TELKOMNIKA, Vol. 11, No. 7, July 2013, pp. 3767 ~ 3773
e-ISSN: 2087-278X

Droplets Fusion in a Microchannel on a Piezoelectric Substrate

Fu Xiang-ting, Zha Yan, Zhang An-liang*
School of Information Science and Engineering, Ningbo University
No. 818 Fenghua Road, Ningbo, Zhejiang, China, +86-574-87600582
*Corresponding author, e-mail: zhanganliang@nbu.edu.cn

Abstract

Fusion droplets is a key operation in a microfluidic device for microfluidic analysis. A new fusion method for droplets was presented. An interditigal transducer and a reflector were fabricated on 128^0-yx $LiNbO_3$ piezoelectric substrate using microelectric technology. A poly-dimethyl silicone micro-channel was made by soft lithography technology and mounted on the piezoelectric substrate. Droplets in the microchannel were actuated by surface acoustic wave and fussed each other. Coloured dye solution droplets were used to fusion experiments. Results show that the two droplets in the microchannel can be fused by help of surface acoustic wave, and size of droplets, distance of droplets and RF signal power can affect successful fusion of the droplets. The fusion method is valuable for microlfuidic biological and chemical analysis in a microfluidic device.

Keywords*: surface acoustic wave, fusion, droplet, microchannel.*

1. Introduction

Microfluidic devices have been proven to be powerful platforms for biological and chemical analysis due to their advantages, such as rapid speed, small size and low reagent consumption. Due to these advantages, microfluidic devices have been widely applied in the fields of DNA sequencing, protein analysis, single cell analysis, drug screening and food safety [1-4]. Comparison to the microfluidic device working with continuous fluid, the microfluidic device working with droplets (digital microfluid) has been obtained more attraction due to the advantages of smaller size, lower cost and less cross contamination. In order to implement microfluidic analysis, sample preliminary treatment is usually indispensible. Fusion, in which droplets from multiple sources are merged together to form a desired combined droplet, is a crucial function for droplet-based systems, and also is an important preliminary treatment operation in a microfluidic analysis system. Several fusion methods have been reported till now. Nicolas Bremond and his groups [5] have implemented the fusion of microfluids in a micro-channel by varying the size and structure of micro-channels. The method can implement the fusion of microfluids easily. However, the fusion of microfluids does only appear at special site in the micro-channel. Luis [6] has demonstrated a method for microfluid fusion based on a surface energy pattern on the walls of a mcirofluidic device. The advantages of the method for microfluidic fusion are no active elements and need not accurate synchronization of the microfluids to be fused. It also allows fusion of more than two droplets at a single step. However, the surface modification is increasing the cost of the micro-channel and the hydrophilic pattern of micro-channel is usually instability, which needs to be improved. Michele Zagnoni [7] has presented electrically initiated upstream coalescence cascade of microfluid, and finished electrocoalescence of water microdroplet in oil populations in microfluidics. The coalescence mechanism has also been investigated. However, the upstream coalescence is depended on the microfluid size and distribution. Thus, the method for fusion microfluid is also to be improved. Liu and his co-operators [8] has designed and fabricated a circular chamber in a micro-channel. When two microfluids to be fused are transported to the chamber, the fusion of the two microfluids can appear. However, the microfluids fusion will occur only when the frequencies of two kinds of microfluids are sufficiently close. Shoji Takeuchi [9] describes an electro-fusion device for controlling the precise moment of fusion between droplets by applying an electric field. The main advantages of the fusion device allows accurate determination of the

Received January 26, 2013; Revised April 16, 2013; Accepted April 28, 2013

start of chemical/biological reactions, iminating surface absorption problems and easy fabrication. Thus, the method has been used for the fusion of b-galactosidase and fluorescein di-b-Dgalactopyranoside droplets. However, standard lithographic and MEMS processes in fabrication should be improved. In addition, there has been reported that droplet fusion is demonstrated by utilizing size and frequency matching [10], converging fluidic channels [11], or patterned ITO electrodes [12], which result in the deceleration and collision of droplets. The main disadvantage of these methods is the employment of syringe pumps as driving sources, which made it costly when trying to scale up the complexity and productivity of the systems. In order to solve these problems, the new fusion method should be invented.

