Spatial control of very high frequency plasma generation for large scale plasma applications

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Spatially uniform and large scale very high frequency (VHF) plasma has been required for several kinds of plasma application. However, VHF plasma is usually generated only on a part of the electrode due to the influence of standing wave. In this paper, the control of VHF plasma generation position by using the terminal impedance change is demonstrated. Spatially uniform VHF plasma all over the electrode was successfully obtained by the temporal scan of the spatially-localized plasma.

1. Introduction

Very high frequency (VHF) plasma has been paid much attention for semiconductor manufacturing such as chemical vapour deposition, etching and so on [1-4]. VHF plasma enables to achieve higher processing speed and film quality compared with conventional radio frequency (RF, 13.56MHz) plasma, because VHF plasma has higher electron density and lower electron temperature [1, 4]. For practical applications of VHF plasma, it has been greatly required to generate spatially uniform and large scale VHF plasma. Meter-order VHF plasma [1, 2, 4], however, is difficult to be generated uniformly all over the electrode due to the influence of standing wave. The standing wave takes place by convolution of two waves of which traveling directions are the opposite each other.

In this research, we have been developing the method to generate spatially uniform VHF plasma on large scale electrode [1, 4]. The concept of this method is to change the generation position of VHF plasma temporally all over the electrode. As the VHF plasma generated at each position has the same characteristics, spatially uniform and large scale applications can be achieved. In this paper, the standing wave and the resulting VHF plasma generation position are controlled by the terminal impedance change. Also, spatially uniform VHF plasma all over a meter-order electrode is obtained by temporally scanning of the plasma generation position.

2. Experimental setup

Figure 1 shows a schematic drawing of an experimental setup for large scale VHF plasma using terminal impedance change. Facing two parallel plate electrodes (1.1 m×0.2 m, Z_0=47.2 Ω) were installed in a chamber. These electrodes have many small holes to watch plasma behind the electrode. Pressure was kept constant in pure Ar or H_2 during the experiments.

A VHF power supply (60 MHz) was connected to one edge of the electrodes (left edge in Fig. 1) through a power divider, and applied the electromagnetic power to two electrodes. The electrode length of 1.1 m is about one fourth of a wavelength (λ= 5 m) of the VHF voltage wave. In such geometry, it is necessary to consider electrode itself as a part of the distributed circuit. The phase difference between two voltage waveforms applied to each electrode was kept π as shown in Fig. 2. As the

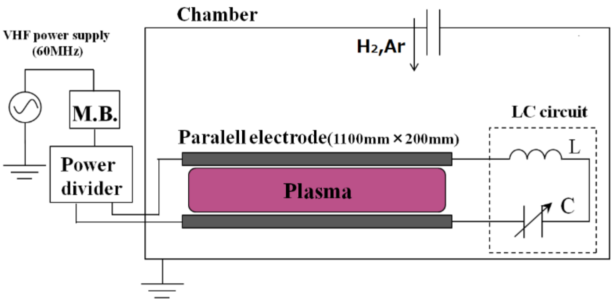


Fig. 1. Schematic drawings of experimental setup for large scale VHF plasma using terminal impedance change.

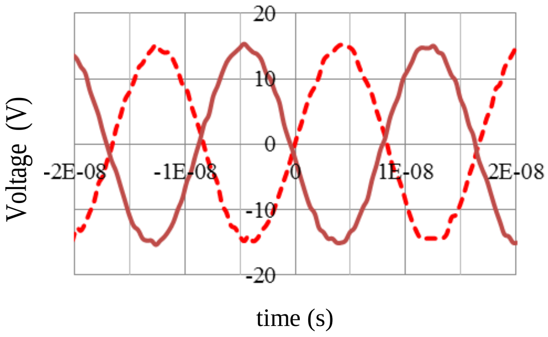


Fig. 2. VHF voltage waveforms measured at one edge of the electrode before a breakdown. A solid line and a broken line is for one electrode and the other, respectively.

