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Pulse Width Modulated Atmospheric Plasma Generation using Micro Electrode Array

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1. Introduction

Atmospheric pressure plasma has been of interest due to its versatile usages, such as air pollution control and surface treatments. Microstructure electrodes have been reported to be able to generate the atmospheric plasma, which was not easily obtained using a conventional millimeter gap electrode due to instability of the plasma. Recently, a stable atmospheric plasma generation was demonstrated at a low voltage using micro-machined electrodes [1]. A large volume of the plasma, which is very of importance in practical use to produce reactive ions, is desirable but it has been hard to realize even with an array due to non uniform gap and transition to arc. In this work, we investigate feasibility of the uniform atmospheric plasma generation at a low voltage by optimizing the bias scheme for an array of micro gap electrodes.

2. Experiment

For the atmospheric plasma generation at a low voltage, a micro gap electrode was fabricated using micromachining technique as shown in Fig. 1.

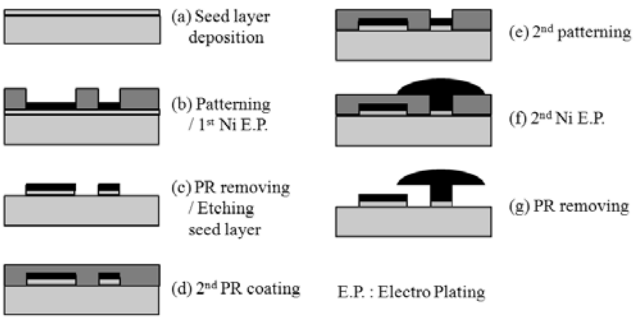

Fig. 1. Fabrication process flow for the micro electrode.

Nickel electroplating was used to build the electrodes with a pre-patterned photo-resist layer. Through this process, an uniform micron gap can be obtained in precious accuracy. A range of micron gaps from 8 μm to 15 μm was fabricated. Each device has a pair of anodes, which is 4 mm long and it has a space of 300 μm. Fig. 2 shows an array of the completed micro electrodes and a cross-sectional view confirms the micro gap of 8 μm for the fabricated device. To demonstrate uniform atmospheric plasma generation, an array of 12 electrodes was fabricated.

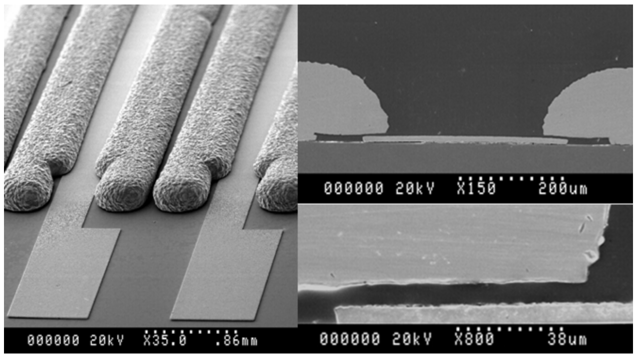

Fig. 2. SEM images of a micro electrode array

3. Result and discussion

Breakdown voltages for the micro-gaps were measured as a function of a discharge current as shown in Fig. 3. The discharge current was adjusted by varying ballast resistors. A low breakdown voltage below 240 V can be achieved for glow discharge mode using the micro-gap of 10 μm. After the breakdown, I-V characteristics of the micro-gap electrodes were measured as shown in the inset of Fig. 3. The I-V characteristic exhibits a positive dV/dI, which is contrary to Staack' work [3]. It was reported that a negative dV/dI was observed using a 50 μm gap. Such different behavior may be accounted for fast electron absorption to the electrodes in the very small gaps.

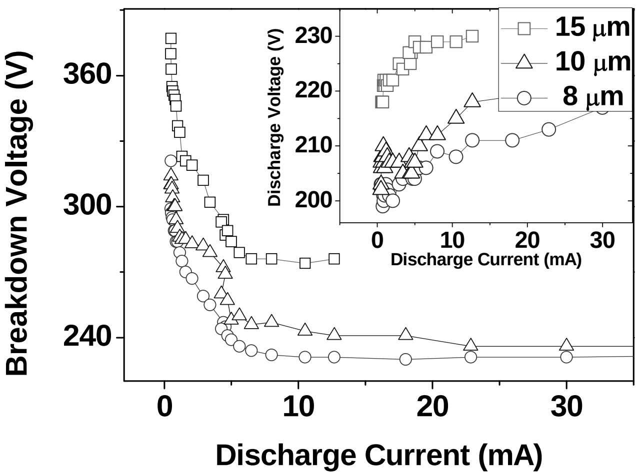

Fig. 3. Breakdown voltage dependence on discharge current for micro-gaps.

To investigate the effect of the ballast resistance (R_b) and pulse width modulation in the applied voltage, atmospheric plasma was generated by varying R_b and the duty ratio. Fig.4 illustrates images of the plasma formation during the experiments. The images clearly indicate more uniform atmospheric plasma can be obtained for lower R_b and higher duty ratio. However, for the duty ratio > 50 % the electrodes were damaged in a few tens minutes as the glow discharge makes a transition to arc, as shown in Fig. 4.

