Electron Temperature and Density Measurement of Cylindrical Parallel MCS Discharge Plasma in Atmosphericpressure

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We propose a cylindrical parallel microhollow cathode sustained (MCS) discharge plasma as a new large-area plasma source at atmospheric pressure. We measured the electron temperature and the density of this plasma source by using a Langmuir probe method and spectroscopy. The electron temperature at r=R/2 was measured to be 0.18 eV by using the Boltzmann plot method under the conditions that the inner radius of cylinder was R = 6.3 mm; MHCD supply voltage, –600 V at 50 s and 1 kHz; MHCD current, 10 mA for each electrode; the voltage of the third electrode, 1.5 kV; and pressure, 10 kPa. Furthermore, this temperature remained approximately constant irrespective of the pressure and the MHCD current.

Keywords: MHCD, MCS, plasma diagnostic, Langmuir probe, spectroscopy, atmospheric pressure

1. Introduction

Microhollow cathode discharge (MHCD) is a promising technique used for generating atmospheric-pressure glow plasma [1][2]. Furthermore, microhollow cathode sustained (MCS) [3] glow discharge, in which the MHCD becomes the electron source and the electrode for the third-electrode discharge, is used for expanding plasma volume along approximately one direction. For a three-dimensional expansion of the plasma volume, parallel operations of the MCS discharge are required. We propose a method using a cylindrical parallel MCS discharge plasma, in which several MHCD electrodes are placed on a cylindrical tube and the third electrode is a line electrode at its center, for carrying out parallel operations of the MCS discharge [4][5].

In the plasma process such as gas treatment, thin film deposition and etching, it is important to know the plasma parameter of its temperature and density so that we understand the mechanism of the process and control those. In this study, we measured the electron temperature and the density of the MHCD plasma, MCS discharge plasma, and the cylindrical MCS discharge plasma by using a Langmuir probe method and spectroscopy.

2. Experimental setup

We used an MHCD electrode composed of glass-epoxy double-sided polychlorinated biphenyls. The thickness of the glass-epoxy layer was 0.05 mm. The hole diameter of the MHCD was 0.6 mm.

Figure 1 shows the electric circuit with a negative pulse voltage source E_{MH}, a DC voltage source E_3 (max. 20 kV, 2 mA), two MHCD electrodes (C_1 and C_2), and the third electrode A2. I_{MH} is the MHCD current from electrode A1 to a ground point. E_{MH} is composed of a negative high-voltage DC source and two series-connected insulated gate bipolar transistor switches (max. voltage: 1.2 kV for each) controlled by a pulse generator.

Figure 2 shows the electrode structure of cylindrical parallel MCS discharge. The MHCD electrodes, whose structures are the same as those of the electrodes shown in Fig.1, were placed on the outer surface of a cylindrical tube (outer diameter: 15 mm and inner diameter: 13 mm).

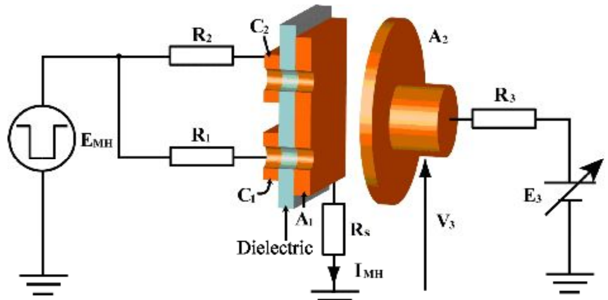

Fig.1 Experimental circuit

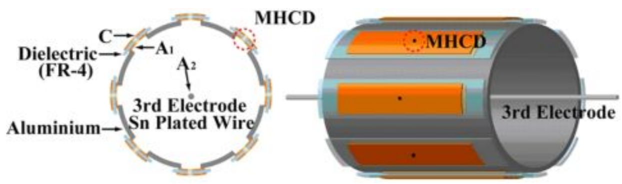

Fig.2 Schematic diagrams of cylindrical parallel MCS discharge

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The third electrode was composed of a tinned copper wire (diameter: 0.5 mm) at the center of the aluminum electrode. We applied the voltage to a cylindrical parallel MCS discharge electrode (Fig.2) by using an experimental circuit similar to that shown in Fig.1 and obtained a cylindrical parallel MCS discharge.

The Langmuir probe used was composed of a tungsten wire (diameter: 0.3 mm), which was isolated by a polyvinyl chloride line (diameter 0.7 mm). The probe current was measured by using a R_{s2} resistance and a differential amplifier circuit. Figure 3 shows the electrode arrangement and the circuit.

