ABSTRACT

Experimental investigations on characteristics of air-water two-phase flows in square and rectangular microchannels in polymer microfluidic chips were carried out. The microchannels, thermoformed on a polymer substrate, had different, higher and asymmetric surface roughnesses compared to the microchannels etched in the silicon substrate used previously. The effect of the surface characteristics on the gas-liquid two phase flow was determined by comparing flow patterns and transitions between flow regimes in microchannels fabricated by different methods.

Thermoforming of polymer microfluidic chips is a cost-effective method of producing disposable bioreactor chips. Understanding gas-liquid two-phase flow in a polymer microchannel is required in order to use segmented flow for processing a large number of aqueous reagent plugs. The segmented flow enables use of a minimal volume of reagent by substituting gas for liquid and an increase in molecular diffusion and heat transport by increasing the surface to volume ratio. Experimental investigations of gas-liquid two-phase flow have been reported with square microchannels fabricated in molecularly smooth silicon substrates using deep reactive ion etching (DRIE) [1]. Surfaces of the etched microchannel had the root mean square (RMS) roughness varying between 5 and 50 nm [2]. Three different fabrication methods for polymer microfluidic chips, direct micromachining of poly(methyl methacrylate) (PMMA) (RMS ≈ 384 nm), hot embossing of PMMA with a micromachined brass mold insert (RMS ≈ 402 nm), and hot embossing of PMMA with an X-ray LIGA mold insert (RMS ≈ 78 nm), produced different values of RMS roughness on the surface of microchannels as shown in Figure 1.

Figure 2 shows a microchannel network for generating and observing air-water two-phase flow and a polymer microfluidic chip. Square and rectangular microchannels with hydraulic diameters of 133 µm and 200 µm were fabricated using hot embossing of PMMA with a micromachined brass mold insert, which had the roughest surface among the chips. This fabrication method provided a shorter process time than fabrication of an X-ray LIGA mold insert and higher manufacturing rates than direct machining of polymer substrates. Thermal fusion bonding of thin, 125 µm thick, PMMA cover slips and the thermoformed microfluidic chips provided enclosed microchannels and enabled visual observation of the flow patterns. Air-water two-phase flow patterns and the normalized area of the bubbles within a plug flow regime were determined by image processing of frames acquired thorough a CCD camera equipped with a microscope. The value of each data point was acquired by averaging the spatial pixel values from 8-bit gray scale images. Four main air-water two-phase flow patterns, capillary bubbly, plug, annular and dry flows, were observed as shown in Figure 3. Transitions between flow regimes were determined for fixed values of the liquid volumetric flow ratio defined by $\beta_L = Q_L/(Q_L + Q_G)$ where $Q_L$ is the liquid flow rate and $Q_G$ is the gas flow rate, to compare the effect of the surface characteristics on two-phase flow patterns. Figure 4 shows insignificant deviations in flow patterns and transition lines observed from microchannels etched on silicon [1] and fabricated on polymer substrates.
Figure 1. (a) Optical measurement of surface roughness of a microchannel sidewall hot embossed with a micromachined brass mold insert. (b) Surface profile of microchannel sidewalls of polymer microfluidic chips fabricated with different methods.

Figure 2. (a) Schematic of the microfluidic channels for generating and observation sections of air-water two-phase flow. (b) Photograph of a PMMA microfluidic chip fabricated with a brass mold insert.

Figure 3. Air-water two-phase flow patterns (a) $\beta_L=0.793$ (b) $\beta_L=0.296$ (c) $\beta_L=0.056$ (d) $\beta_L=0.01$ and (e) $\beta_L=0.0006$.

Figure 4. Flow pattern map and transition lines for air-water two-phase flow in 200 µm square channels etched in silicon and fabricated with PMMA. Flow regimes in parentheses show flow regime of the Cubaud and Ho [1].

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REFERENCES