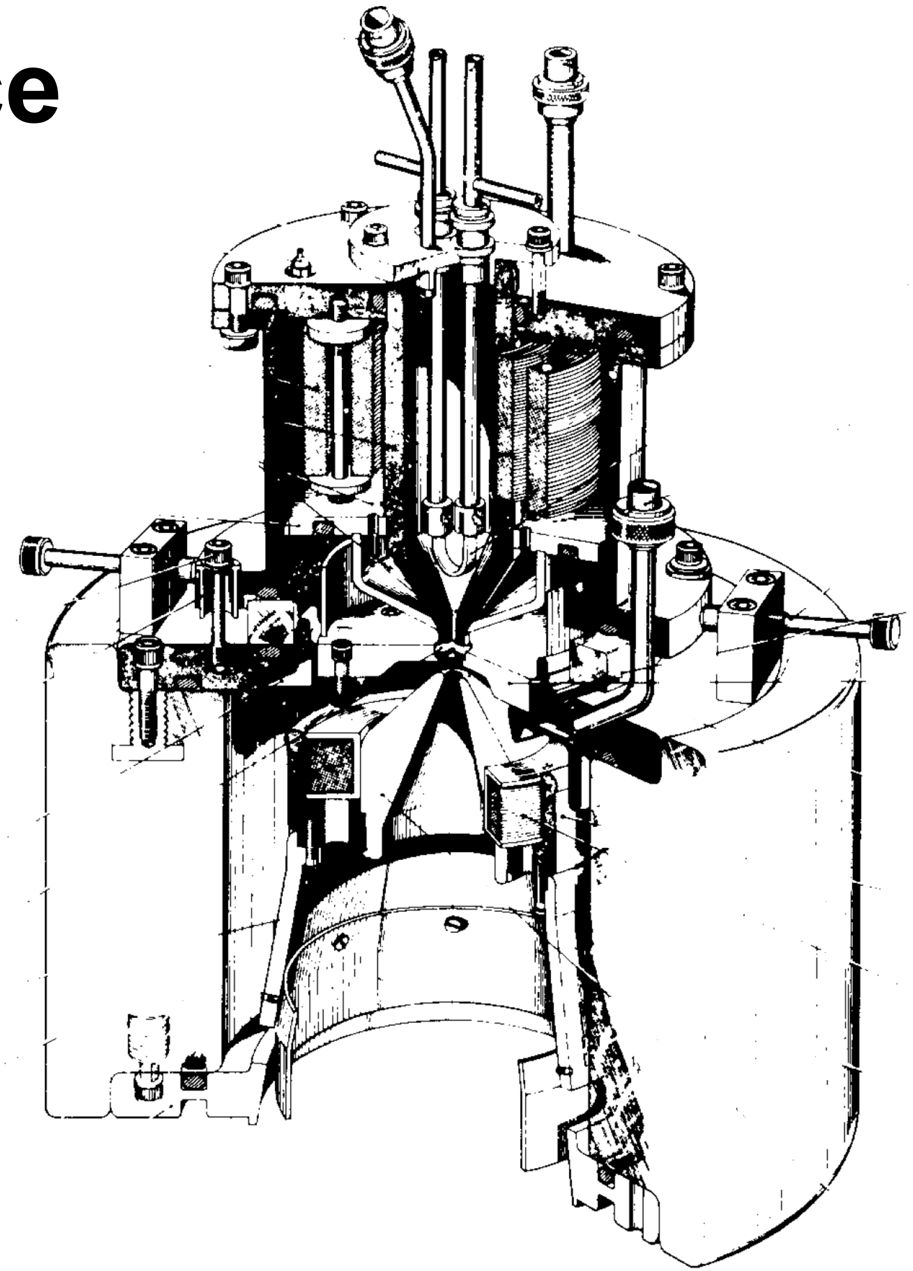
ION BEAM CONTROL IN A DUOPLASMATRON SOURCE

L. E. COLLINS and R. J. BROOKER

Atomic Weapons Research Establishment, Aldermaston, Berks.

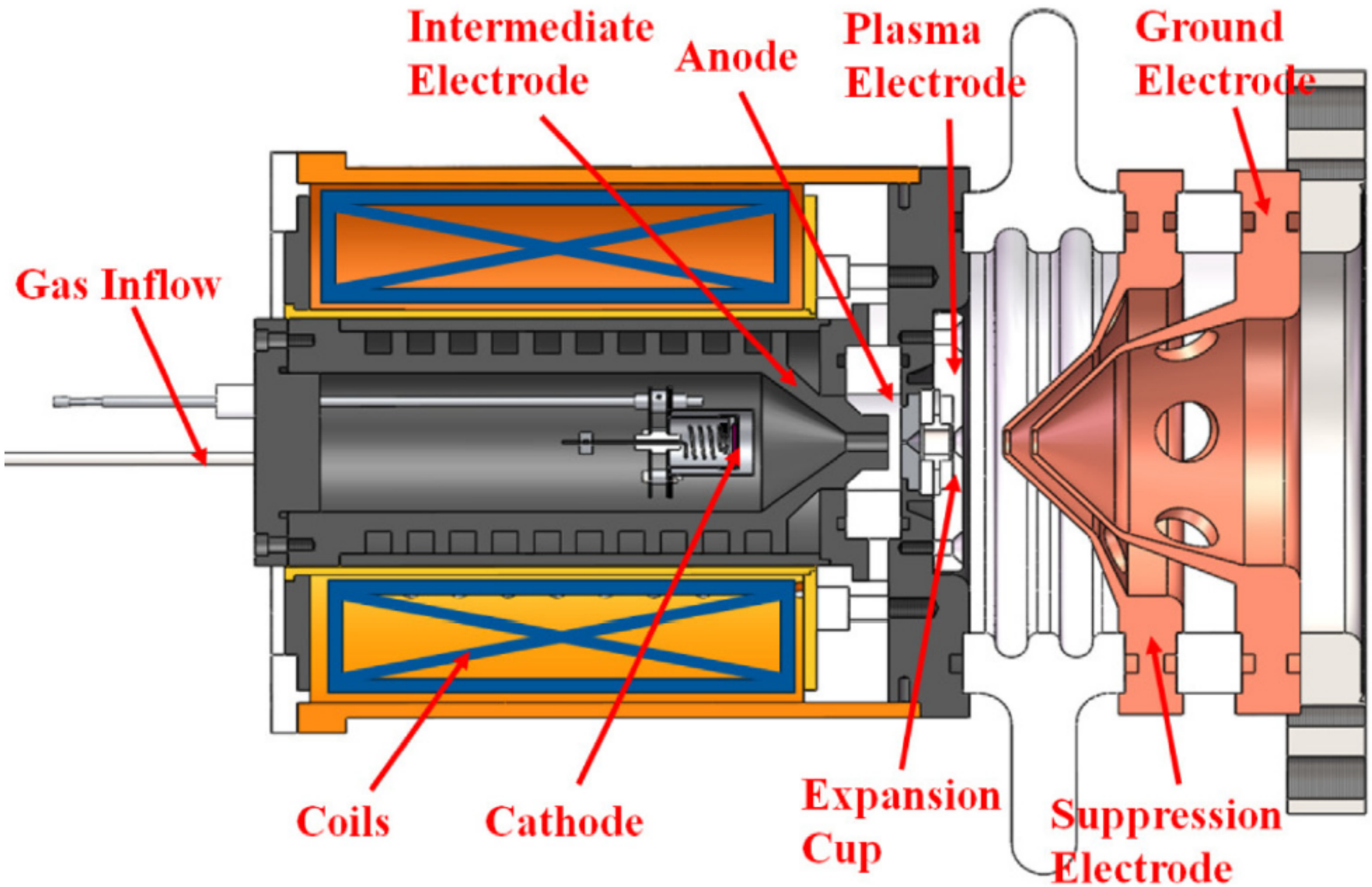
Received 28 December 1961

- Structure fixed in 1950s.
- Plasma is compressed geometrically and magnetically.
- High degree of ionization made the plasma density too high for achieving focused ion beam.
- “Expansion cup” creates plasma suitable foe ion extraction without reducing degree of ionization.



