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Development of plasma window apparatus

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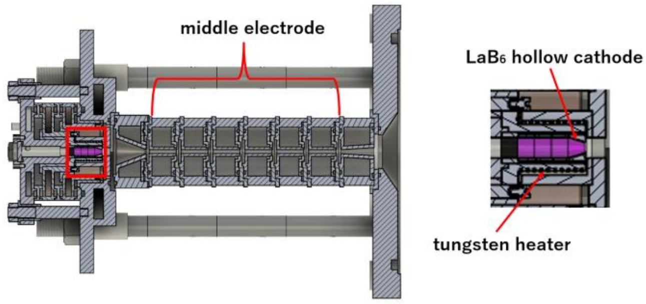
Plasma window (PW) is a plasma application technology that virtually separates the atmosphere and vacuum without solid materials such as metal or glass. PW is a cascade arc discharge device consisting of an anode, a middle electrode, and a cathode. The high-temperature, high-density plasma produced inside the cylindrical holes of each electrode, termed channel, heats the neutral gas inside the channels [1]. The viscosity of neutral gas increases as its temperature rises [2]. This increase in viscosity prevents flow in the channel. As a result, the pressure difference between the atmosphere and the vacuum is maintained. PW uses plasma to maintain the pressure difference, and quantum beams such as electron beams and soft X-rays are passed through while maintaining the pressure difference. We aim to utilize this property to commercialize electron beam welding under atmospheric pressure. Electron beam welding can join metals precisely, but the size of the workpieces that can be joined is limited by the size of the vacuum vessel. Therefore, if electron beam welding can be performed at atmospheric pressure, it would enable precise welding of large structures that were previously unsuitable for this method. Therefore, we are developing an apparatus that achieves an atmospheric pressure of 100 kPa and an in-vessel pressure of 1 Pa in a channel with an inner diameter of 3 mm.

Our purpose is to maintain stable pressure bulkheads over extended periods. However, we have issues such as water leakage from the middle electrode and heater failure. Therefore, we developed a new PW device to address these challenges.

The schematic of the PW we developed is shown in Figure 1-(a). The cathode is cylindrical LaB6 with a tapered tip to confine the plasma inside the hollow cathode. The LaB6 is heated by a heater using tungsten wires. These are shown in Figure 1-(b). We changed the wire diameter from 0.5 mm to 1.0 mm to increase the temperature of LaB6. Furthermore, the number of heater failures was reduced by increasing the wire diameter. The middle electrode has an inner diameter of 3 mm, the material has been changed from molybdenum to oxygen-free copper, and the welding method has been changed. These changes were made to improve cooling efficiency and increase strength. We have also considered its application to electron beams. We transmitted 20 keV electron beam through the PW channel with 3 mm diameter to observe the beam spot size dependence on the ambient pressure.

We will introduce the results of the study. The increased wire diameter of the heater successfully heated the LaB_6 to over 1600 °C. The new PW successfully sustained a pressure difference of 70 kPa and 2.7 Pa for one hour. In addition, 100 kPa at the high-pressure side and 76 Pa at vacuum chamber were successfully maintained for more than 15 minutes. The results are shown in Figure 2. Also, through two middle electrodes with a channel diameter of 3 mm and a length of 75 mm, a spot of the electron beam was successfully projected onto a screen about 1.7 m away from the electron gun tip.



(a) (b)

Fig.1 Schematic diagram of the new PW

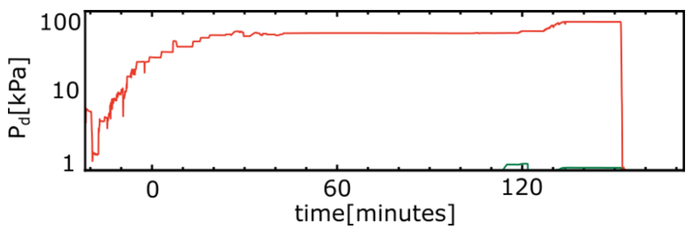


Fig.2 Pressure differential and retention time produced by our PW

References

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