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Significant high-viscous Ar plasma generation for application of electron beam welding in atmosphere

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Plasma window has been paid attention as an innovative plasma technique, by which the dense plasma can separate vacuum from atmosphere (100 kPa) [1]. Such a high-density thermal plasma is generated in a small discharge channel (~3mmϕ) under Ar atmospheric pressures. The reason for this phenomenon is caused due to a higher gas viscosity in hot dense gas. For example, in the case of Ar gas the viscocity is 9×10^{-5} kg/m/s (0.01 bar) at 2000 K, while at 11,000 K (1 bar) it is as high as 2.7×10^{-4} kg/m/s. First, a few eV electron experiences the Coulomb collision with ion, and then the energy relaxation between them. Subsequently, a charge exchange process enhances the gas temperature, resulting in the high viscous gas to suppress the gas flow significantly in the narrow plasma channel. The most promising applications of the plasma window enable to transmit the electron and ion through plasma channel without significant beam scattering, whereas the neutral gas flow is suppressed significantly. Thus, there are various applications, such as, for electron beam welding in atmosphere [2]. The innovative technology makes it possible to realize that the size of work piece for the welding is substantially mitigated and to apply this method to aircraft, ship, and large social infrastructures, which are required for precise micro-fabrication. In addition, in the scientific field, extraction of synchrotron soft X-ray radiation and laser plasma X-rays into atmospheric conditions is very attractive for observation of nanoscale, ultrafast phenomena.

In general, a cascade arc discharge and TPD (Test Plasma by Direct current) plasma sources have been employed to increase plasma temperature and density over 50 years. In the channel, the gas temperature is considerably heated due to the interactions between particles. However, the present pressure gradient was 100 kPa and ~100 Pa, so that the further increase of the gas viscosity is essential to realize the practical plasma window. Thus, our final goal is to demonstrate the pressure difference of 100 kPa-1 Pa (5 orders). In this study, by reconsidering the electrode assembly we have tried to significantly increase the gas dynamic viscosity by much higher plasma density and temperature generation.

Figure 1 shows a schematic diagram of the TPD device developed. Several water cooled intermediate electrodes (Molybdenum) between an anode (Mo) and cathode (LaB_6) were equipped to heat the arc plasma and increase the gas viscosity in the channel. The Ar gas was fed into the cathode side up to 5 L/min. The discharge current and voltage were ~up to 100 A and <200 V, respectively. The hot dense plasma classified into a viscous flow was expanded through the anode nozzle into a large vacuum chamber with a supersonic speed.

The weak points of the TPD discharge as plasma windows are (1) the electrode structure and assembly method were complicated, and it took several hours to replace the electrode parts, damaged by an accidental spark discharge between the electrodes, (2) the cooling water stream into electrodes was a particular structure. In addition, the water pressure was very high (10 atm), so that frequent fully cleaning in the electrodes was necessary, and (3) the intermediate electrodes were seriously damaged after a long time operation.

In order to solve the problems mentioned above, first we changed the method to assemble/disassemble the electrodes. Previously, each electrode was fixed one by one by screws. In order to replace the damaged one, we have employed pile up approach, as shown in FIG. 1. For 2nd one, we redesigned the cooling water flow structure for plasma facing material, by which cooling efficiency was improved significantly.

For (3), we changed the size, material, and thickness of insulators for the prevention of accidental spark discharge between the electrodes that could cause serious damages.

This device is expected to create the virtual plasma interface of 100 kPa and 10 Pa.

In this presentation, we will talk about the improved new electrode and discuss how they works well in details.

References

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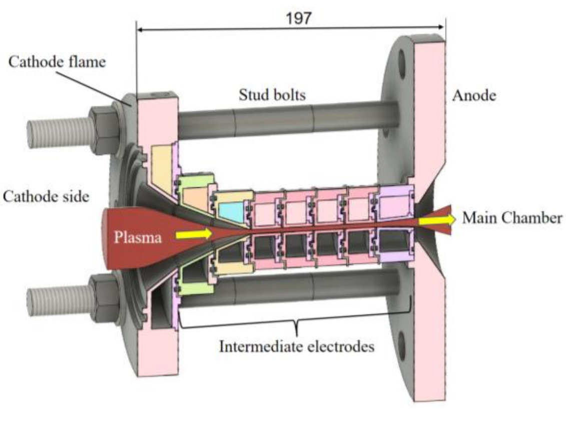

FIG.1. Schematic of the electrode assembly developed.