Current controlled Plasma-on-a-chip for atmospheric plasma generation

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ABSTRACT

We present a plasma-on-a-chip operated in a current controlled bias scheme for atmospheric plasma generation. The plasma-on-a-chip was fabricated using micromachining techniques and includes an array of vertically formed micro gaps between an anode and a cathode, ranging from 5 um to 10 um [1]. Use of a few micron gap enables atmospheric plasma generation at a relatively low voltage (~250 V). To enhance stability of the glow discharge, a current controlled bias scheme is suggested using a current mirror circuit. Compared to voltage controlled bias scheme, the current controlled scheme may improve stability of the glow discharge by suppressing excessive current flow occurred during the glow discharge, which may be caused by electrode-sputtering induced gap narrowing or elevated temperature. Electron and gas temperatures of the generated atmospheric plasma were measured to be 2550 K and 1000 K, respectively.

Keywords: atmospheric plasma, electron temperature, discharge current, MEMs

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 keeps maximum discharge current under control during plasma generation and it can suppress the arc transition. By utilizing the plasma-on-a-chip, we demonstrate a micro ozone generator, which operates at a low voltage and controls amount of ozone generation with a high precision.

2 EXPERIMENTS

2.1 Fabrication

Micro-scale device for atmospheric plasma was fabricated using micromachining techniques as described in our previous work [4]. Completed micro electrodes are shown in Figure 1. Nickel electroplating was performed to build metallic micro electrodes and a photo-resist (AZ 9260) 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.

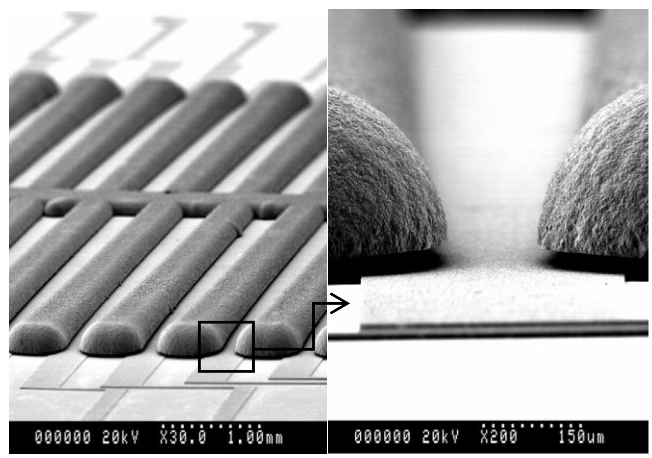

Figure 1 : SEM images of fabricated micro-gap electrodes

2.2 Bias circuit

To control a discharge current through the micro electrodes, a current mirror circuit was used as shown in Figure 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 250 V 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.

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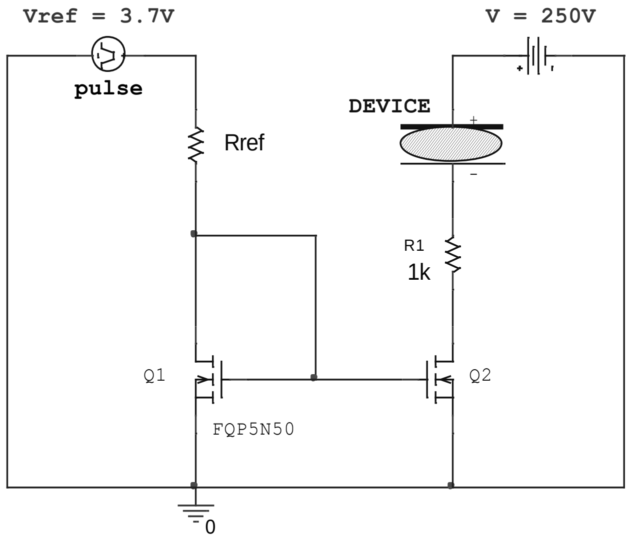

Figure 2 : Current controlled plasma generation using a current mirror circuit

2.3 Experimental Set-Ups

The experimental set-ups for OES (optical emission spectroscopy) and ozone generation are shown in Figure 3. A spectrometer Ocean Optics USB 4000 (377-1072nm) was used for optical emission diagnostics. And to measure ozone concentration, semiconductor ozone sensor (MICS-2610) was used.