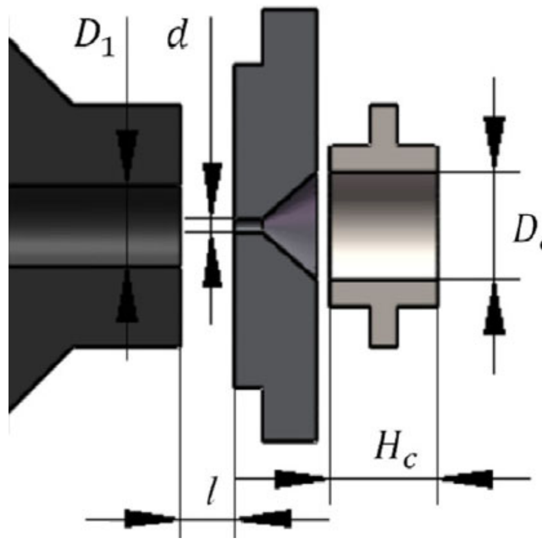
Contemporary source

B. Zhou, H. Zhang, P. Zhang et al. Nuclear Inst. and Methods in Physics Research, A 1010 (2021) 165550



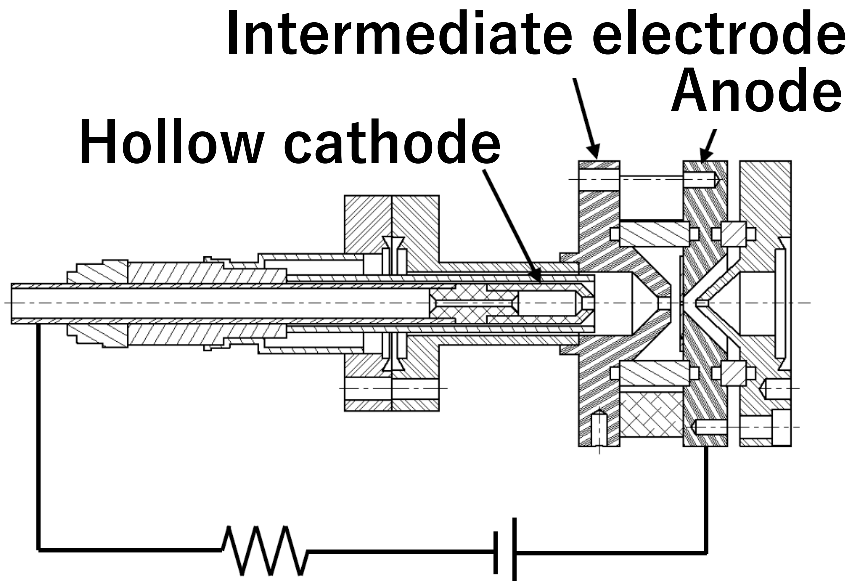
- Magnetic circuit closed at the plasma electrode.
- Plasma is compressed down to less than 6 mm, and pass through a 1 mm diameter orifice.

D_1 : 6 mm
d : 1mm
l : 4 mm
H_c : 8 mm
Dc :8 mm

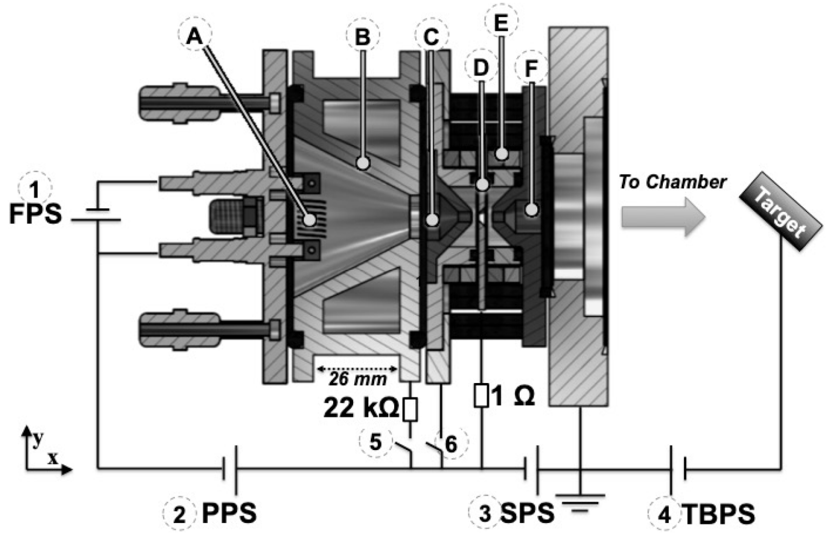


Recent activities

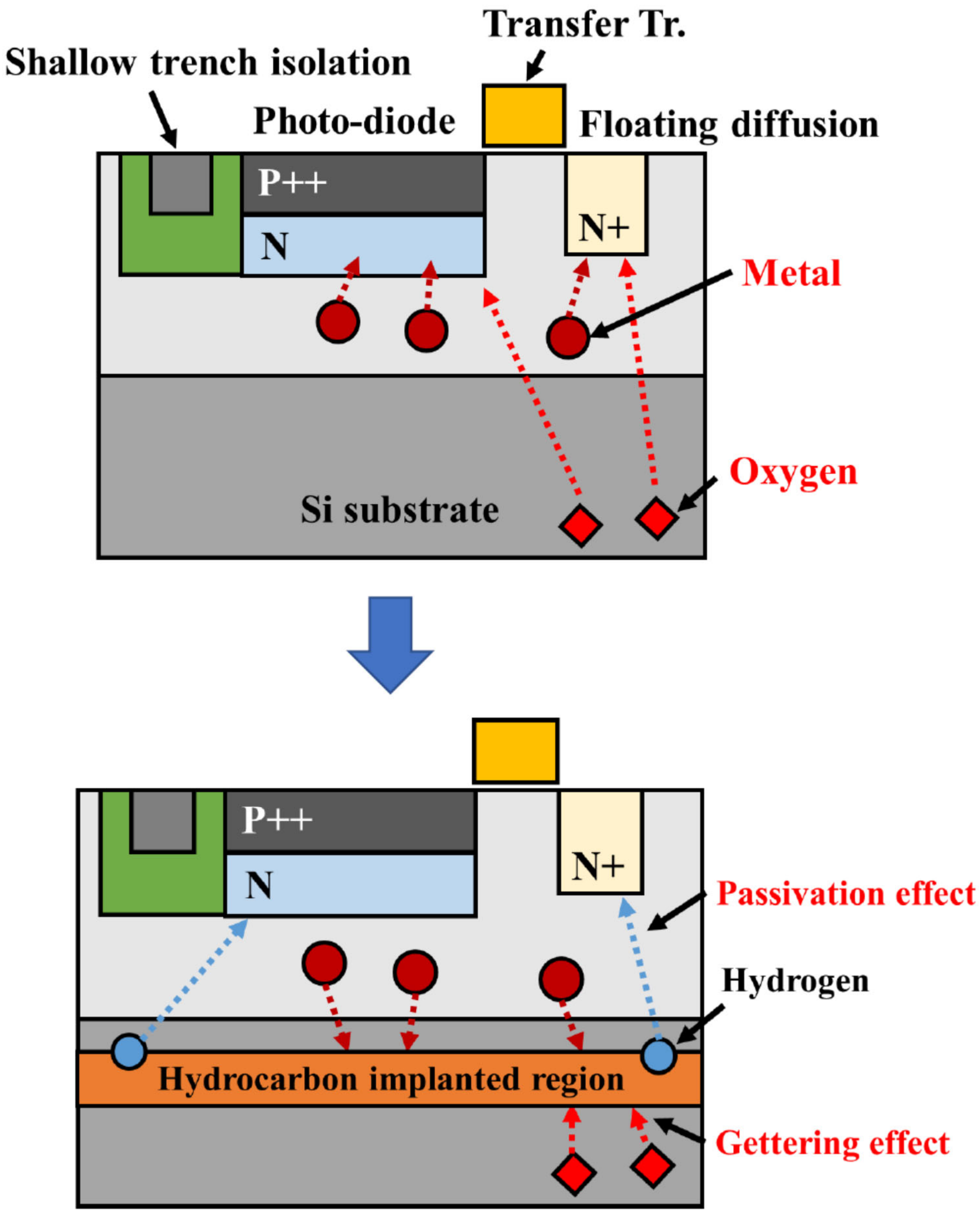
- Compact ion source attached to an ICF-34 flange. RSI, 91, 013505 (2020).



- Plasma cathode for a linear field device.
  Plasma Fusion Res. 15, 1401048 (2020).



Miniturization using high energy density permanent magnets.

