Langmuir-probe measurement through the plasma grid aperture of hydrogen negative ion source

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Neutral Beam Injection (NBI) is an essential tool for plasma heating and current drive

- To satisfy the Lawson criteria of fusion plasmas, we need to realize high performance plasmas of T_i=10keV and n_i=10^{20} [m^{-3}] with external plasma heating. In addition, current drive by external power injection is necessary in tokamak device.
- In order to fulfill these requirements, NBI can be robustly applied as an external power source.
- Realization of efficient NBI system is one of the key issues in realizing efficient fusion power plant.

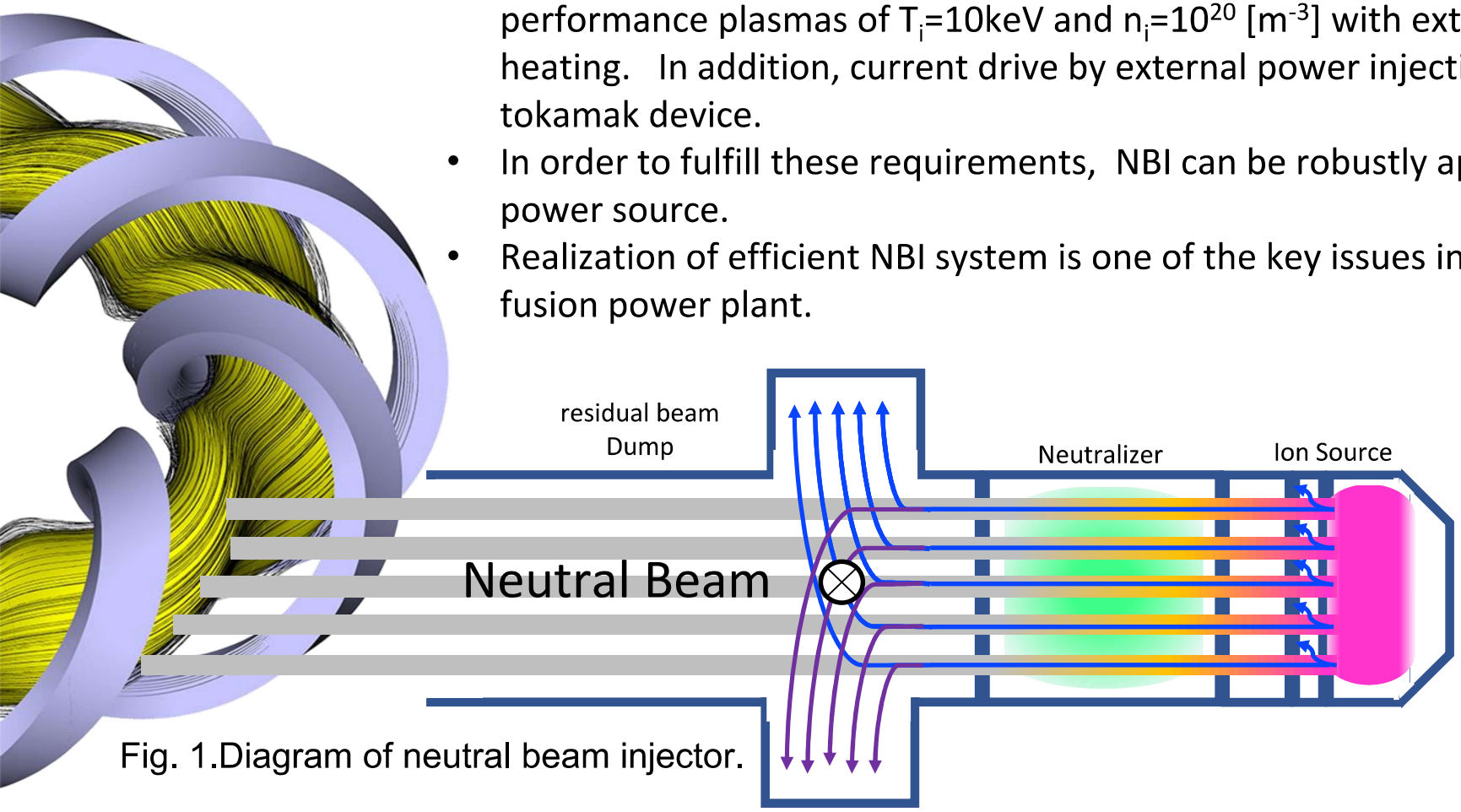


Fig. 1.Diagram of neutral beam injector.

Beam Extraction Boundary

- In the vicinity of the PG aperture called “extraction area”, a meniscus is formed as a boundary between plasma and beam regions as shown in Fig. 2.
- Beamlet focusing is strongly affected by the meniscus shape, which depends on the variations of negative-ion density and applied extraction voltage

