Microscale Plasma Actuator for Active Flow Control

Yoshinori Mizuno, Marius Blajan, and Kazuo Shimizu

Organization for Innovation and Social Collaboration, Shizuoka University,

3-5-1 Jyouhoku, Hamamatsu, 432-8561, JAPAN. E-mail : shimizu@cjr.shizuoka.ac.jp

Introduction

In various mechanical systems, flow control by active method is an important factor to improve the efficiency or decrease the environmental load. To control the air flow, many mechanical actuators have been developed and used effectively. Recently, Plasma actuator has attracted attention due to the its advantages such as no moving parts, simple construction, high frequency compared with mechanical actuators.

The plasma actuator consists in a grounded electrode, a high voltage energized electrode and thin dielectric layer. When a plasma actuator is energized by high voltage, a high electric field ionizes the air near the plasma actuator. Ions are drifted by the Coulomb force. While traveling through the air, ions collide with neutral gas molecules and transfer their momentum to neutral molecules induced air.

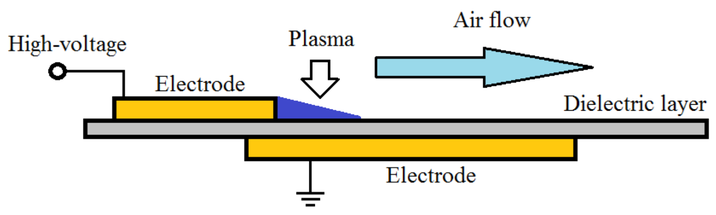


Fig. 1 Principle of air flow induced by plasma actuator.

In this study, the microscale plasma actuator was developed and investigated. Due to the micro scale gap, our microplasma actuator could be driven at 1 kV, relativity low voltage.

Experimental Setup

(1) Microplasma actuator

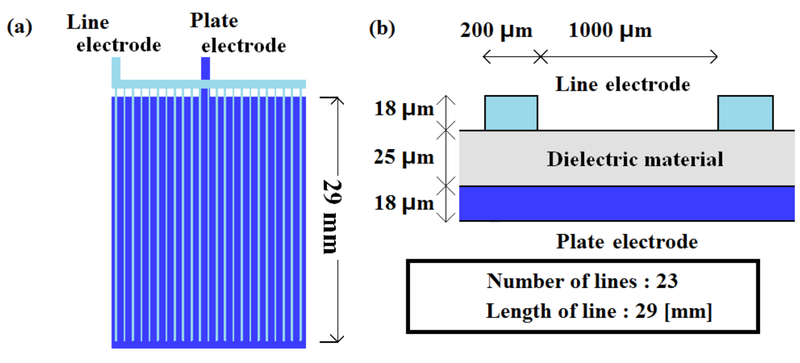


Fig. 2 Geometry of microplasma actuator.

The microplasma actuator developed and used in this study consists in dielectric layer was placed between two metallic electrodes. Due to the electrode configuration, the microplasma actuator is capacitive load of 200 pF. Discharge gap was set at 25 μm. As a result, atmospheric air plasma could be generated at about 1 kV, relatively low discharge voltage. Such low voltage is easily controlled by semiconductor switches without step-up transformer. This contributes to the miniaturization of the system.

(2) Experimental Setup

Plasma actuator was energized by a pulsed negative high-voltage. Air flow caused by the microplasma actuator was visualized and measured by Particle Imaging Velocity (PIV) method. Alumina 5 μm diameter were used as tracer particles. Nd YVO4 laser 532 nm was used for irradiation.

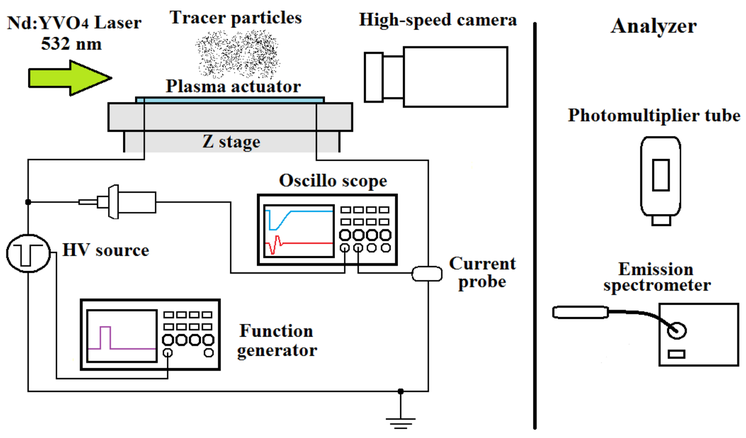


Fig. 2 The experimental setup for visualization the Air flow induced by the microplasma actuator.

