A LARGE VOLUME HIGH PRESSURE PLASMA SOURCE BY USING CYLINDRICAL PARALLEL MCS DISCHARGE

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(Received: 2 September 2008 / Accepted: 22 January 2009)

We developed a cylindrical parallel microhollow cathode sustained (MCS) discharge plasma source as an atmospheric-pressure plasma source that is applicable to gas processing. The electron supply by the MHCD plasma and the electron trapping effects of the logarithmic potential can be expected because of the cylindrical configuration. Several MHCD electrodes were placed on an external cylinder surface that is 6.3mm in radius, and a thin wire was placed at the center axis of the cylinder. MHCD electrodes were supplied a repetitive pulse voltage (f=1kHz、pulse width=50us、and discharge current=15mA for each electrodes), and the central wire anode was supplied DC voltage through the current limiting resistor (750kΩ). We measured the pressure condition for a stable glow discharge with and without MHCD and demonstrated that a cylindrical glow discharge plasma was obtained uniformly up to 20kPa by using parallel MHCD plasma sources.

Keywords: Plasma, MHCD(Micro Hollow Cathode Discharge), MCS (Micro Cathode Sustained), cylindrical configuration, atmospheric- pressure plasma

1. Introduction

Recently, plasma has been used in various fields (plasma coating, pollution processing, etc [1].) and an atmospheric- pressure plasma source is actively researched from the point of improving processing speed, simplifying operation process, and so on. Microhollow cathode discharge (MHCD) can generate a stable glow discharge at atmospheric pressure and in plasmas with a high current density [2]. Because a volume of single MHCD is very small, that is extended to one dimension by Micro Cathode Sustained (MCS) discharge that is discharge between MHCD and third electrode. Moreover, the parallel arrangement of the MHCD electrodes is used for extending the plasma volume to a third dimension [3][4][5]. A parallel MCS discharge can be controlled by MHCD [6][7].

In this paper, we propose a cylindrical parallel MCS plasma source that is applicable to gas processing. Several MHCD electrodes are placed on an aluminum cylinder surface, and a thin wire is placed at the central axis of the cylinder. In this electrode configuration, electron trapping effects of logarithmic potential can be expected from the research of a Wire Ion Plasma Source (WIPS) discharge [8].

Furthermore, we measured the conditions of the cylindrical parallel MCS and demonstrated that a cylindrical parallel MCS plasma is obtained uniformly up to 20 kPa by using parallel MHCD plasma sources.

2. Experimental setup

Figure 1(a) shows the electrode configuration of the cylindrical parallel MCS discharge. Several MHCD electrodes were placed on the outer surface of an aluminum cylinder tube with a radius of 6.3 mm; a tin-plated wire with a diameter of 0.4 mm was placed at the central axis of the cylinder. MHCD electrode is composed by spacer between the copper electrode, glass-epoxy with a thickness of approximately 0.2mm, and hole diameter of MHCD is 0.6mm.

A repetitive pulse voltage (frequency = 1 kHz, pulse width = 50 s, and discharge current = 15 mA for each electrode) was applied to the MHCD electrodes through the current limiting resistor R_1 = 18 kΩ, and DC voltage was applied to the central wire anode by using the current limiting resistor R3 = 750 kΩ in 35–20 kPa of air. Figure 1(b) shows the electrode arrangement of a WIPS wire in discharge. The discharge condition is the same as that for MCS.

Optical emission spectroscopy of this plasma is carried out by using MMS UV-VIS II manufactured by Carl Zeiss; the specifications of this spectroscope are as follows: resolution = 7 nm, pixel count = 256, and the wavelength range that can be measured = 250～785 nm.