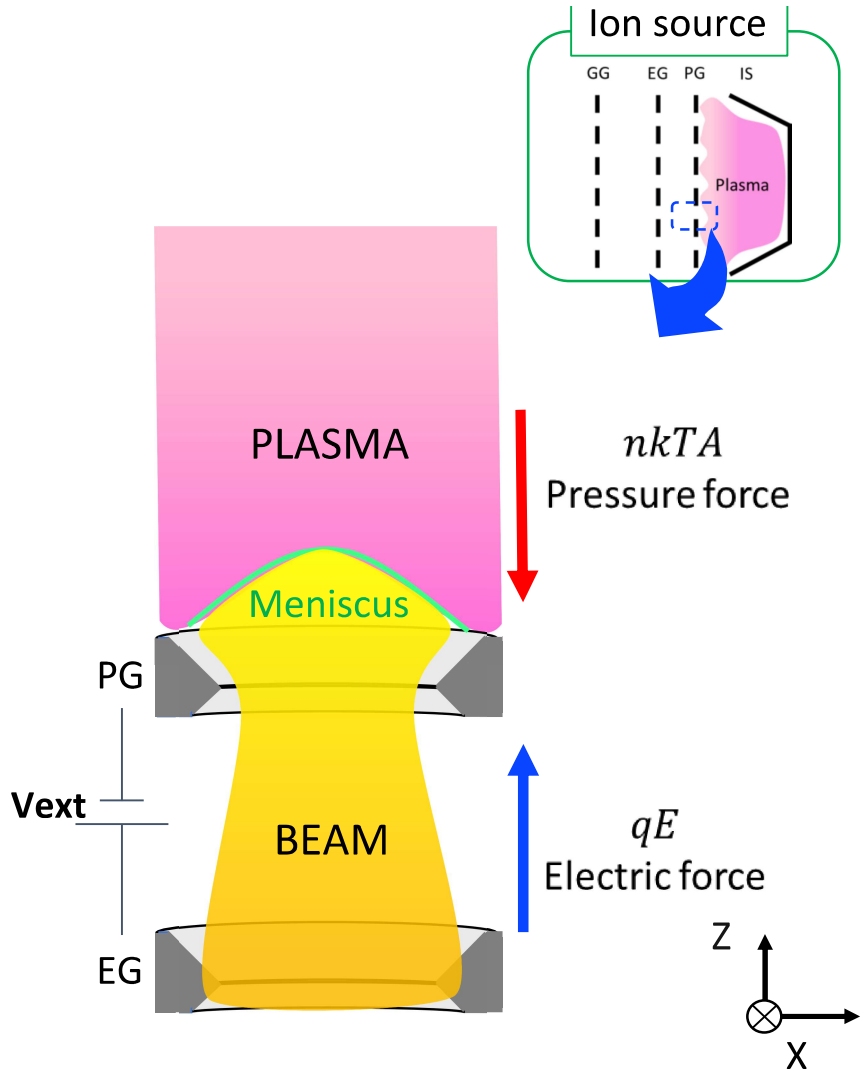


Fig. 2. Definition of the meniscus in the vicinity of the PG aperture.

Negative ion plasma

- Negative ion plasma consists of negative ion, positive ion and electron. Mainly, negative ion and positive ion conserve charge neutrality properties.
- Negative ion plasma is produced on the PG surface with lowered work function by adsorption of caesium atoms on the surface.
- The shielding mechanism to electrostatic fields in the negative-ion rich plasma can be different from ordinary plasma. This affects the formation and shape of the meniscus.

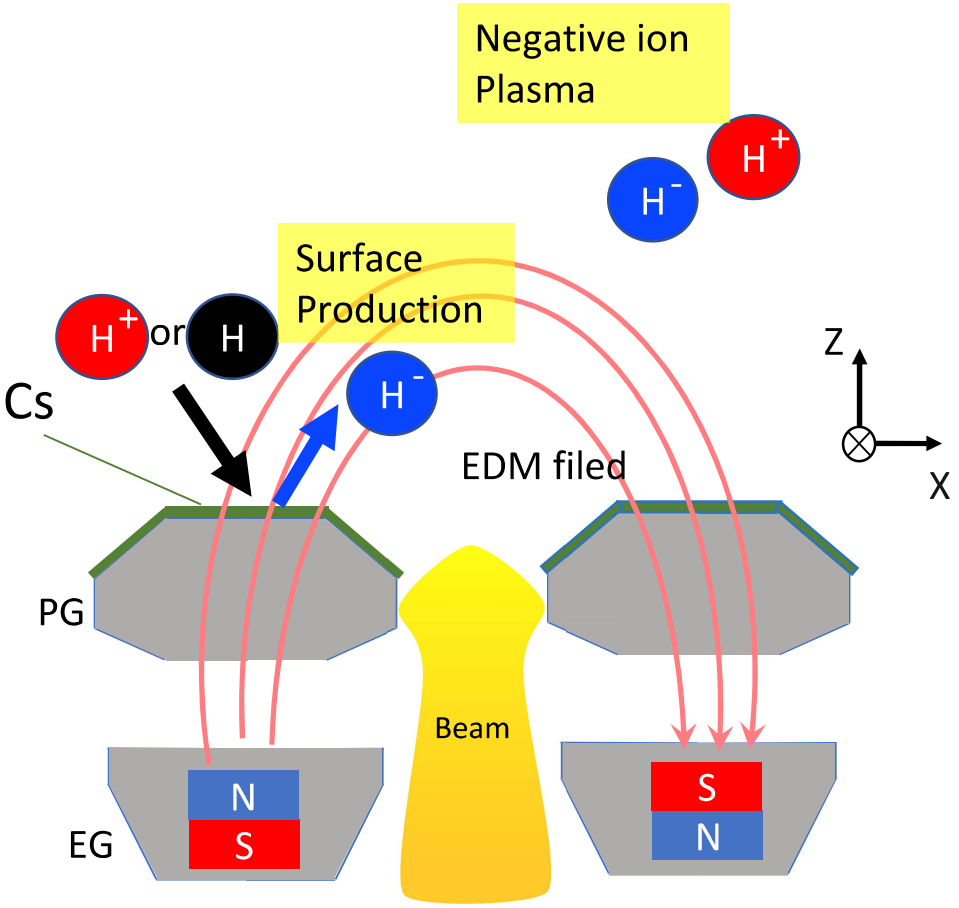


Fig. 3.Mechanism of negative ion production.

Experiment Setup

Ion Source Condition

Research and development Negative ion source at NBI-Test Stand is a single stage acceleration. We define extraction voltage Vext and don't apply acceleration voltage in this experiment.

- Ion Source : filament-arc type
- Input discharge power: 50kW
- Plasma density: 2 x 10^17 m-3
- Puffing gas H2 :0.8 Pa
- with and without Cs seeding

- Accelerator Grid: PG, EG, and GG
- Bias voltage 0.4V
- Extraction voltage 0,150,250,300,500V

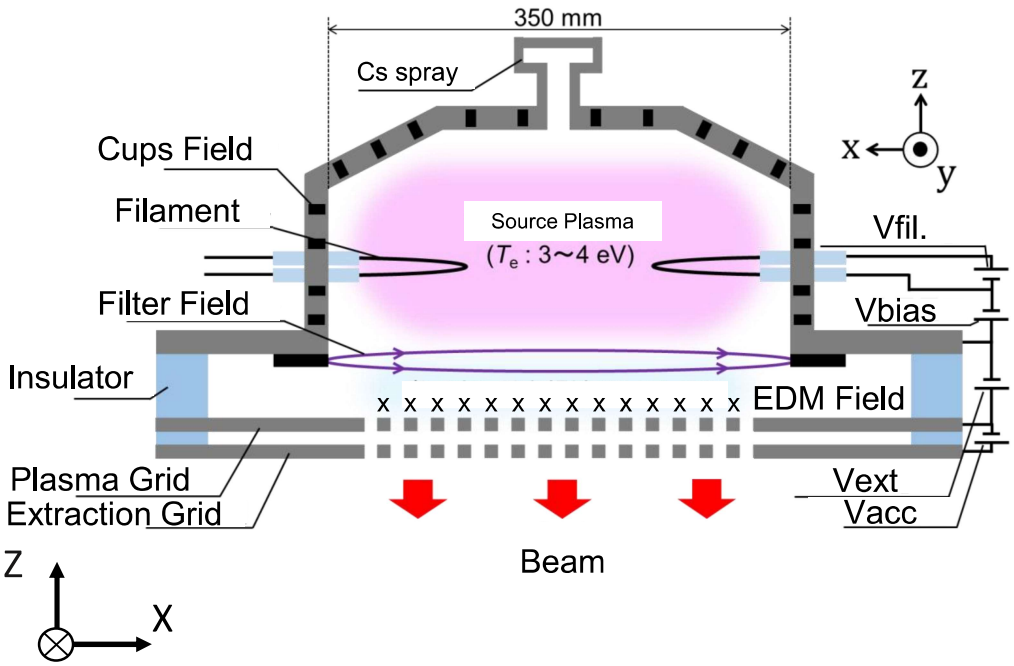
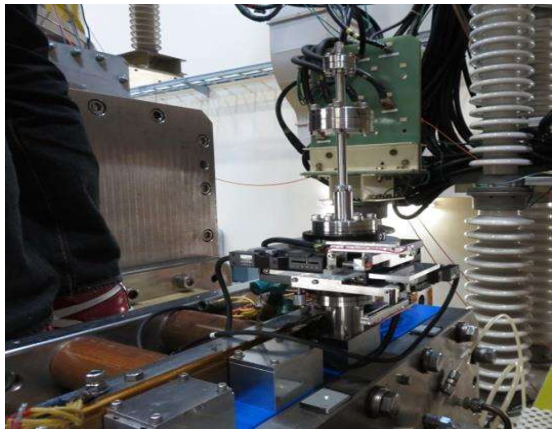