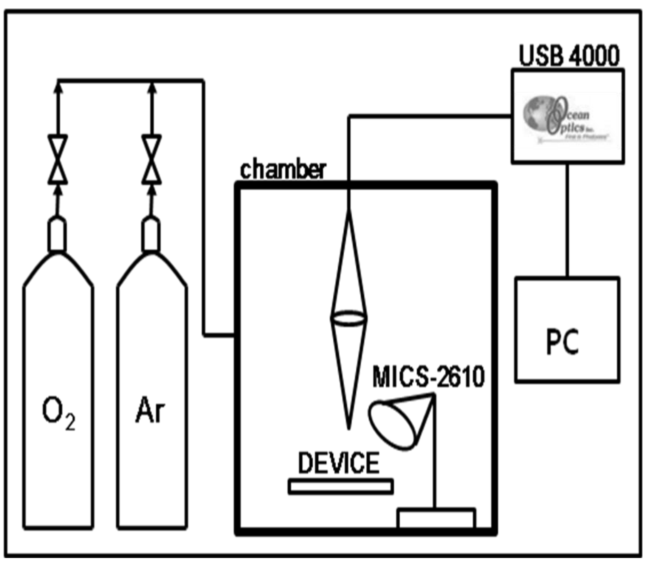

Figure 3 : OES and ozone concentration experimental set-ups

3 RESULTS AND DISCUSSION

Glow discharge was uniformly generated using the microelectrodes with an applied voltage of 250 V in argon gas ambient. Figure 4 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 accordingly increases. Reduction in effective resistance of the MOSFET results in a shorter RC delay and thus faster breakdown between the electrodes.

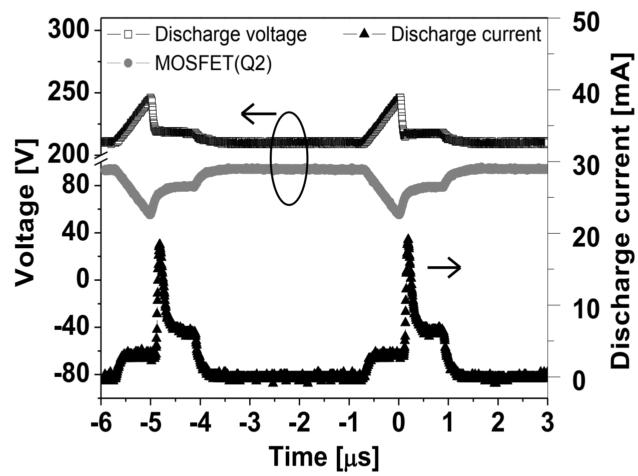

Figure 4 : Temporal discharge I-V characteristics in current controlled mode

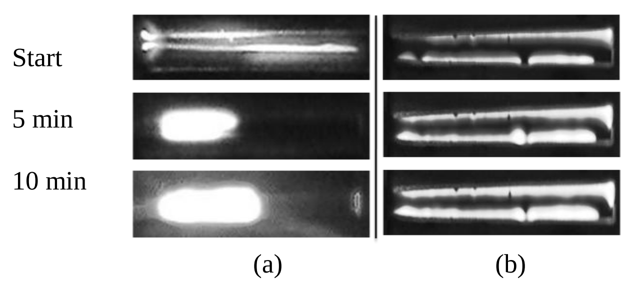

Figure 5 : Photo images of atmospheric discharge for different bias schemes. After 10 minutes, voltage controlled bias mode (a) changes to arc-discharge, but current controlled bias mode (b) maintains glow discharge

Figure 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 (Figure 6 and Figure 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

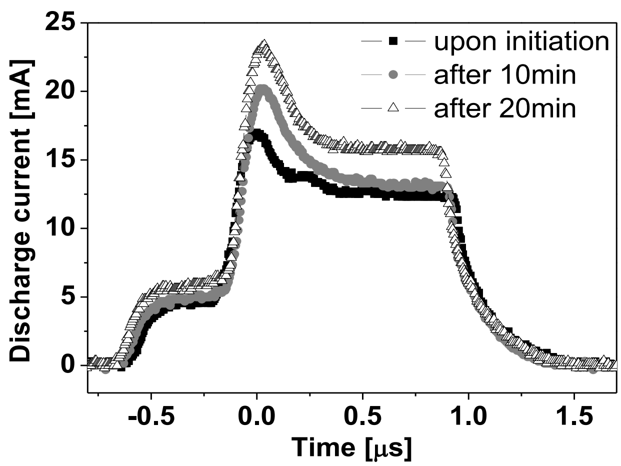

Figure 6 : Discharge current change during pulsed plasma generation in current controlled mode. The discharge current is maintained around 13 mA during operation.

