마이크로-PIV를 이용한 마이크로채널 내부 유동계측

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Flow Measurement in Microchannels using Micro-PIV

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Introduction

A lab-on-a-chip, the integration of various biochemical / biomedical analyses onto a single chip, consists of numerous microfluidic components such as valves, pumps, and channels of different geometry for various mixing, sorting, and dispersion processes involved. The fluid inside the whole channel system is generally pressure-driven, or electrokinetically-driven, and various literatures involving the physical phenomena inside microchannels have been published[1,2,3].

Although fluid flows in microchannels are of low Reynolds number and the general flow pattern predictable, the velocity field of the fluid inside the whole channel is difficult to measure. Also, many such channels are used for microscale analyses such as chemical mixing, particle/molecule sorting, and dispersion control, for which the specific flow characteristics are difficult to analyze quantitatively[3]. Flow visualization and quantitative analysis of flows in microchannels are necessary for the development of efficient active and passive mixers.

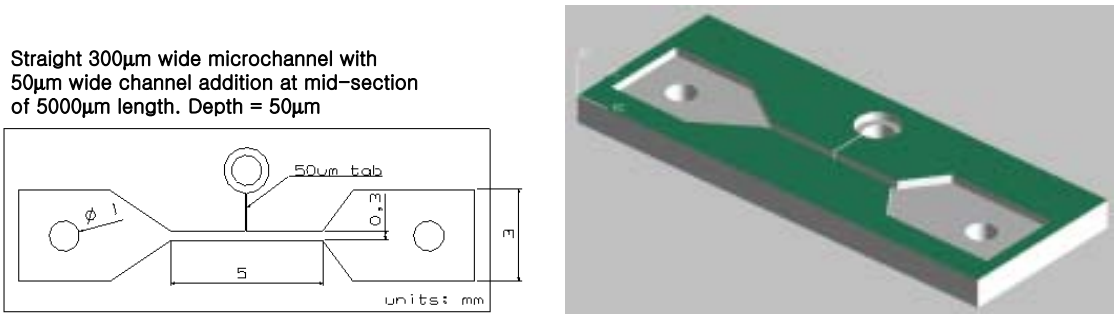
Particle image velocimetry(PIV), which has become an indispensable tool in fluid flow field measurements, have been successfully applied for flow measurements in microscale structures. Santiago et al.[4] measured the Hele-Shaw Flow around a microscale circular structure, at a vector resolution of 3.2μm×3.2μm. Meinhart et al.[5,6] also applied PIV to measure the flow inside a microfabricated inkjet printhead, and a straight microchannel at a resolution of 5.0μm×1.3μm. Santiago et al. and Meinhart et al. both used intensified CCD cameras with an epi-fluorescence microscope system.

In this paper, a home-assembled epi-fluorescence optic system was used for the measurement of microchannels with a non-intensified 8-bit CCD camera, relatively low cost compared to intensified CCD cameras. The basic optics were setup by Lee et al.[7,8] for straight microchannel measurements, and recently, a vector-to-vector resolution of 2μm×2μm was obtained by Choi and Lee [9] at a T-junction microchannel.

Experiment

Certain requirements must be met in order for particles to be used in micro-PIV: its size must be small enough to accurately follow the flow, but large enough to be imaged through the optics and onto the CCD cell. Red fluorescing particles of 620nm in diameter were used, having excitation and emission wavelengths of 530nm and 612nm respectively.

The 3D draft and the specifications of the T-shaped microchannel used in the experiment are shown in Fig. 1. The depth of the channel is 50μm, with the main straight channel width of 300μm, and 5000μm in length. A 50μm width channel exists perpendicular to the main straight channel at the mid section, forming a T-junction with the main 300μm-width horizontal channel. The channel was cast on PDMS from a silicon mold, which was then O_2-ion bonded onto a slideglass.



(a) (b)

Fig. 1 Dimensions and geometry of the microchannel

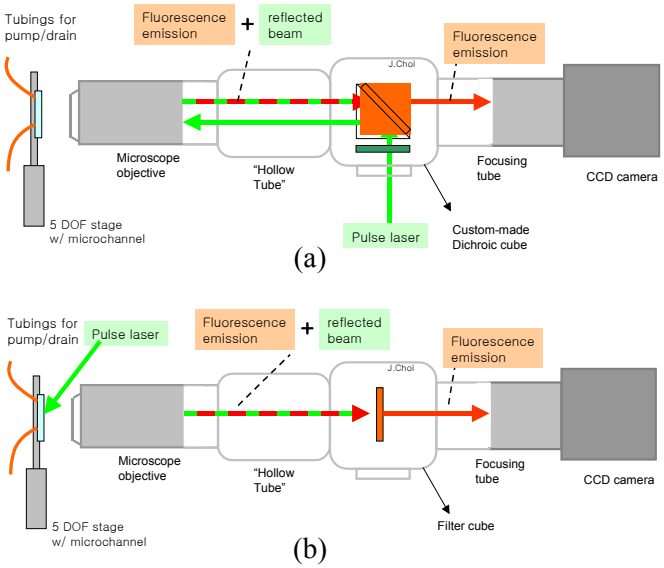


Fig. 2 Schematics of the custom-made micro-PIV optics
(a) 50X setup, used with 50X objective
(b) 100X setup, used with 100X objective