Fig. 4. Diagram of the ion source setup.

Probe structure



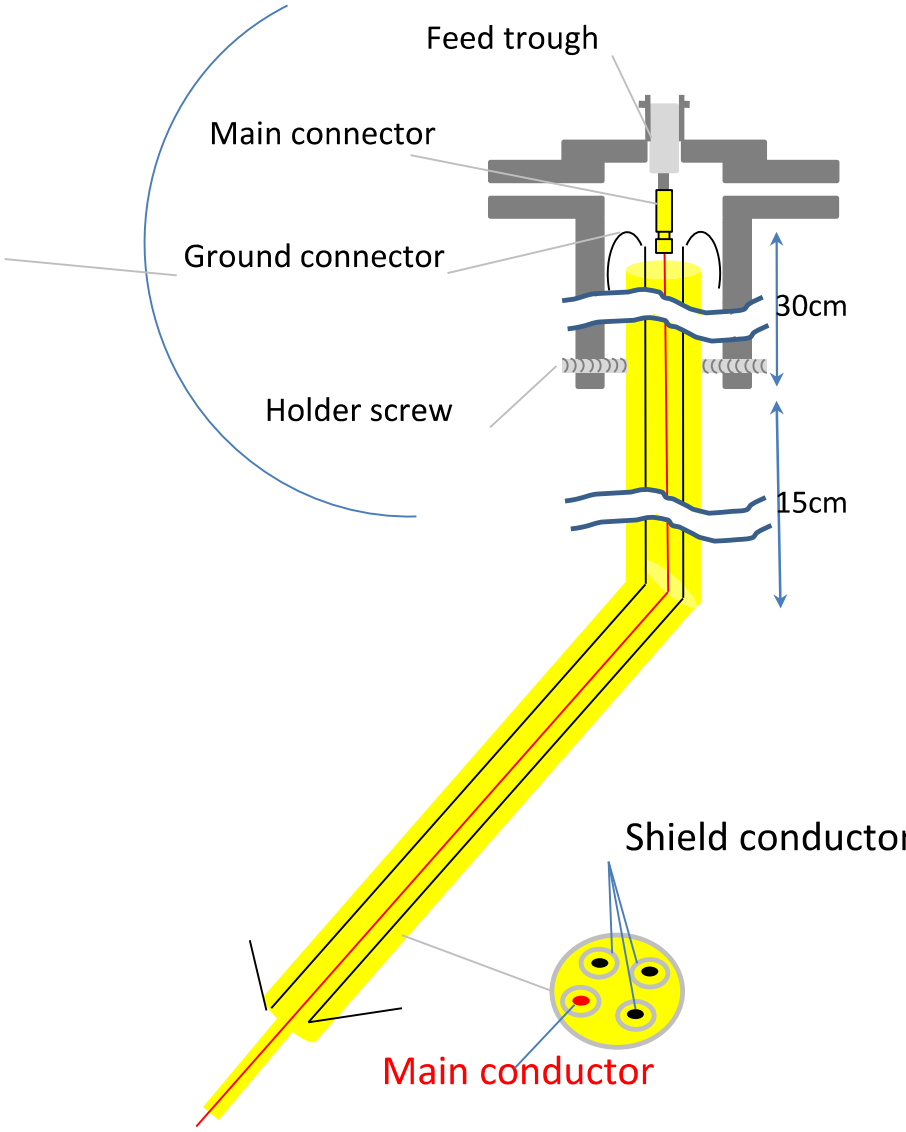
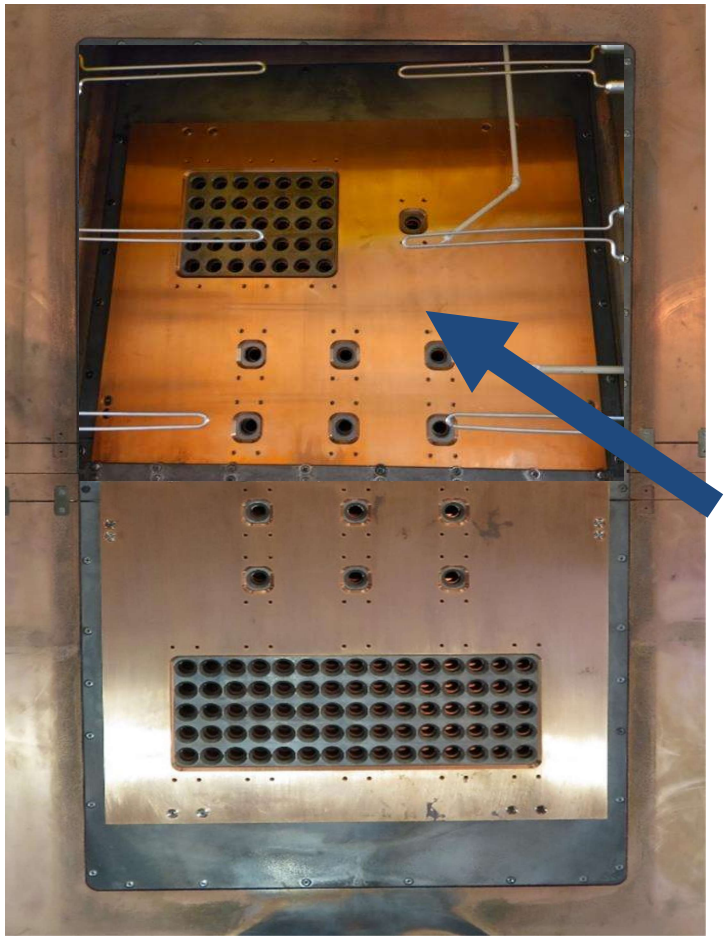
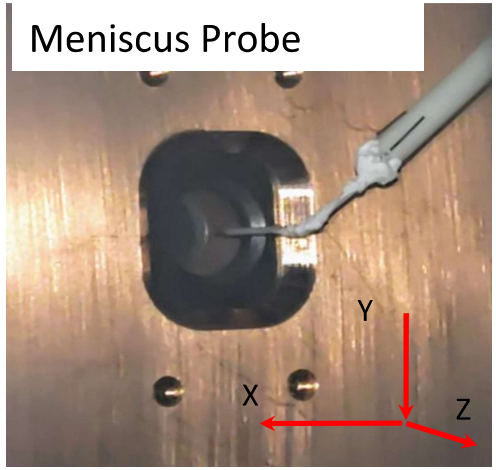
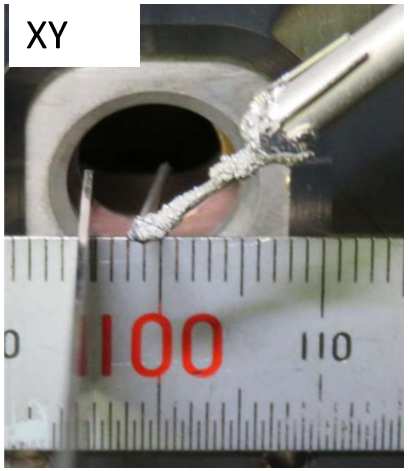