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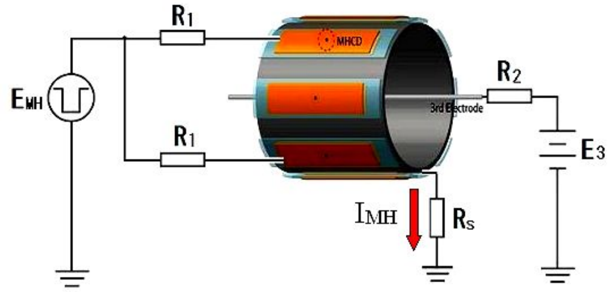
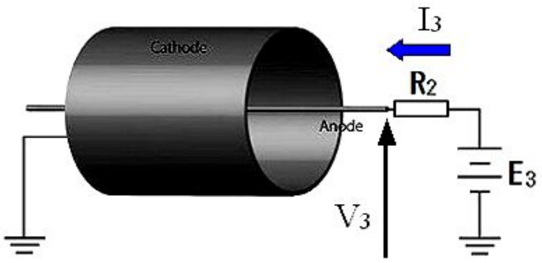


(a) Cylindrical parallel MCS discharge



(b) WIPS discharge

Fig.1 Arrangement of (a)cylindrical parallel MCS discharge and (b)WIPS discharge.

3. Experimental Results

3.1 The parallel cylindrical MCS discharge

We investigated the characteristics of the cylindrical parallel MCS discharge by using the total MHCD current I_{MH}, pulse width T_{pw}, repetitive frequency f, and the pressure P at which the MCS discharge can be generated.

By applying DC voltage E3 to the third electrode, we could generate a parallel cylindrical MCS discharge between the eight MHCD electrodes and the third electrode provided that I_{MH} was larger than a certain value. Figure 2 shows a typical waveform of V_3 in case of I_{MH} = 150 mA, P = 2 kPa, T_{pw} = 25 s, f = 1 kHz, and E_3 = 1kV, in steady state. V_3 decreased to 800 V at t = 40 s, and gradually returned to the initial value V_3 = 1kV at t =0 s. Therefore a parallel cylindrical MCS discharge could be controlled by I_{MH}.

Figure 3 shows a photo of the MCS discharge taken from the axial direction. We confirmed the eight discharges between the eight MHCD electrodes and the thin central wire.

Figure 4 shows the relationship between I_3 and Vs where I_3 was the discharge current flow into the third electrode, and V_s is the saturated value of V_3 near the end of I_{MH}. A gradient of dV_s/dI_3 showed a negative resistance property and to be dV_s/dI_3 equiv 500k Ω. Thus, the condition R3 > 500kΩ was necessary for a stable glow discharge.

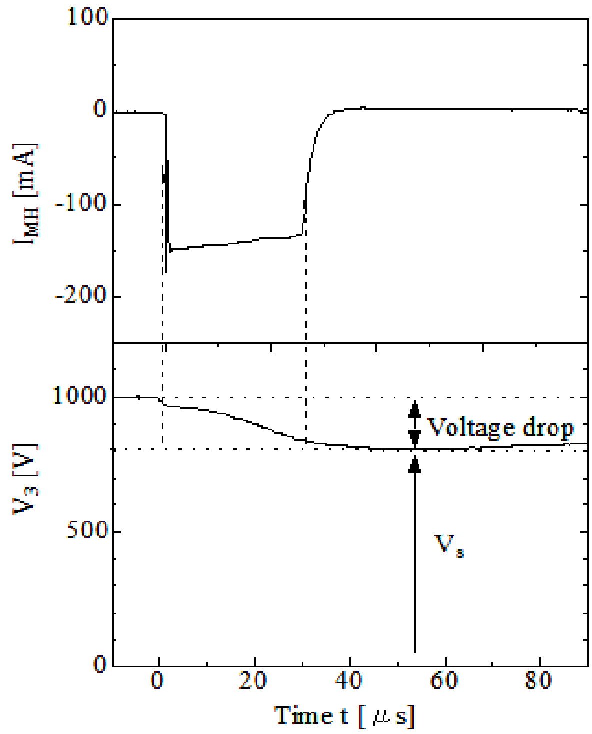


Fig.2 Waveform of voltage of the third electrode V_3 and total MHCD current when generated eight cylindrical parallel MCS discharges