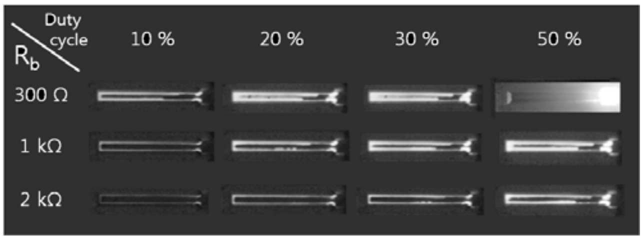

Fig. 4. Photo images of plasma generated by varying duty ratio and ballast resistor. (expose time : 0.1 sec)

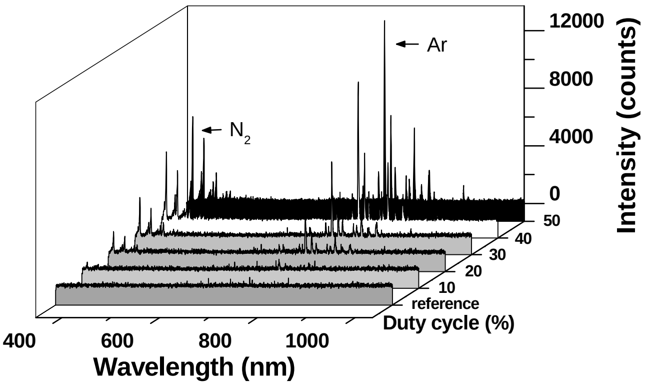

Fig. 5. Plasma emission spectroscopy for various duty ratios at atmospheric Ar ambient.

The generated plasma was characterized by measuring an emission spectroscopy as shown in Fig. 5. It confirms that the plasma loading power strongly depends on the duty ratio. Through the optimization of the R_b and the duty ratio, a large volume of atmospheric plasma was successfully demonstrated using the array of 12 devices under Ar ambient (Fig. 6). The rise time of the pulses was kept below 100 ns to improve plasma uniformity as reported in a previously published our work [2].

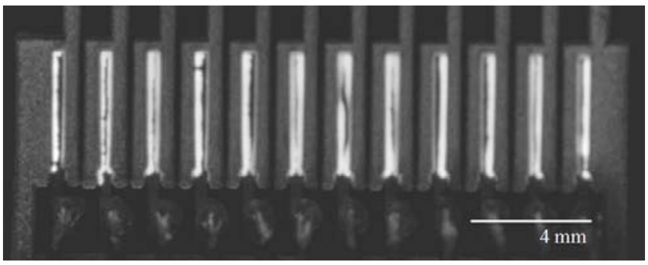

Fig. 6. Atmospheric plasma generation using an array of 12 devices by applying a 250 V pulse (exposure time : 0.1 sec)

For understanding the effect of pulse width modulation on the plasma formation, discharge currents of the micro electrodes were measured for different pulse width modulation. Fig. 7 shows that there is a RC delay of 0.3 μs prior to initiation of breakdown. The average plasma loading power for the array was measured to be 14.5 W (duty ratio=60%) and 3.5 W (duty ratio=10%), respectively.

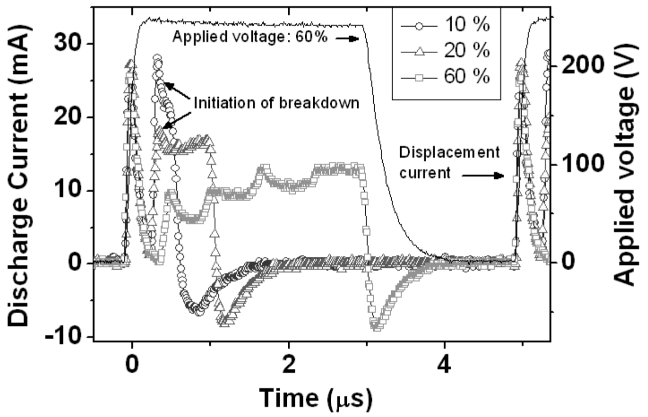

Fig. 7. Discharge currents for pulse width modulated voltages. The discharge current is adjusted by modulating a pulse width.

Interestingly, the discharge current in the glow mode seems to decrease as the duty ratio increases. Such dependence of the discharge current is speculated to be caused by device temperature difference during the plasma generation. Based on the emission spectroscopy and I-V results, the plasma loading power for the 60 % duty ratio appears to be more than four time larger than one for 10 %. Thus, it is very likely that the device temperature is raised when the 60 % duty ratio is used. To verify the temperature difference, temperature measurements using infrared and UV spectroscopies are underway.

3. Conclusions

We successfully demonstrate an uniform atmospheric plasma generation using micro-machined electrodes and pulse width modulation of an applied voltage. A large volume of the atmospheric plasma generation can be achievable even at a low voltage by utilizing the suggested bias scheme.

Acknowledgements

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References

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