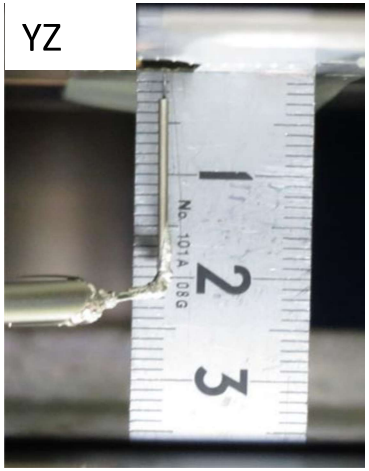
Fig. 5. Diagram of mechanical parts and probe.

Probe Geometry









Position of probe tip is measured with position sensor .
We set orientation of the tip to
X positive is west
Z positive is south (upstream side)

Fig. 6. Probe location and calibration.

Scanning Region

Because mechanical movement is slow, the measurement point are changed after discharge finish.

From the figure 7, asterisk in red is a map for data analysis point and in blue is quality check the discrepancy from begin and finish of the batch.

The resolution in x direction is higher than z because we focus on precision of movement in z direction of plasma and avoid plasma parameter fluctuation by rejecting abnormal point and get more resolution when the point is valid.

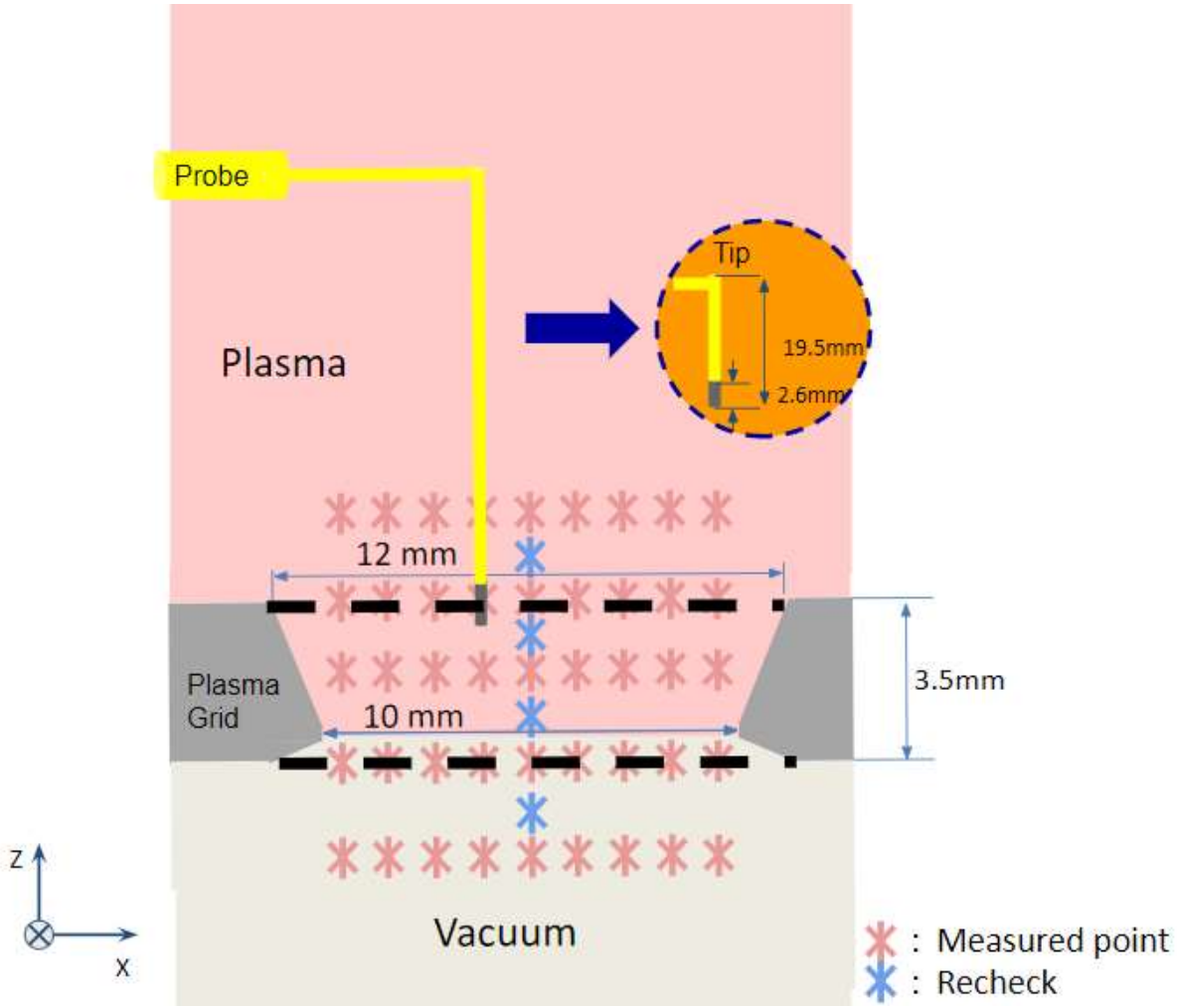
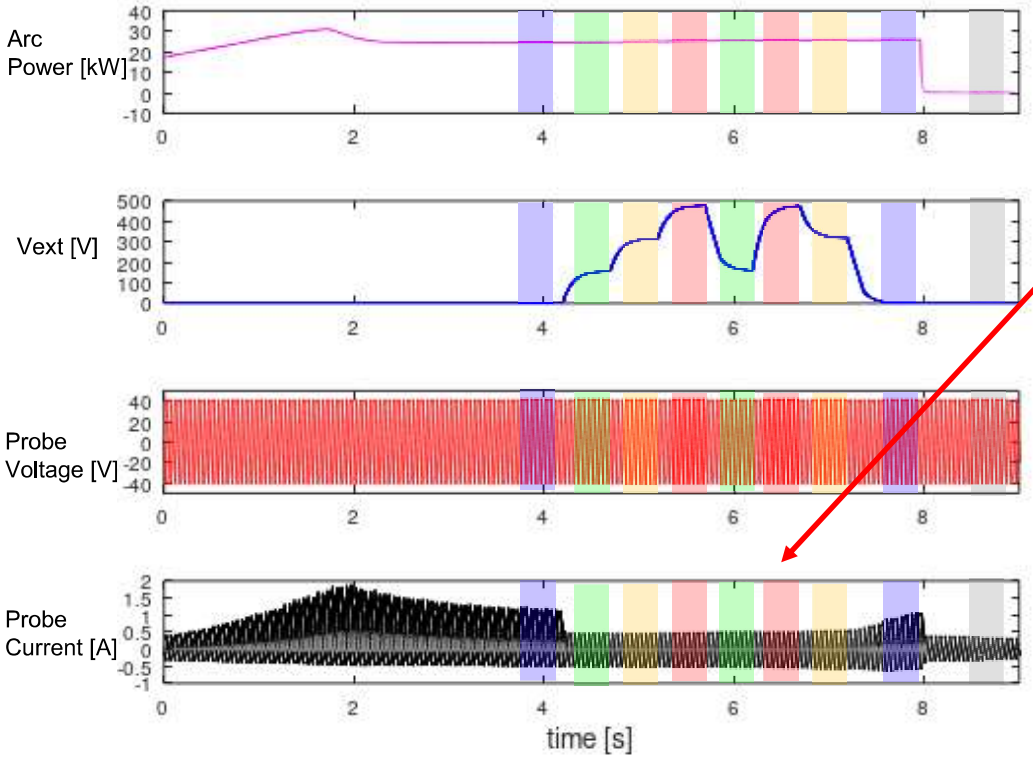
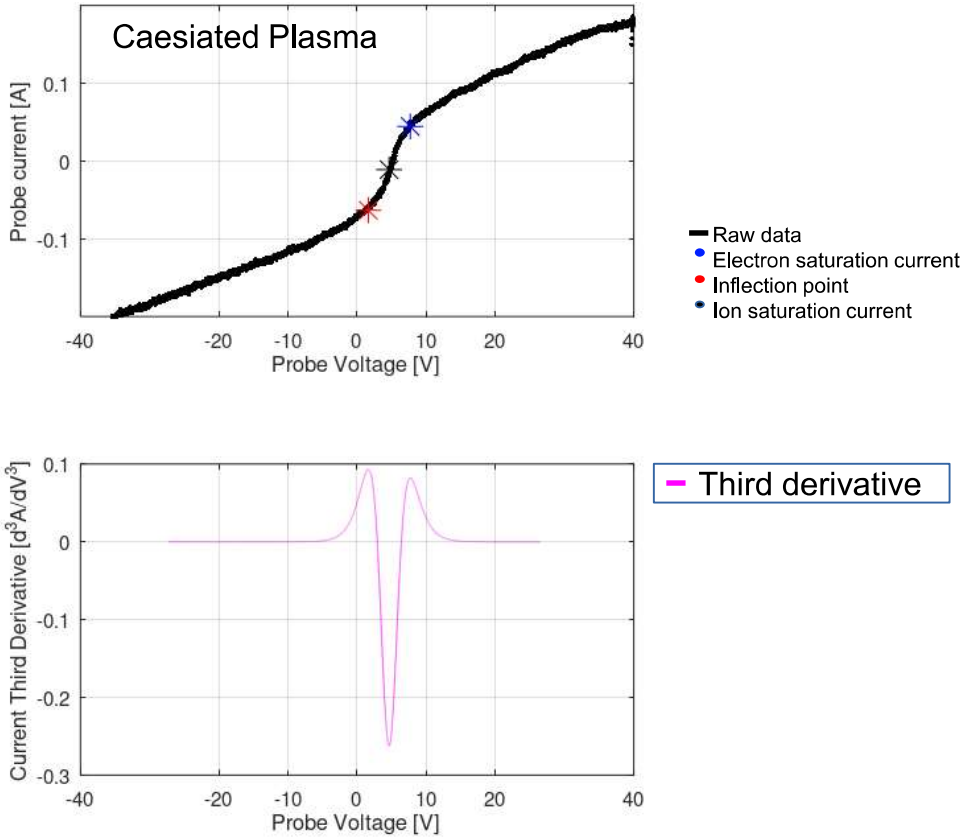


Fig. 7.Diagram of measurement point.

Typical discharge waveform and Langmuir probe signal



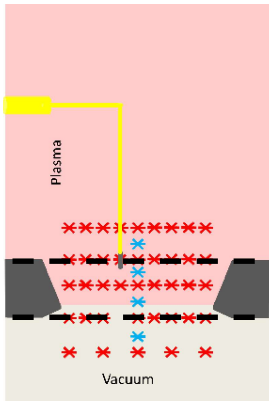


Probe bias is sweeping for diagnostic through out the time of discharge.
The color hatch on the trace indicate group of sample we take for each Vext level.