Fig.3 Picture of eight cylindrical parallel MCS discharges

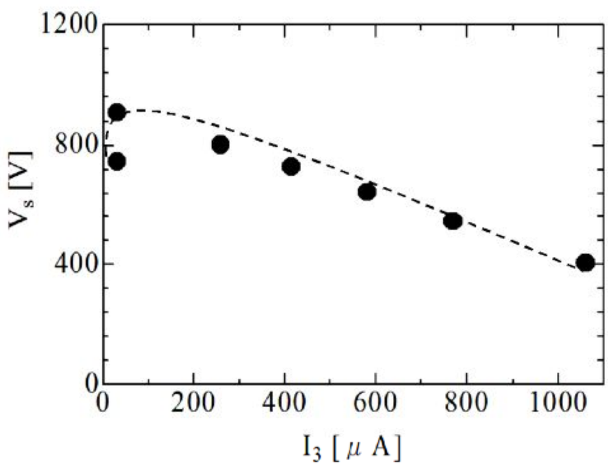


Fig.4 Relationship between V_s and I_3

3.1.1 Effects of MHCD current

After the MCS discharge began, the parallel MCS discharge could not be sustained if V_3 dropped sharply to zero. Therefore, we measured the relationship between Vs and I_{MH} when P = 5 kPa, T_{PW} = 25 s, f = 1 kHz, and E_3 = 1 kV.

A waveform of V_3 in case of four parallel MHCD electrodes and I_{MH} = 80 mA to 175 mA is shown in Fig.5. The voltage drop of V_3 varied due to I_{MH}, in other words V_s varied by I_{MH}. The value of V_s decreased with increasing $|I_{MH}|$ and varied greatly between $|I_{MH}|$ = 90–100 mA.

Figure 6 shows the relationship between Vs and I_{MH} in case of two, four, and eight MHCD electrodes. V_s dropped sharply at approximately –100 mA irrespective of the number of MHCD electrodes. It was considered that the discharge in case of $|I_{MH}|$ < 100 mA was a pre-discharge phase and in case of $|I_{MH}| \geqq$ 100 mA was a MCS glow discharge. This corresponds to the result of reference [3]. Further, V_s did not degrease to zero when I_{MH} increased, and a sustainable glow discharge was possible.

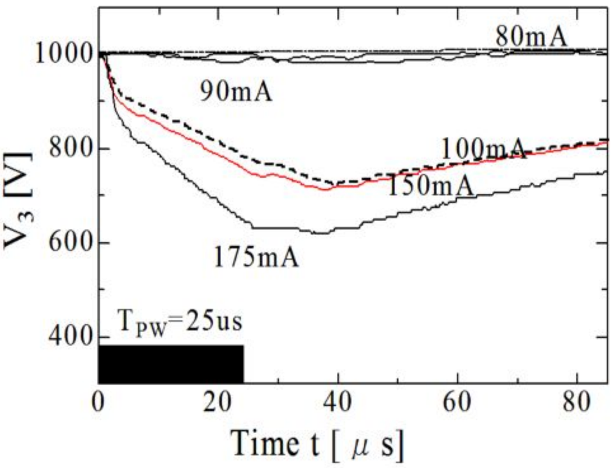


Fig.5 Saturated voltage of the third electrode, Vs, for each MHCD current I_{MH}

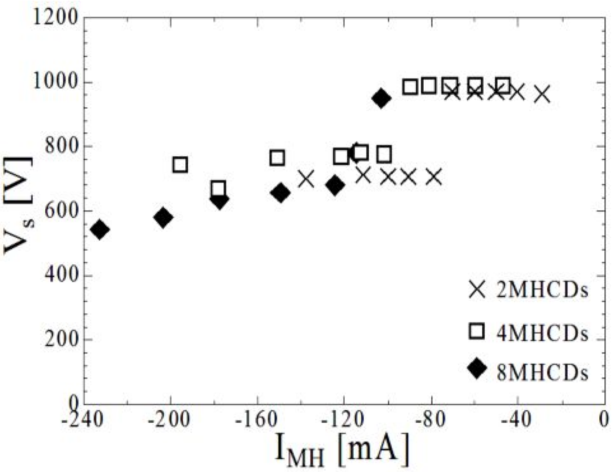


Fig.6 V_s of 2,4,and 8 parallel MHCD electrode parallel between approximately I_{MH} = –20 to –230 mA

