Stationary He arc discharge apparatus using an indirectly heated LaB_6 hollow cathode electron emitter

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Plasma window (PW) [1] is an application technology of plasmas, by which vacuum conditions can be separated from atmospheric pressure (or high-gas pressure) without a large pumping apparatus. The cascade arc discharge (wall-stabilized arc) among the electrode of the PW generates high-temperature and high-density plasma inside the center of the electrodes (channel) and heat neutral gas. The increase in the gas temperature causes a rise in the pressure and the viscosity of the neutral gas, resulting in the choke of the gas flow. Owing to the choke of the flow inside the channel, the PW can separate the atmospheric pressure and the vacuum through the channel. The feature of the PW is that it can transmit electrons, ions, and X-rays, which cannot pass through glass windows, through the plasma-filled channel. Therefore, the PW is expected to open a way for the new application of quantum beam science.

Recently, the PW is considered as an alternative differential pumping system of a helium gas charge stripper in the heavy-ion accelerator at the RIKEN Radioactive-Isotope Beam Factory (RIBF). The gas stripper is composed of five differential pumping stages equipped to both sides of the central gas cell which is maintained at 7 kPa. The stages sequentially reduce the chamber pressures to 700, 90, 1, 2×10^{-2}, and 5×10^{-4} Pa, respectively [2]. Since the gas stripper becomes huge due to the multiple pumping systems with 21 pumps, it is necessary to reduce the number of pumping stages for simplifying the system. In order to replace the differential pumping systems with PW, we need to develop a PW with a channel diameter of more than 6 mm, the diameter of the uranium beam in RIBF.

We have improved the TPD (Test Plasma by Direct current discharge) devices, which is one of the cascade arc discharge devices, and constructed a large arc discharge source having a channel diameter of 8 mm. The PW apparatus can replace the 700- and 90- Pa differential pumping stages since we have succeeded in separating vacuum from pressures of 5-10 kPa [3]. However, this apparatus cannot pass the uranium beam since the needle shape cathode is placed at the center axis of the channel. Thus, the cathodes allowing the beam to pass are required for practical use of the PW in RIBF. Therefore, the purpose of this study is to develop a new cathode having the beamline and to make clear the performance of the PW with the cathode.

An indirectly heated hollow cathode was developed and first introduced into the TPD apparatus. Hollow cathodes have been used in electric propulsion devices for space crafts. FIG. 1 shows a schematic view of the cathode, which is composed of three main parts, electron emitters, a heater, and a keeper electrode. The electron emitters are hollow cylinders, whose inner diameter and outer diameter are 8 mm and 14 mm, respectively, made of lanthanum hexaboride (LaB_6), located inside a molybdenum (Mo) tube. The thermionic emission area is 15 cm^2, which is enough size for up to 100 A. In hollow cathode discharges (HCD), thermionic emission provides abundant electrons, to form the dense and highly ionized plasma [4]. High gas temperature is expected to be achieved because of the increase in collision frequencies among electrons, ions, and neutrals. Thus, performance improvement owing to the increase in gas viscosity can be expected. A heater made of C/C composite is placed around the Mo tube. The maximum heater voltage and current are 45 V and 40 A, respectively. The LaB_6 insert is heated over 1600 ℃ by the heater beforehand to facilitate the discharge. A keeper electrode made of Mo is electrically floated and draws out electrons to outside from emitters. A glass window at the end of the cathode flange enables us to observe the plasma inside the hollow cathode using spectroscopy. To achieve the separation of 7 kPa and 1 Pa, the HCD plasma and the neutral gas need to reach the following parameters: electron density of 10^{14}-10^{15} cm^{-3}, and gas temperature of 1 eV at the hottest region.

We introduce the characteristics of the HCD plasma and discuss the gas flow rate and input power dependence of the achieved pressure ratio.

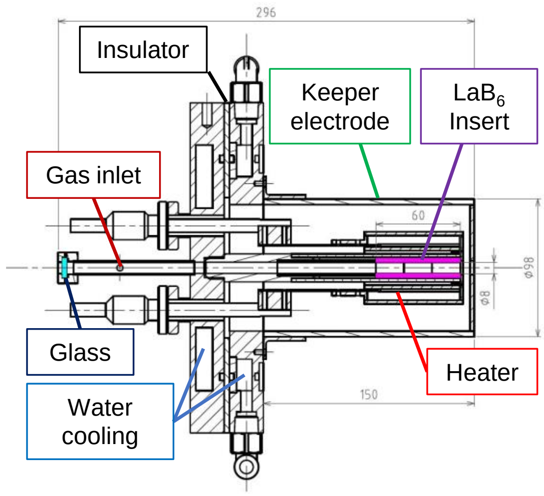

FIG. 1. Schematic of the hollow cathode.

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