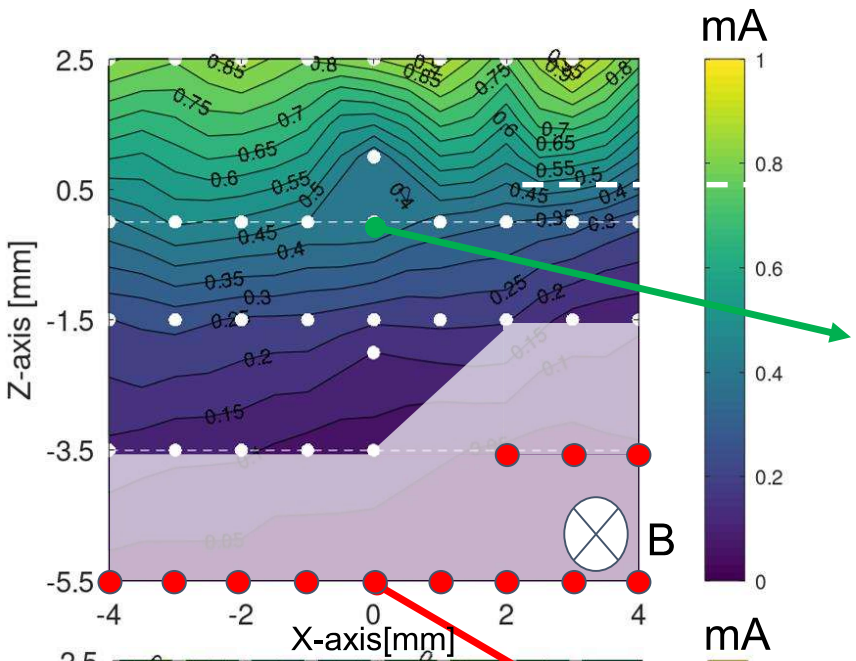
Each I-V curve sample are fitted by specific curve. The function will track voltage position of the retard region.
Third derivative is calculated from the fitted function. The positive peak of third derivative on lower value and higher probe bias voltage is use as saturation voltage for electron saturation current and location of ion saturation current.

Preliminary analysis on saturation current measurement through a beam extraction hole

