Microplasma Actuator for Active Flow Control: Experiment and Simulation

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INTRODUCTION

For active flow control applications, dielectric barrier discharge (DBD) plasma actuators offer the advantages such as no moving parts, fast response due to the electric field and simple construction. Traditionally plasma actuators are energized at voltages of tens of kV. Such high voltages are hard to insulate and requires a large size power supply. Our study was carried out to investigate a micro scale plasma actuator energized at 1.4 kV. The numerical simulation of the flow modification was carried out using Suzen model, which was assuming that the electric potential of plasma actuator potential can be split in the potential due to the external electric field and potential due to the charge density of plasma.

By calculating these two potentials the body-force could be determined. Furthermore the calculation of body force was implemented in the Navier-Stokes equations and the flow was obtained.

EXPERIMENTAL SETUP

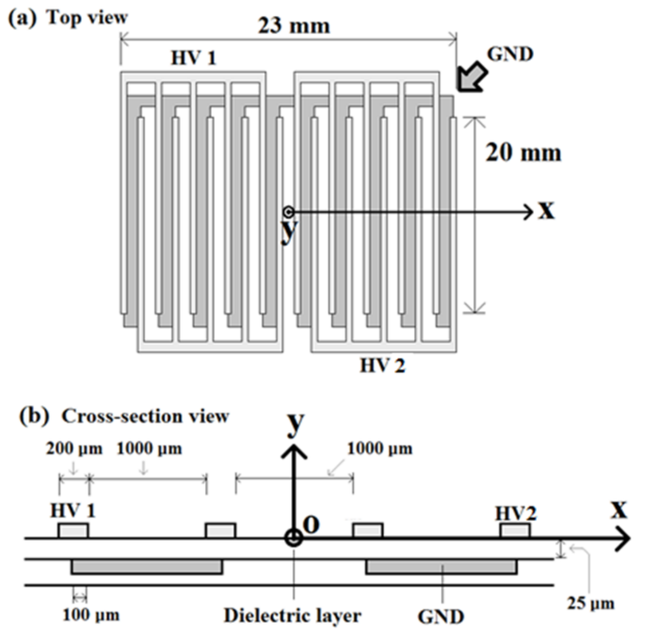

Fig. 1 Microplasma actuator. Schematic image: top view showing 20 stripes like electrodes (a); cross-section view (b).

Fig. 1 shows a schematic image of DBD microplasma actuator. Alternating stripe like electrodes (top-side electrode) are placed above a plate like electrode (bottom-side electrode) having a dielectric layer of 25 µm thicknesses in between. The stripe's width was 200 µm and thickness was 16µm. The number of stripe like electrodes was 20. Copper was used for electrodes and resin film was used for dielectric layer. Due to the microscale gap, a high electric field ($10^7 \sim 10^8$ V/m) could be obtained at the top-side electrode by applying only 1.4 kV. Flow was visualized by the Particle Image Velocimetry (PIV). Sub-micron incense smoke was used for tracer particle. Nd YV04 532 nm laser was utilized to visualize the flow. The phenomena induced by the microplasma actuator, was measured with a high-speed camera.

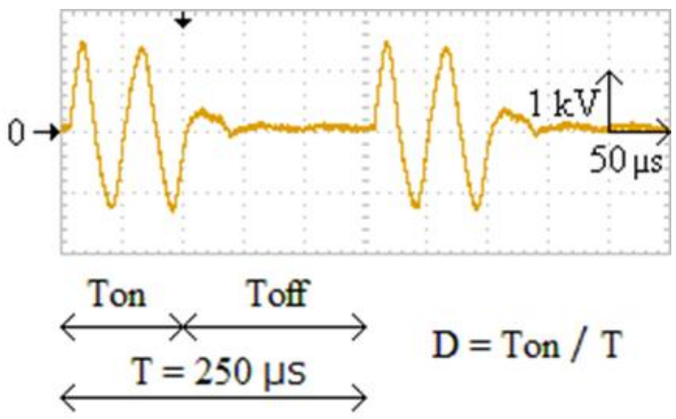

Fig. 2 Discharge voltage.

Microplasma actuator was energized at low discharge voltage at about 1.4 kV as shown in Fig. 2. For the simulation was considered a positive pulse voltage with amplitude 1 kV and duty ratios of 70% and 80%. The value of 1 kV corresponds to the effective value of the AC voltage of 1.4 kV amplitude since the relation between amplitude and effective value is Ueffective=Amplitude/$\sqrt{2}$.

