Non-thermal equilibrium effect on plasma window with large diameter

N. Ikoma,[*1,*2] Y. Miyake,[*1] M. Takahashi,[*1] H. Okuno,[*1] S. Namba,[*3] K. Takahashi,[*2] T. Sasaki,[*2] and T. Kikuchi[*2]

The disposal of high-level radioactive waste (HLW) is a serious social problem. To address it, a transmutation scheme of long-lived fission products (LLFP) employing a high-power accelerator, which provides deuteron beams of 400 MW, was proposed in the ImPACT Fujita program.[1)] In such a system, a beam window, which separates the accelerator and target region, is considered one of the key issues. A plasma window (PW),[2)] which exploits a large pressure gradient generated by an arc plasma filling the discharge channel, is considered a promising candidate. However, the first PW invented by Hershcovitch[2)] had an aperture of 2.36 mm, while the beam-spot size required in our case is 100 mm or larger.

Therefore, we developed a PW with a maximum diameter of 20 mm, as shown in Fig. 1, and demonstrated conductance reduction by the PW.[3)] Furthermore, a comparison between the achieved cell pressure P_{cell} and the pressure estimated from Eq. (1)[4,5)] suggested that the gas (or heavy-particle) temperature T_h was lower at larger diameters due to the low-input power density.[3)]

$$P_{cell} \simeq \sqrt{\frac{16\eta k T_h}{\pi m_h}} \frac{\sqrt{QL}}{r^2}, \tag{1}$$

where η, k, m_h, Q, r, and L are the viscosity of the gas, Boltzmann constant, mass of gas particles, mass flow rate, channel radius, and channel length, respectively.

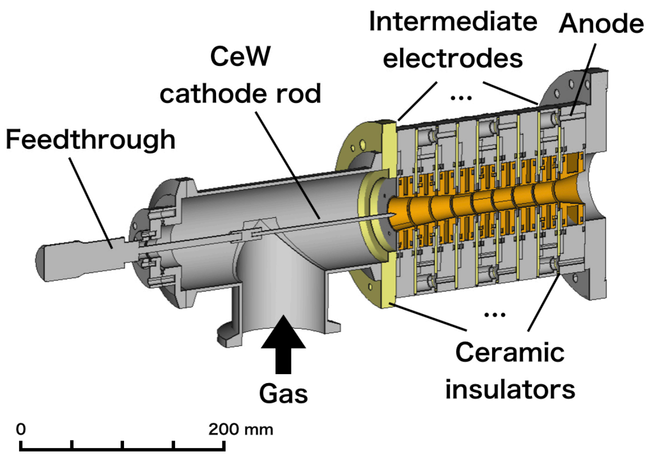

Fig. 1. Structure of the PW developed in this study.

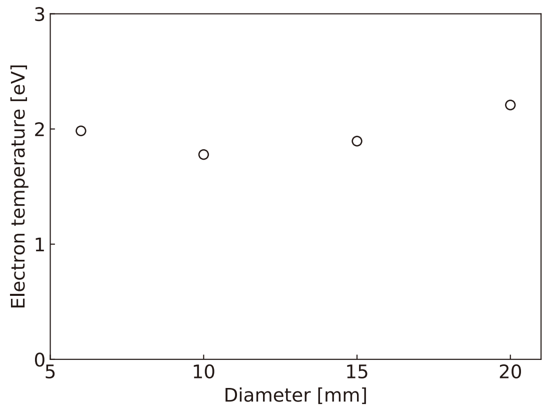

Fig. 2. T_e *vs.* PW diameter.

In this paper, the typical electron temperature T_e was estimated based on the report that the axial electron temperature variation in cascade arc devices is small.[6,7)] The T_e is described by the Spitzer formula:

$$T_e \approx \left(\frac{\ln \Lambda}{2 \times 10^4} \sigma \right)^{2/3}, \tag{2}$$

where σ is the average electrical conductivity of the plasma obtained from discharge current, voltage, and geometry of the channel, assuming a uniform cylinder. The Coulomb logarithm $\ln \Lambda$ was assumed as 10.

In contrast with the tendency of the heavy-particle temperature,[3)] the estimated T_e shown in Fig. 2 was almost constant regardless of the diameters. This may indicate that the temperatures of electrons and heavy particles attain a non-equilibrium state as the diameter increases. Because T_h is the most important factor in the performance of the PW as described by Eq. (1), the non-equilibrium effect will be discussed with the conductance-reduction effect of plasma ignition.

This work was supported by RIKEN Junior Research Associate Program. Furthermore, this work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

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*1 RIKEN Nishina Center
*2 Graduate School of Engineering, Nagaoka University of Technology
*3 Graduate School of Engineering, Hiroshima University