Experimental Visualization of Bubble Generation and Breakup In T-junctions of Microchannels

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ABSTRACT

It has recently been demonstrated that microchannel T-junction bubble generator (MTBG) enables highly monodispersed bubbles to be fabricated efficiently. We propose to integrate a second microchannel T-junction into MTBG to significantly reduce bubble size without reducing microchannel size. We visualize and record the bubble formation (characterized by the formation pattern, the bubble size and distribution) at the first T-junction and the bubble interaction/breakup (characterized by the interaction/breakup pattern, the bubble size and distribution) at the second T-junction as functions of flow rates of two fluids and geometrical parameters of the system with a high speed digital imaging system equipped with a long distance microscope.

Key words: Monodispersed bubble; Bubble generation; Microchannels; Flow pattern

1 INTRODUCTION

As the development of MEMS and the techniques of micro-fabrication, bubble generator becomes more and more important. Gas bubbles could be used as spacers for samples in a channel or to act as a piston to produce pressure-driven flow on top of the electrokinetic flow. Flow valves and pumps that employ air bubbles, like those in the ink reservoir of ink jet printers, are being tested for mcirochannels [1]. Micro-bubbles are known to be useful to improve water quality and to promote the growth of shellfishes, such as oyster and pearl oyster [2]. Bubble generator can also be used in pharmaceutical and diagnostic devices to improve the accuracy of the drug quantity. While microchannel fabrication is the simplest process in micro-fabrication technique, works on the monodispersed bubble generation by microchannels appear very limited.

The present work proposes a micro-bubble generator that employes two T-junctions of microchannels and is capble to fabricate monodispersed bubbles effectively.

2 MATERIALS AND METHODS

2.1 Materials and Reagents

De-ionized water was used as the dispersing liquid. Aerosol oT ($C_{20}H_{37}NaO_7S$; Jiashan Jufeng chemical, Zhejiang, China)， with a concentration of 0.07wt%, was used as the surfactant solved in de-ionized water [3]. Argon gas was used as the dispersed fluid.

2.2 Microchannel T-junction Bubble Generator(MTBG)

A schematic diagram and a photo of Microchannel T-junctions Bubble Generator, MTBG, are shown in Figs. 1 and 2, respectively.

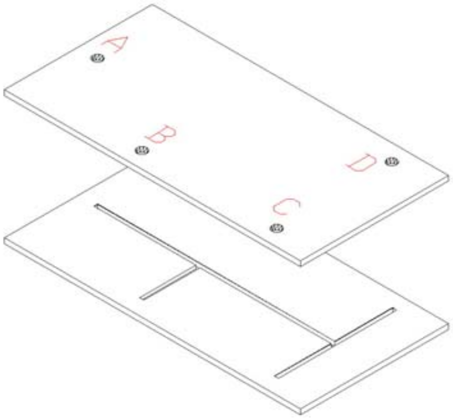

Fig.1 Two-T-junction Bubble Generator

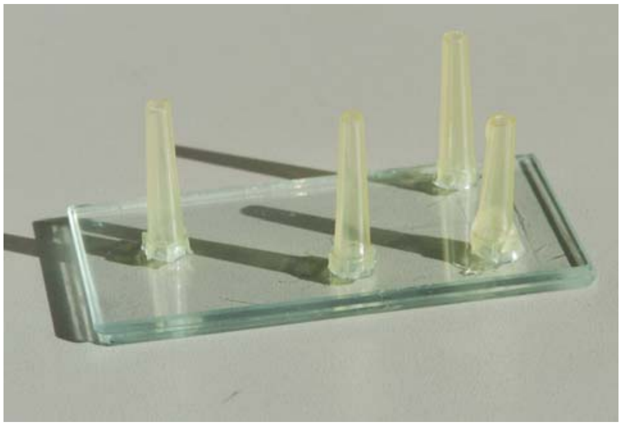

Fig. 2 Photo of MTBG

Two generators with different hydraulic diameters were employed: 150x40um and 80x25um. The MTBG plate, fabricated at Zhejiang Universty, was made up of two pieces of glasses (60mmx30mmx2.8mm). Four holes were drilled on the upper glass. Tie-in A and Tie-in B were glued to the glass by epoxy glues as the inlets of two fluids, respectively. Tie-in C and Tie-in D glued on the glass serve as the two outlets for the mixture of dispersing and dispersed fluids. Rectangular microchannels were etched on the lower glass.