RESULTS

(1) Experimental Results

In the initial part of the discharge the HV1 electrodes were energized at a voltage having duty ratio 70% and HV2 electrodes were energized at a voltage having a duty ratio of 30% (D = 70 %). A diagonal flow was obtained as shown in Fig. 3(a). After achieving a steady state the duty ratio of the voltage applied to HV1 electrodes was increased to 80% and the duty ratio of the voltage applied to HV2 electrodes was decreased to 20% (D = 80%). The angle of the diagonal flow changed and after 50 ms it was achieved a steady state as shown in Fig. 3(b).

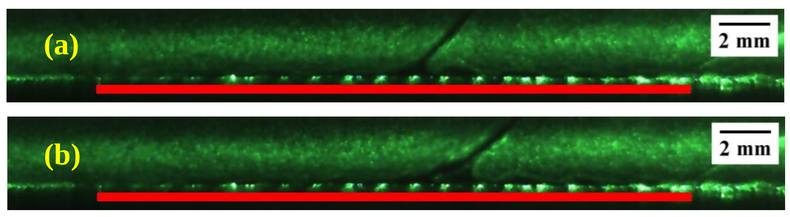

Fig. 3 Flow visualization: (a) Initial state (steady state at D = 70 [%]): (b) After 50 [ms] (steady state at D = 80 [%]).

(2) Numerical Simulation

Fig. 4 shows the potential due to the external electric field, potential due the charge density of plasma and the resultant body force.

The numerical simulation results (Fig. 5) showed similar results with the experimental ones. When duty ratio was D = 70% the diagonal flow was obtained as shown in Fig. 3(a). The HV1 electrodes generated counter clockwise flow with higher flow velocity and HV2 electrodes generated clockwise flow with lower flow speed. The duty ratio of D = 80% generated a diagonal flow at an angle that positioned the flow more above the HV2 electrodes as shown in Fig. 3(b). The velocity of the flow generated by the HV1 electrodes is higher at D = 80%.

