Study of response of negative ion beam to bias voltage in phase space

M. Kisaki[1,2], K. Nagaoka[1,3], R. Nakamoto[4], K. Tsumori[1,2], H. Nakano[1,2], S. Masaki[2], K. Ikeda[1], Y. Fujiwara[1], M. Osakabe[1,2]

[1]National Institute for Fusion Science, National Institutes of Natural Sciences, Toki, Japan.
[2]The Graduate University for Advanced Studies, Toki, Japan.
[3]Graduate school of Science, Nagoya University, Nagoya, Japan.
[4]Graduate School of Engineering, Nagaoka University of Technology, Nagaoka, Japan.

Introduction

- In the previous study (M. Kisaki et al., RSI 91, 023503 (2020)), we demonstrated that the negative ion beam width changes with negative ion density along the same curve despite different bias voltages, while it changes with other plasma parameters along different curves (see Fig. 1).
- These results suggest that the meniscus formation is determined by only the negative ion density.
- To confirm this, the response of the negative ion beam to the bias voltage was investigated **by measuring the phase space structure**.

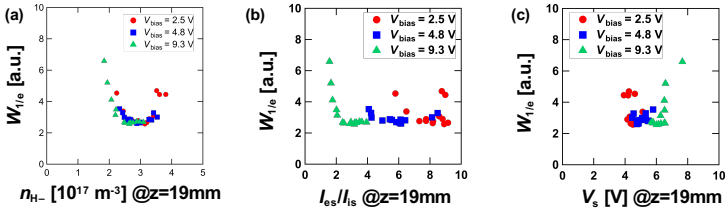

Fig. 1. Beam width as a function of (a) negative ion density, (b) negative-to-positive saturation current ratio of Langmuir probe, and (c) plasma potential at different bias voltages. Plasma parameters were measured at a distance of 19 mm from the plasma grid surface.

Experimental setup

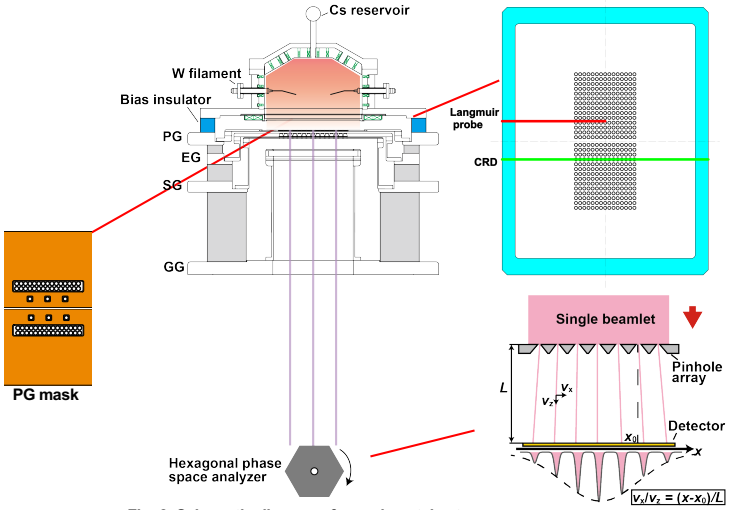

Fig. 2. Schematic diagram of experimental setup.

- Plasma parameters in extraction region were measured by means of **Langmuir probe** (plasma density n_p, electron temperature T_e, plasma potential V_s) and **cavity-ring-down method** (negative ion density n_{H-}).
- Beam optics was evaluated using a **hexagonal phase space analyzer** consisting of copper plate with pinholes and thin polyimide sheet.
- By rotating the anaylzer, the phase space structure can be measured three times without breaking a vacuum.

Variation of plasma parameter during beam irradiation

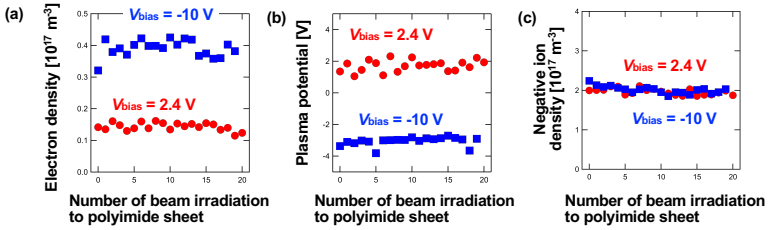

Fig. 3. Variation of (a) electron density, (b) plasma potential, and (c) negative ion density during beam irradiation.