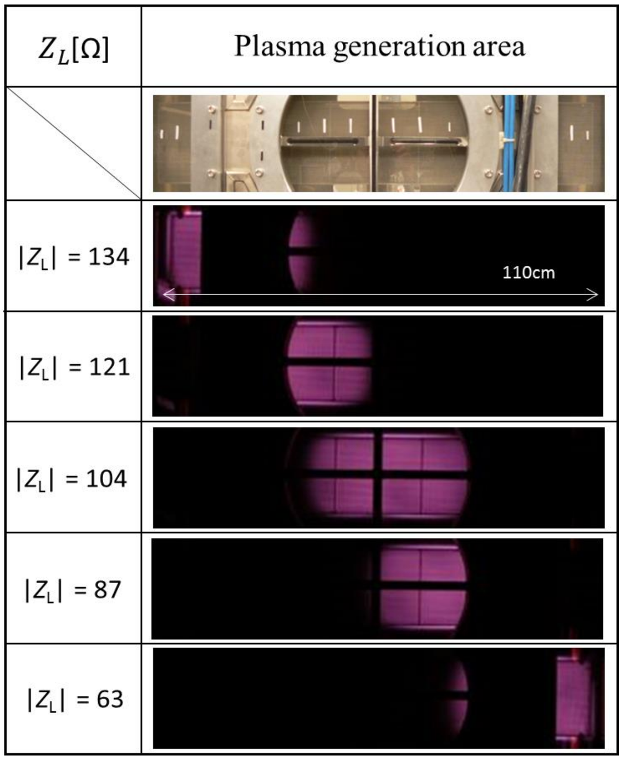


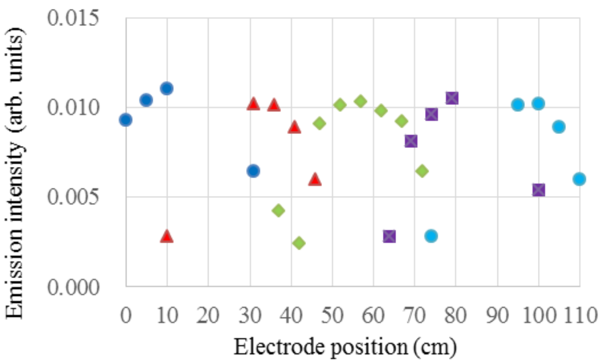
Fig. 3. Photographs of VHF plasma generated at various positions as a function of the terminal impedance Z_L.

result, VHF plasma was generated only between the electrodes without any abnormal discharge. Variable LC circuit was attached between opposite edges of two electrodes (right edge in Fig. 1). The terminal impedance was varied ($|Z_L|$=29 – 250 Ω) by changing of the value of a variable capacitance that was connected to an induction motor that was placed outside of the chamber and controlled electrically by an inverter and a PC. Reflectivity of the VHF voltage wave at the electrode terminal edge was varied from -0.7 to 0.3, and the resulting VHF plasma generation position was controlled by changing of the terminal impedance.

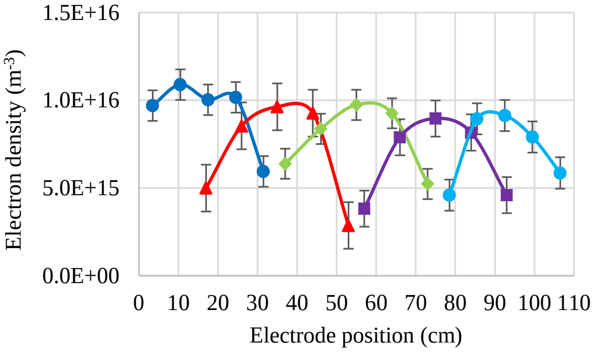
In order to evaluate characteristics and spatial distribution of the VHF plasma, an optical emission, electron density, and electron temperature of the VHF plasma was measured at each generation position by using a digital camera, a pin photo diode, and a floating double electric probe [5].