A pulsed negative high-voltage supply used in this study. Negative2 kV is easily controlled by a 5 V signal.

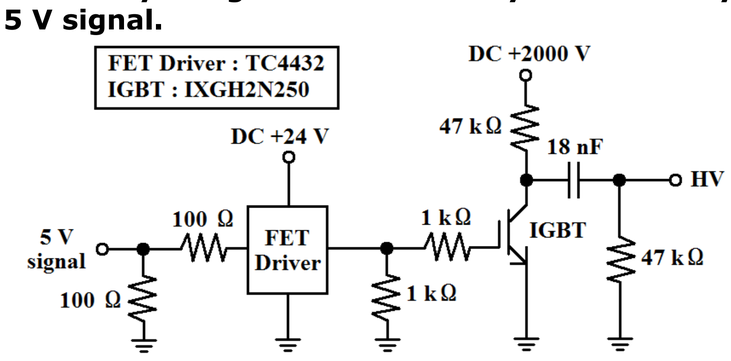


Fig. 3 Schematic of pulsed negative high-voltage supply.

Results and discussions

(1) Electrical characteristics

When discharge voltage was 2 kV and pulse width was 500 ns, discharge current and power could be up to 8 A and 12 kW, respectively. Energy consumption by applying one shot pulse was about 550 μJ at both polarity. Average power consumption was calculated by the product of 550 μJ and pulse frequency of 1 kHz and was estimated at about 550 mW.

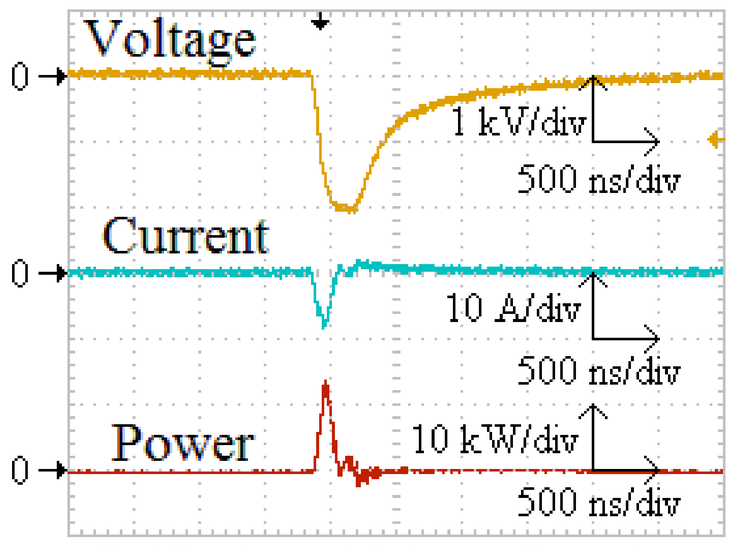
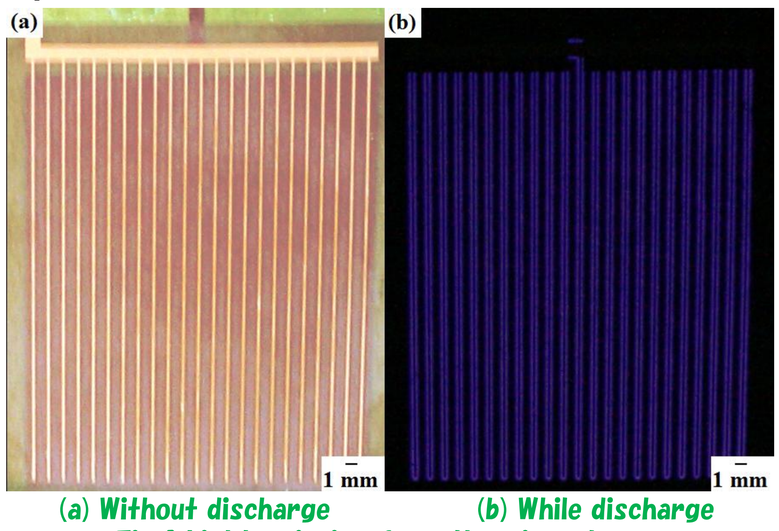


Fig. 4 Waveforms of discharge voltage and corresponding discharge current and power.

