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Generation of Atmospheric-Pressure Line Plasma with Narrow Gap Slot Antenna
狭ギャップスロットアンテナを用いた大気圧ラインプラズマ生成

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A long line plasma is produced by 2.45 GHz microwave in helium or argon gas under atmospheric pressure with a newly-designed antenna which consists of a loop-structure waveguide with a narrow-gapped long slot and a microwave circulator transmitting only traveling waves in one-direction. Spatio-temporal behavior of the plasma was investigated by a digital still camera and a high speed camera. Pseudo-continuous line plasma was realized by fast movement of small plasmas along the slot antenna of 0.5 mm in width in the direction of the microwave propagation. When narrowing the slot gap to 0.1 mm in width, plasma became genuine-continuous line plasma.

1. Introduction

Atmospheric pressure plasmas have been given much attention because of its cost benefit and a variety of possibilities for industrial applications such as large area processing. In recent years, various kinds of plasma production techniques have been studied using corona discharge, DBD, pulsed discharge, plasma jet, and so on. Above all, microwave discharge plasma sources using slotted waveguide antenna produces stable and dense plasmas. So far, we have developed a 2.45 GHz microwave long line plasma source which consists of a loop-structure waveguide antenna and a microwave circulator transmitting only traveling waves [1]. When we generated the plasma with a slot antenna of 900 mm in length and 0.5 mm in width, and "pseudo-continuous" line plasma that looked like continuous line plasma by fast movement (~10 m/s) of small plasmas (a few mm in length) along the long line slot was realized with 800 mm in length. It was also found that the plasma speed was almost proportional to time-averaged input power [2]. To produce genuine-continuous plasma, investigations of plasma characteristics are required and, in this study, variations of plasma size and speed are investigated at different slot gap widths by a high-speed camera measurement.

2. Experimental

Figure 1(a) shows a schematic of the microwave

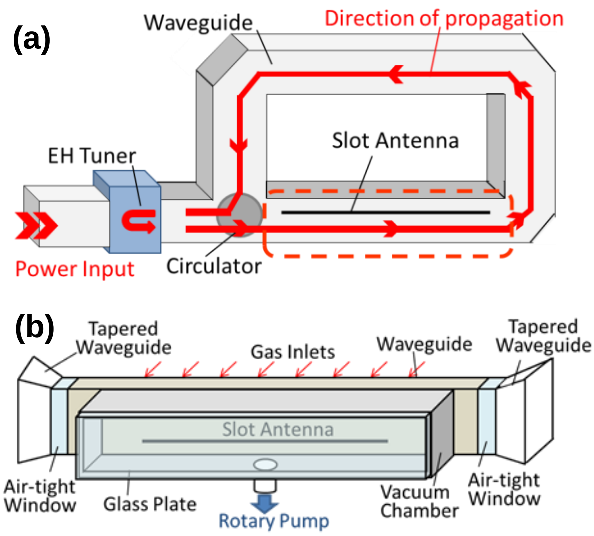

Fig.1. schematic of microwave line plasma source; (a) loop-structure waveguide, (b)vacuum-sealed part.

line plasma source that is composed of a loop-waveguide, a narrow-gap slot (600 mm in length, 0.1-0.5 mm in width), an EH tuner and a microwave circulator. The circulator permits energy flow in only one direction and the EH tuner reflects the power into the loop again by impedance matching as red arrow. Thus power flow of only traveling wave is superimposed in the loop suppressing energy loss and induces high electric field in the slot. A pulse-modulated microwave source (pulse-frequency: 20 kHz, duty cycle: 20-100%, peak power: 1.0-2.0 kW) is connected to the loop waveguide system. The detailed structure of the slot antenna inside dashed circle in Figure 1(a) is described in Figure 1(b). A section of the loop waveguide that includes the slot is vacuum-sealed by two air-tight windows and is connected to a vacuum chamber that is evacuated by a rotary pump. After the evacuation, the chamber and the sealed waveguide are filled with helium or argon gas at a flow rate of 5000 sccm through small 33 holes on the waveguide. Spatio-temporal behavior of the plasma is investigated through a glass plate by a digital still camera and a high speed camera (exposure time: 50 μs, frame rate: 6000 fps).