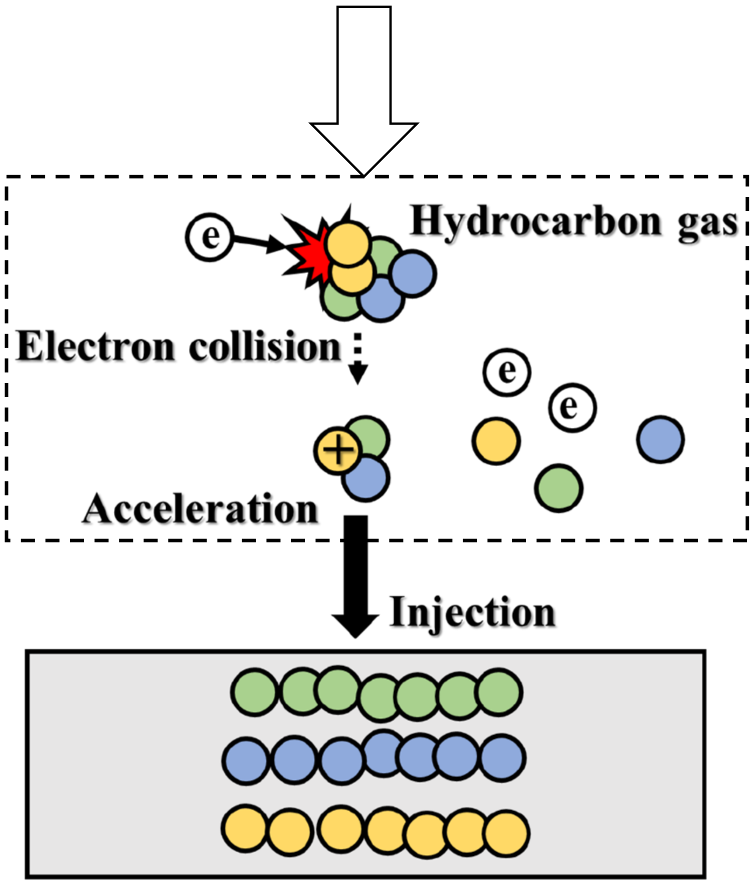


Motivation for this time

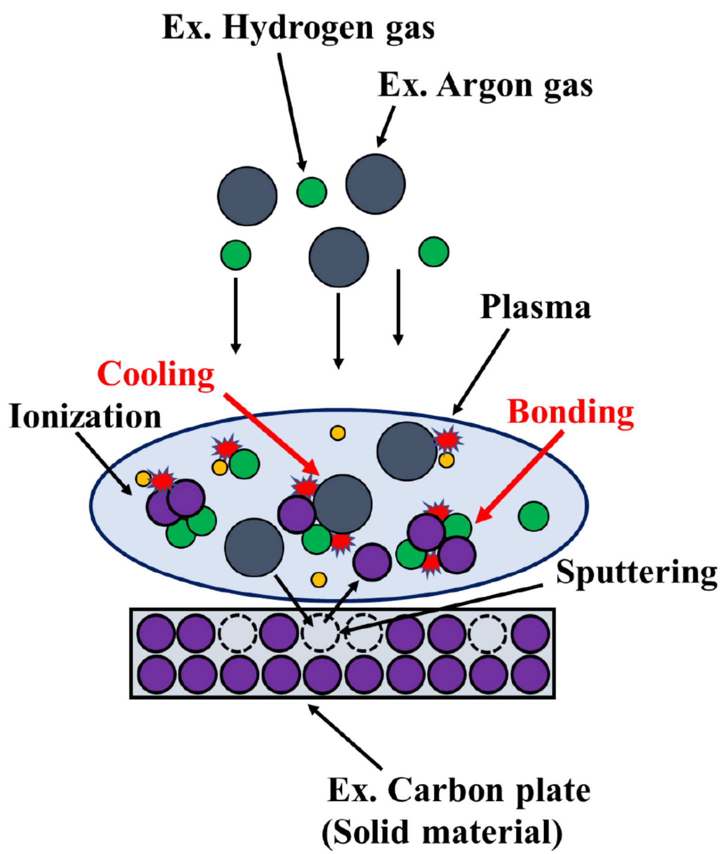
- Compact device → H^0 source.
- Plasma cathode → Light source (Spectroscopy)

- Production of carbon (hydride) molecular ions for shallow implantation.
- The goal is to prepare an implantation layer rich in C_nH_m to improve performance of an image capture device.

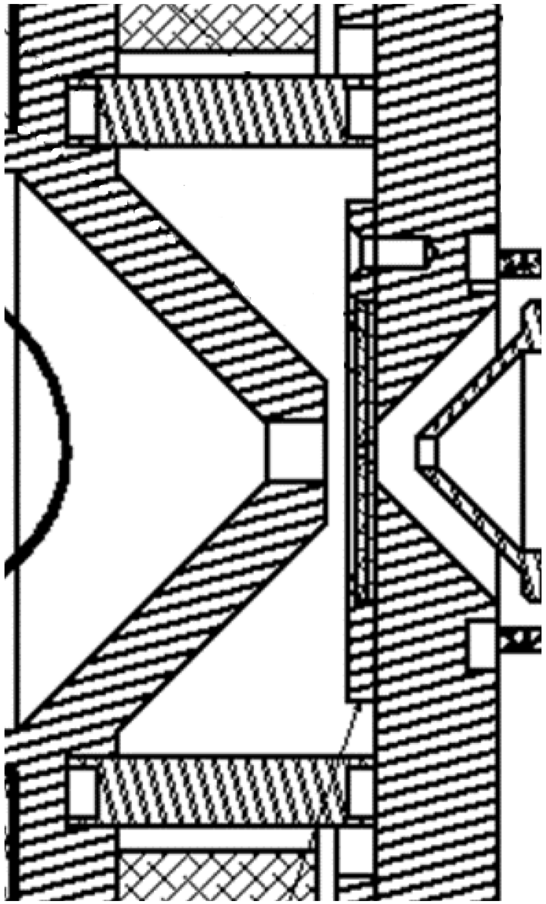
Two approaches

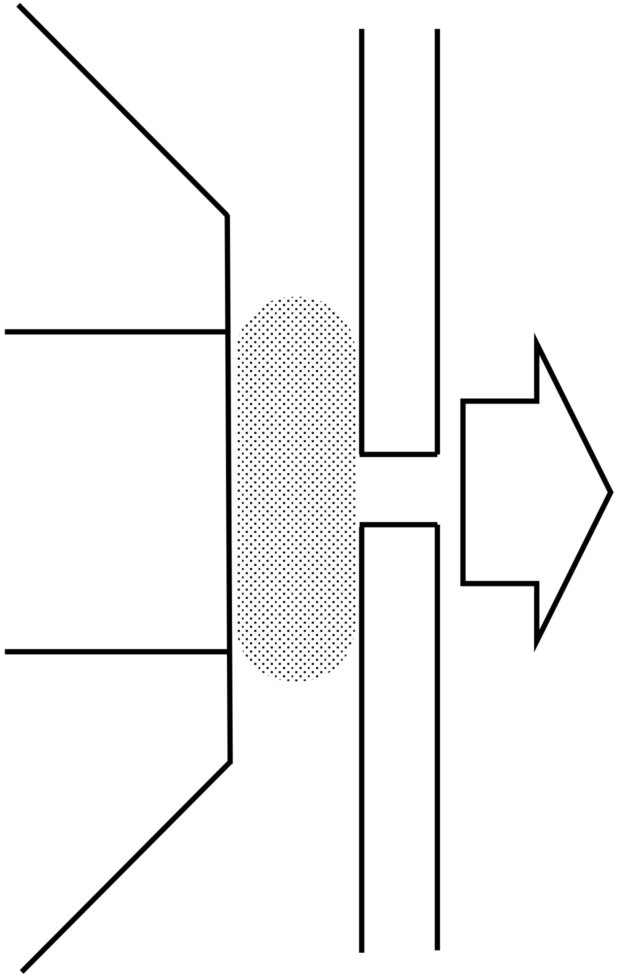


- Volume process and surface process.
- Fundamental data are available from plasma-wall interaction study for nuclear fusion experiment.
- Carbon surface in hydrogen plasma is saturated with hydrogen.
- Cluster ions formed by Ar^{+} bombardment.