3.1.2 Effects of the pulse width T_{PW} on the parallel MCS discharge

We measured V_3 while varying T_{PW} as shown in Fig.7 in case of P = 5 kPa, f = 1 kHz, E_3 = 810 V, I_{MH} = 80 mA, and four parallel MHCD electrodes. V_3 dropped early as the T_{PW} became longer, especially T_{pw} = 60 s and 80 s. The changes of initial slopes of V_3 at t = 0, in spite of the identical initial slope for the same plasma condition, show that the previous plasma in case of T_{pw} affects following discharges.

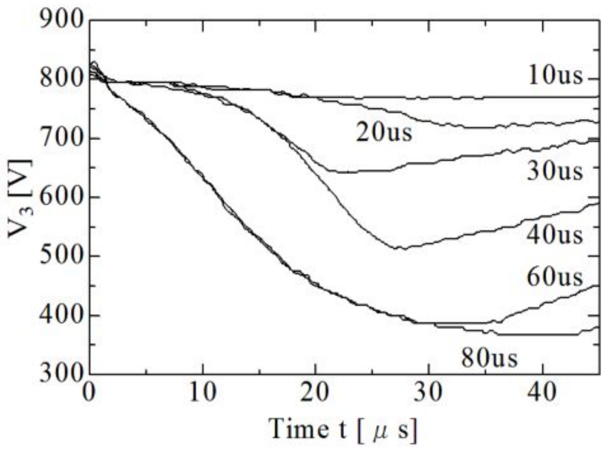


Fig.7 V_3 while varying T_{PW}

3.1.3 Effects of repetitive frequency

We measured the threshold voltage E_B, which is defined as the minimum voltage of E_3 at which V_3 decreases by –30mA V after I_{MH} was applied, while varying the frequency in the case of 5, 10, and 15 kPa, I_{MH} = 80 mA, duty ratio = 2.5%, and number of parallel MHCD electrodes = 4, as shown in Fig.8. E_B increased gradually with the pressure and the frequency, and saturated to constant voltage where the frequency f was a critical f_{cr}. A similar characteristic was obtained when argon was used instead of air.