In this study, we used Spectrometer MMS UV-VIS II manufactured by Carl Zeiss in order to measure the generated by the MHCD and MCS plasmas. Its specifications are as follows: number of pixels = 256, wavelength range = 190–720 nm, and resolution = 7 nm. Figure 4 shows the schematic diagrams of spectroscopy. We condensed the light emitted by the discharge by using plane-convex lenses and measured it by using a spectroscope. The entrance slit of the spectroscope was 0.5 mm in diameter.

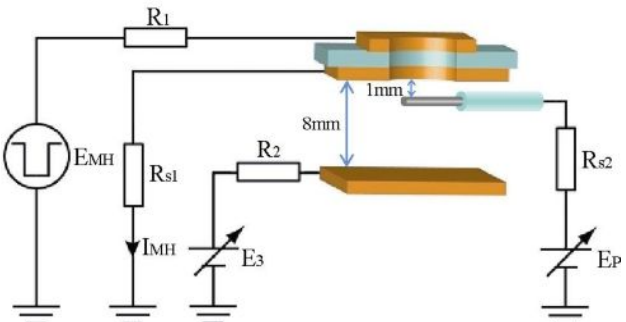
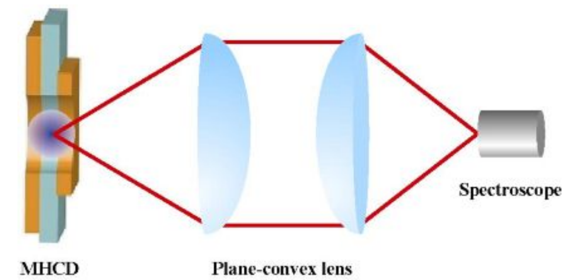
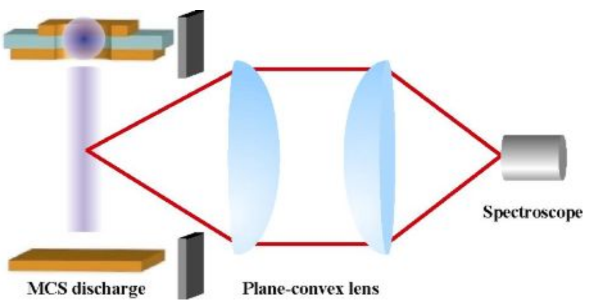


Fig.3 Schematic diagram of the probe circuit



(a) MHCD



(b) MCS discharge

Fig.4 Schematic diagrams of the spectroscopy

3. Experimental results

3.1 Probe measurements of MHCD and flat MCS discharge plasmas

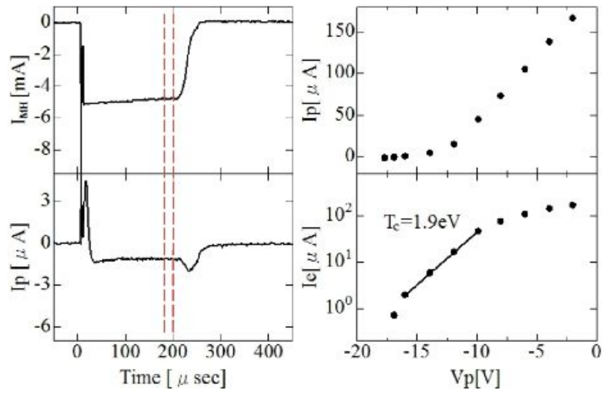
(a) MHCD plasma

We generated the MHCD plasma under the conditions that the MHCD supply voltage was 600 V at 200 s and 1 kHz and the pressure was 2 kPa, and measured the electron temperature and the density of the plasma with a Langmuir probe. The distance between the top of the probe and the anode of MHCD electrode assembly was set to 1 mm. We changed the voltage E_p from –2 V to –18 V and measured the probe voltage V_p and the probe current I_p. Figure 5 (a) shows the typical waveforms of I_{MH} and I_p in the case of $V_p = -18$ V. We assumed that the I_p at $V_p = -18$ V was the ion saturation current I_i, and calculated the electron current I_e. Figure 5 (b) shows the I_p, I_e–V_p characteristics. If I_e is plotted for V_p with the logarithmic scale, a linear curve will be observed from $V_p = -10$ to –16 V. The electron temperature T_e was measured to be 1.9 eV. The equation used for the calculation was as follows:

