MEASURING METHOD OF ELECTROOSMOTIC FLOW VELOCITY AND ELECTRIC FIELD DISTRIBUTIONS USING MICRO-PIV

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ABSTRACT
A μPIV measurement using two kinds of tracer particles with different electric surface properties is proposed to obtain the distributions of electroosmotic flow velocity and electric field intensity in this study. Discussion is made on the validity of the present method through the use of two types of channels, namely, straight and U-bend channels. The results were compared with the experiment using fluorescent dye and also with numerical simulation, and a good agreement was achieved.

KEYWORDS: μPIV measurement, Electroosmotic flow, Electric field

INTRODUCTION
Measurements of electroosmotic flow velocity and electric fields in micro-channels are important and challenging issues in terms of developing micro fluidic devices. Many researches focusing on the measurements of the electroosmotic flow have been reported using the florescent dye [1], intensity of the electric current [2] and μPIV [3, 4]. These methods, however, are mostly limited to geometrically simple straight channel flows.

The problem incurred in μPIV measurement when an electric field is applied to the channel is that the electrophoretic force is exerted on the tracer particles, and, therefore, the particle behaviours will no longer represent the fluid motion. To tackle this problem, two kinds of particles with different electric surface properties were used as the tracer particles in the present study. If the apparent velocity of the particles can be regarded as a superposition of the components induced by hydraulic and electrophoresis forces, then, the electric and flow fields can be obtained by analyzing the velocities of these particles. A calibration experiment was first conducted with μPIV measurement and flow visualization using fluorescent dye in a straight micro-channel to obtain the correlation functions between the apparent electric field intensity and particles velocities. μPIV measurement was, then, carried out for the target channel to simultaneously measure the electroosmotic flow and electric fields by applying the same two kinds of tracer particles and the correlation functions.

EXPERIMENTAL
Calibration experiment was conducted using a straight channel made of PDMS (polydimethylsiloxane). The channel dimension is shown in Fig. 1. DC electric field was applying to the channel by platinum electrodes inserted in each reservoir. The working fluid was a buffer fluid of pH=6.86 (Nacalai tesque Co. 37220-35). Measurements were conducted in the area located at z/H=0.5 and at the streamwise center of the channel.

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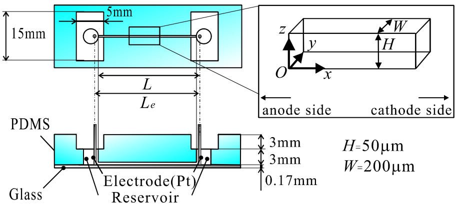

Fig. 1 Schematic of straight-type-channel.

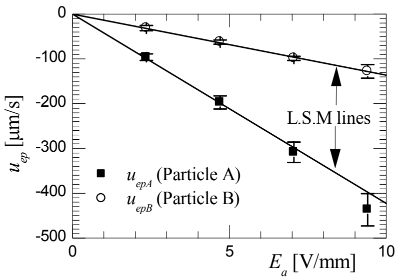

Fig. 2 Correlation between u_{epA}, u_{epB} and E_a.

The capsule-type fluorescent tracer particles employed in the experiment were made of polystyrene with carboxylate-layer (Molecular Probes Co. F8819: referred to as particle A) and melamine (Sigma-Aldrich Co. 90518: particle B) respectively. The nominal diameters of both particles were 1μm. The particles were excited by a light of wave length 530nm, and the fluorescent images of the particles were recorded by a high-speed camera. μPIV analysis was applied to these images to calculate the velocity field. In addition to this, electroosmotic flow velocity, u_{eof}, was obtained by measuring the velocity of the interface between the fluids with/without fluorescent dye (Rhodamine B) injected into the channel using a high-speed camera.

Figure 2 shows the correlation between the electrophoretic velocity, u_{ep}, of each particle and the intensity of the electric field, E_a. u_{ep} was obtained by subtracting u_{eof} from the apparent velocities, u_A and u_B, which were obtained respectively from the measurements using fluorescent dye and μPIV. From this relation, a correlation function of u_{ep} and u_{eof} against u_A and u_B were derived respectively.

