Clearance conditions of electrodes for the cylindrical parallel micro hollow cathode sustained plasma source

T. Kujirai, R. Yahagi, H. Iizumi, Y. Oka, N. Watanabe, and M. Maeyama

Saitama University, Saitama, Japan

Introduction

Micro hollow cathode discharge (MHCD) plasma can exhibit high current density, although its volume is small. Furthermore, it can generate stable glow discharge at atmospheric pressure(1). Therefore, Nagano and colleagues suggested a cylindrical parallel micro-hollow cathode sustained (MCS) plasma(2) source of radius D = 9.5 mm. They used MHCD as a plasma cathode and enabled parallel operation. This device is a type of atmosphere plasma source, and applications of ozone generation and gas processing are expected. However, a clearance of d ≥ 6 mm between each MHCD electrodes is necessary for stable parallel MCS operation(1)(3). Therefore, in this study we aimed to realize of the plasma source of large capacity of high integration rate using the plate-type parallel MCS plasma source and demanded the conditions to operate in parallel a stable MCS discharge at atmospheric pressure. Furthermore, on the basis of the condition obtained using the plate type plasma source we improved the influence on parallel operation by the placement the MHCD electrodes using the cylindrical plasma source.

1. Experimental setup

Figure 1 shows the plate-type parallel MCS plasma source. The MHCD electrode is sandwiched between copper plates 20 μm thick from both sides of the insulating layer of glass-epoxy 60 μm thick, and was created by the hole of the electrode diameter 600 μm. The distance between the 3rd electrode and the MHCD electrodes can be adjusted to D = 5.0 ~ 14.5 mm using the slider. The MCS discharge is generated between the MHCD electrodes and the 3rd electrode.

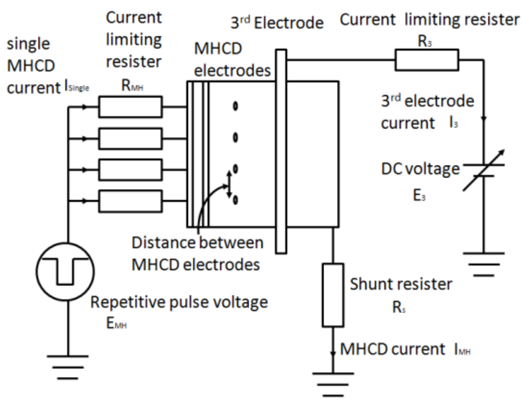

Figure 1: The plate-type parallel MCS plasma source

Figure 2 shows the cylindrical parallel MCS plasma source. Four MHCD electrodes are located on the outer aluminium cylinder of radius D and 1 mm thickness in a spiral, and two adjacent electrodes subtend an angle of 90° to the center.

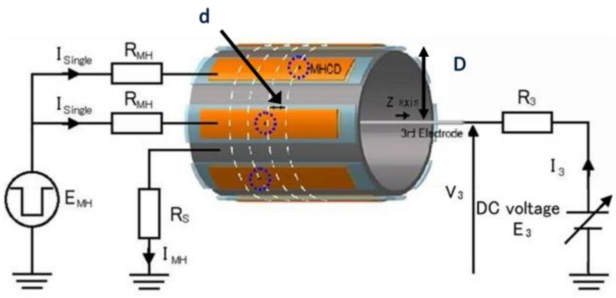

Figure 2: The cylindrical parallel MCS plasma source

2. Experimental results

First, we measured the influence of the frequency f on the MHCD, the current-limiting resistor R_3 of the 3rd electrode, the MHCD current I_{Single}, and the pulse width τ of the MHCD, with a voltage of E_3 = 11 kV applied to the 3rd electrode and with D = 12 mm, d = 4 mm, ballast resistance R_{MH} = 82 kΩ, shunt resistance R_S = 100 Ω, f = 1 kHz, τ = 20 μs, I_{Single} = 13.5 mA, and R_3 = 100 kΩ uniformity. We changed each f, R_3, I_{Single}, and τ, and took a photograph from the *x* direction with an exposure time of five seconds. As a result, the parameters f = 0.1 ~ 2 kHz, I_{Single} = 5 ~ 33 mA, and R_3 = 50 ~ 750 kΩ confirm the small influence on the parallel operation of the MCS discharge.