$$d \ln I_e(V) / dV_p = e / kT_e$$

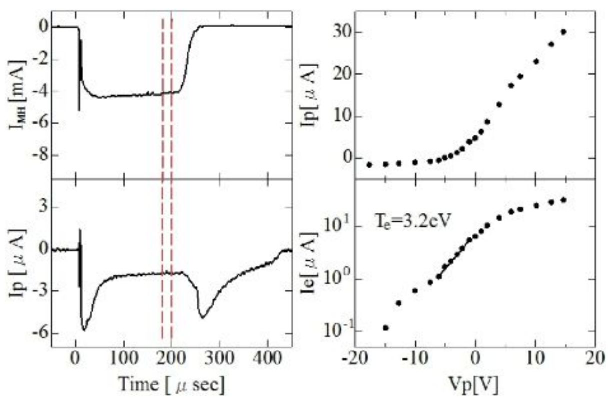
Furthermore, by assuming that the probe had been inserted to a distance of 0.5 mm in the MHCD plasma, we estimated the electron density N_e as 5.9×10^{15} m^{-3}. The equation used for the calculation was as follows:

$$I_i = 0.61 N_e e \sqrt{kT_e / m_i} S$$



(a) I_{MH} and I_p ($V_p = -18$ V) (b) I_p, I_e–V_p characteristics

Fig.5 Results of MHCD



(a) I_{MH} and I_p ($V_p = -18$ V) (b) I_p, I_e–V_p characteristics

Fig.6 Results of MCS

(b) Flat MCS discharge plasma

The distance between the MHCD electrode and the third flat electrode was set to 8 mm. We generated the MCS discharge plasma under the conditions that the MHCD supply voltage was 600 V at 200 s and 1 kHz, the voltage of the third electrode was 600 V, and the pressure was 2 kPa. The distance between the top of the probe and the anode of the MHCD electrode was set to 1 mm. We changed the E_p from 15 V to –18 V and measured V_p and I_p in the same manner as that used in the case of MHCD plasma. Figure 6 (a) shows the waveforms of I_{MH} and I_p in the case of V_p = –18 V. Figure 6 (b) shows the I_p, I_e–V_p characteristics. The electron temperature T_e of the MCS discharge plasma was measured to be 3.2 eV and the electron density N_e was estimated to be 6.7×10^{15} m^{-3}.

3.2 Spectroscopy of MHCD and flat MCS discharge plasmas

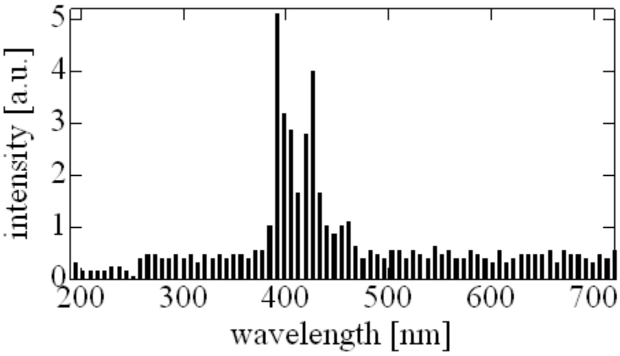


Fig.7 Result of the spectroscopy

(a) MHCD plasma

We generated the MHCD plasma under the conditions that the MHCD supply voltage was –1200 V at 50 s and 1 kHz and the pressure was 100 kPa, and measured the electron temperature by using spectroscopy. We placed the spectroscope on the cathode side of the MHCD electrode assembly and condensed the light emitted by the MHCD plasma by using plane-convex lenses. Figure 7, 8 shows the result of the spectroscopy. We selected three spectrums (wavelengths: 391.79 nm, 400.19 nm, and 427.24 nm), because emission from MHCD is weak and these spectrums were clearly distinguished. We calculated the electron temperature to be 0.62 eV by using the Boltzmann plot method. The equation used for the calculation was as follows:

$$\ln(\varepsilon\lambda / Ag) = -E / kT + \ln K$$

We measured the change in the electron temperature of the MHCD plasma by using spectroscopy when the discharge condition was changed. Figure 9 shows the relationship between the electron temperature of MHCD plasma and each discharge condition. When the discharge condition (pulse width or frequency) was changed, a comparable result was obtained. The electron temperature of MHCD plasma was found to be independent of the discharge condition.