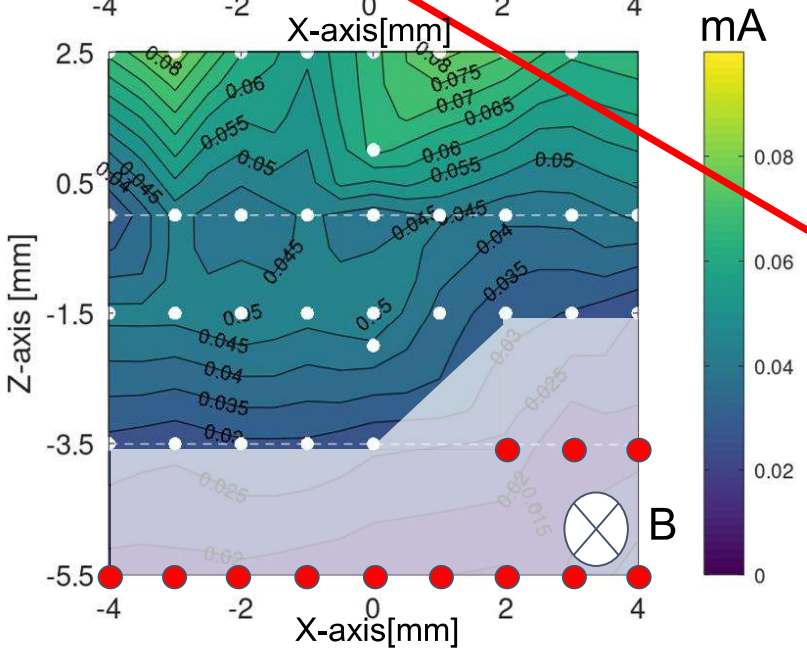
w-Cs Vext=0



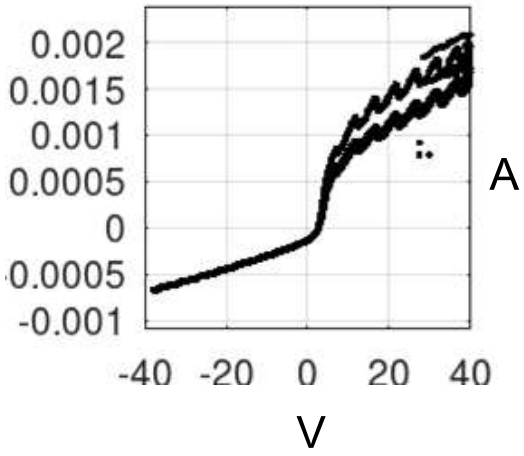
Negatively Charged
Saturation Current



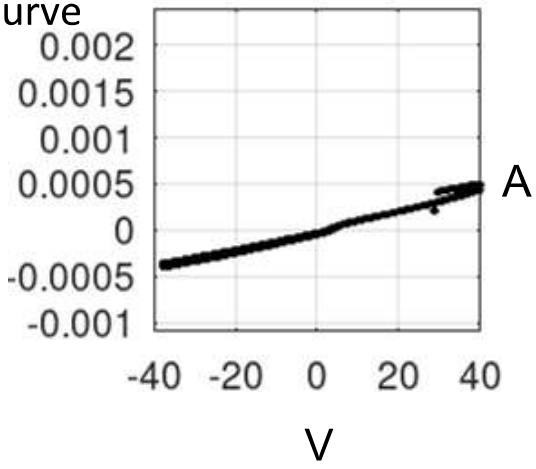
Positively Charged
Saturation Current



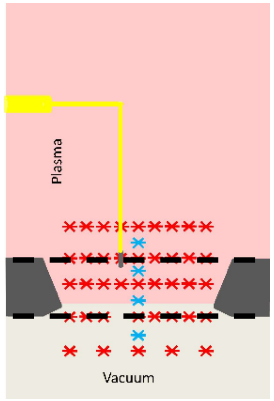
Normal IV ○
curve



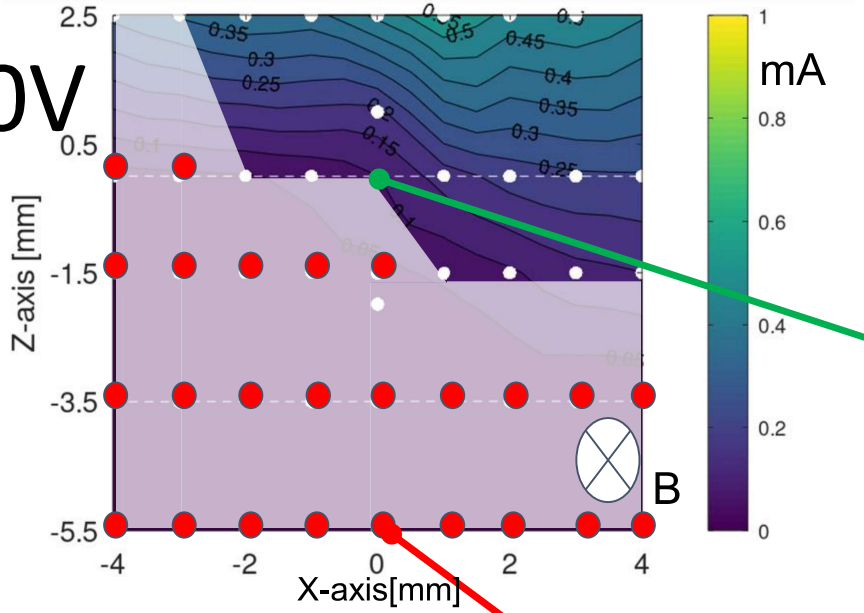
Anomaly IV ●
curve



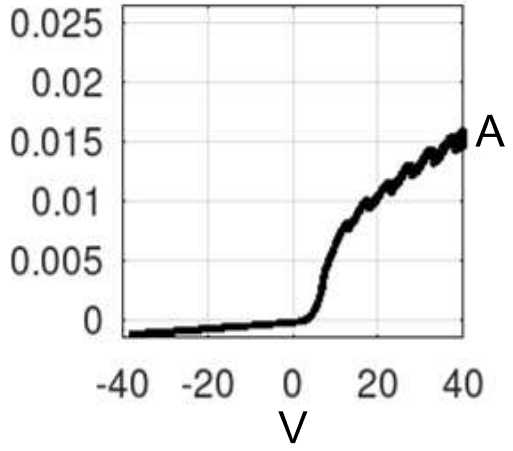