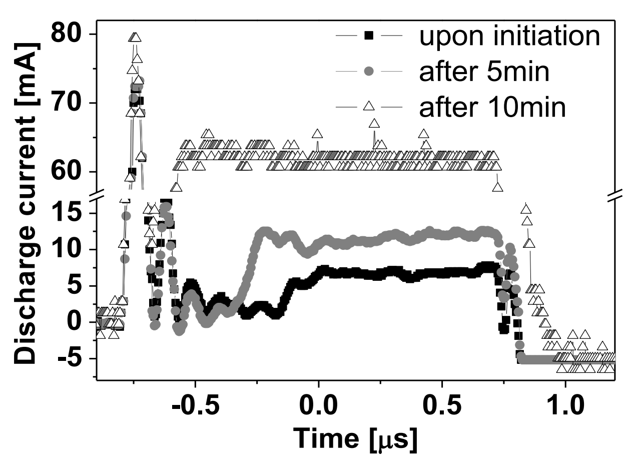

Figure 7 : Discharge current change during pulsed plasma generation in voltage controlled mode. After 10 min, the discharge current is rapidly increased by a factor of six due to arc-transition

slightly increases and it is speculated to be caused by heating of the MOSFET in the mirror circuit. The results clearly indicates 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. Optical emission spectrums from the generated plasma were measured in air and oxygen ambient as shown in Figure 8.

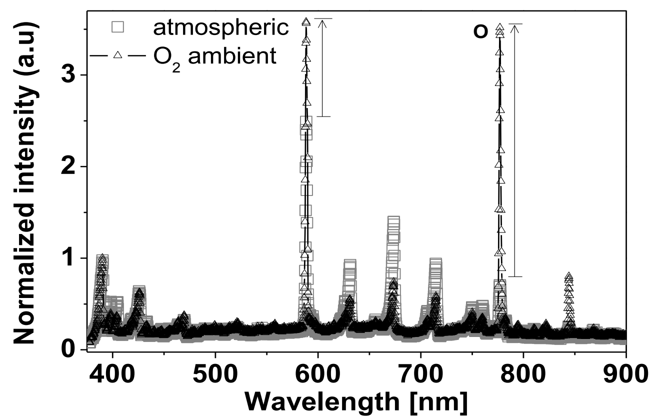

Figure 8 : Emission spectrum of atmospheric plasma in air and O2 ambient

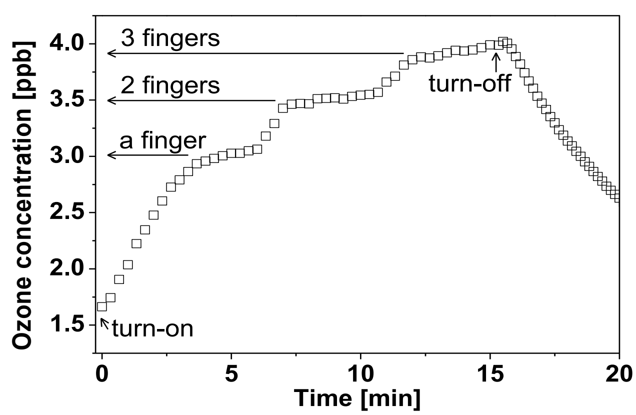

Figure 9 : Ozone generation in air ambient

Using the fabricated plasma-on-a-chip, a micro ozone generator was demonstrated by forming a glow discharge in air ambient. Amount of generated ozone was measured by the ozone sensor (MICS-2610) and it was well correlated with plasma loading power or a number of the electrodes being turned on. A level of 1 ppm ozone can be easily achieved and the ozone concentration was controlled by the number of the microelectrodes being on. Figure 9 exhibits linear dependence of the ozone concentration on the number of devices being on. In addition to the ozone generation rate, response time, like ozone lifetime in afterglow, was measured to be a few minutes as shown in Figure 9.

ACKNOWLEDGEMENTS

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