Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp671-672

Discharge current controlled atmospheric microplasma generation

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1. Introduction

Stable atmospheric plasma plays a key role in realizing plasma based spectroscopy and hazardous gas control[1-2]. To ensure the stability of the atmospheric plasma, arc transition from glow discharge needs to be minimized. The arc transition has been known to be caused by thermal loading during atmospheric discharge generation. To avoid the thermal issue, non-equilibrium plasma can be used in a low pressure of 1-10 Torr. For atmospheric plasma, duty cycle of an applied pulse voltage can be carefully adjusted to keep the temperature of the device low [3]. In this study, we propose a pulse current control scheme for atmospheric plasma generation. Use of a current mirror circuit enables limiting maximum discharge current during plasma generation and it can suppress the arc transition by preventing uncontrolled excessive discharge current.

2. Experimental

Micro-scale device for atmospheric plasma was fabricated using micromachining techniques as described in our previous work [4]. Completed micro electrodes are shown in Fig.1. Nickel electroplating was performed to build metallic micro electrodes and a photoresist was used as a sacrificial layer to form an uniform gap between anode and cathode. A range of micro gaps from 8 μm to 10 μm was fabricated.

To control a discharge current through the micro electrodes, a current mirror circuit was used as shown in Fig. 2. Power MOSFETs (FAIRCHILD FQP5N50) with a threshold voltage of 3.5 V were used in the circuit. A 200 kHz pulsed voltage was applied as a reference bias while a DC bias of 250V was applied in the load circuit. The discharge currents were measured using a resistor (R1) connected to the microelectrodes in series. For comparison, a conventional voltage controlled bias scheme with a ballast resistor was also tested.

3. Results and Discussion

Glow discharge was uniformly generated using the microelectrodes with an applied voltage of 250 V in argon gas ambient. Fig. 3 shows temporal I-V characteristics in the current controlled mode when the glow discharge occurs. Induced voltages across the anode and the cathode vary from 210 V to 250 V while the MOSFETs were switched by the pulse voltage, resulting in a very small displacement current compared to the voltage controlled mode. As the reference current increases by increasing the amplitude of the reference voltage, the discharge current increases accordingly as shown in Fig. 4. Reduction in effective resistance of the MOSFET results in a shorter RC delay and thus faster breakdown between the electrodes.

Fig. 5 illustrates how the current controlled bias scheme can affect the reliability of generated glow discharges. Two independent microelectrodes were used for the experiments and each device was continuously operated under a pulsed plasma generation mode. Duty cycle of 35 % was used to accelerate degradation of the microelectrodes. Photo images clearly show that the glow discharge can be maintained for a longer time in the current controlled mode while the glow discharge in the voltage controlled mode makes a transition to arc state only after 10 min. For fair comparison, dissipated power during on-period at the microelectrodes was kept same to 2.8 W for both bias schemes. Note that a steady state discharge current in the current controlled mode was intentionally adjusted larger than one in the voltage controlled mode because the on-period was longer in voltage mode than in the current one (Fig. 6 and Fig. 7). For voltage controlled mode, the discharge current increases up to 60 mA when an arc transition was made. However, in the current controlled mode, the discharge current has been maintained to a preset current (15 mA) determined by the current mirror circuit. After 20 min, the discharge current slightly increases and it is speculated to be caused by heating of the MOSFET in the mirror circuit.

The results successfully demonstrate that the current mirror circuit is capable of preventing an undesirable excessive discharge current during operation and thus the current controlled scheme can improve the temporal stability of the glow discharge.

4. Conclusion

A current controlled atmospheric plasma generation is suggested. Use of a current mirror circuit enables improvement in reliability of the glow discharge by suppressing arc transition. Despite complexity of bias circuit, the current controlled scheme may be preferred over the conventional voltage controlled one due to stability of the atmospheric glow discharge.

Acknowledgements

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government(MEST) (No. 2009-0078875)

References

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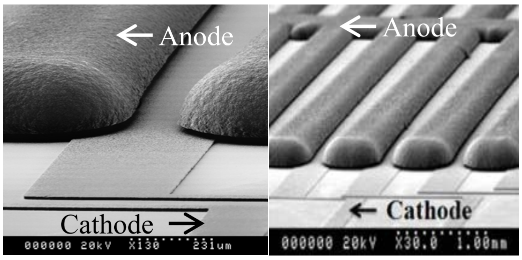