2.3 Apparatus and Procedure

The experimental apparatus are shown in Fig.3. Two tanks were used as water and Argon gas containers and as pressure sources of fluid flows. Both micro- adjusting-valves and cut-off valves were used to control the flow of high pressurized Argon gas to the two tanks. Two releasing-valves were also used for each of the two tanks for adjusting their pressures. Two pressure transducers (Xi'an Zhongfei sensor technique Co., Ltd. ,Xi'an, China; model ZFBY 3801 with an accuracy of 0.2% and a full measuring range of 1Mpa) were used to measure the pressures of the two tanks. They were calibrated by a pressure sensor with an accuracy of 0.075%. It was confirmed that their accuracy is higher than 0.2%.

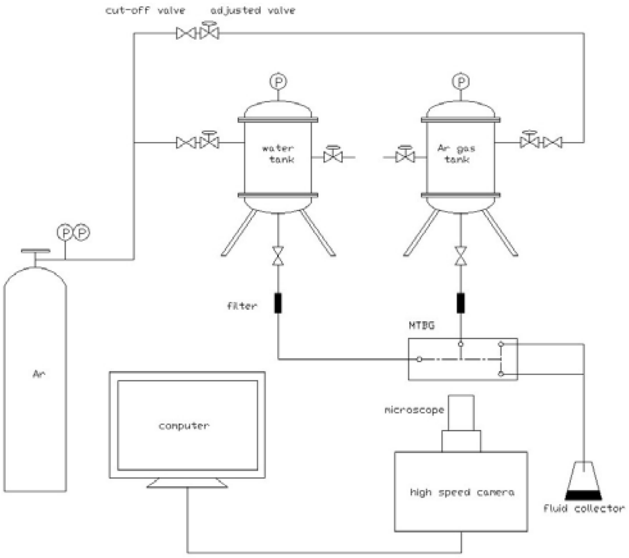

Fig.3 Schematic diagram of the experiment setup

A high speed camera (Cordin 220A-8), equipped with a microscope (BX-301B; Jinan Qiangsheng Photoelectric Instrument Co., Ltd., Jinan China), was used to visualize and record the bubble generation and breakup. The camera was controlled by a personal computer and can have 100 million images per second. The software accompanied with the camera was also used to analyze bubble size, distribution and motion. Bubble diameter and distribution were determined through analyzing images of 100 bubbles captured by using the accompanied software.

The dispersed gas and dispersing water are introduced into the test section first through filters by pressurized reservoirs containing water and argon gas. All connections among the containers, the valves, the filters and the test section are by Tygon tubes.

For the experiments, we first set the water pressure at a fixed value, and then vary the gas pressure to visulize and record bubble generation and breakup. Another water pressure value will then be used to repeat the test.

3 RESULTS AND DISCUSSION

3.1 Bubble Generation at the First T-junction

Two MTBGs were tested in present work. Their microchannels are with width and height of 150x40um (hydraulic diameter of d_h=63.2um) and 80x25um (d_h=38.1um) respectively. Fig.4 shows the phase diagram. In the figure, W-B stands for water flow-bubbly flow transition, B-L bubbly flow-layered flow transition, and L-G layered flow-gas flow transition. Both MTBGs are capable of generating well-contorlled monodispersed bubbles in certain region marked as bubbbly flow in the figure. The region becomes wider as the microchannel size reduces. A decrease of channel size also leads to a more steady generation process of monodispersed bubbles and a smaller bubble size. The regions for the other flow patterns are also shown in Fig. 4. The readers are refereed to [4] for the detailed discussion of different patterns. Fig. 5 details the bubble generation process in bubbly flow region.