3. Results and discussion

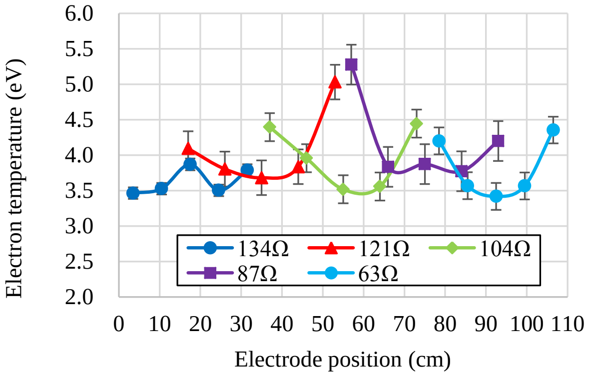
Figure 3 shows the photographs of VHF plasma generated at various positions as a function of the terminal impedance, which were taken from the back side of the electrode. These plasmas were generated under the same condition of 300 mTorr in H_2, input power of 30 W, electrode separation of 30 mm. As can be seen in Fig. 3, plasma generation position was controlled by changing of the terminal impedance.



(a) Optical emission intensity



(b) Electron density



(c) Electron temperature

Fig. 4. Spatial distributions of (a) optical emission intensity, (b) electron density and (c) electron temperature of VHF plasma generated at various positions as a function of the terminal impedance Z_L.

Figure 4(a), 4(b) and 4(c) shows spatial distribution of optical emission intensity, electron density and electron temperature of the spatially-localized VHF plasma generated at various positions as a function of the terminal impedance Z_L, respectively. As can be seen in Fig. 4(a), the peak intensities at each plasma generation position are almost constant. And the full widths at half maximum of spatial distribution of the optical emission are also constant of 350 mm. As can be seen in Figs. 4(b) and 4(c), peak value of electron density n_e and electron temperature T_e of each plasma is almost same as 1.0×10^{16} m^{-3} and 3.5 eV, respectively. Also, the spatial profiles of n_e and T_e at various VHF plasma generation positions are almost similar. Furthermore, the spatial distribution of n_e of each plasma is almost similar as the one of the optical emission. These results show spatially uniform VHF plasma could be obtained on large electrode area by temporal scan of spatially-localized plasma which has same characteristics and spatial distribution at each position.

Figure 5 shows a photograph of VHF plasma scanned its generation position temporally by changing of the terminal impedance. The plasma was generated at the same experimental condition of Fig. 3, and the photograph was taken by the digital camera with a diaphragm value of 8.0 and a shutter speed of 5.0 s. The value of the terminal impedance $|Z_L|$ was changed from 63 Ω to 134 Ω with gradually-changed scan speeds in the range of 30 – 60 Ω/s, then the spatially-localized VHF plasma was moved from the power feed edge to the terminal one for 5.0 s. As can be seen in Fig. 5, a spatially uniform and large scale VHF plasma can be obtained by temporal scan of the spatially-localized plasma. In order to evaluate the spatial uniformity of the scanned VHF plasma, spatial distribution of the emission intensity all over the electrode was estimated from the photograph (Fig. 5) by using a free software (ImageJ). As the result, the uniformity of the emission intensity was obtained to be within ±13 %. This uniformity should become better by further optimizing of the scanning speed of the localized plasma.

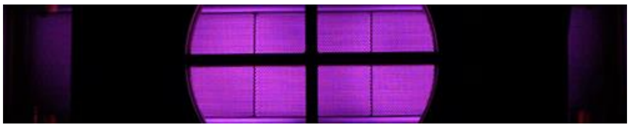


Fig. 5. Photograph of VHF plasma scanned its generation position temporally by changing of the terminal impedance Z_L.

4. Conclusion

Spatially uniform and large scale VHF plasma was obtained successfully by using the terminal impedance change. This method is seemed to be very useful for the future VHF plasma applications.

5. References

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