3. Results and Discussions

Figure 2 compares duty cycle dependences of the length and the speed of one moving plasma at slot gap widths of 0.1 mm and 0.5 mm, respectively. Peak input power was fixed at 1.0 kW at duty cycles less than 60%, the plasma speed increased linearly with increasing duty cycle with a slight increase of the each plasma size, irrespective of the slot gap widths. At duty cycles more than 60%, however, the behavior was different depending on the slot width. At a gap width of 0.5 mm, the speed and the size monotonically increased with increasing the duty cycles over 60%. In the case of 0.1 mm gap width, however, the speed decreased and the size increased drastically with increasing the duty cycles over 60%, and the plasma became almost continuous at duty cycles over 92%.

To investigate experimental conditions to obtain “genuine” line plasma, i.e., single stable plasma with plasma lengths comparable to that of the slot length, peak microwave power was increased to 2 kW at a slot gap width of 0.1 mm. Figure 3(a) shows an image of the plasma emission in this condition at a duty cycle of 60%. Very long line plasma is clearly observed. The same plasma was observed by the high-speed camera, and neither discrete small plasmas nor the plasma movement were observed, and production of the single stable line plasma was confirmed. Figure 3(b) shows emission intensity profile along the slot measured at an exposure time of 2 ms. Uniform line plasma more than 30 cm was realized at center region of the slot. It is expected longer line plasma can be produced by increasing the slot length.

4. Conclusion

Line plasma generation inside long line slot antenna using traveling microwave was investigated.

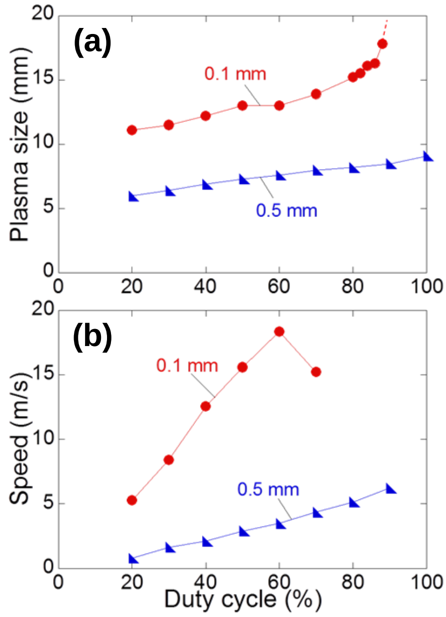

Fig.2. Dependence of (a) plasma size and (b) speed on slot gap width and duty cycle.

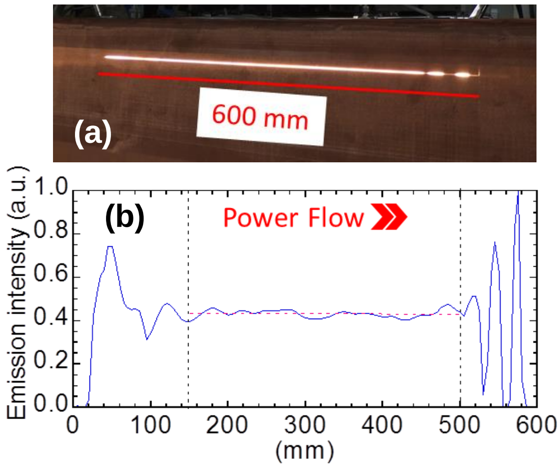

Fig.3.(a) An image of the plasma emission and (b) its distribution of the emission intensity along the slot.

At low microwave powers and duty cycles, movement of small plasmas along the slot was observed. Both length and speed of small moving plasmas increased with increasing the duty cycles. At a slot gap width of 0.1 mm, drastic increase in the length of the moving plasma was observed at higher duty cycles. By increasing the peak microwave input power, “genuine-continuous” line plasma was produced at a slot gap width of 0.1 mm.

Acknowledgments

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