§9. Development of Plasma Window Device by using TPD Cascade Arc Discharge

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A thermal plasma having a high gas-plasma viscosity can significantly suppress the gas flow rate in the discharge channel. Thus a cascade arc (*plasma window*) could be used as an interface to separate a vacuum chamber from the atmosphere without needing a large differential pumping system [1]. As a result, many applications of plasma windows are expected. For example, the following processes could be carried out under *atmospheric* conditions using plasma windows [2]: (1) welding, cutting, and fine processing using an electron beam, (2) creation of novel materials and nanoprocessing by ion implantation, and (3) imaging of living biological cells with soft x-rays. Hershcovitch *et al.* transmitted an electron beam into air through a plasma window and welded a stainless steel plate in the atmosphere.

In order to realize a practical arc plasma source having a high potential as the vacuum interface, we have investigated the TPD (Test Plasma by Direct current discharge) device at NIFS [3]. This apparatus that is one of the cascade arc type discharges. The He or Ar dc discharge is initiated between an anode and a cathode. Intermediate floating electrodes are installed to stabilize the cascade discharge.In this study, by modifying the electrodes of TPD device, atmospheric thermal Ar plasmas are generated. The aim is to enhance the performance of the plasma window as a vacuum-atmosphere interface by producing dense, high-temperature plasmas (exceeding 4 eV and 10^{17} cm^{-3}).

FIG. 1 is a schematic of the TPD cascade arc discharge. The cathode is a needle-shaped CeW rod that is 3.2 mm in diameter, and the anode is made of tungsten with an opening of 3 mm in diameter. The intermediate electrodes consist of ten plates made of stainless steel or molybdenum. These openings form a throat around the cathode so that the gas can flow smoothly. Their potentials are electrically floating and are thus determined by the plasma itself to maintain a stable discharge. Argon gas is fed into the discharge section at a constant flow rate of 3.3 L/min. A power supply provides a discharge current of up to I_d = 100 A. The plasmas between the cathode and anode expand in an expansion section exhausted by a mechanical booster and a rotary pump. The discharge is initiated in a glow mode (with I_d = 1 A at V_d = 1 kV). Subsequently the cathode is self-heated up to the working temperature, resulting in a transition from the glow mode to the cascade arc discharge (with V_d~130 V) accompanied by intense plasma emission. FIG. 2 shows a comparison of the plasma emission for the (a) glow and (b) cascade arc discharge modes. The plasma parameters were characterized by means of emission spectroscopy.

Before plasma initiation, the gas pressure is fixed at P_d = 33 kPa. With increasing discharge current, the pressure increases and reaches P_d = 118 kPa at I_d = 20 A. The pressure P_e in the expansion section is 290 Pa. Consequently, the ratio of the pressures in the cathode side to that in the expansion region is 1/407, with and without the booster pump, respectively.

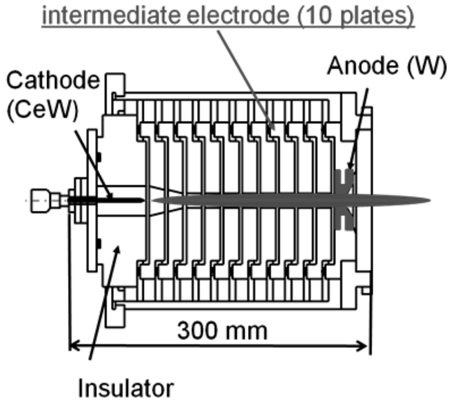

Fig. 1. Schematic of the TPD cascade arc discharge.

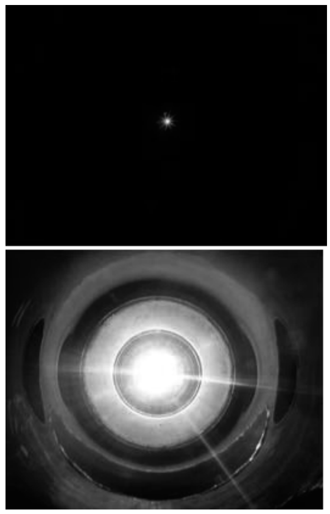

Fig. 2. Photos of plasma emission taken from end viewing port. (a) glow mode and (b) cascade arc discharge.

The steep pressure gradient between the discharge and expansion chamber is caused by plasma plugging owing to the high viscosity of the thermal plasma. Since the gas flow rate is constant, any pressure increase in the discharge pressure indicates that the gas/plasma temperature is also increasing. Assuming that the initial gas temperature is 300 K, a equation of state yields a gas temperature of 1100 K around the cathode. At 100 kPa the viscosities at 300, 1100, and 10 000 K are 2.3×10^{-5}, 5.8×10^{-5} and 2.7×10^{-4} Pa·s, respectively. In addition, the viscosity of charged particles may contribute to the plugging effects. As a result, gas flow through the plasma channel is significantly suppressed.

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