Surface acoustic wave (SAW) is an elastic wave, which is propagated along the surface of piezoelectric substrate. Acoustic device has widely applied in electric system [13, 14] due to small size, compact and simple technology. In recent years, surface acoustic wave has been seen the increasing application in microfluidic system [15, 16].

In this paper, a new method for the fusion of droplets in a dimethyl silicone polymer (PDMS) micro-channel was presented. Surface acoustic wave was used to actuate droplets in the PDMS micro-channel, and then fused in the micro-channel. The fusion of coloured dye solution droplets was demonstrated. The several factors, which could affect the successful fusion of coloured dye solution droplets, were discussed.

2. Research Method

When a RF signal with near the synchronous frequency of an interdigital transducer (IDT), which was fabricated on a piezoelectric substrate, is applied to the interdigital transducer, surface acoustic wave can be excited due to acoustic-electrical effect of piezoelectric material. The amplitude of the surface acoustic wave is determined on the radio frequency (RF) signal power. The number of interdigital transducer pairs, weighting fashion and the characteristics such as electromechanical coupling factor of the piezoelectric substrate are also affect the SAW amplitude under the same RF signal power. The synchronous frequency of the interdigital transducer is determined on the finger spacing, finger width, and the transportation velocity of surface acoustic wave on the piezoelectric substrate.

When hitting a droplet on the piezoelectric substrate, the major part of the incident wave energy could radiate into the microfluid by Rayleigh angle θ_R, which can be expressed as following formula [17]:

$$\theta_R = \arcsin(\frac{V_w}{V_R}) \tag{1}$$

Where V_W is the velocity of sound propagation in fluids and V_R is that in piezoelectric substrate. The sketch of the acoustic radiation is shown in Figure 1.

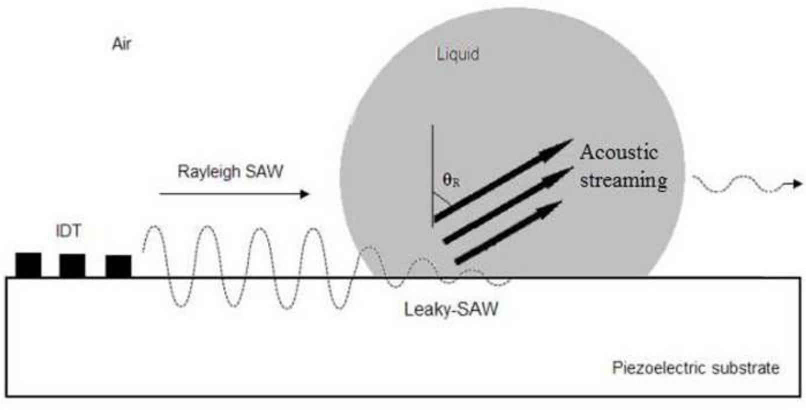

Figure 1. Acoustic radiation into a droplet

As shown in Figure 1, when surface acoustic wave is radiated into the droplet, acoustic streaming is generated and a force per volume is actuated the droplet [18]. When the force is larger enough, the droplet can be transported along the surface of the piezoelectric substrate.

In order to demonstrate the fusion of droplets, fusion device was fabricated on a 128^0 yx-$LiNbO_3$ piezoelectric substrate. The fabrication process of the fusion device to fuse droplets is depicted schematically in Figure 2.