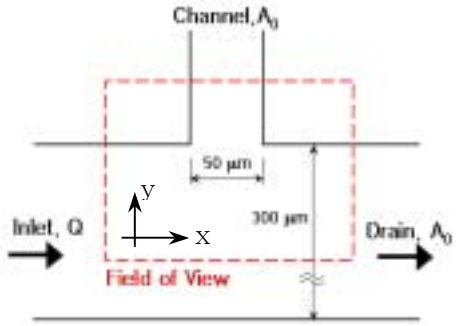


Fig. 3 Field of view of PIV measurements

The schematic of the micro-PIV system optics is shown in Fig. 2. It consists of the microscope objective, a custom-made dichroic cube, the focusing tube, and a 8-bit 1K×1K CCD camera. Figure 2 shows how the custom made optics were used for PIV measurements. The two microscope objectives used in this experiment were of magnifications 50X and 100X, with working distances of 13mm, and 6mm respectively. The beam path shown in Fig. 2(a) is typical for epi-fluorescence microscopy, and this setup was used for measurements with the 50X objective. Figure 2(b) shows another optics setup, which was used for measurements with the 100X objective, and enables maximum laser power for better illumination of the field of view without endangering the optic system to the high intensity of the laser beam. The green pulse laser used is a two-head Nd:YAG laser with a maximum power output of over 300mJ with a wavelength of 532nm. The dichroic cube consists of three main optic components: the excitation filter, the dichroic mirror, and the emission filter, for which the characteristic wavelengths were order-made to meet the 530nm excitation and 612nm emission wavelengths of the fluorescent particles. The CCD camera was synchronized with the pulse laser with the camera's shutter feedback as the master signal. Time delays of 3~5μs between particle images were needed for flow rates of 2.0, 4.0, and 6.0 mL/hr.

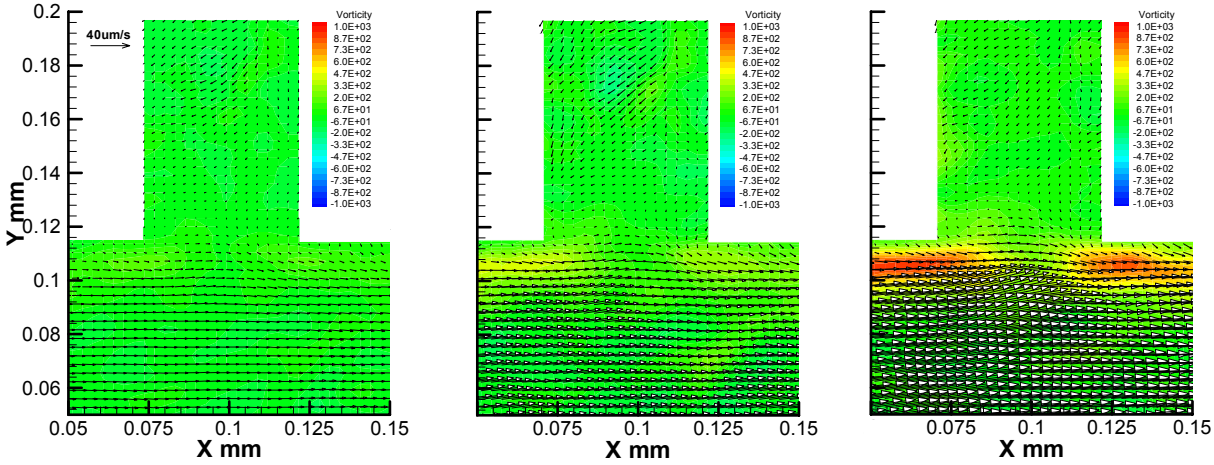


Fig. 5 Mean velocity vector field result with 50X setup

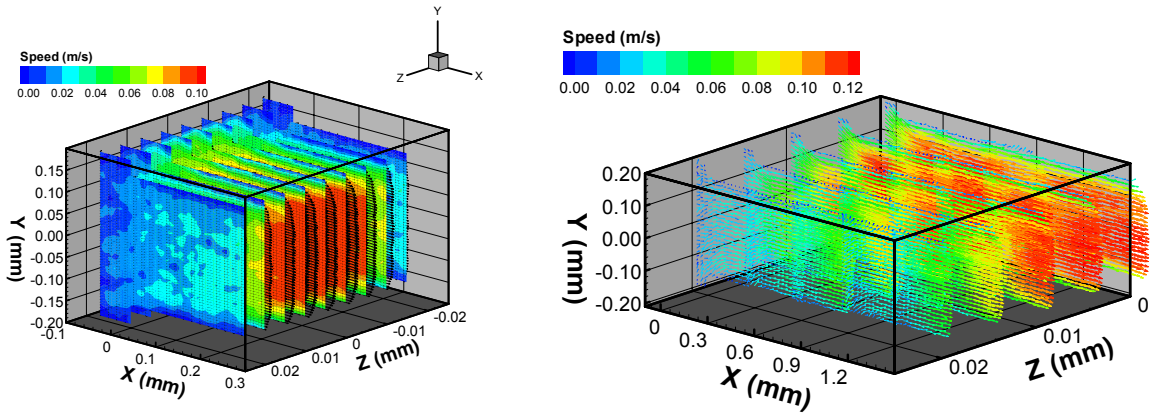


Fig. 6 Three-dimensional plots of mean velocity vector field results at entrance of straight channel