RESULTS AND DISCUSSION

Two types of channels were applied to evaluate the present method. One was a straight channel made of SU-8 (MicroChem Co.). The other was a U-bend channel as shown in Fig. 3. In the U-bend channel, due to the existence of the singular point generated at the corners, two-dimensional profiles of not only the velocity field but also the electric field are expected to be generated.

In the straight channel case, the channel shape, size and measuring location were identical to those of the calibration experiment. The velocity distributions of the two tracer particles were first obtained by μPIV measurement, and, then, the correlation functions obtained from the calibration experiment was applied to calculate the electroosmotic flow velocity, u_{eof}. The results are shown in Fig. 4. The abscissa, E_{a2}, is the intensity of the electric field obtained from the voltage applied to the electrodes. In addition to this, u_{eof} obtained by an experiment using

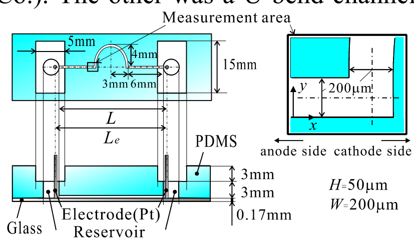

Fig. 3 Schematic of U-bend-type-channel.

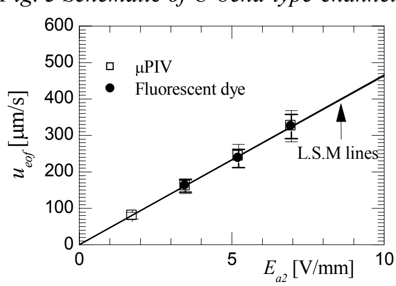

Fig. 4 Relation between u_{eof} and E_{a2}.

fluorescent dye is also plotted in the figure. Both results show an excellent agreement under all E_{a2} conditions.

In the U-bend channel case, two-dimensional numerical simulation of the electric fields of the fluid and solid parts were conducted using a commercial code ANSYS Multiphysics v11.0 (Cybernet Systems Co.). The results were compared with those obtained from the experiment.

Figure 5 shows the contour distributions of electric field intensity, E_a, obtained in the 'measurement area' illustrated by the square in Fig. 3. Here, E_a is normalized by E_{am}, which is the averaged value of E_a within the area. In Fig. 5 (a), E_a/E_{am} takes a maximum peak at the inner corner of the bend section, and is minimum at the outer corner. In the numerical result shown in Fig. 5 (b), a similar tendency is observed indicating the validity of the present method for measuring the two-dimensional distributions of the electric field.

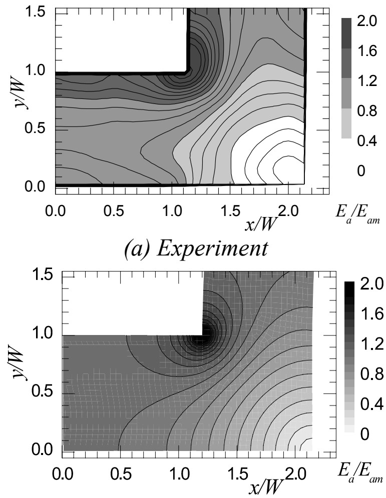

Fig. 5 Electric field intensity distributions.

Figure 6 shows the distributions of the absolute value of the electroosmotic flow velocity, $|u_{eof}|$, obtained from the experiment. $|u_{eof}|$ takes maximum and minimum values at the locations of the inner and outer corners respectively. The electroosmotic flow velocity in the area adjacent to the outer corner became relatively small due to the flow stagnation and also smaller electric field intensity appearing at the outer corner compared with that at the inner corner.

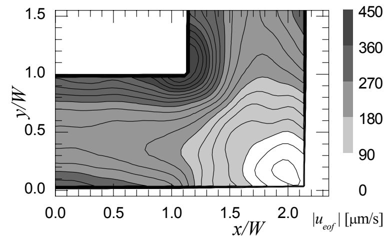

Fig. 6 Flow velocity distributions (Exp.).

CONCLUSIONS

The present results indicated that the two-dimensional distributions of the electroosmotic flow velocity and electric field intensity in straight and U-bend micro channels can be obtained by the present μPIV measurements with two types of tracer particles of different electric surface properties.

ACKNOWLEDGEMENTS

This research was partially supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology.

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