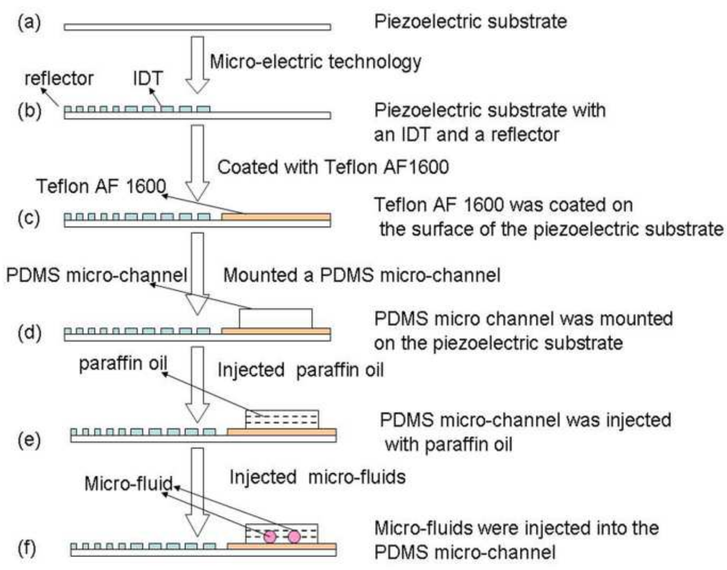

Figure 2. The fabrication process of the fusion device

As sketched in Figure 2, an interdigital transducer and a reflector were at first fabricated on a 128^0 yx-$LiNbO_3$ piezoelectric substrate (Hua Ying electronics Co. Ltd., China) using micro-electric technology (Figure 2 (a) and (b)). Then, Teflon AF 1600 film (Dupont, USA) was coated on the acoustic path of piezoelectric substrate (Figure 2(c)) and PDMS (Dow Corning 184, China) micro-channel was mounted on it (Figure 2 (d)). The PDMS micro-channel was implemented using soft lithography technology. At last, paraffin oil and droplets to be fused were injected into the PDMS micro-channel using a micro-syringe (Figure 2 (e) and (f)).].

In order to verify the present method, fusion experiments were demonstrated using the homemade fusion device. The experimental setup for the fusion of two droplets is shown as Figure 3.

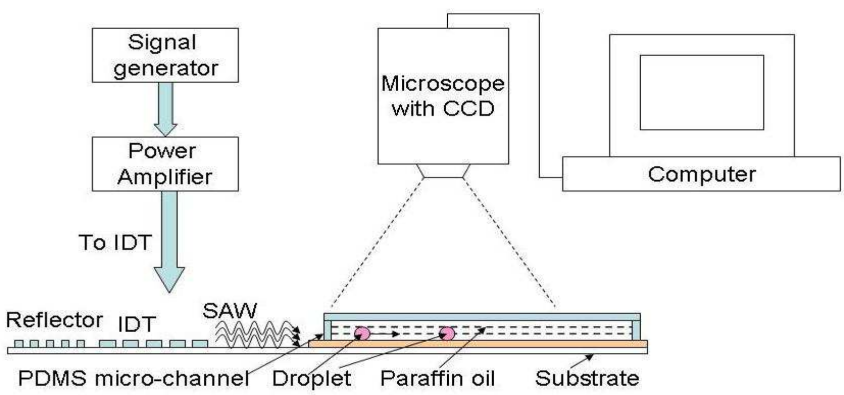

Figure 3. Experimental setup for fusion of droplets

In Figure 3, the interdigital transducer and the reflector is fabricated on the 128^0 yx-$LiNbO_3$ substrate using micro-electric technology. The size of the interdigital transducer is 4320 µm of aperture, 36µm of the width and 144µm of the period. The interdigital pair number of the interdigital transducer is 35. The aluminium electrodes thickness of the interdigital transducer and the reflector is 500nm. The area free of aluminium electrodes is coated with Teflon AF1600. The PDMS micro-channel is fabricated using soft lithography technology, and mounted on the piezoelectric substrate. The RF signal generator (SP1461, China) is used to supply a signal of 27.5MHz synchronous frequency of the interdigital transducer. The power amplifier (TSA002A, China) with 48dB gain is used to amplify the RF signal. Maximal unsaturated output power of the power amplifier is 30 W. A power meter (YM2462, China) is used to measure the power applied to the interdigital transducer on the piezoelectric substrate. A microscope with charge-coupled device (CCD) is used to monitor the droplet transportation and fusion in the PDMS microchannel. MDVNT software (Novel, China) is used for camera control and image processing.

3. Results and Analysis

In order to observe the fusion of the droplets in the PDMS microchannel, coloured dye solution droplets were used in the fusion experiments. At first, paraffin oil was pipetted into the PDMS micro-channel. Then, two coloured dye solution droplets were also pipetted into the micro-channel. After a RF signal with 27.5MHz central frequency was applied to the interdigital transducer, two coloured dye solution droplets were transported and fused each other in the micro-channel. Figure 4 shows the fusion of the two red dye solution droplets in the PDMS micro-channel.