Ion production from plasma-surface interaction

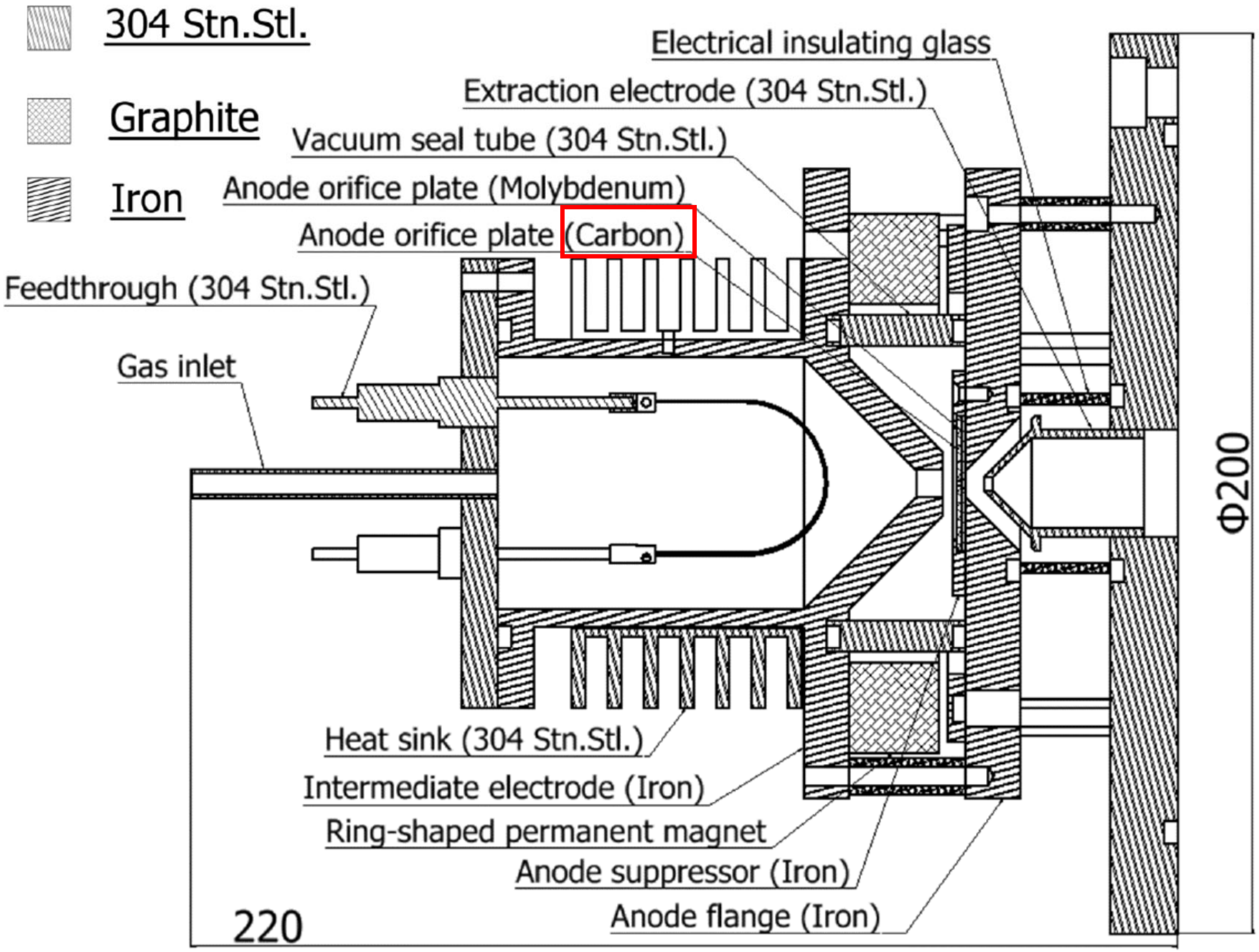




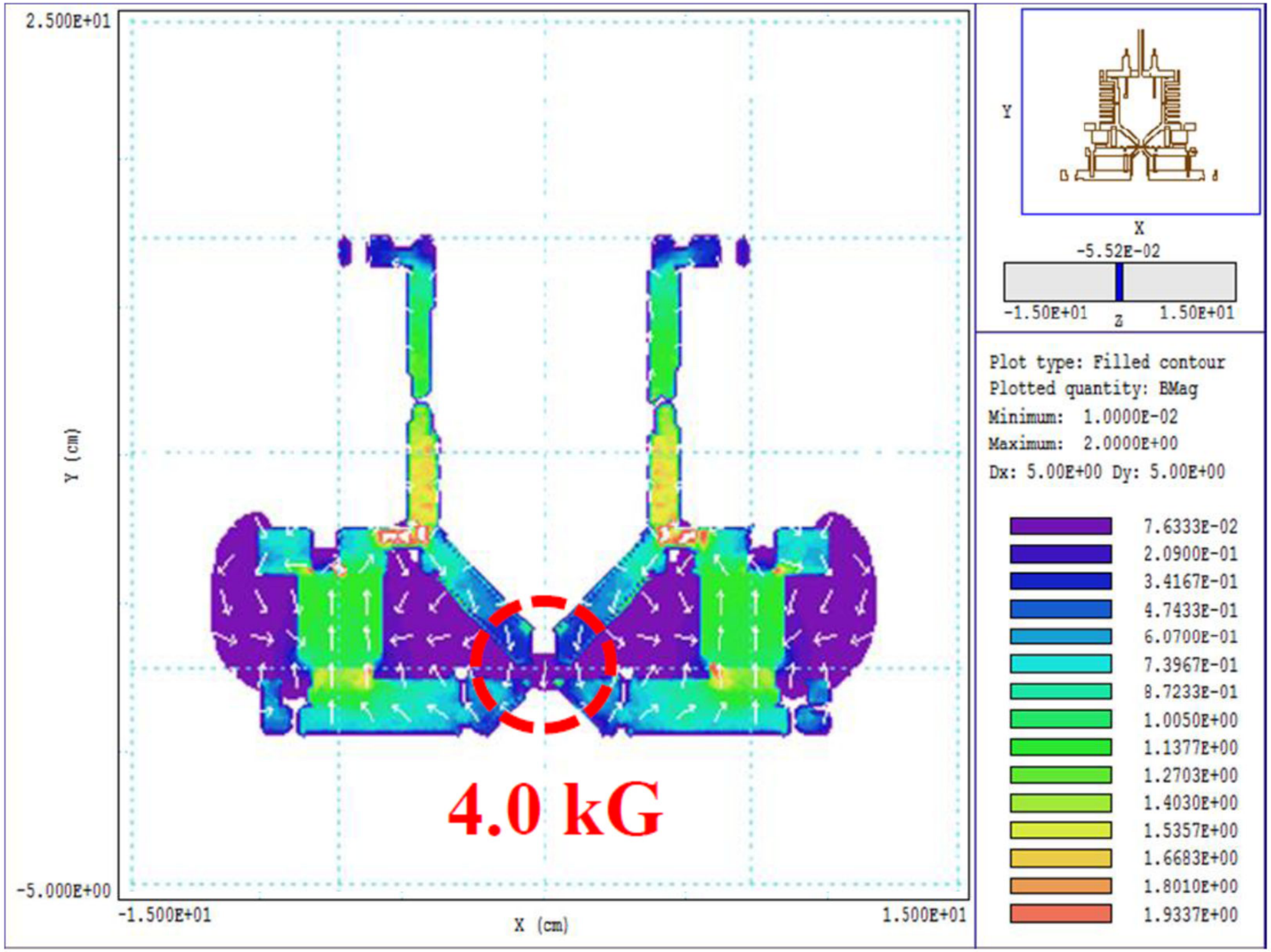
- Carbon surface produce carbon molecular ions by plasma surface interaction.
- Carbon clusters are known to be formed by heavy ion bombardment.
- Carbon hydride ions are produced by hydrogen saturated carobn surface

Basic design

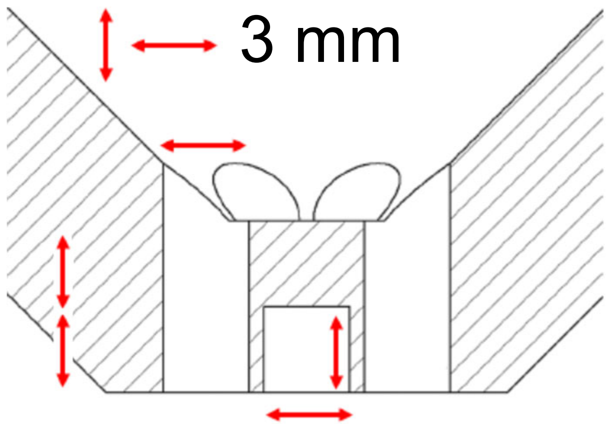
- Permanent magnet (single toroidal magnet) produces compression field.
- Low power density operation without expansion cup.
- High temperature discharge cathode.
- Forced air cooling.
- Single gap extraction.