w-Cs Vext=450V



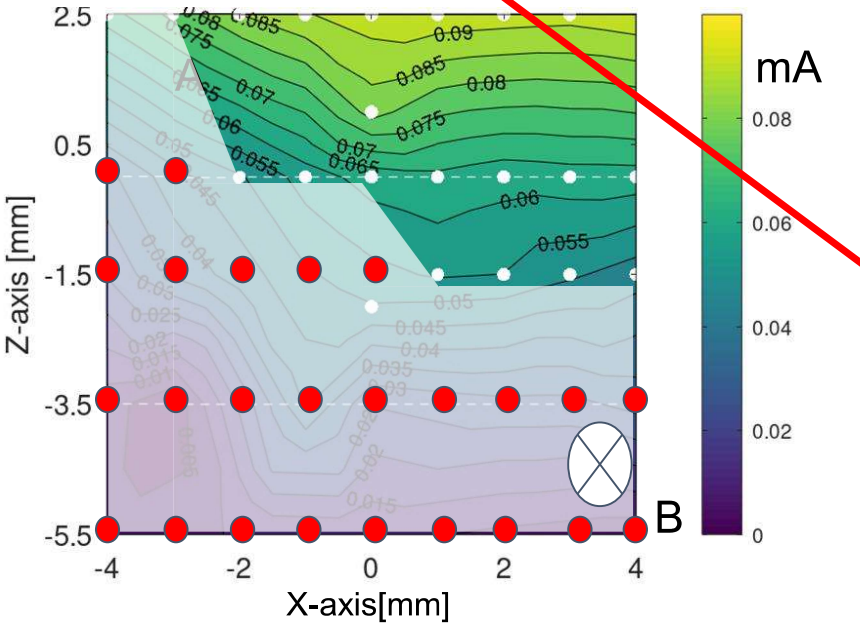
Negatively Charged
Saturation Current



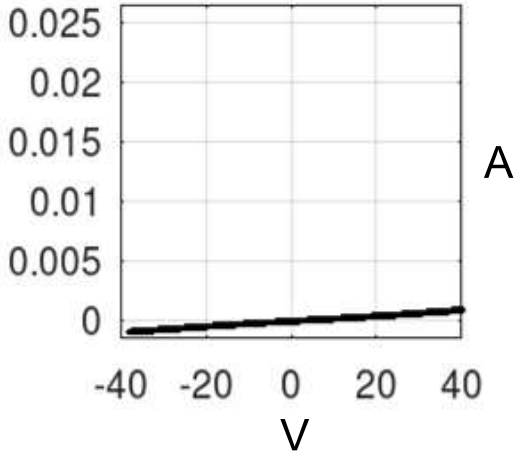
Normal IV ○
curve



Positively Charged
Saturation Current



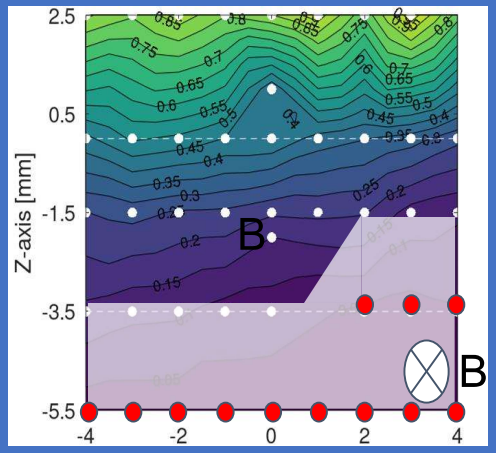
Anomaly IV ●
curve



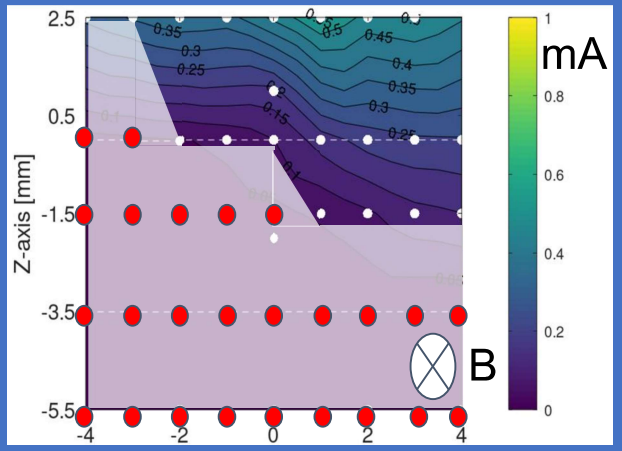
Comparison of Saturation currents with/without Extraction voltage

