Multichannel Development for the "Air-Bubble Coating"

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Coating technology has been developed and applied in many fields for a long time. However, producing a discontinuous film pattern on a substrate is still not an easy task up to date. Different ideas and methods have been developed, including photolithography[1], stamping[2], screen printing[3] and so on. For these methods, precise mask, stamp and screen are needed, respectively. Moreover, they have to be made again when the pattern is changed to a new design, which increases processing time and manufacturing cost. Therefore, a simple and inexpensive method is still required. In recent years, developing a "maskless" patterning method becomes one of the most important issues in this field. There are several kinds of method have been brought out, for example, dip-pen nanolithography[4], ink-jet printing[5], and patch coating with mechanical stopper[6][7]. However, dip-pen nanolithography

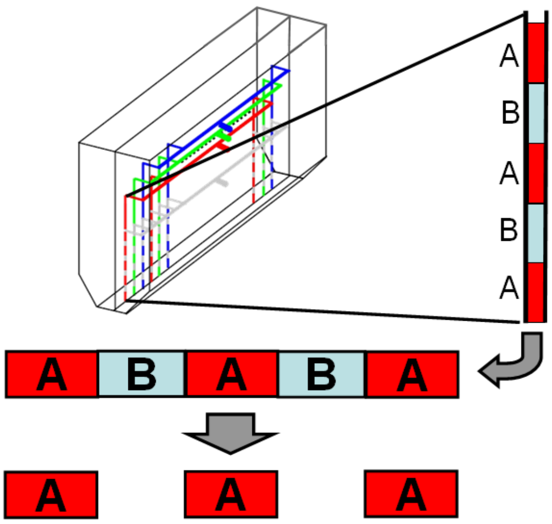

Figure 1 Schematic diagram of multichannel air-bubble coating for producing color filter. In each coating channel, the coating fluids are separated by air bubbles. During coating process, the fluids flow out of the channels sequentially and the air bubbles (B) are sacrificed to leave the liquid films (A) on the substrate.

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method has not been applied widely due to the low production rate and high maintenance cost. Contrarily, ink-jet printing becomes one of the key technologies recently. In the latter, several micrometer-monosized droplets can be produced through the ink jet nozzles and thousands of droplets can be arranged on the substrate to form patterns. Principally, it is easy to control and to change design patterns by using ink-jet printing method with flexibility, but low production rate, high maintenance cost, poor pattern uniformity and small range of workable fluid viscosity are still the major challenges. Patch coating methods combine precision wet coating methods with mechanical valves for cutting liquid films. Nevertheless, with the mechatronic methods, complex equipments and process are required to produce micro-size and high-precision patterns.

In the 14th ISCST symposium, the novel “maskless” patterning method, “air-bubble coating”, has been developed and conceptually demonstrated[8]. Micro-slug flow is used to be the upstream discontinuous coating source, shown in Figure 1, in which micro air bubbles (B) are inserted to separate the coating fluid segments (A). During the coating process, the two-phase segmented fluids flow out of the channels sequentially and the air bubbles (B) are sacrificed to leave the liquid films (A) on the substrate. Using this method, uniform patch films can be directly, speedily and repeatedly produced. However, the productivity of single-channel coating is relatively low. In this paper, for real application approach, a multichannel air-bubble coating device has been designed. The synchronized two-phase flow generator has been tested and demonstrated the synchronization ability.

In the literature, there are different ways to produce micro-slug flow. For instance, Garstecki et al.[9], and Cubaud and Ho[10] pump two immiscible fluids into a T-shape microchannel (or cross-shape channel) and the two immiscible flows will cut each other to continuously producing a slug flow. But the typically flow rate is on the order of tens microliters per minute, which is too low for industrial applications. Hence there are recently an increasing interest in parallelizing the generation of two-phase segment flow in large scales[11]-[14] for approaching the levels of practical applications.

The challenge in the scaled-up production is the flow coupling effect between each channels, which could affect the segment generation results due to different frequencies, broad size distribution, out-off-phase, and different patterns[11]. Barbier et al. have studied segment generation frequency and brought out a flow map to indicate the boundary between thesynchronized and non-synchronized frequency regions[12]. Li et al. reported droplet size control in a quadra-droplet generator, and the size variations have been reduced to less than

