Structural Bifurcation of Microwave Helium Jet Discharge at Atmospheric Pressure

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(Received 9 January 2008 / Accepted 4 February 2008)

Structural bifurcation of microwave-sustained jet discharge at atmospheric gas pressure was found to produce a stable helium plasma jet, which may open the possibility of a new type of high-flux test plasma beam for plasma-wall interactions in fusion devices. The fundamental discharge properties are presented including hysteresis characteristics, imaging of discharge emissive structure, and stable ignition parameter area.

Keywords: atmospheric-pressure plasma, structural bifurcation, microwave-sustained plasma jet, helium plasma torch

DOI: 10.1585/pfr.3.012

Atmospheric-pressure plasmas have attracted much interest recently for applications in materials synthesis, medical treatment, environmental applications, etc. They may also have great potential for the very high-flux plasma beam intended for fundamental research on plasma-wall interactions in next-generation fusion devices, such as ITER and DEMO. Recently, the Pilot-PSI device has employed a cascaded DC arc discharge for such a plasma production [1], where the so-called “transfer arc” is used to produce heat on the conducting target from arc discharges. The main heat carriers are the electrons in this scheme. Such a situation is quite different from the plasma-wall interactions on the divertor plate where the ion bombardment is essential. This deficiency arises from the electrostatic potential structure determined by the DC arc configuration.

In order to overcome such difficulties, the microwave-sustained plasma torch at atmospheric gas pressure is considered as a new plasma source with high particle and heat fluxes, because it is free from any external electrostatic potential configuration and the high power microwave helps to heat the plasma electrons along the plasma beam by dissipative surface wave propagation. The present work shows some fundamental discharge properties motivated by the above objectives. Helium gas is employed since it is an important species in fusion devices as well as hydrogen isotopes.

We employed the TIAGO (Torche à Injection Axiale sur Guide d’Ondes, in French) nozzle developed by Moisan for the microwave-sustained (2.45 GHz) plasma torch [2], as shown in Fig. 1. It is installed on a waveguide with a narrow gap for enhancing the microwave electric field obtained using tapered waveguides and a short-plunger at the circuit end. The conical structure of the nozzle enhances the microwave field around the top where the main discharge occurs. Some typical images of torch plasmas are shown in Fig. 2, where (a) is a very stable straight laminar helium discharge with around 20 cm in length produced by ignition with a sufficient preset gas flow. On the other hand, a curved discharge (b) appears with a reduced preset gas flow, in which the foot of the discharge on the nozzle is not at the top center, but at the circumferential edge of the nozzle head: this produces a curved discharge channel clearly as shown in these images. The foot turns from time to time around the circumferential edge, either clockwise or anti-clockwise.

Spectroscopy can clearly discriminate between these

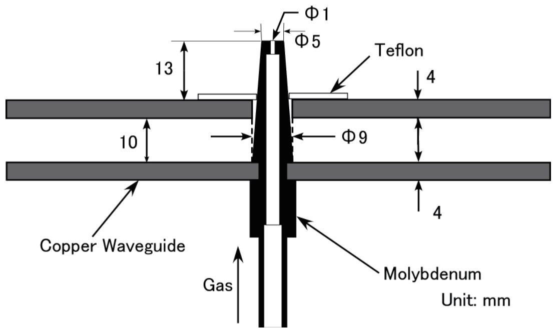

Fig. 1 Detailed drawing of TIAGO nozzle for microwave-sustained plasma jet installed on a waveguide.

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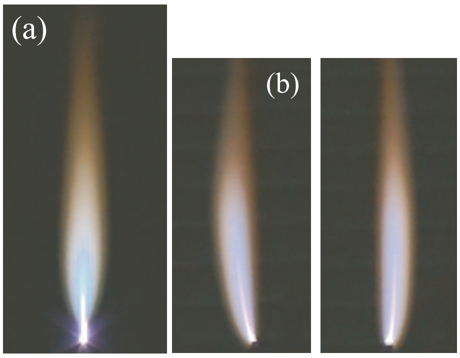

Fig. 2 Still photos of microwave-sustained plasma jet. (a) stable helium plasma jet and (b) curved discharge modes.