Negatively Charged Saturation Current

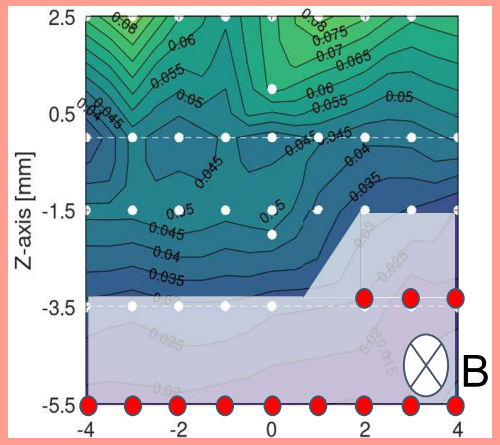
Extraction OFF

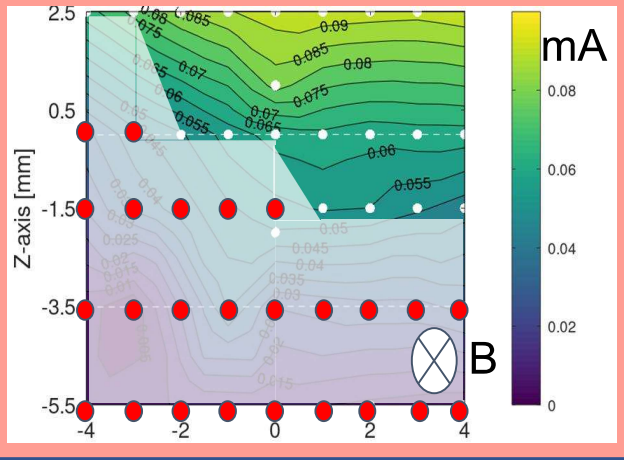


Extraction ON



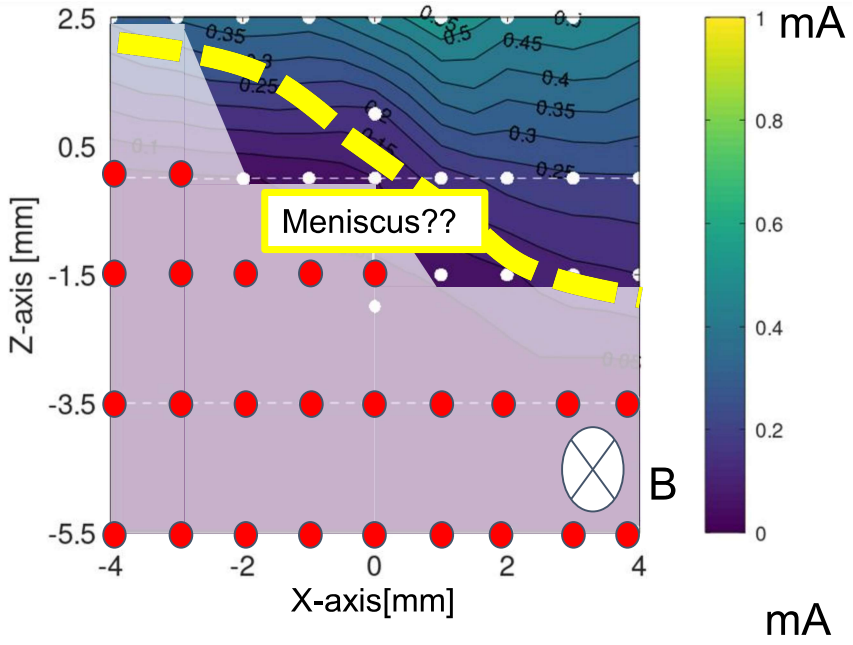
Positively Charged Saturation Current



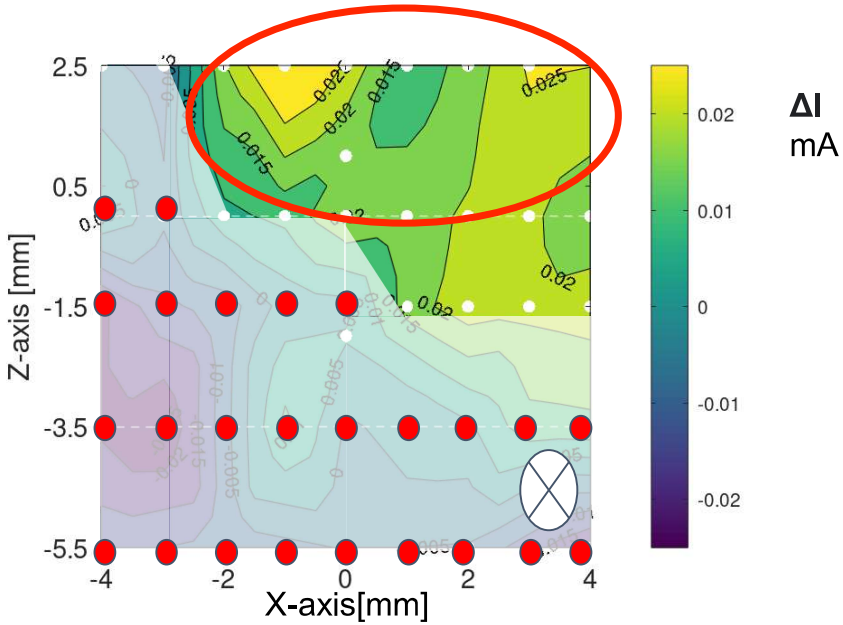


Meniscus Boundary

The boundary of plasma can consider by appears of anomaly I-V curve which is correspond to current contour.

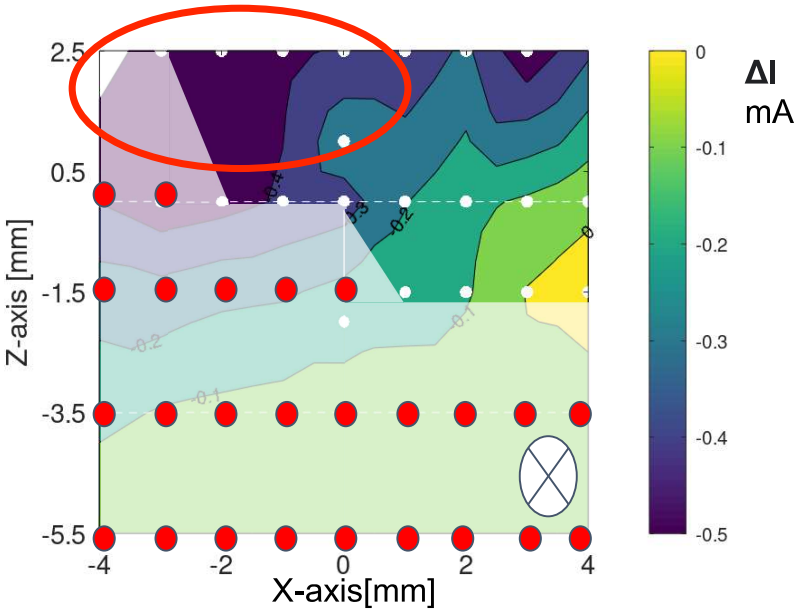


Accumulation of charge particle



The difference of Positively charged saturation current between Vext = 450V and Vext = 0V

ΔI = Ipos_sat_V450 – Ipos_sat_V0



The difference of Negative charged saturation current between Vext = 450V and Vext = 0V

ΔI = Ineg_sat_V450 – Ineg_sat_V0

The difference of current shows accumulation of charge particle

Summary

1. We conducted the Langmuir probe measurement through plasma grid aperture.
2. Analytical method was developed for evaluation of the saturation current from *I-V* curve in the negative ion plasma.
3. Preliminary measurement of plasma distribution is demonstrated in this research.