Figures 3 and 4 show the state of the MCS discharge and the waveforms of I_3 and I_{MH} when changing the 1, 3, 20, 35, and 50-μs pulse width τ. We found that it became possible to increase the number of emission lines of MCS discharge by making τ small, as shown in from Fig. 3. At τ = 1 μs, we confirmed MCS discharge in four MHCD electrodes. However, using only the photograph, it is difficult to determine that the discharge occurred in four MHCD electrodes at the same time as in the photography with a 5-s exposure time, shown in Fig. 3. Figure 5 shows the waveform of I_3 in Fig. 3 (a) and at d = 6.0 mm and τ = 20 μs. Figure 5 indicates that the peak value of I_3 at d = 6.0 mm is 6.0 mA; the peak value of I_3 in Fig. 3 (a) is 6.1 mA. Thus, we evaluated the parallel operation of the MCS discharge using Fig. 3 (a).

The typical duration of the MCS current I_3 is approximately 1 μs. Therefore, charged particles that have not been extracted into the MCS discharge in τ larger than 1 μs may remain in a hole of an MHCD electrode. The residual of those particles at the next MCS discharge increases with the MHCD duration tau, and its non-uniform distribution may influence the parallel MCS operation.

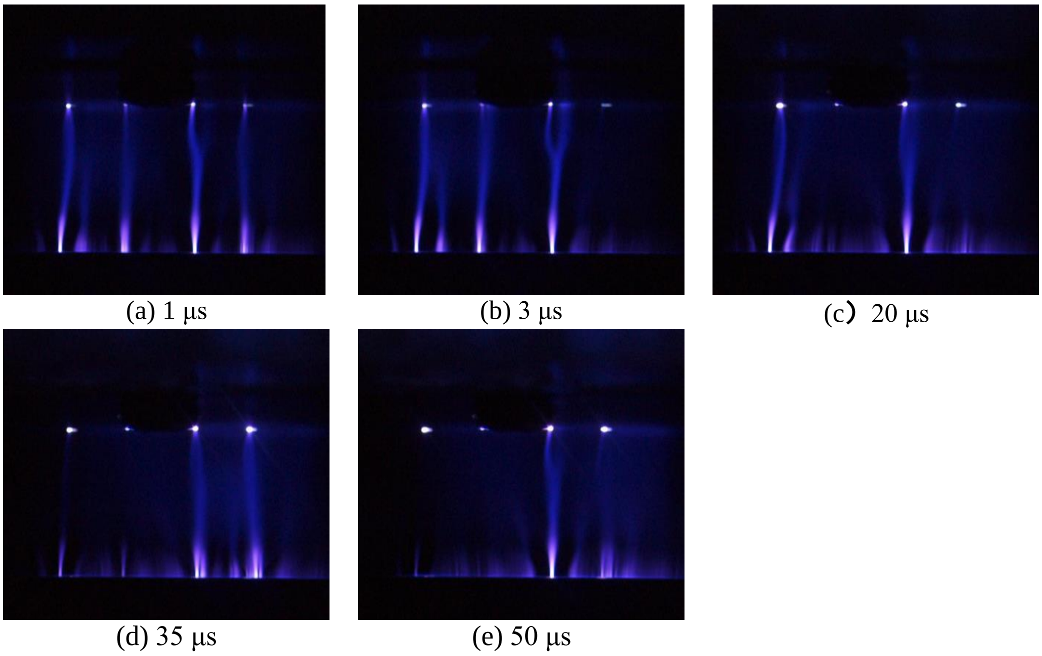

Figure 3: State of MCS discharge a of changing τ =1, 3, 20, 35, 50 μs

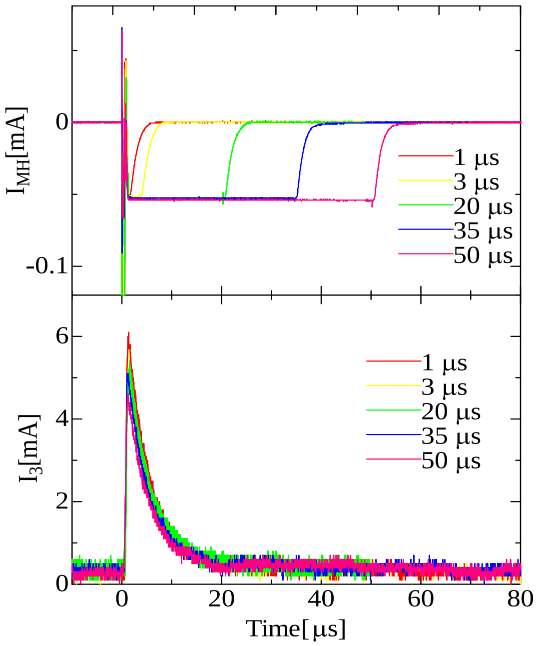

Figure 4: The waveforms of I_3 and I_{MH} at the time of changing τ =1, 3, 20, 35, 50 μs.

