Development of New Concept In-Vessel Cryo-Sorption Pump for LHD Closed Helical Divertor

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The in-vessel cryo-sorption pump for the Closed Helical Divertor (CHD) in the Large Helical Device (LHD) has been developed at the National Institute for Fusion Science (NIFS). An organic adhesive-free bonding technique for attaching activated carbon pellets to a copper cold panel was invented, which employs the indium solder with intermediate materials. The prototype of the CHD with the newly developed cryo-sorption pump was installed in the LHD. Performance of the cryo-sorption pump was estimated in the LHD vacuum vessel. A satisfactory result of the maximum pumping speed up to 9 m^3/s was obtained with one divertor module in one toroidal section (10% of the torus), which is equivalent to the required pumping speed of the CHD.

Keywords: in-vessel cryo-sorption pump, inorganic adhesion, closed helical divertor, LHD

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In order to obtain the high-performance plasma in toroidal devices, the neutral particle control by divertor is indispensable. For the effective divertor function, a strong pump is required, together with an effective closed configuration with baffles. In DIII-D [1] and EAST [2], in-vessel cryo-condensation pumps installed near the divertor plates are employed. The cryo-condensation pump evacuates neutral particles, condensing them on the cryo-panels cooled by liquid helium (~4 K). Thus a huge cryogenic system consisting of the helium liquefier and supply lines is required. On the other hand, the cryo-sorption pump evacuates neutrals, adsorbing them on a cryo-panel (~20 K) with highly adsorbing materials, e.g., activated carbon or zeolite. Since the temperature of the cryo-panel of the sorption pump may be higher than that of the condensation pump, the required cryogenic system may be small.

For bonding the activated carbon to the cryo-panel, the organic adhesive has been used so far, which, however, results in the unfavorable outgassing during the non-cooled phase. Furthermore, deterioration of the organic adhesion due to age sometimes causes the activated carbon to be detached from the cryo-panel. For these reasons, the cryo-sorption pump has not been used as an in-vessel pump for divertor pumping in fusion experimental devices, although the high pumping speed due to the high conductance is expected in the directly connected system. Therefore, the bonding technique without organic adhesive is desired to develop the efficient divertor pumping system. At the NIFS, a new soldering technique between activated carbon and copper has been developed [3] in the collaboration framework with KYODO International Corporation, and the prototype of the outgassing-free in-vessel cryo-sorption pump was installed in the vacuum vessel of the LHD. In this paper, a technical summary of the newly developed cryo-sorption pump and preliminary results from the performance test are presented.

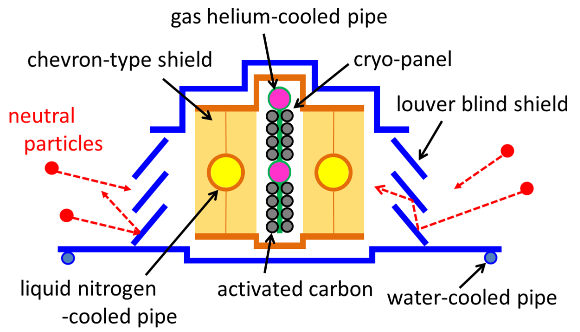

Fig. 1 Cross-section of the in-vessel cryo-sorption pump. The pump is installed behind the dome structure in CHD.

Figure 1 shows the cross-section of the in-vessel cryo-sorption pump for the LHD divertor. The pump is installed behind the dome structure of the CHD [4, 5]. The water-cooled louver blind structure is installed between the liquid nitrogen (LN_2) cooled chevron-type shield and the divertor striking point in order to shield the direct radiation from the divertor plasma and its striking point. The cryo-panel is behind the LN_2-cooled shield (~80 K) in order to shield the direct radiation from the water-cooled shield. The cryo-

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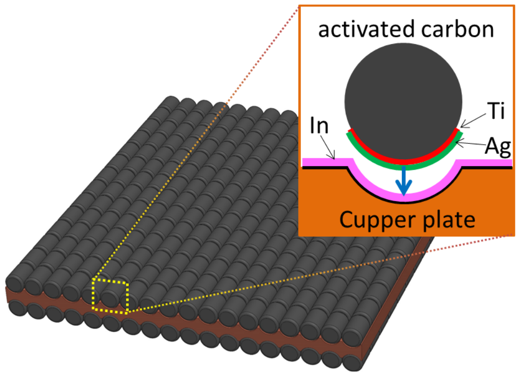

Fig. 2 Schematic view of the cryo-panel and its detail of the adhesive part.

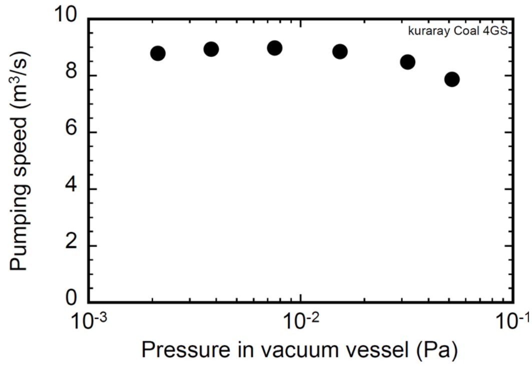

Fig. 3 Pumping speed as a function of the vacuum vessel (plenum) pressure.

panel consists of the copper heat sink and the cooling tubes for gas helium coolant. On the surface of the heat sink, the activated carbon pellets are bonded with indium solder, which is described in detail in the following paragraph.

The activated carbon is the well-known porous material. However, its pores are too fine (0.4 - 50 nm in diameter) for normal tin solder to permeate. Therefore, it is difficult to bond the activated carbon to the copper heat sink by soldering. A new adhesion technique with the indium solder and intermediate materials is developed. Figure 2 shows the schematic view of the cryo-panel and its detail of the adhesive part. Both sides of the cryo-panel are covered with activated carbon pellets of 4 mm in diameter. The pellets are precisely aligned along the grooves on the copper heat sink to maximize the quantity to be bonded. Before soldering the pellets to the copper heat sink, the bonding area of each pellet is precoated with titanium and silver by the sputtering technique. These intermediate materials dramatically improve the solder wettability.

Six units of the newly developed cryo-sorption pump were installed in one of the ten CHD modules in LHD. The pumping speed and capacity were measured, introducing constant and continuous hydrogen flow into the LHD vacuum vessel. The effective pumping area of the cryo-panel is 0.21 m^2 in one toroidal section. The pumping speed up to 9 m^3/s was recorded, as shown in Fig. 3, which is almost the same as the target pumping speed of one CHD module [4, 6]. The pumping speed slightly decreases as there is an increase in the plenum pressure. It is thought that the increase of the plenum pressure causes deterioration of the thermal insulation of the cryo-panel, which results in the increase of the panel temperature. The pumping capacity of 3,320 Pa m^3 was also confirmed, which corresponds to the total amount of the fueled particles in the high-density experiment for one day.

The new bonding technique between activated carbon pellets and the copper heat sink without organic adhesive was established. This outgassing-free cryo-sorption pump has a potential not only for fusion plasma experiments but also for various applications of the ultra-clean vacuum environment, e.g., process plasma instruments, semiconductor factories, etc.

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