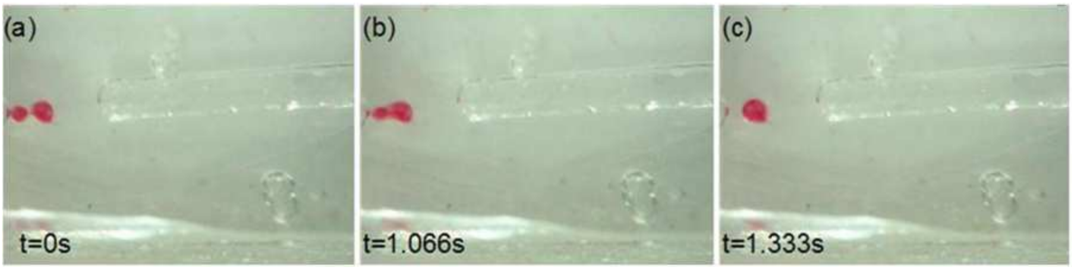

Figure 4. Two red dye solution droplets were fused in a PDMS micro-channel by help of SAW.

According to Figure 4, the two red dye solution droplets are transported and fused by help of surface acoustic wave. The RF signal power was 33.4dBm.

In Figure 4, the distance of the two red dye solution droplets is small, thus the two droplets is fused in 1.333s.

In order to further observe the fusion of droplets, the distance of two coloured dye solution droplets is increased and two colour droplets are used in the fusion experiment. A blue dye solution droplet and a red dye solution droplet were used to fusion experiment. The snapshots from record video are shown in Figure 5. In the fusion experiment, the RF signal power applied to the interdigital transducer is 34.8dBm.

In Figure 5, Figure 5 (a) shows the state of two droplets in the PDMS micro-channel filled with paraffin oil. Figures 5 (b) to (f) shows the fusion procedure of the two coroued solution droplets by help of SAW.

According to Figure 4 and Figure 5, surface acoustic wave with enough amplitude can implement fusion of droplets in a micro-channel.

In order to further study the effect of the RF signal power, size of droplets and attenuation distance of surface acoustic wave on fusion, several experiments of droplets fusions were also demonstrated.

Table 1 shows the fusion comparison of two red dye solution droplets with different distance and droplet size.

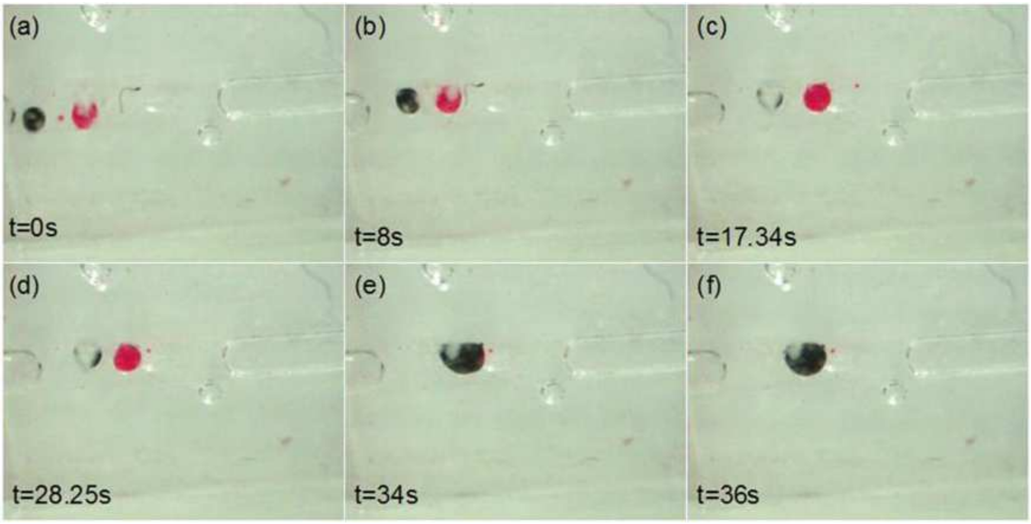

Figure 5. The fusion of red dye solution droplets and a blue dye solution droplet in the PDMS micro-channel by help of SAW.

