Preliminary estimation of electron density and temperature of plasma in 28-GHz electron cyclotron resonance ion source

O. Kamigaito[*1] and T. Nagatomo[*1]

Electron density (n_e) and temperature (T_e) of plasmas in electron cyclotron resonance (ECR) ion sources (ECRIS) are essential parameters for production of multiply charged ions.[1] Electron density also governs electromagnetic wave propagation in magnetized plasmas, and its study is in progress in a recent ECRIS.[2] Although a Langmuir probe is commonly used to measure the electron density and temperature of a plasma, our ion sources are not equipped with it. First, we evaluated the electron temperature and density using a biased disk as a substitute for a Langmuir probe.

A 28-GHz ECRIS[3] of RILAC was used for the estimation; it has a biased disk of 50 mm in diameter, as shown in Fig. 1. The biased-disk current, I, was measured while varying the disk voltage, V, when $^{51}V^{13+}$ ions were produced with nitrogen as the support gas. The results are shown in Fig. 2. The input rf power during the measurement was approximately 2.4 kW, and the vacuum in the plasma chamber was 3.1×10^{-5} Pa. The extracted current of $^{51}V^{13+}$ was 100–150 electric μA (eμA) at an ion extraction voltage of 13 kV.

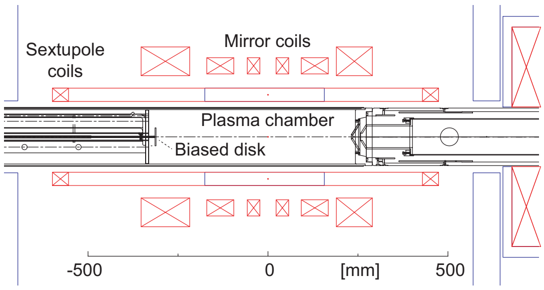

Fig. 1. Plasma chamber of 28-GHz ECRIS. Biased disk is located 21 mm from chamber end.

The data were analyzed according to a reference study.[4] First, the probe current, $I(V)$, near the the floating potential, V_f, can be written as follows:

$$I(V) = -I_i \left(1 - \exp \frac{e(V - V_f)}{kT_e}\right). \qquad (1)$$

Fitting the data in Fig. 2 with this function yields $kT_e = 23$ [eV] and $I_i = 4.9$ [mA]. Second, the following equation is used to determine the electron density from these values:

$$n_e = \frac{I_i \cdot \bar{q} \cdot (kT_e)^{-1/2}}{0.61 \cdot S \cdot e} \cdot \left(\sum_{\mathrm{E},q} \frac{\alpha_{\mathrm{E},q} \cdot q^{3/2}}{{M_\mathrm{E}}^{1/2}} \right)^{-1}, \qquad (2)$$

where M_E is the atomic mass of element E, q is the charge state, $\alpha_{\mathrm{E},q}$ is the the fraction of the E^{q+} component in the beam extracted from the source, $\bar{q}$ is the average charge state of the beam, and S is the surface area of the biased disk. Because $N^{3+,4+,5+}$ ions almost equaly dominate in the extracted beam, as shown in Fig. 3, we set $\alpha_{\mathrm{N},3} = \alpha_{\mathrm{N},4} = \alpha_{\mathrm{N},5} = 1/3$ for simplicity. These values yield $n_e = 5.0 \times 10^{14}$ [/m^3]. This density is smaller than the critical density[5] at 28 GHz, which is $n_{\mathrm{cr}} = 1.0 \times 10^{19}$ [/m^3], by four orders of magnitude.

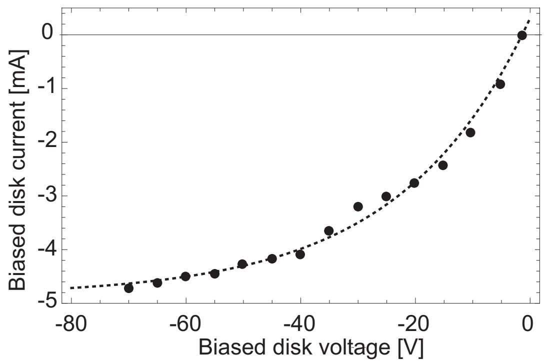

Fig. 2. Measured biased-disk current (black dots) and curve fitted with Eq. (1) (dotted line), where $V_f = -1.4$ [V].

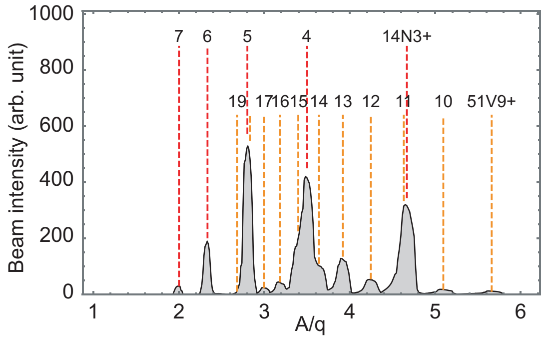

Fig. 3. Extrated beam spectrum at $V = -30$ [V].

The region measured in this study was away from the center of the plasma chamber. We plan to survey an area closer to the ECR zone with a smaller electrode in the future.

References
1) R. Geller, *Electron cyclotron resonance ion sources and ECR plasmas*, (CRC Press, 1996), Sec. 1.4.
2) Y. Kato *et al.*, J. Phys. Conf. Ser. **2244**, 012001 (2022).
3) T. Nagatomo *et al.*, Rev. Sci. Instrum. **91**, 023318 (2020).
4) L. Kenéz *et al.*, Nucl. Instrum. Methods Phys. Res. B **187**, 249 (2002).
5) F. Chen, *Introduction to plasma physics and controlled fusion*, 2nd ed., (Prenum Press, New York, 1984), p. 116.

*1 RIKEN Nishina Center

DOI:10.34448/RIKEN.APR.57-036