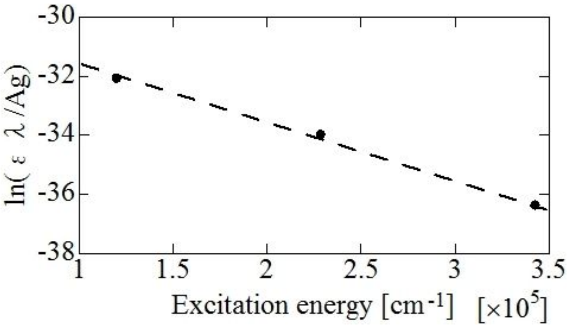
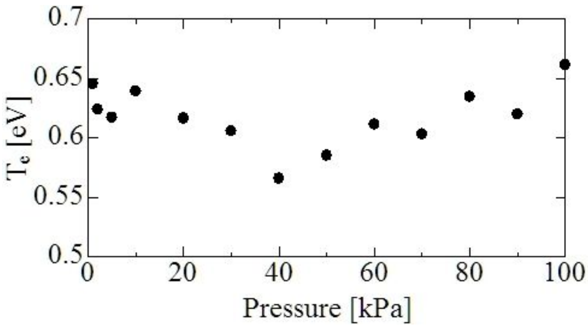
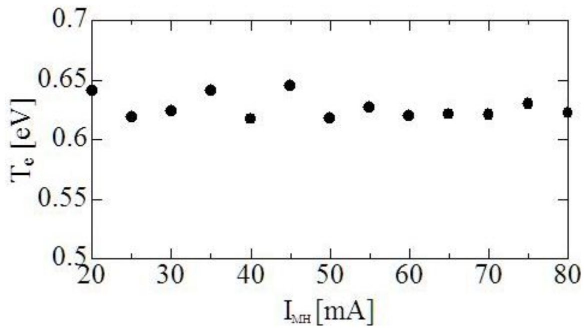


Fig.8 Result of the spectroscopy



(a) 20 mA, 50 s, 1 kHz



(b) 100 kPa, 50 s, 1 kHz

Fig.9 Relationship between the electron temperature of the MHCD plasma and each discharge condition

(b) Flat MCS discharge plasma

The distance between the MHCD electrode and the third flat electrode was set to 8 mm. The MCS discharge plasma was generated under the conditions that the MHCD supply voltage was –1200 V at 50 s and 1 kHz, the voltage of the third electrode was 1.8 kV, and the pressure was 30 kPa. We shielded the light emitted by the MHCD plasma and condensed the light emitted by the MCS discharge plasma by using plane-convex lenses. We measured the properties of the MCS discharge plasma and found its electron temperature T_e to be 0.12 eV.

The electron temperature measured using spectroscopy is a spatially averaged temperature of the plasma, but using Langmuir probe method is a local temperature of the plasma. Therefore, we thought that the electron temperature using Langmuir probe method was calculated higher than spectroscopy. Moreover, we measured T_e of MHCD plasma by using a Stefan-Boltzmann law, and found its T_e to be about 0.5 eV. Therefore, we thought the spectroscopy measurement was superior and reliable than the probe measurement.

3.3 Spectroscopy of cylindrical MCS discharge

We measured the change in the electron temperature of the cylindrical MCS discharge plasma and parallel MCS discharge plasma by using spectroscopy when the discharge condition was changed.

Figure 10 shows the relationship between the electron temperature and the MHCD current I_{MH}. When a discharge condition (pressure, pulse width, or frequency) was changed, a comparable result was obtained. The electron temperature of the plasma was found to be independent of the discharge condition. The electron temperature of the cylindrical MCS discharge plasma was found to be higher than that of the parallel MCS discharge plasma.

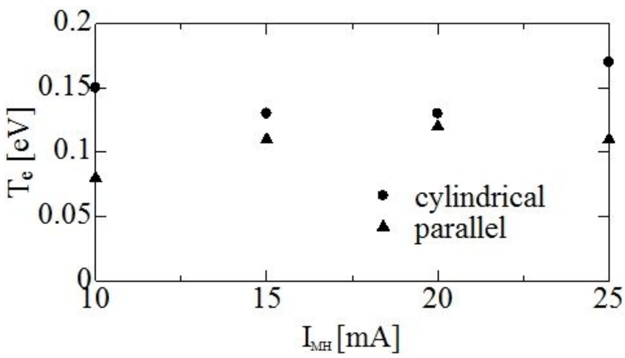


Fig.10 Relationship between electron temperature and I_{MH}

4. Conclusions

The experimental results using Langmuir probe method showed that the electron temperature of the MHCD plasma was measured to be 1.9 eV, and the electron temperature of the MCS discharge plasma was measured to be 3.2 eV. The electron dencity of MHCD plasma was measured to be 5.9×10^{15} m^{-3}, and MCS discharge plasma was measured to be 6.7×10^{15} m^{-3}. The experimental results of the electron temperature measurement for MCS discharge plasma and cylindrical MCS discharge plasma using spectroscopy showed that the electron temperature of the cylindrical MCS discharge plasma was higher than that of the parallel MCS discharge plasma. Those results were independent of the discharge condition.

5. References

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