Table 1. The fusion comparison of two red dye solution droplets

Experiment serial number	Size of a droplet (mm)	Size of another droplet (mm)	Distance (mm)	Power on IDT (dBm)	Fusion time (s)
1	0.290	0.3847	0.060	33.4	1.333
2	0.370	0.376	0.298	33.8	14.67

According to the Table 1, fusion time is determined by the distance of two droplets, when the RF signal power and droplet size are near. The fusion time is increasing with the distance of the two droplets.

The fusion comparison with different colour droplets is also demonstrated. Table 2 shows the comparison experiments with a red dye solution droplet and a blue dye solution droplet.

Table 2. The fusion comparison of a red dye solution droplet and a blue dye solution droplet

Experiment serial number	Size of a droplet (mm)	Size of another droplet (mm)	Distance (mm)	Power on IDT (dBm)	Fusion time (s)
3	0.47	0.402	0.35	34.8	27.734
4	0.44	0.501	0.50	34.8	36

According to the Table 2, when RF signal power and the size of one of droplet is near, the fusion time of two different colour droplets is also determined by their distance, which is the same with that in the Table 1.

Compared Table 1 with Table 2, we can further deduce that the size of droplets do also affect the fusion time. The fusion time is increasing with the size of the droplets in the PDMS microchannel.

In order to analyze the fusion of two different colour droplets, grey-scale maps before and after fusion are obtained as shown in Figure 6.

In Figure 6, Figure 6 (a) is the grey-scale map of the two droplets just touching each other, and Figure 6 (b) shows that after fusion, of which the image is as shown in Figure 5(f). According to the Figure 6, we can observe that the grey value is more flat after fusion, which shows the two droplets have been finished fused.

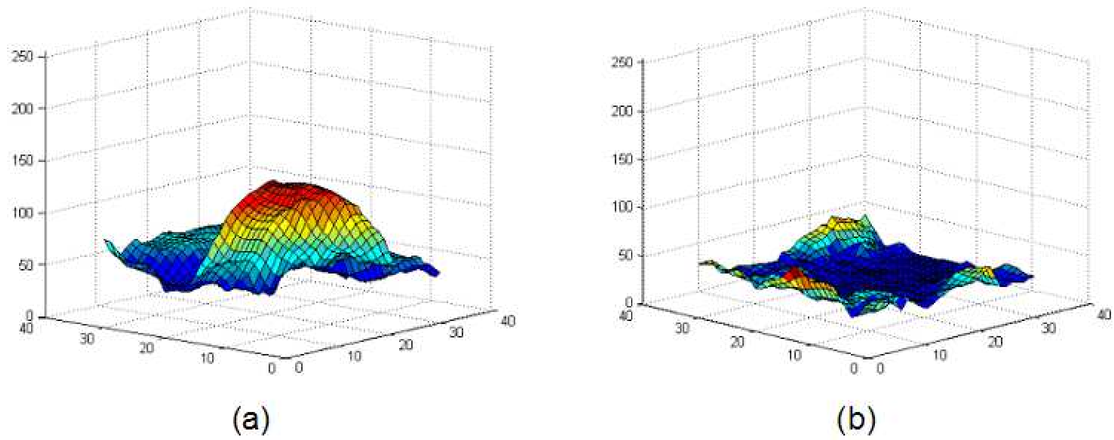

Figure 6. The grey-scale maps of two droplets before (a) and after (b) fusion by help of SAW

4. Conclusion

A device for droplets fusion was designed and fabricated on a 128^0 yx-$LiNbO_3$ substrate using micro-electric technology. A PDMS micro-channel was made using soft lithography technology, and mounted on the piezoelectric substrate. Two droplets in the PDMS micro-channel were fused by help of surface acoustic wave. For observation, red and blue dye solution droplets were used to fusion experiments. Some conclusions can be drawn from the experiment results: (1) Surface acoustic wave can be used to implement the fusion of two droplets in a PDMS micro-channel; (2) The size of droplets to be fused could affect their transportation in the micro-channel; (3) A RF signal power could greatly affect successful fusion of droplets in the micro-channel. The work is valuable for microfluid biological and chemical analysis in a microfluidic device.

Acknowledgements

The work was financially supported by the Science and Technology Department of Zhejiang province (2009R50025), Natural Science Foundation of Ningbo municipal (2011A610108) and the key discipline of Zhejiang province (Xkl11077). This work was also partly sponsored by KC Wong Magna Fund in Ningbo University.