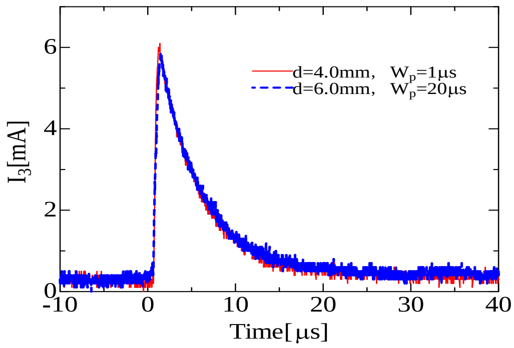

Figure 5: The comparison of the waveform of I_3 in figure 3 (a) and at d = 6.0 mm and τ = 20

Next, we measured the influence of the placement d of the MHCD electrodes on the cylindrical parallel MCS plasma operations using the results of the plate type parallel MCS plasma source. At atmospheric pressure, we measured the number of emission lines and I_3 of τ = 1 and 20 μs with 4 ways of 4, 5, 5.5, and 6 mm. In addition, because there is a possibility of variation in the creation of MHCD electrodes, we measured the probability of 4 parallel

MCS discharges being generated in 4 similar experiments. I_3 described the waveforms when the value is maximized.

T he experimental conditions assumed E_3 = 8.68 kV, D = 9.5 mm, R_{MH} = 82 kΩ, R_S = 100 Ω, f = 1 kHz, I_{Single} = 13.5 mA, and R_3 = 100 kΩ. Figure 6 shows the discharge probability when changing τ = 1 and 20 μs at each d. The discharge probability was increased by changing τ from 20 to 1 μs, even in the case of the d. Then the discharge probability could be 100% in the 4 parallel at d = 5.5 mm. It was possible to generate MCS discharge in the 4 parallel with d = 4 mm in the plate type, but the discharge could not be 100% in the cylindrical type. In the case of the cylindrical type, it is made in such a form that it coils itself around cylinder-shaped aluminum to fix the board of MHCD electrodes; the inside diameter of the aluminum is 8.5 mm for D = 9.5 mm. Therefore, with the cylindrical type, we supposed that we were unable to reproduce the results obtained using the plate type for the electric field strength, with the MHCD electrode having weakend.

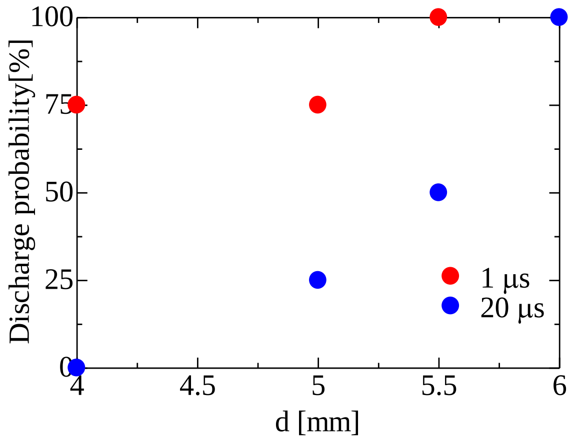

Figure 6: The discharge probability when changing τ = 1, 20 μs at each d

3. Conclusion

With the plate-type parallel MCS plasma source, we investigated the necessary conditions for the stable parallel operation of the MCS discharge at atmospheric pressure. We found that it is possible to increase the emission lines of the MCS discharge by reducing the τ of the pulse voltage applied to the MHCD electrodes. Further, for the cylindrical type, we improved the effect of the parallel operation by the MHCD electrodes placement by changing from 20 to 1 μs, and we confirmed that stable parallel operation is possible at d = 5.5 mm.

References

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