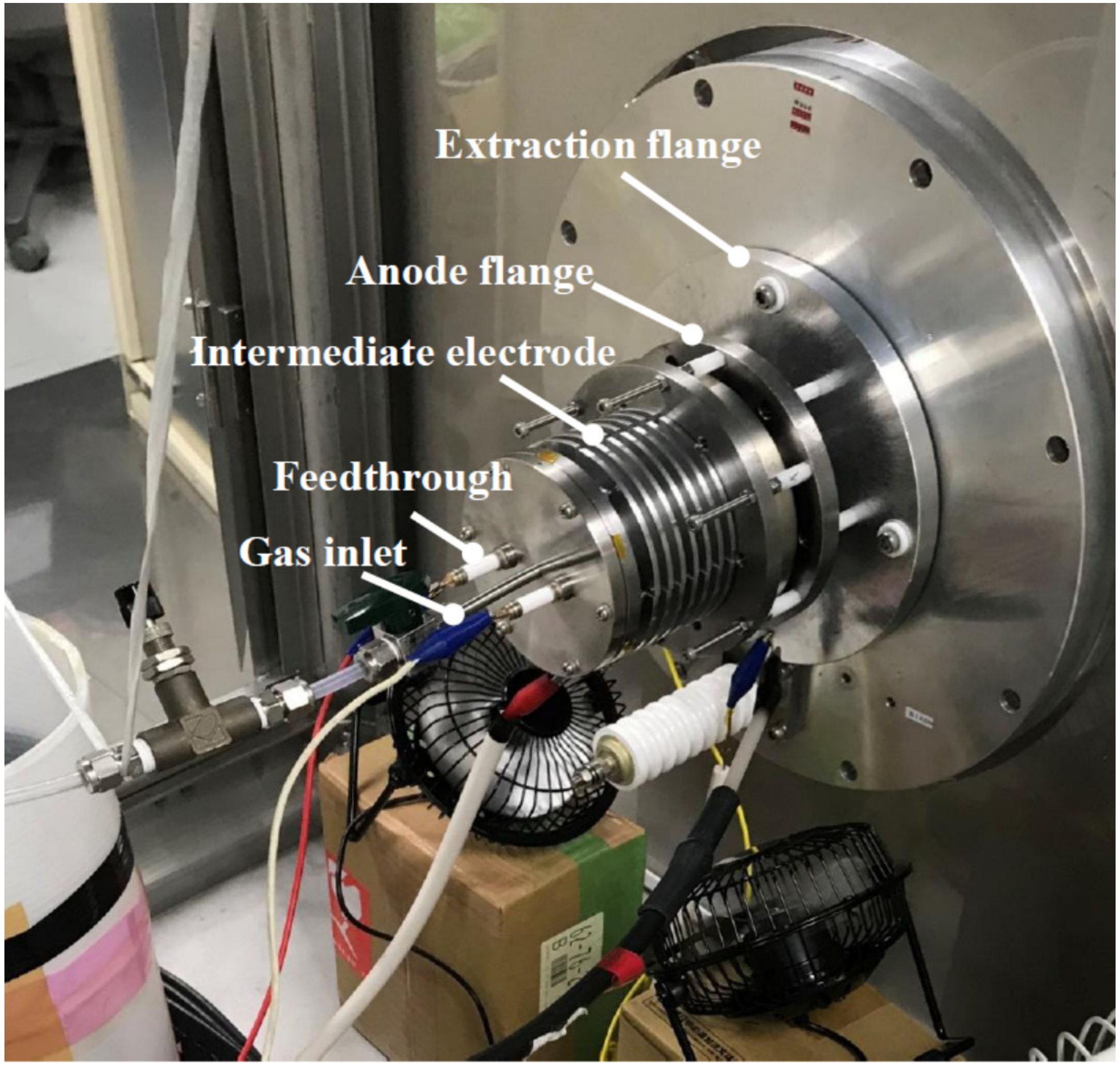
Design modification

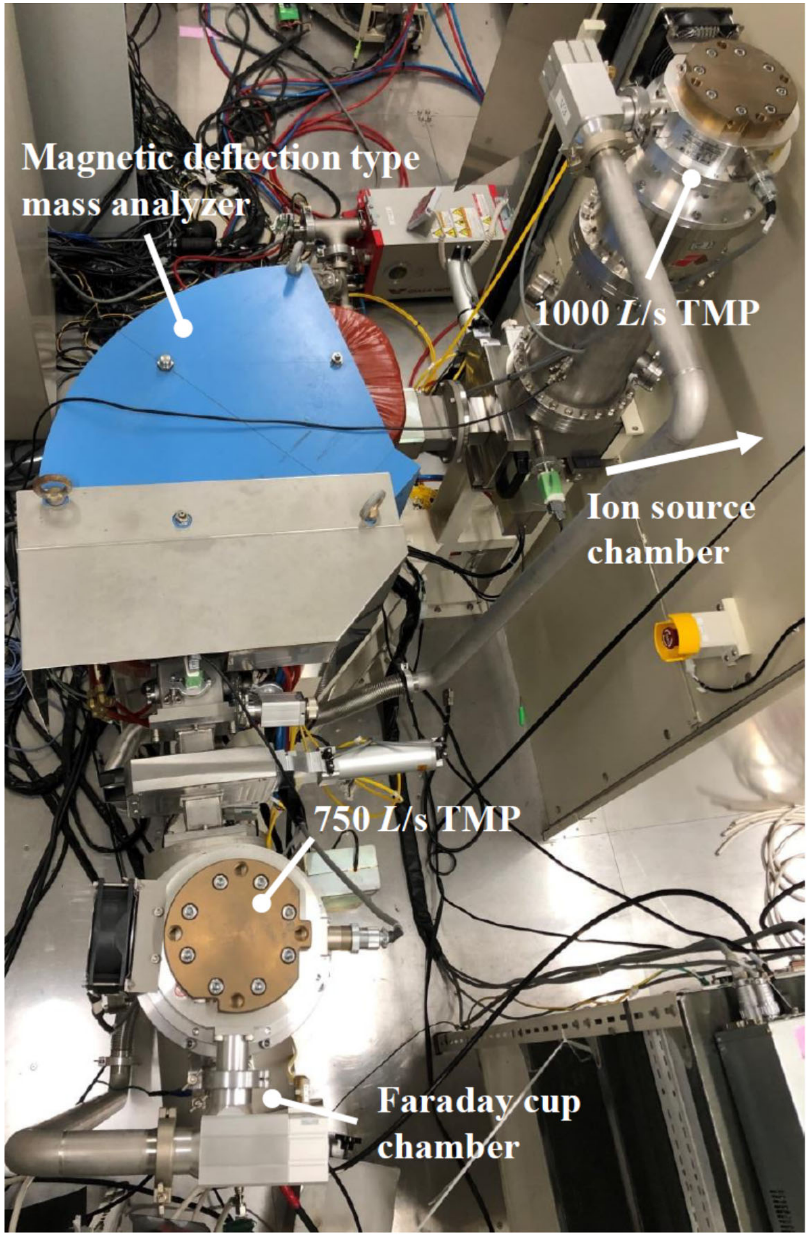


- A calculation result shows broad region of high B-field intensity.
- Opened six holes for plasma channels in the intermediate electrode.