(2) Emission spectra

Light emission was observed by applying pulsed negative 2 kV to the microplasma actuator. Emission spectra of microplasma in atmospheric air were measured by an emission spectrometer.



(a) Without discharge (b) While discharge

Fig.4 Light emission from the microplasma

N_2 Second Positive Band System and were measured at 315, 337, 357, 375, and 380 nm. And, Nitrogen First Negative System 391 and 427 nm was observed.

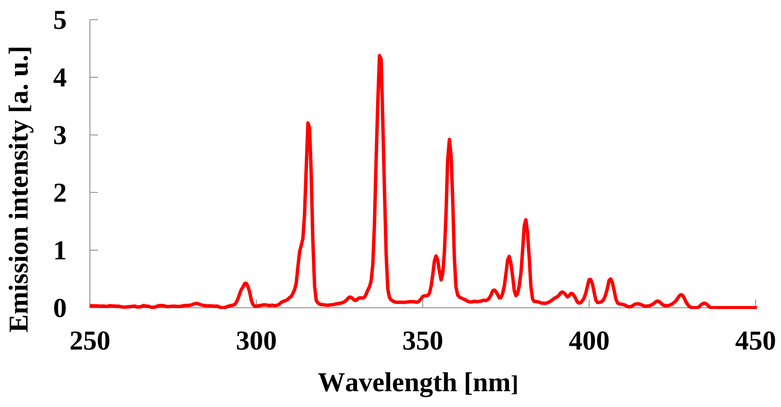


Fig.5 Emission peaks from microplasma.

Knowing behavior of ions and electrons, excited species in the microscopic region could be very important for driving or optimization of plasma actuator. Furthermore, time resolved emission intensity from the microplasma was measured by an emission spectrometer and a photomultiplier tube. Emission of N_2 second positive system 337.1 nm is shown in Fig. 6. Lifetime emission signal was only 50 ns. Lifetime emission signals from other N_2 SPS peaks at 315 nm, 353 nm, 357 nm, 375 nm and 380 nm were also for 50 ns.

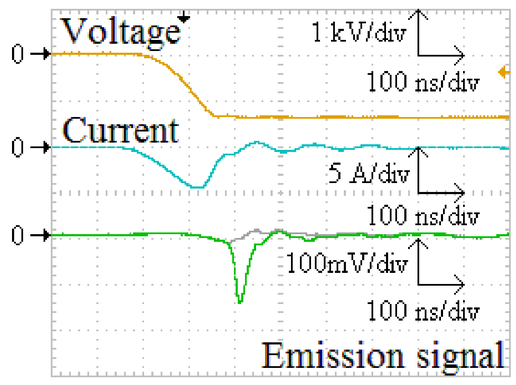


Fig. 6 Time resolved emission intensity from Nitrogen Second Positive System, 337.1 nm.

(3) Air flow visualization and investigation

Air flow was visualized by using tracer particle and laser. High-speed camera was used for the observing the air flow. Without driving the microplasma actuator, there is no flow. When the electrodes are energized and plasma turned on a time resolved air flow movement caused by the microplasma actuator is observed. Discharge voltage was negative 2 kV, pulse width was 500 ns and pulse frequency was 1 kHz. Air flow caused by the microplasma actuator changed its state from transition one to stationary one 1 second after driving the microplasma actuator. At the center of the microplasma actuator, scattering lights of tracer particles were concentrated near the 1 mm from the microplasma actuator. This shows that air flow induced by the microplasma actuator could reach up to 1 mm height from the microplasma actuator. At edge of the microplasma actuator, a vortex was developed with time (left side: clockwise rotation, right side: anticlockwise rotation). Air flow velocity was about 0.1 m/s at 1 mm height and edge of the microplasma actuator.