Fig. 1. SEM images of fabricated micro-gap electrodes

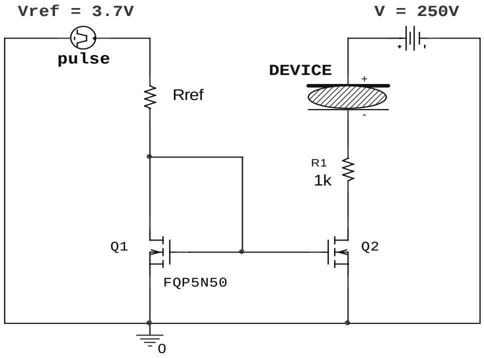

Fig. 2. Current controlled plasma generation using a current mirror circuit

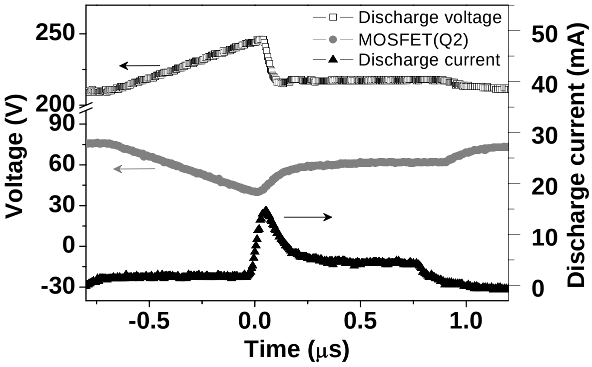

Fig. 3. Temporal discharge I-V characteristics in current controlled mode

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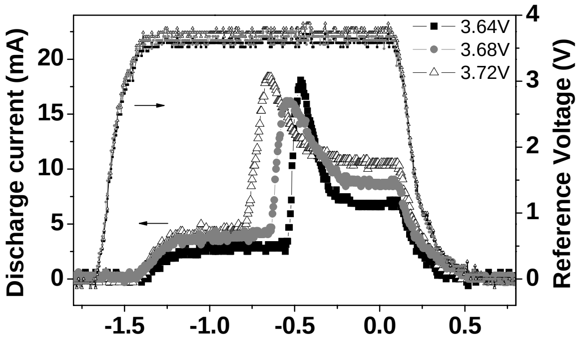

Fig. 4. Discharge current for varying reference voltage in current mirror circuit.

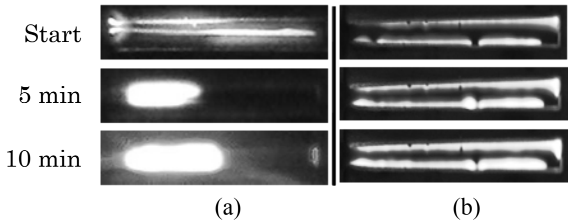

Fig. 5. Photo images of atmospheric discharge for different bias schemes.
(a) voltage controlled discharge; after 10 minutes, changes to arc-discharge. (b) current controlled discharge; maintains glow discharge.

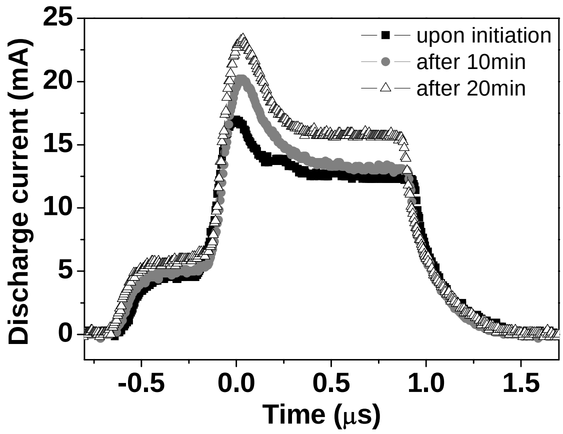

Fig. 6. Discharge current change during pulsed plasma generation in current controlled mode. The discharge current is maintained around 13 mA during operation.

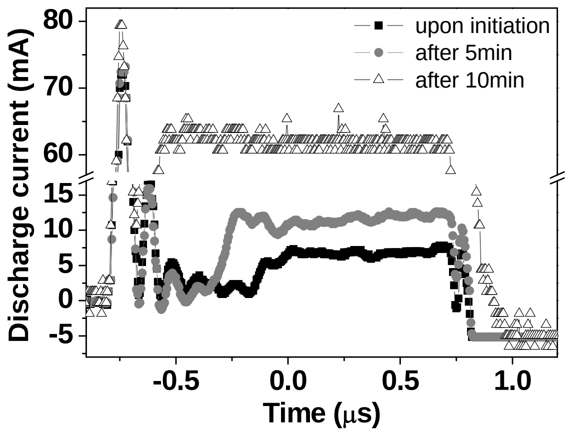

Fig. 7. Discharge current change during pulsed plasma generation in voltage controlled mode. After 10 min, the discharge current is rapidly increased by a factor of six due to arc-transition.