Experimental arrangement

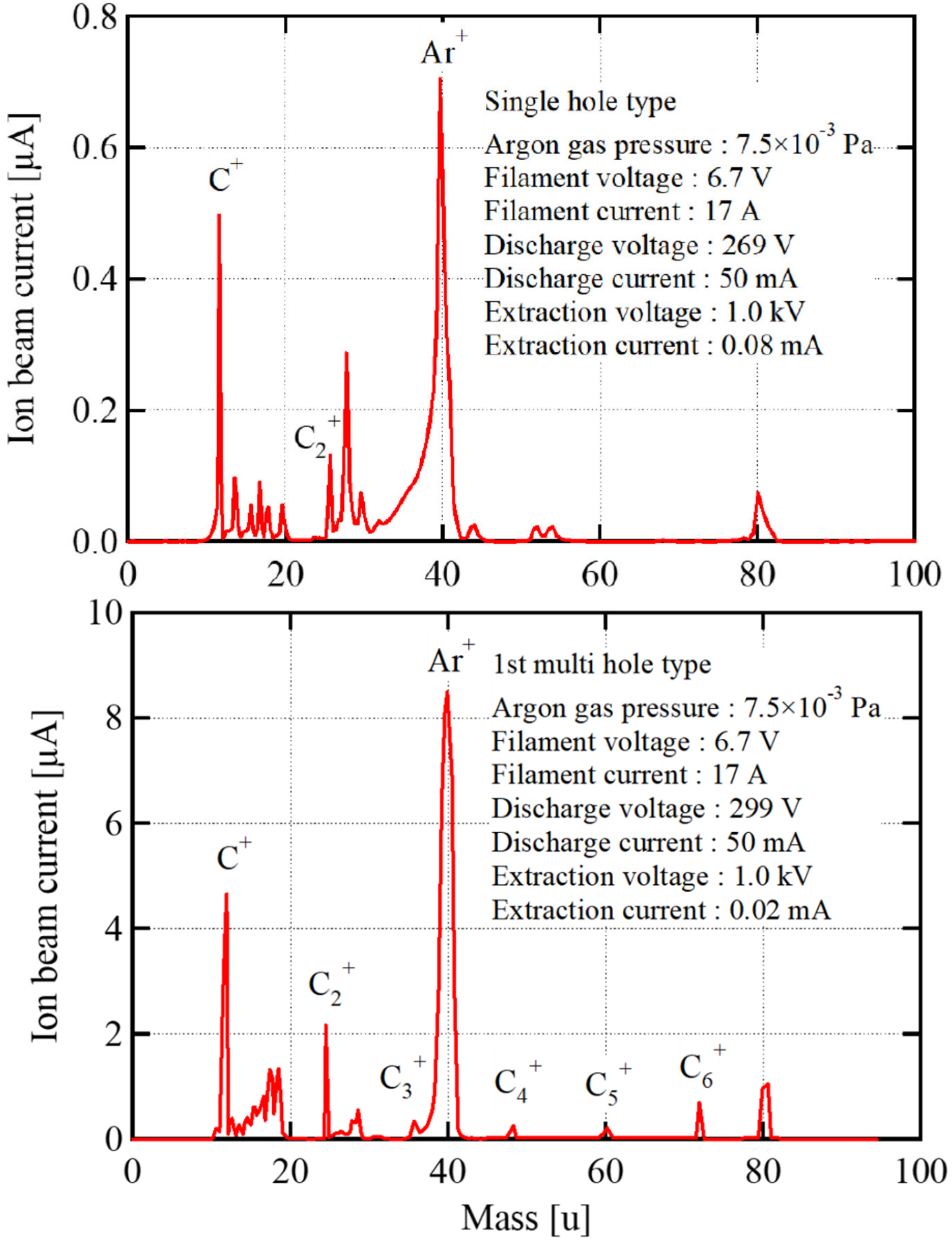




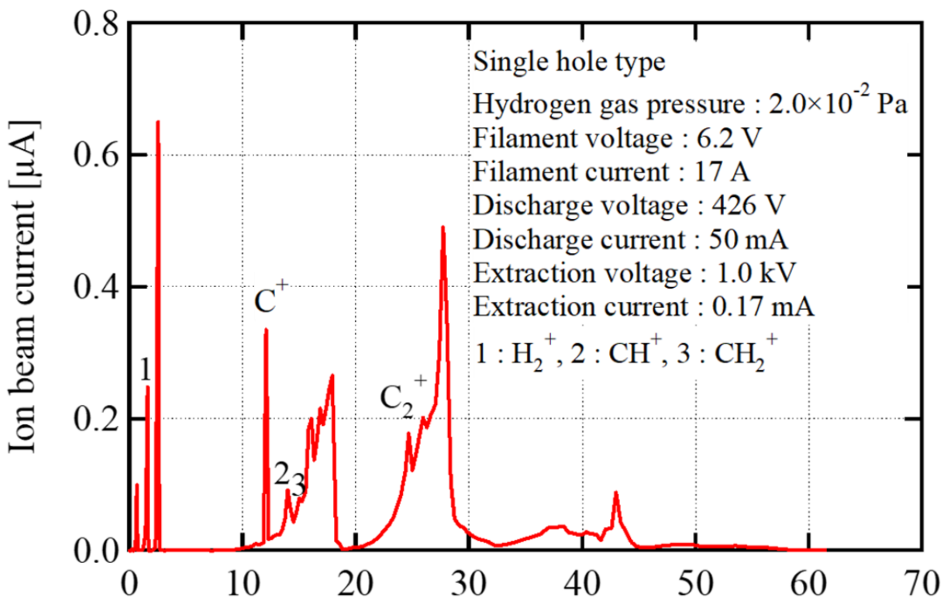
Center hole → side holes

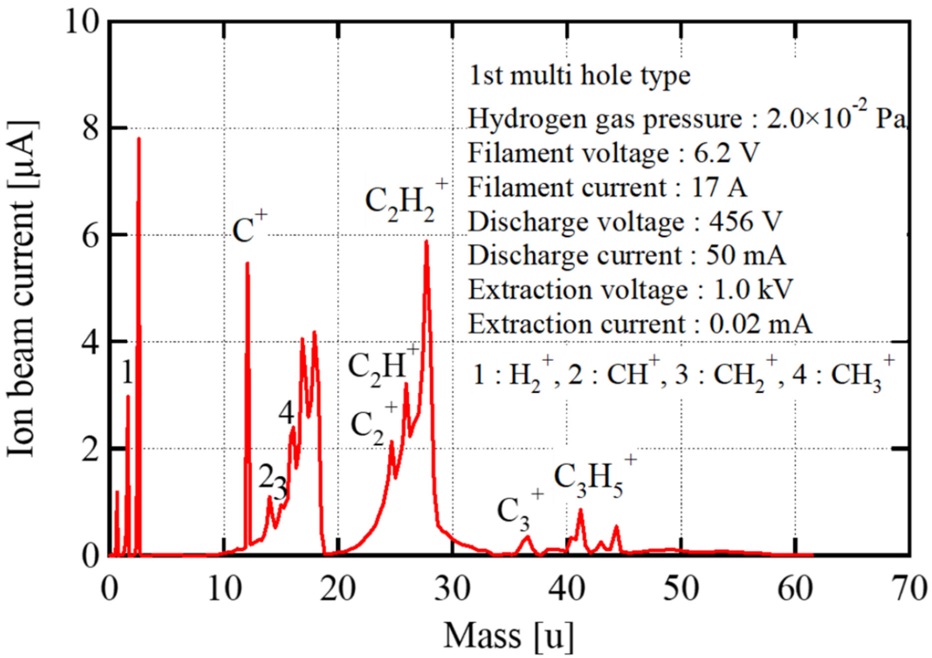
Experiment with Ar gas.

- Single hole intermediate electrode did not produce enough beam (may be due to absence of expansion cup.)
- Charge exchange component was present for Ar^+ beam.
- Cluster ion upto C_6^+ was observed.