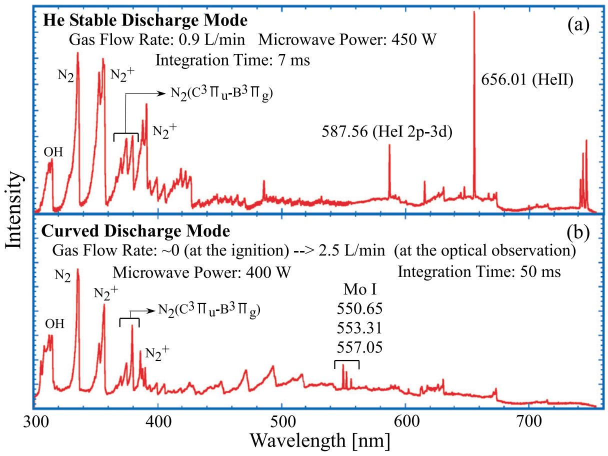

Fig. 3 Spectra of optical emissions from the foot of plasma-jet just close to the nozzle head. (a) was obtained from the stable helium plasma jet, while (b) corresponds to the curved discharge mode.

two discharge modes as shown in Fig. 3 where (a) shows the spectrum from the stable helium plasma close to the nozzle head with strong helium species emissions, while (b) corresponds to that from the curved discharge plasma with few He emissions. The latter indicates an air discharge with molybdenum contamination.

Figure 4 shows the area corresponding to stable ignition in the parameter space of gas flow rate and incident microwave power. The figure shows the ignition conditions: the stable ignition area expands with increase in incident power. Once we obtain a stable ignition with an appropriate preset gas flow rate corresponding to Figs. 2 (a) and 3(a), we can reduce the flow rate while sustaining a stable mode even below the boundary of the curved ignition area. Insufficient initial helium gas flow gives an unstable curved discharge even at an increased flow rate after ignition as shown in Fig. 3 (b), where the preset He gas flow is close to zero at ignition and then increases to as much as 2.5 L/min.

We now try to explain this bifurcation in discharge

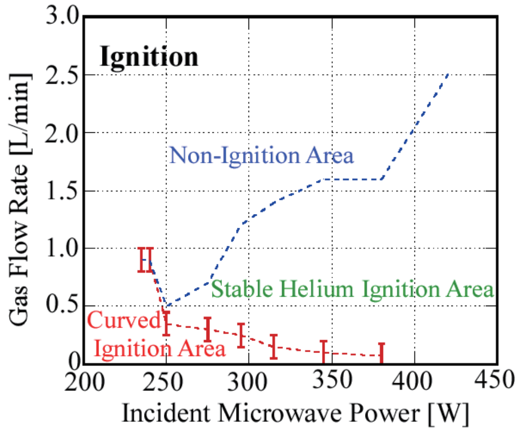

Fig. 4 Ignition area for the straight laminar helium discharge in the parameter space of helium gas flow rate and incident microwave power. The area between the two boundaries corresponds to stable helium discharge ignition. The upper line shows the boundary for stable discharge ignition, above which we do not have any initial ignition. The lower broken line shows the boundary for curved ignition discharge, below which we have rotating curved discharge.

structure. Based on the spectroscopic analysis and image observations, the curved discharge mode is considered to form a roundabout discharge channel bypassing the straight helium gas flow. The reason behind this phenomena is not clear at the moment. Possible explanations are that the surrounding air region with lower flow speed is more likely to be ionized than the central helium gas region with a higher flow speed. Curved bypassing discharges are maintained even after increasing the helium gas flow rate. The easier ionization in the surrounding area might be due to the difference in the ionization process related to particle balance and/or the influence of gas flow speed on energy balance. No bifurcation of the argon plasma jet is found, which may give some indications on the physical mechanism.

The azimuthal rotation of the curved discharge channel may come from a weak fluctuation of transverse air wind, because there is no force equilibrium in this direction.

In conclusion, we identified a stable ignition area in the parameter space of preset helium gas flow rate and incident microwave power for ignition of the plasma-jet at atmospheric pressure. Such a structural bifurcation of discharge could be explained by the self-organized selection of a discharge channel either along helium gas flow channel or through the surrounding air bypass.

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