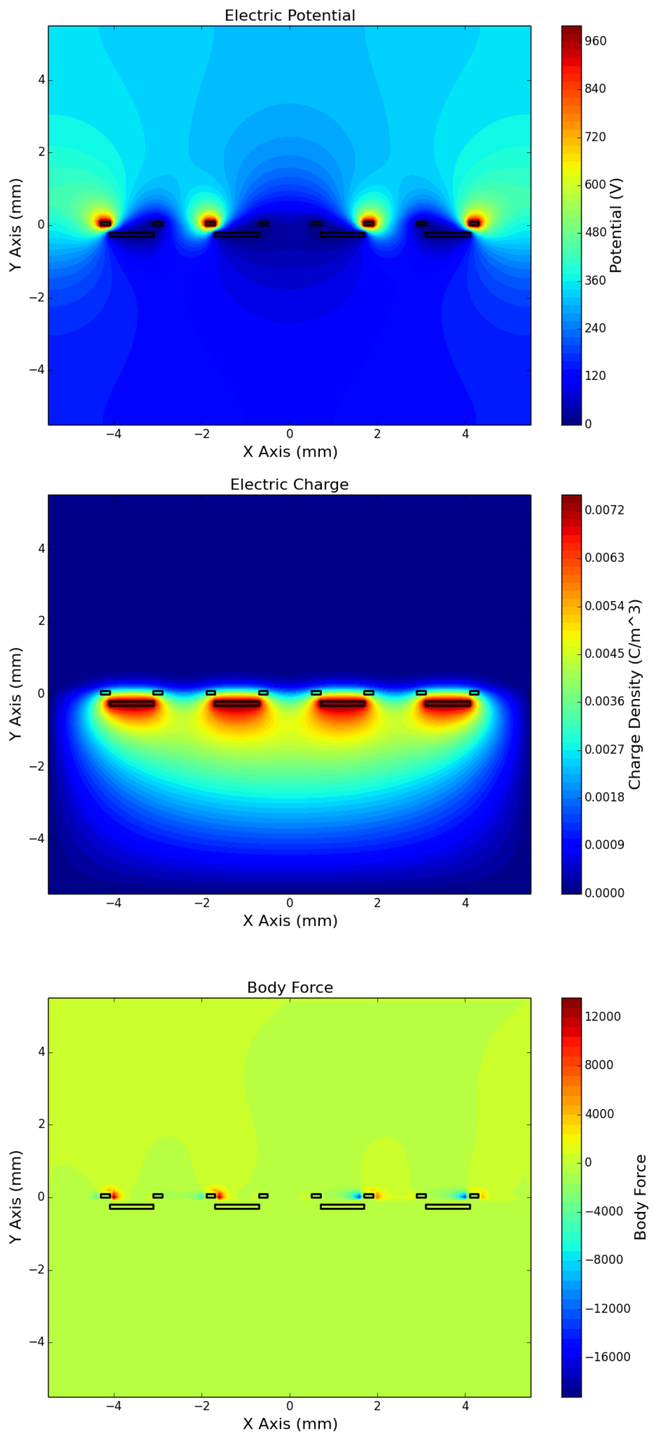

Fig. 4. Electric potential, charge density and body force: Electrodes upper 1, 3, 6 and 8 from left=1000 V: Remaining= 0 V.

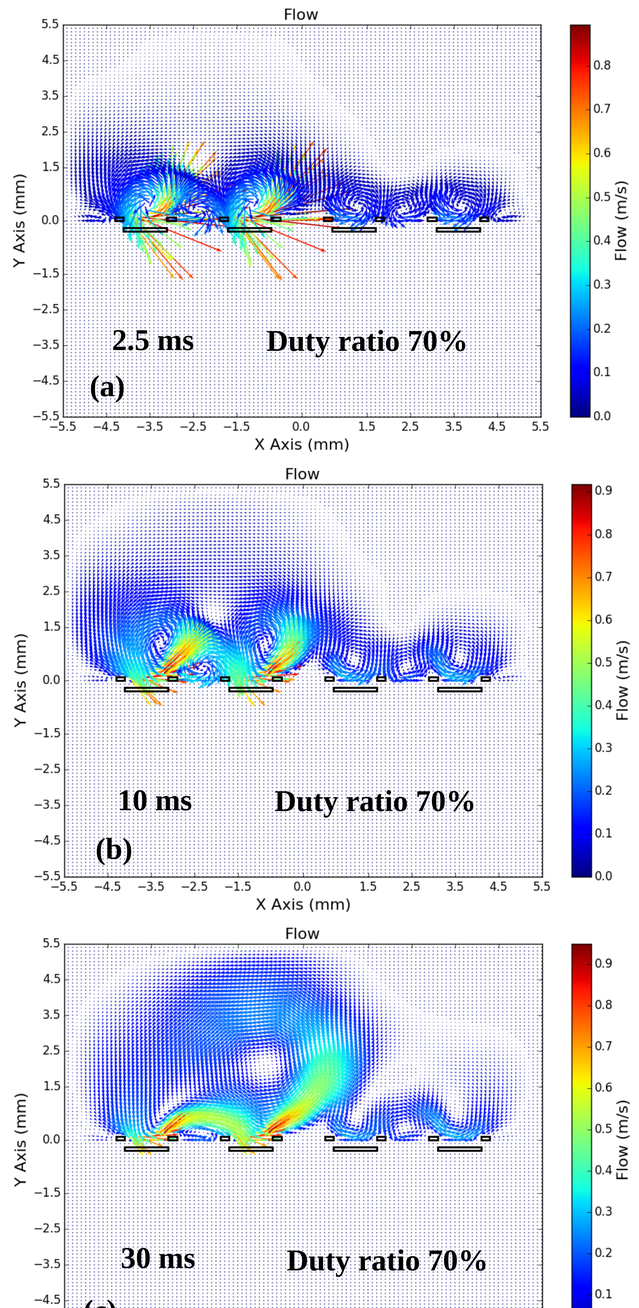

Fig. 5. Numerical simulation of the flow: (a) Initial vortexes: (b) Development of the vortexes: (c) Diagonal flow: (d) Steady state at D = 70 [%]: (e) Steady state at D = 80 [%].

CONCLUSIONS

Microplasma actuator is a simple and efficient solution for flow control. Due to its size and structure it can be easily integrated in other components. The experimental results showed that the flow could be changed in different directions by modifying the duty ratio of the voltage which energizes different parts of the actuator. When duty ratio was D = 70% a diagonal flow was obtained. The angle of the diagonal flow was changed after the duty ratio was increased to 80%. The simulation results were in agreement with the experimental one.