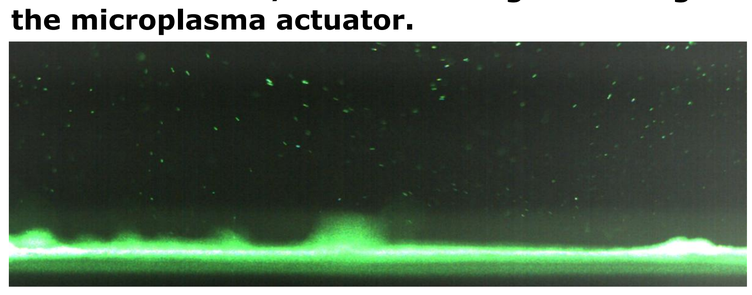
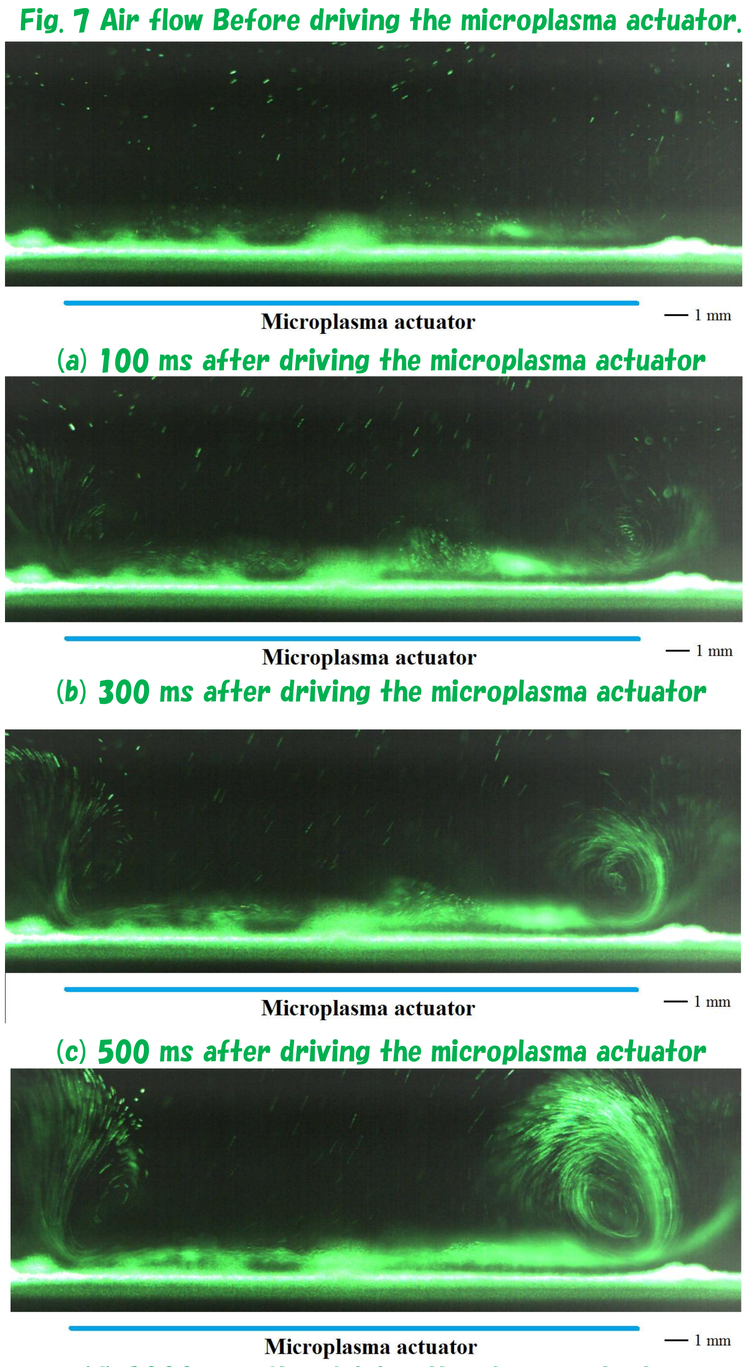


Fig. 7 Air flow Before driving the microplasma actuator.



(a) 100 ms after driving the microplasma actuator

(b) 300 ms after driving the microplasma actuator

(c) 500 ms after driving the microplasma actuator

(d) 1000 ms after driving the plasma actuator

Fig. 8 Time resolved air flow induced by the microplasma.

Conclusions

In this study, air flow induced by microscale plasma actuator was investigated and following conclusions were obtained.

1) When microplasma actuator energized by pulsed negative high-voltage, 2 kV and 1 kHz, power consumption was 550 mW.
2) Air flow made the transition to stationary state 1 second after driving the microplasma actuator.
3) At center of the microplasma actuator, air flow induced by the microplasma actuator could reach up to 1 mm height from the microplasma actuator.
4) At edge of the microplasma actuator, air flow vortex was generated and its velocity was about 0.1 m/s at 1 mm height.

Acknowledgement

The authors would like to thank Prof. Toshiyuki Sanada of Shizuoka University and Prof. Hitoki Yonoda of The University of Electro-communications for the fruitful discussions.