Center→side

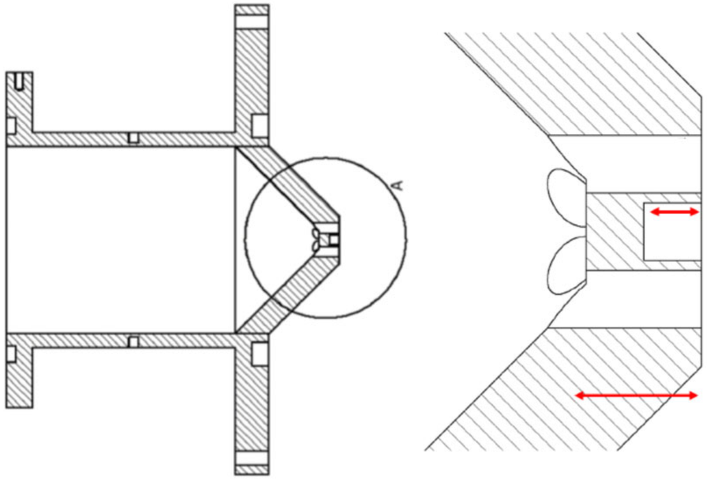


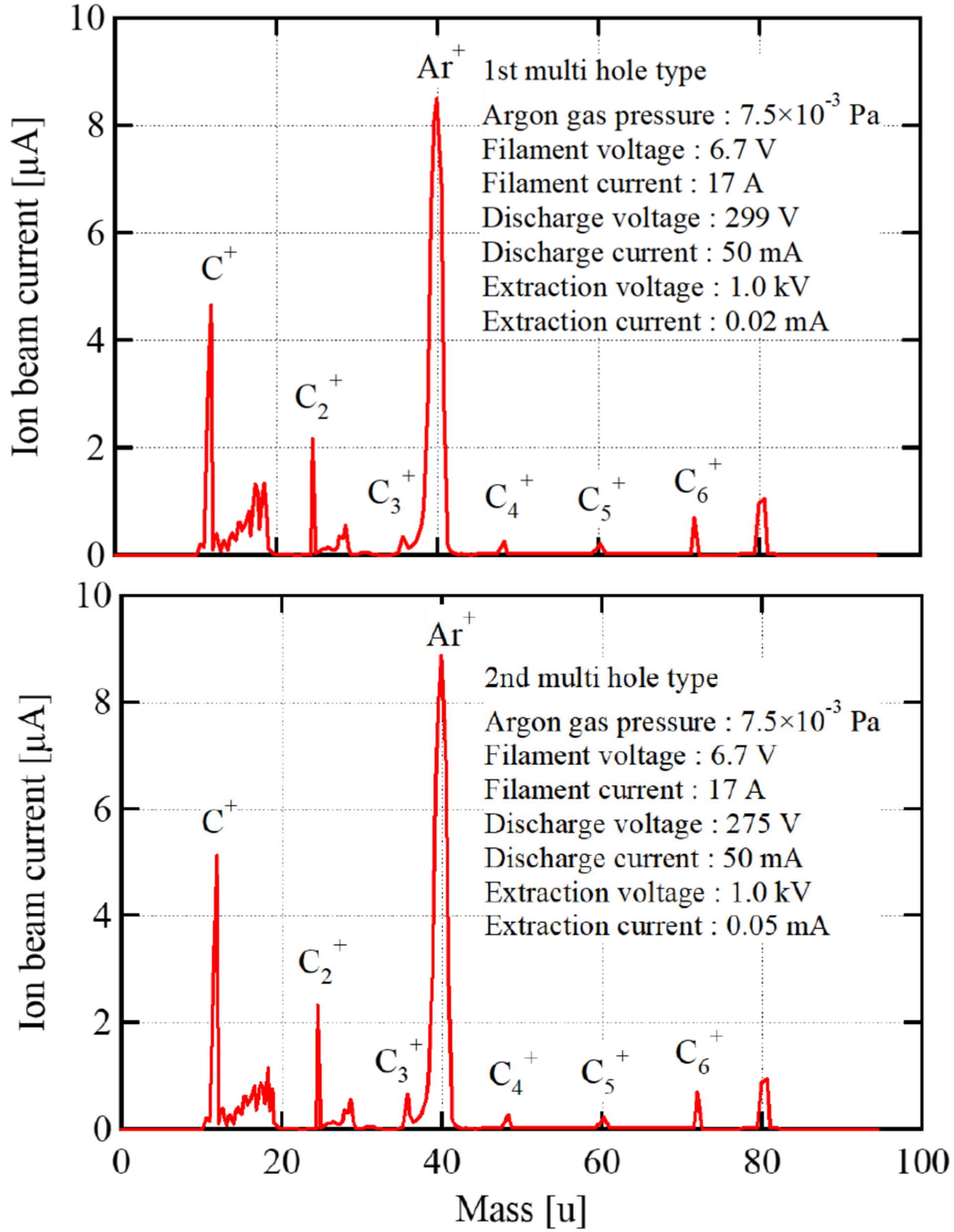


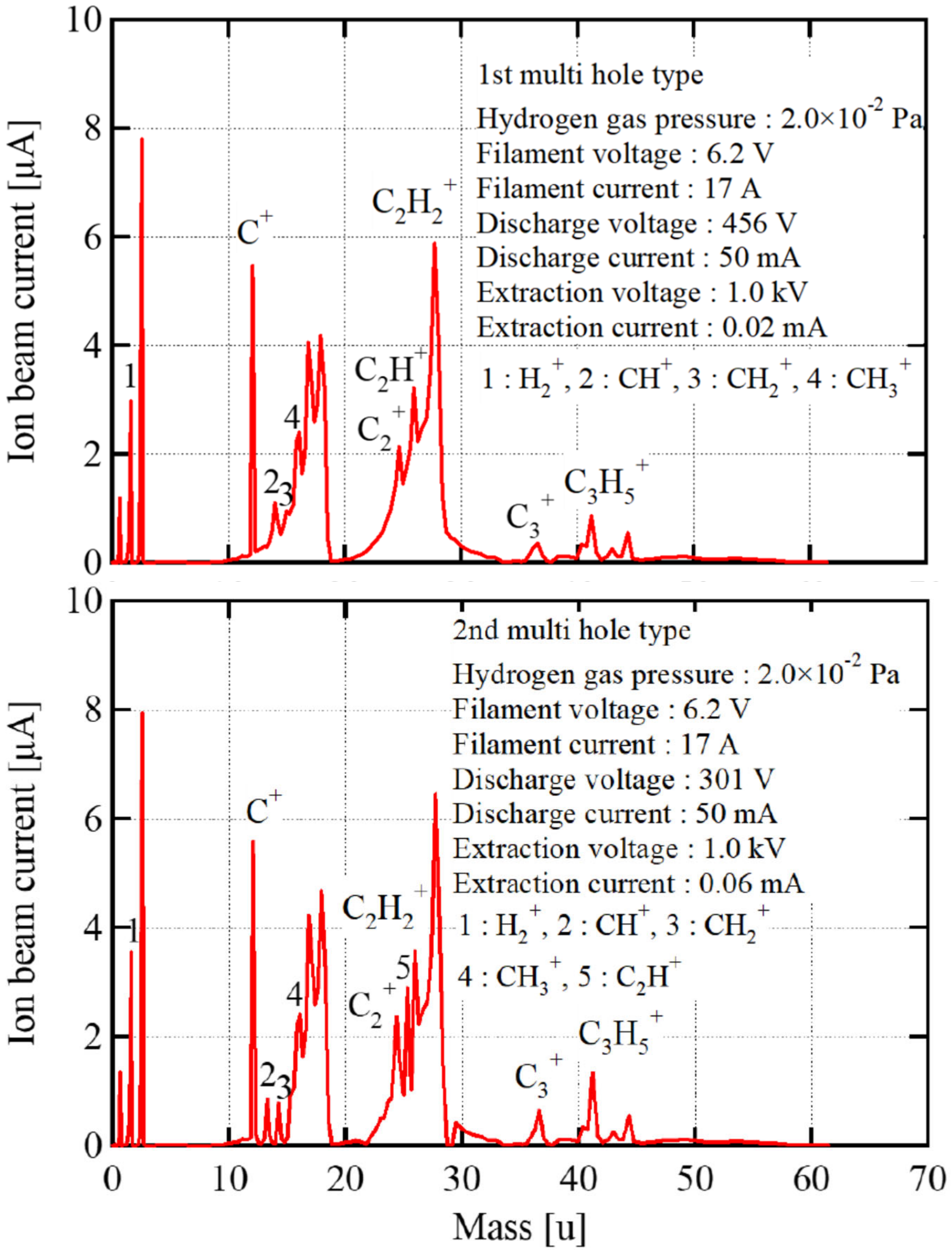
- Hydrogen discharge produced C_nH_m.
- Multihole intermediate electrode did not change the mass spectrum much. (Possibly, some smaller charge exchange component, that revealed C_3^+ peak. Also, C_2H^+ current increased a little.)
- Ratio of carbon containing molecular ion beams to hydrogen ion beams seems a little larger for
- The beam intensity increased by one order of magnitude.

Addition of reaction volum

- The effect due to enlarging the volume in the extraction region did not appear clearly for Ar.
- When the intensities of carbon containing ions were normalized to Ar^+, no substantial enhancement by the extraction volume was recognized.