- Stable source operation was achieved during the beam irradiation, and the variation of plasma parameters was successfully suppressed.
- **Negative ion densities were the same in both bias voltages, while other parameters were different.**

Phase space structures

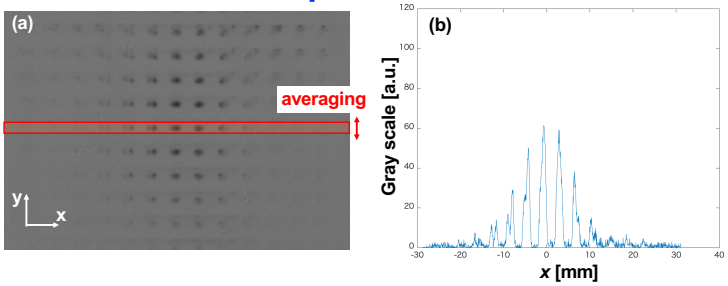

Fig. 4. (a) footprint of beam fraction passing through pinholes on the polyimide sheet and (b) averaged line profile of gray scale in the region enclosed by the red rectangle.

Assumptions in analysis
1. Phase space in x direction is occupied by 3 gaussian components.
2. The velocity dispersion ($\sigma_{vx/vz}$) is common.
3. Slope (λ) of phase space ellipse is unique for each component.

$$\Delta\eta = \Sigma u_n exp[-\frac{(x - x_{u0} - n\lambda_u)^2}{\sigma^2_{vx/vz}}]$$
$$+\Sigma l_n exp[-\frac{(x - x_{l0} - n\lambda_l)^2}{\sigma^2_{vx/vz}}]$$
$$+\Sigma c_n exp[-\frac{(x - x_{c0} - n\lambda_c)^2}{\sigma^2_{vx/vz}}]$$

Phase space structures **at V_{bias} = 2.4 and -10 V** were evaluated by fitting multiple-gaussian to the line profiles with above assumptions.

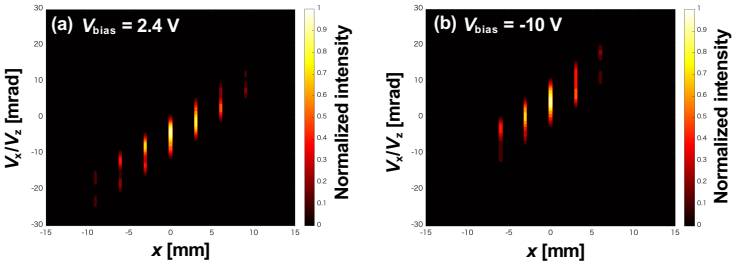

Fig. 5. Phase space structures at V_{bias} = 2.4 V (a) and -10 V (b).

Phase space structures do not change with the V_{bias} with constant negative ion density.
→This gives an additional supporting evidence that the meniscus formation is governed by the negative ion with negligible contribution from the electron.

Discussion

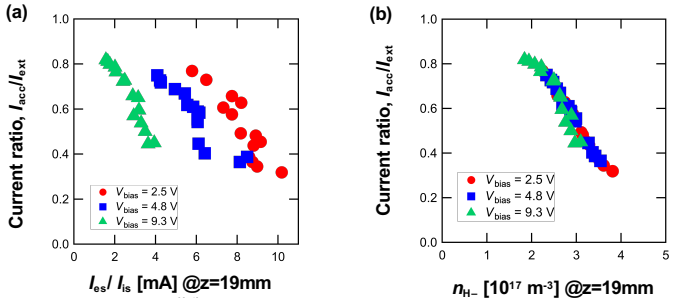

Fig. 6. Power supply drain current ratio as a function of (a) probe saturation current and negative ion density.

- The variations of I_{acc}/I_{ext} with I_{es}/I_{is} for different V_{bias} follow the same trend, but the curves are separated from each other.
- On the other hand, the I_{acc}/I_{ext} follow the same curve with respect to the n_{H-}.
- **These results suggest that the negative-ion-to-electron density ratio in the very vicinity of extraction holes is determined by the ion transport across the electron deflection magnetic field while the bias voltage strongly affects the electron density far from the holes.**

Summary

- It was demonstrated that the phase space structure does not change with the bias voltage with the same negative ion density.
- This confirms that the negative ion density determines the meniscus shape in the negative ion extraction from caesiated plasmas.