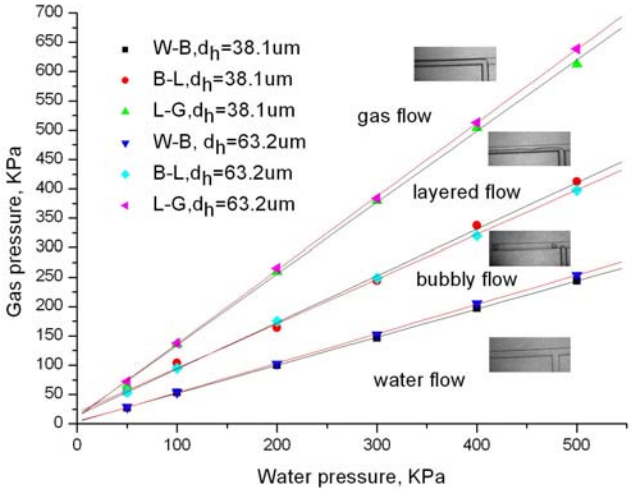

Fig.4 Phase diagram of bubble generation

This method not only produces monodispersed bubbles but also offers the controling of bubble sizes by varing pressures of two fluids. Also the standard deviation of bubble diameters are normally below 2%. Even at the worst case with a highly unsteady bubble formation, the standard deviation of bubble diameters was 9% which is much lower than that by traditional methods.

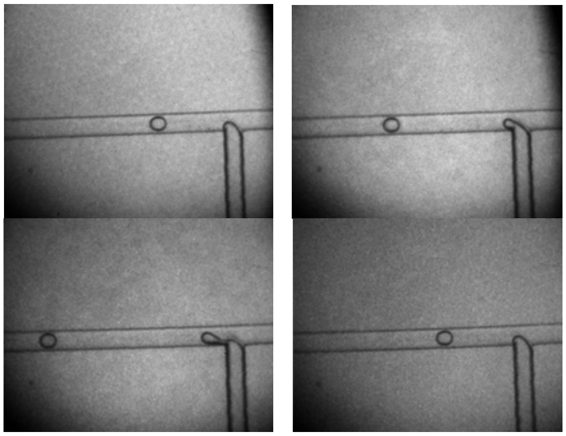

Fig.5 Bubble generation process

3.2 Bubbles Breakup at the Second T-junction

Figs. 6 and 7 are the phase diagrams of bubble breakup at the second T-junction for two MTBGs respectively. Bubbles, generated at the first T-junction, can break up at the second T-junction. The breakup-starting pressure is a little higher than the bubble generation pressure, shown as curve "start to break" and curve W-B in Figs. 6 and 7. This difference of gas pressure becomes smaller as the water pressure increases. Therefore, the generator works better at a higher value of water pressure in bubbly flow region.

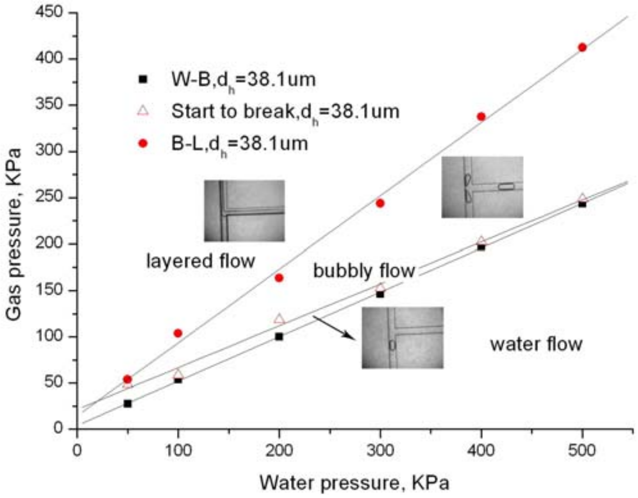

Fig.6 Phase diagram of bubble breakup (d_h=38.1um)

The generator with a smaller channel size (d_h=38.1um) has a lower value of gas pressure when the bubbles start to break and has a wider bubbly flow region at the second T-junction as shown in Fig. 8. Fig. 9 details the bubble breakup process characterized by bubble deformation and breakup. The standard deviation of the bubbles broken at the second T-junction is also below 2%.