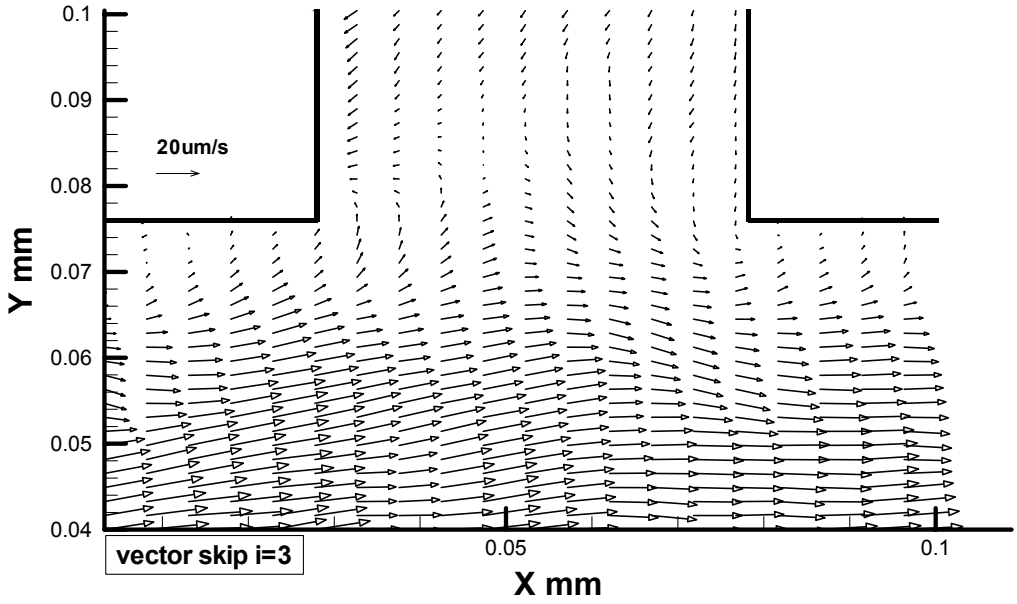


Fig. 7 Mean velocity vector field result with 100X setup (vector-to-vector spacing: 2μm×2μm, only every 3rd vector in the x-direction shown)

Results & Discussion

The field of view(FOV) for the experiment is shown in Fig. 3: a rectangular area was selected which included the 50μm channel in the center. The FOV for the 50X and 100X setups were approximately 200μm-square and 100μm-square, respectively. With a 32-pixel square interrogation window at 50% overlap, this lead to a vector plot with a vector-to-vector distance of approximately 4μm, and 2μm for the 50X and 100X setups, respectively. The object plane was manually positioned at about the mid-depth of the channel, at approximately 25 from its bottom surface, through translation of the microscope objective with an attached micrometer.

Acquired raw particle images showed particles sizes of approximately 3~6 pixel-area and 7~10 pixel-area for the 50X and 100X setups, respectively. Due to the small field of view, the particle images acquired with the 100X setup were low in brightness relative to the increase in laser intensity. 100 instantaneous velocity vector fields were averaged to obtain each mean velocity vector fields, and are shown in Fig. 5 through Fig. 7.

Figure 5(a), 5(b), and 5(c) are the results for fluid injections rates of 2.0, 4.0, and 6.0mL/hr, respectively. It is found that the main horizontal flow from left to right slightly deforms as it passes the 50μm channel and that the flow inside the 50μm channel is negligible for all fluid injection rates. However, the vorticity field along the wall of the 300μm-width main channel, is increased in strength as the fluid injection rate is increased. A discontinuity in the vorticity field is observed at the entrance of the 50μm channel. Figure 6, shows the results with the 50X setup at a channel entrance for a flow injection rate of 5.4mL/hr. Mean velocity field data at various planes are plotted three-dimensionally.

Figure 7 shows a full-field-of-view mean velocity vector field result with a fluid injection rate of 4.0mL/hr, measured with the 100X setup. A vector-to-vector distance of 2μm×2μm can be observed, showing the deformatinon characteristics of the main stream flow. The apparent erroneous velocity gradient in the y-direction near the left edge of the vector field is assumed to be due to particles attached to the wall surface, or over-sized, accumulated particle chunks that cause erroneous vector results in its vicinity.

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