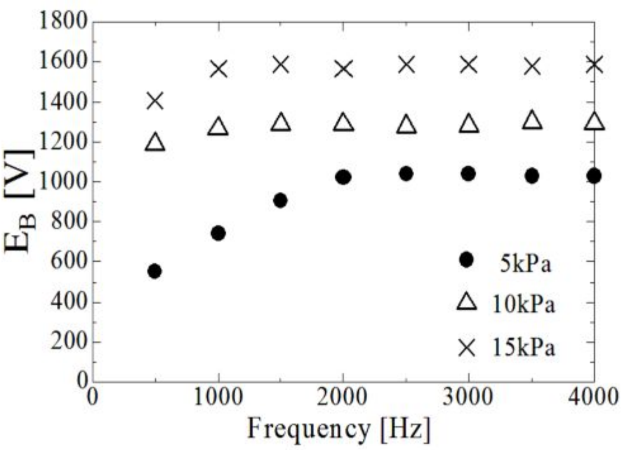
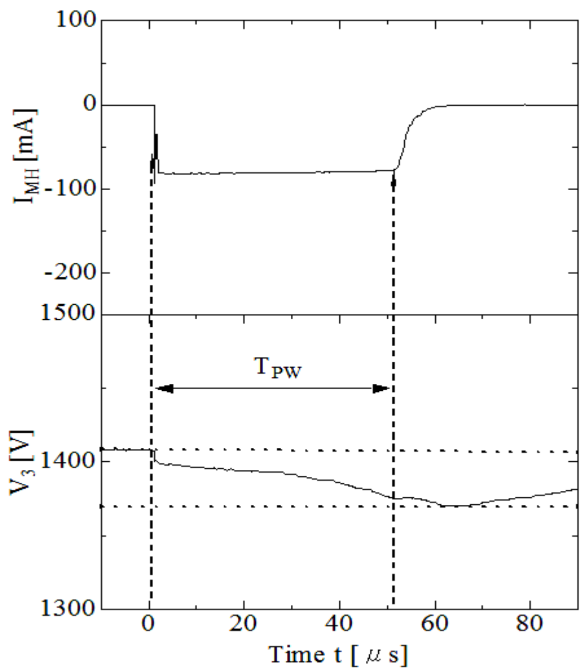
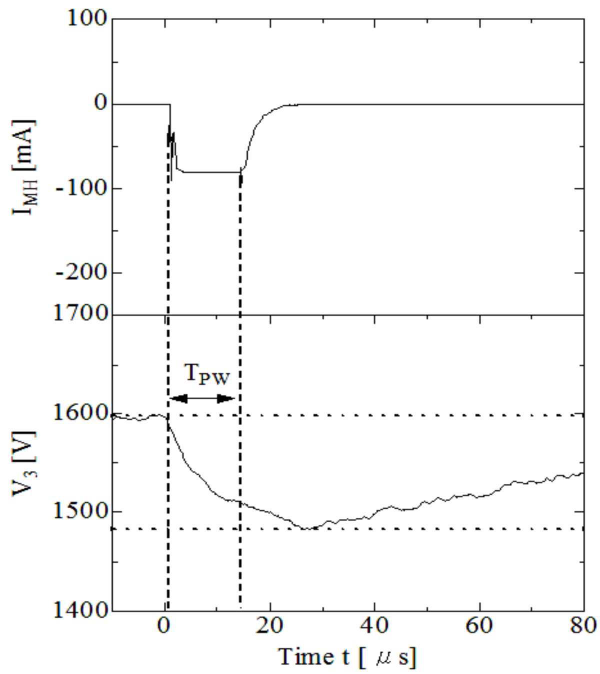


Fig.8 Threshold voltage E_B while varying frequency in case of 5, 10, and 15 kPa

Figure 9 shows the waveform of V_3 in case of f = 500 Hz, 2 kHz, and P = 15 kPa, duty ratio = 2.5 % (T_{PW} is 12.5 s in case of 2 kHz, and 50 s in case of 500 Hz.), and I_{MH} = 80 mA. V_3 dropped sharply at 2 kHz, whereas it did slowly at 500 Hz. V_3 could be sustained where $f > f_{cr}$ but would drop sharply where $f < f_{cr}$. It was considered that the control of T_{PW} on sustaining an MCS parallel operation was more effective than that of frequency.



(a) 500 Hz



(b) 2 kHz

Fig.9 Comparison of the voltage of the third electrode V_3 when 500 Hz and 2 kHz at 15 kPa

3.1.4 Range of pressure for the parallel MCS discharge

Figure 10 shows the threshold voltage of E_B for eight parallel MCS discharges and WIPS discharges in the range of P = 35 Pa–20 kPa. The threshold voltage of a WIPS discharge increased as non-linearly as the pressure increased but that of MCS increased linearly. The threshold voltage E_B of MCS was smaller than the breakdown voltage of WIPS by approximately 700 V. In the case of P > 20 kPa, it was difficult to generate the MCS glow discharge for all the eight electrodes with I_{MH} = 15 mA. Further, in the case when P > 5 kPa, the WIPS discharge could not sustain a glow discharge and shifted to an arc discharge, whereas the MCS discharge was able to sustain a glow discharge.