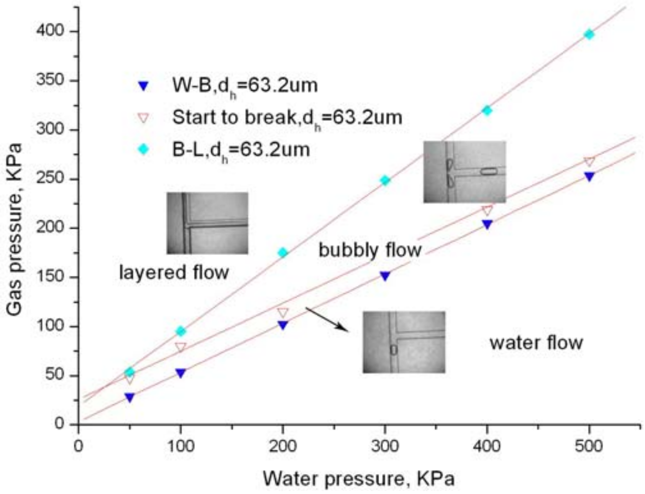

Fig.7 Phase diagram of bubble breakup (d_h=63.2um)

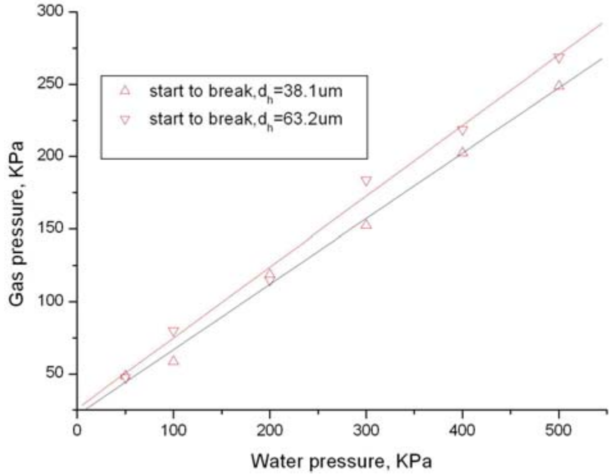

Fig.8 Comparison of bubble breakup pressure

4 CONCLUSION

A novel bubble generator was proposed to fabricate monodispersed micro-bubbles. The formed bubbles can also break up at the second T-junction. The performances of such generators get better as the microchannel size reduces. Phase diagrams of bubble generation at the first T-junction and bubble breakup at the send T-junction are obtained for two MTBGs with different microchanel sizes.

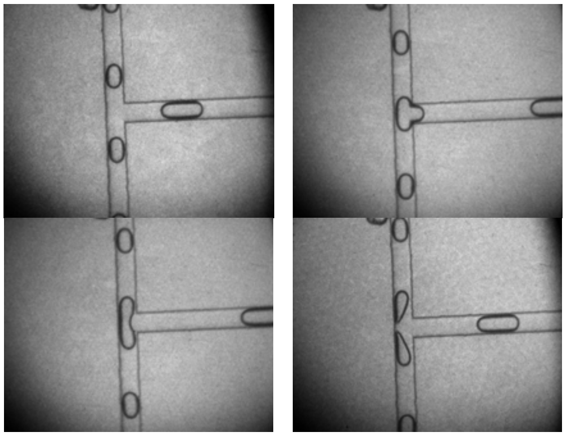

Fig.9 Bubble breakup process

5 ACKNOWLEDGEMENT

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