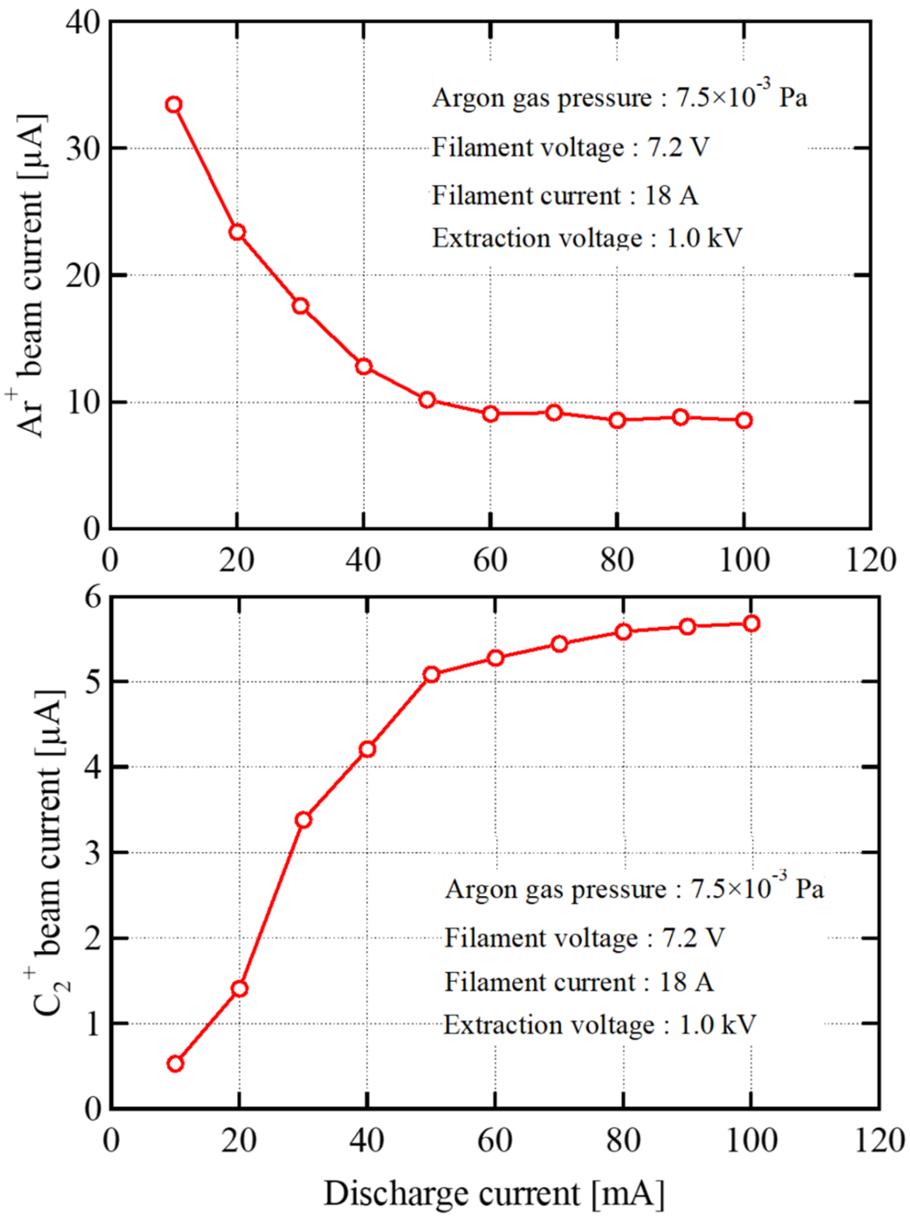


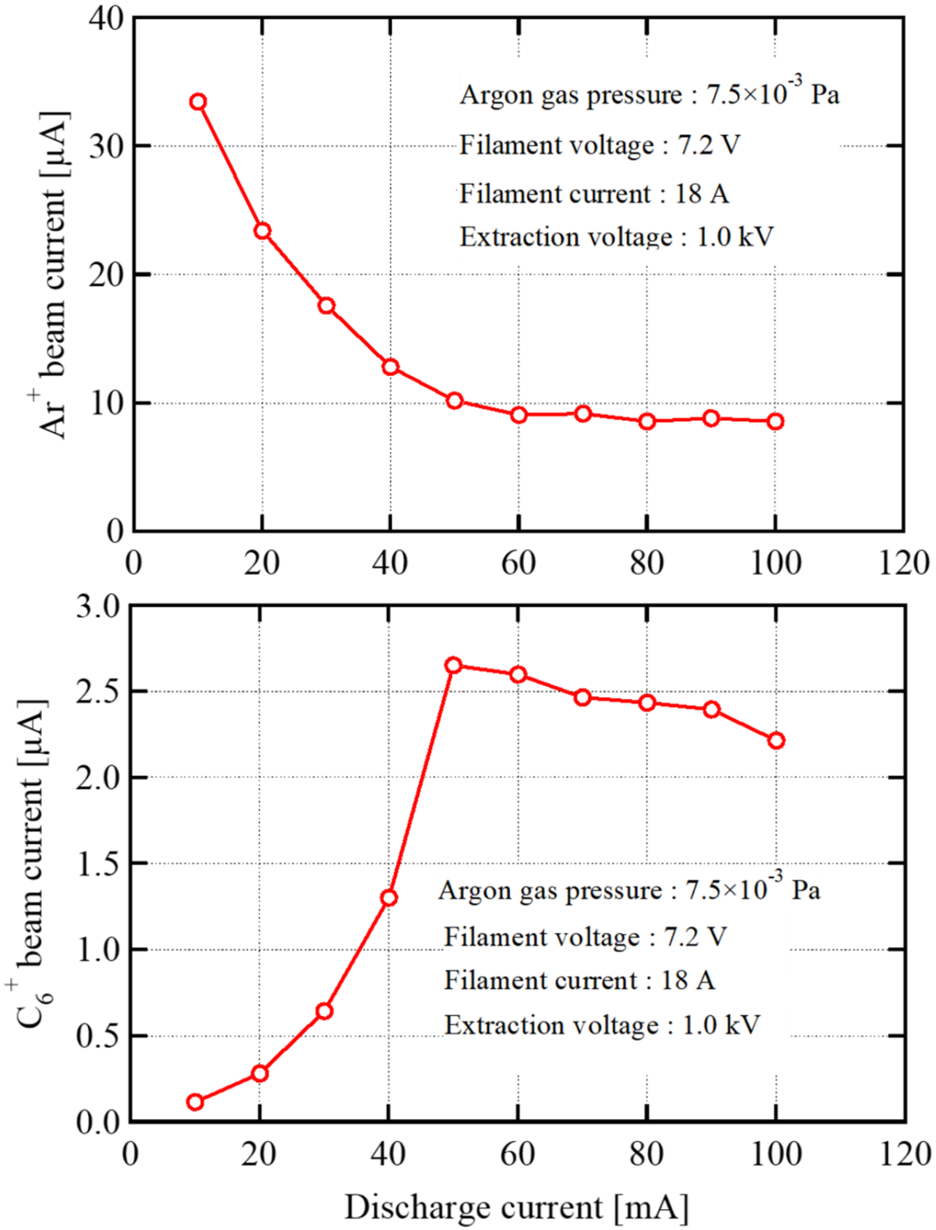
Too small volume?

- Hydrogen peaks (H^+, H_2^+, H_3^+) showed higher intensities.
- Spectrum was obtained with better resolution with the extraction volume. (smaller charge exchange component.)
- Extraction volume made intensities of both C_3^+ and $C_3H_5^+$ peaks larger.

Optimization of operation parameters

- Ar^+ ion beam current decreased against increasing discharge current.
- Meanwhile, C_2^+ ion current increased with discharge current.
- At Id = 50 mA, C_2^+ ion current nearly saturated.
- Dense plasma is needed to produce C_2^+ ions, but the density in the extraction region can be too high for 1 kV extraction. (Field too low.)



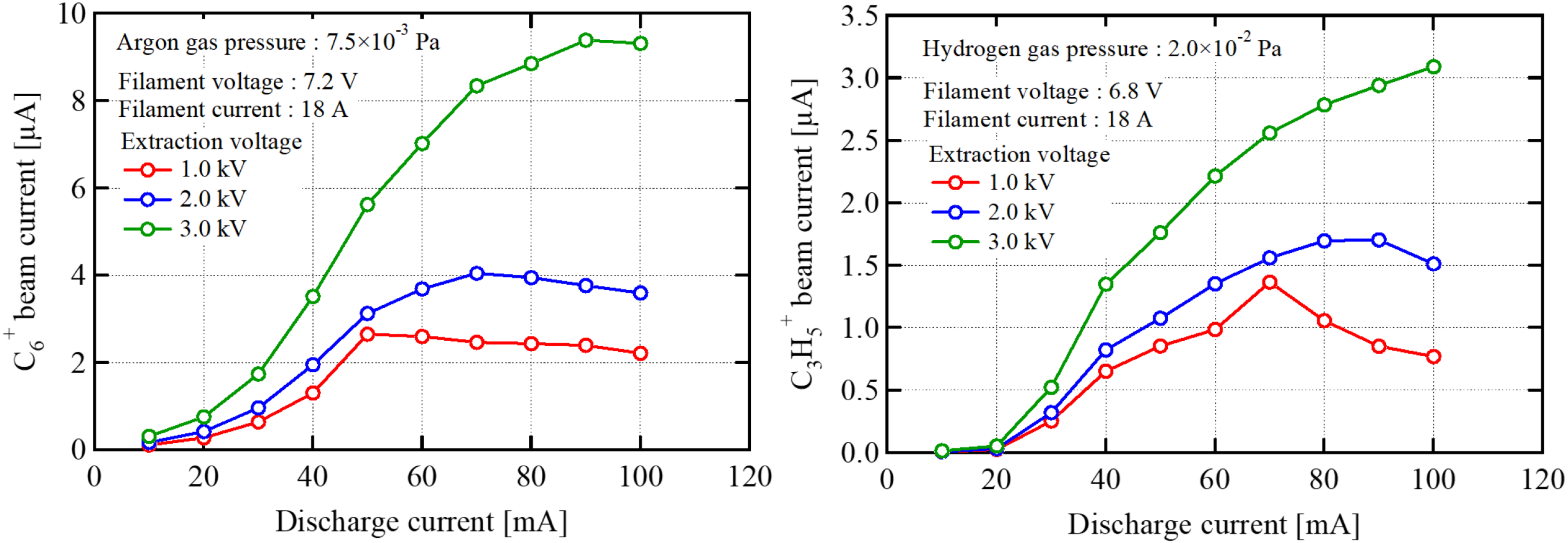


Larger cluster

- Intensity of C_6^+ ion current took the maximum at Id = 50 mA.
- Above 50 mA, the ion current gradually decreased more rapidly than Ar^+ ion current.
- Carbon molecule emissions can depend upon ion flux. (Smaller C_6 molecules at higher Ar^+ ion flux.)
- Carbon molecules can dissociate in denser plasma.

Beam extraction

- The easiest solution is to increase extraction voltage. (But this can go agains "shallow" implantation.)
- Nearly the identical characteristics against extraction voltage were found for $C_3H_5^+$ extraction from H_2 plasma.



Duoplasmatron for molecular ion extraction

- A duoplasmatron ion source with the cabon extraction aperture produced carbon molecular ions.
- The principle of producing carbon molecular ions by plasma-surface interaction was confirmed.
- Carbon molecular ions are extracted from the source with Ar discharge support gas.
- Introduction of hydrogen gas into the source produced $C_nH_m^+$ ions.
- Multi-hole intermediate electrode increased the production rate of carbon molecular ions for Ar discharge support gas.
- Multi-hole electrode also increased the production rate of $C_3H_5^+$ with hydrogen gas operation.
- The source structure can be improved to produce desired ion species.