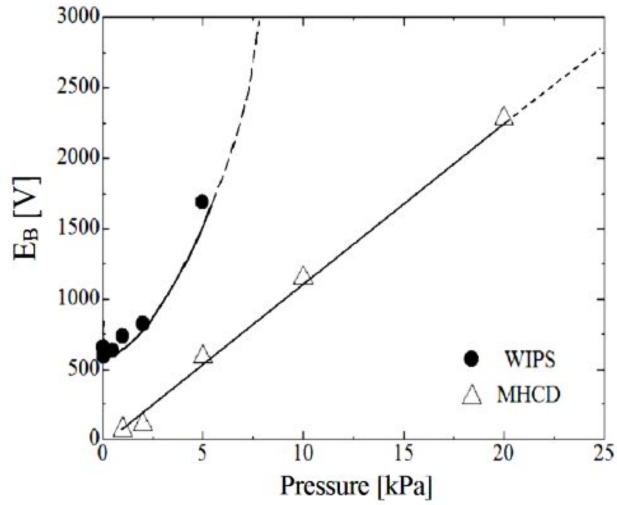
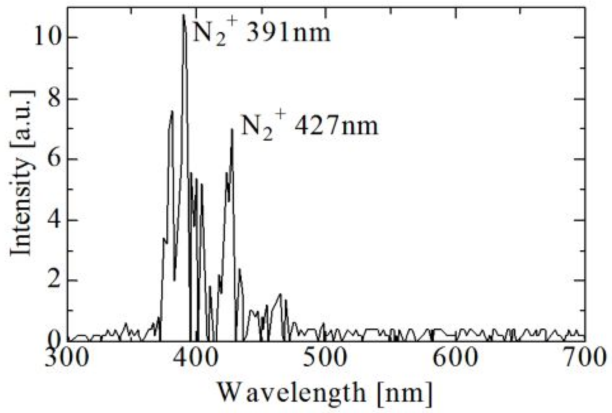


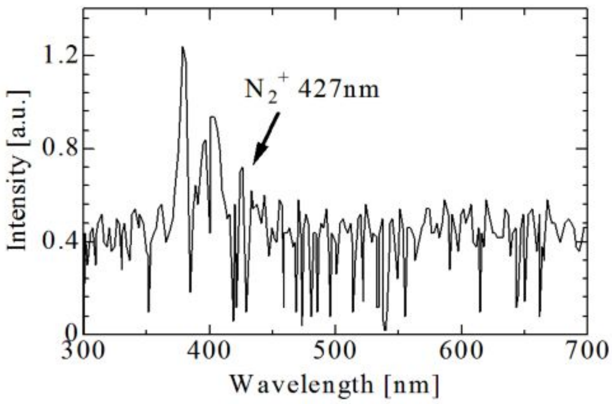
Fig.10 Threshold voltage E_B of eight parallel MCS discharge and WIPS discharge in 35-20 kPa

3.2 Spectral measurements of MHCD and MCS plasma

Figure 11 shows the spectra of (a) MHCD and (b) cylindrical parallel MCS discharge plasmas. The MHCD and the MCS parameters were as follows: P = 30 kPa, T_{PW} = 50 s, f = 2 kHz, I_{MH} = 60 mA, E_3 = 2.5 kV, and number of parallel MHCD electrodes in air = 4. The spectrum of a MHCD plasma and a MCS discharge plasma are normalized on the N_2 391 nm and 427 nm band [9][10][11]. The emission intensity of MHCD was higher than that of MCS discharge and confirmed N_2^+ clearly.



(a) Spectral analysis of MHCD



(b) Spectral analysis of MCS discharge

Fig.11 Spectral measurement of (a) MHCD and (b) MCS discharge

4. Conclusion

We measured the characteristics of cylindrical parallel MCS discharge by using MHCD current, PW, and frequency. By total MHCD current is increased, and two range of pressure, where MCS discharge can be generated, can be extended. In case that T_{PW} is lengthened and repeating frequency is raised, a sustainment of parallel MCS becomes difficult. It was expected that the MCS discharge could be controlled by MHCD, and adjusting the MHCD current, and T_{PW} could be sustained in parallel of the MCS under a high pressure. And, cylindrical parallel MCS glow discharge was demonstrated up to 20 kPa.

We carried out the spectral measurement of MHCD and cylindrical parallel MCS discharge, and confirmed of spectrum in the two cases.

5. References

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