References

[1] Lee T, Kim H, Tran T, Jang J. Diffusion-based Multi-stream Bioluminescent Reaction in a Microfluidic Device. *Chemical Engineering Journal*. 2012; 185(1): 321-327.
[2] Leandro YS, Murilo S, Angelo LG, Lauro TK. Separation and Electrochemical Detection of Paracetamol and 4-aminophenol in a Paper-based Microfluidic Device. *Analytica Chimica Acta.* 2012; 725(1): 44-50.
[3] Tang Z, Akiyama Y, Itoga K, Kobayashi J, Yamato M, Okano T. Shear Stress-dependent Cell Detachment from Temperature-responsive Cell Culture Surfaces in a Microfluidic Device. *Biomaterials.* 2012; 33(30): 7405-7411.
[4] Koji M, Mami T, Yuka K, Toru H, Shinichiro Y, Keiji N. Screening of Sperm Velocity by Fluid Mechanical Characteristics of a Cyclo-olefin Polymer Microfluidic Sperm-sorting Device. *Reproductive BioMedicine Online*. 2012; 24(1): 109-115.
[5] Bremond N, Thiam AR, and Bibette J. Decompressing Emulsion Droplets Favors Coalescence. *Physical Review Letters.* 2008; 100(2): 024501-1-4.
[6] Luis MF, Chris A, Wilhelm TSH. Surface-induced Droplet Fusion in Microfluidic Devices. *Lab Chip.* 2007; 7(8): 984-986.
[7] Zagnoni M, Baroud CN and Cooper JM. Electrically Initiated Upstream Coalescence Cascade of Droplets in a Microfluidic flow. *Physical Review E*. 2009; 80(4): 046303-1-8.
[8] Liu K, Ding HJ, Chen Y, Zhao XZ. Droplet-based Synthetic Method Using Microflow Focusing and Droplet Fusion. *Microfluid and Nanofluid.* 2007; 3 (2): 239-243.

[9] Tan WH, Takeuchi S. Timing Controllable Electrofusion Device for Aqueous Droplet-based Microreactors. *Lab Chip*. 2006; 6(6): 757-763.
[10] Song H, Tice JD, Ismagilov RF. A Microfluidic System for Controlling Reaction Networks in Time. *Angewandte Chemie International Edition.* 2003; 42(7): 768-772.
[11] Hung LH, Choi KM, Tseng WY, Tan YC, Shea KJ and Lee AP. Alternating Droplet Generation and Controlled Dynamic Droplet Fusion in Microfluidic Device for CdS Nanoparticle Synthesis. *Lab Chip.* 2006; 6 (1): 174-178.
[12] Link DR, Grasland-Mongrain E, Duri A, Sarrazin F, Cheng Z, Cristobal G, Marquez M and Weitz DA. Electric Control of Droplets in Microfluidic Devices. *Angewandte Chemie International Edition*. 2006; 45(16): 2556-2560.
[13] Yu C, Guo C, Liang JY, Wang T. Ultrasonic Wind Velocity Measurement Based on Phase Discrimination Technique. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2012; 10(6): 1157-1162.
[14] Ding XB, Liang JY, Liu J, Guo C, Wang T. Measurement Algorithm of Two-Dimensional Wind Vector using Ultrasonic Transducers. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(1) (to be published).
[15] Beyssen D, Brizoual LL, Elmazria O, Alnot P. Microfluidic Device Based on Surface Acoustic Wave. *Sensors and Actuators B*. 2006; 118(1): 380-385.
[16] Zhang AL, Zha Y, Rapid Drop-to-drop Liquid-liquid Microextraction by Help of Surface Acoustic Wave. *Chemical Engineering and Processing: Process Intensification*. 2012; 62(12): 145-149.
[17] Uchida T, Suzuki T and Shiokawa S. Investigation of Acoustic Streaming Excited by Surface Acoustic Waves. *IEEE Ultrasonics symposium*, New York, USA. 1995: 1081-1084.
[18] Shiokawa S, Matsui Y and Ueda T. Liquid streaming and droplet formation caused by leaky Rayleigh wave. *IEEE Ultrasonics symposium*. New York, USA. 1989; 643-646.