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# Production of long-scale atmospheric pressure microwave plasma

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Recently, much attention has been given to non-thermal atmospheric-pressure (AP) plasma as the next-generation plasma processing for its potential of inexpensive and simple system configurations without vacuum systems. So far, various AP sources using corona discharge, dielectric barrier discharge or plasma jet has been proposed aiming at their industrial applications to surface cleaning or modification, and two-dimensional enlargement of these AP plasma sources has been studied by enlargement of plasma source itself or by arraying small plasma sources. However, these plasma sources have rather low plasma densities less than $10^{19}$ $m^{-3}$ and tend to be spatially non-uniform plasma. As an alternative AP source, microwave plasma is attractive because of its high plasma density (>$10^{20}$ $m^{-3}$) compared with conventional AP sources. Recently, we have proposed a new AP microwave plasma source that utilizes travelling wave for uniform plasma production for longer scale. Using this plasma source, it has been demonstrated that spatially-uniform one-dimensional AP line plasma with 40 cm in length can be realized[1,2]. In this talk, concept of the long-scale microwave AP will be presented with its plasma characteristics.

Figure 1 shows a schematic of the experimental set up. The plasma source is composed of a loop waveguide, a microwave circulator and an EH tuner. A microwave source (2.45 GHz, pulse-frequency: 20 kHz, duty cycle: 20-100 %) is connected to the loop waveguide through the circulator and the EH tuner. Microwave power from the power supply flows into the loop waveguide with the circulator through the EH tuner and comes back again to the EH tuner through the circulator. Suppression of the total power reflection from the EH tuner to the power supply, i.e., the impedance matching, realizes the increase in the directional microwave power flow inside the loop waveguide. A long slot (60 cm in length, 0.1 mm in width) is cut in a part of the loop waveguide (9.6 cm × 2.7 cm in waveguide cross section) made of aluminum. Helium, argon or nitrogen gas is introduced into the waveguide through a mass flow controller, filling the waveguide with the discharge gas at a pressure of 100 kPa (atmospheric pressure). Plasma is produced inside the long slot by applying microwave power. Spatial distribution of the plasma is observed by a digital still camera and spatiotemporal variation of the discharges is also investigated by a high-speed camera.

Figure 2 shows an example of the Ar line-plasma. Photograph on the top of the figure shows almost uniform plasma production along the slot with an discharge length of 40 cm. Emission intensity profile along the slot shown in the figure indicates that very uniform plasma production. .

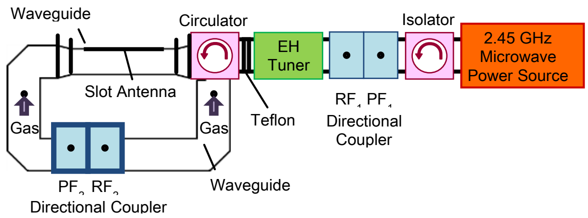


Figure 1 Schematic of experimental apparatus.

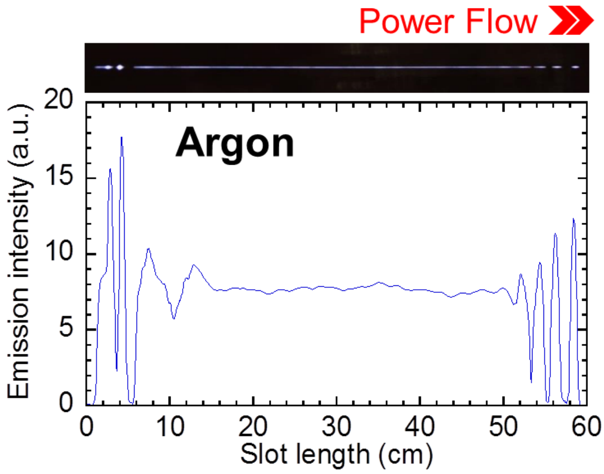


Figure 2 Emission intensity profile along the slot.

Electron density of this plasma is evaluated from Stark broadening of the $H_\beta$ emission line by adding a small amount of hydrogen gas into Ar plasma. By subtracting influences of collision broadening, Doppler broadening etc., electron density of ~$2x10^{20}$ $m^{-3}$ is obtained with very uniform electron density along the slot. Gas temperature is also evaluated by adding small amount of $N_2$ and rotational temperature of $N_2$ emission to be ~400 K and ~600 K in the cases of He and Ar discharges, respectively. Furthermore, by modifying the waveguide structure, AP microwave line plasma is realized by 100% $N_2$ discharge. This result implies that the AP microwave line plasma is attractive for various kinds of plasma processing with large area.

References

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[2] Suzuki H., Nakano S., Itoh H., Sekine M., Hori M., and Toyoda H., Characteristics of an atmospheric-pressure line plasma excited by 2.45 GHz microwave travelling wave, Jpn. J. Appl. Phys. (2016) **55**, 01AH0