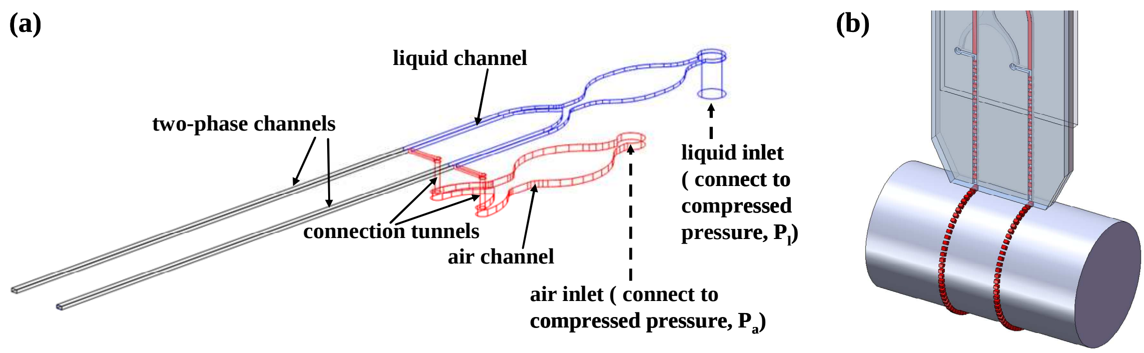

Figure 2 (a) Double side channel structure of the micro- fluidic device for dual channel two-phase flow generation. (b) Schematic diagram which demonstrates the device function of “simultaneous bubbles generation” and “synchronized bubble transportation” for multichannel air-bubble coating.

4% of droplet mean diameter[13]. Damean et al. monitored simultaneous reactions in four parallel droplet streams for reducing time, sample and reagent consumptions[14]. A ladder device was utilized by Prakash and Gershenfeld for synchronizing two bubbles, which were generated by active generators within parallel channels[15]. The large-scale synchronization method of producing plural pairs of bubbles in parallel channels still lacks.

In present work, a microfluidic device for simultaneous and synchronal bubble generation is developed (Figure 2a). The microchannels are fabricated on a double-side polished silicon wafer. The covers of the top and bottom sides are glass and polydimethysiloxane (PDMS), respectively. Two T-junctions are constructed in two parallel two-phase channels. Each two-phase channel is connected to an air and a liquid supplying channel. The air and liquid channels are located on opposite sides of the silicon wafer and connected by two junction holes. In the system, there are only two pressure regulators used to control the back pressure of two working fluids under certain selected pressure, P_l and P_a for liquid and air respectively. The working fluids, glycerol and air are compressed through the fluid inlets and distributed equally to the downstream channels and the two fluids meet together at T-junctions to generate microbubbles simultaneously and the bubbles transport downstream synchronally for further coating process(Figure 2b).

The operation results through flow visualization are shown in Figure 3. In the beginning of each generation period, the air-liquid interfaces locate at the T-junctions of the air and liquid channels (Figure 3a). After increasing the local pressure of the air channel, the interfaces overcome the flow resistance and the air columns of each channel enlarge simultaneously (Figure 3b-3d). Then the air columns are sheared by the liquid flow and broken up to disperse bubbles into the two-phase channels simultaneously (Figure 3e) and transported downstream synchronically (Figure 3f-3h).

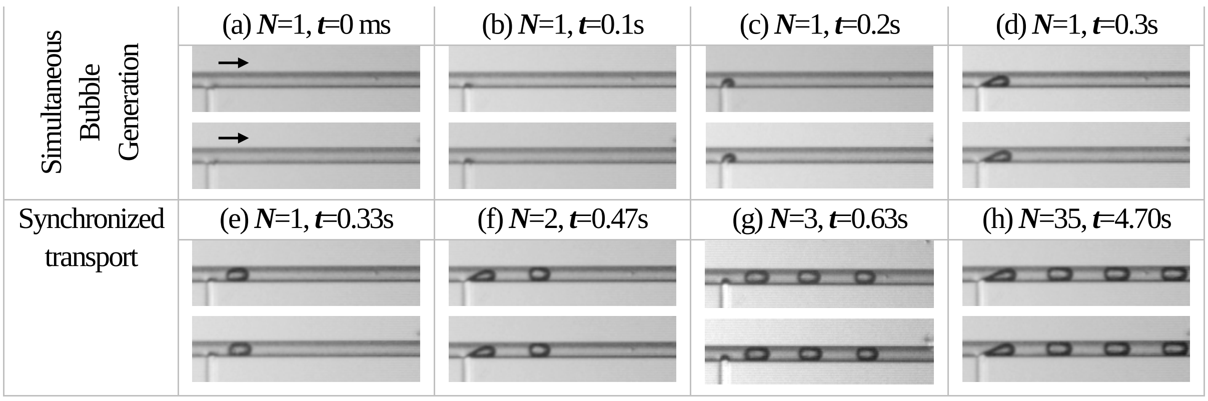

Figure 3 Flow visualization of the flow generation with two-phase segment in dual channels. ***N*** is the number of bubble generation period, and ***t*** is the time sequence for the air stream to flow into the main channel.

For coating application, the multichannel two-phase flow generator is built in the coating machine as a coating die. The synchronized two-phased fluids flow out of the channels to generate pairs of patch films. Figure 4 shows the front view of multichannel air-bubble coating sequential visualization images. During the coating process, the dual channel two-phase flow generator generates synchronized bubble stream into each channel to segment the coating fluid continuously. Meanwhile, the segmented coating fluid flow out of the channels to coat on the rolling roller (Figure 4a-4b) and then the liquid bridges are cut off by pairs of synchronized bubbles to leave pairs of liquid patches on the roller (Figure 4c-4d).

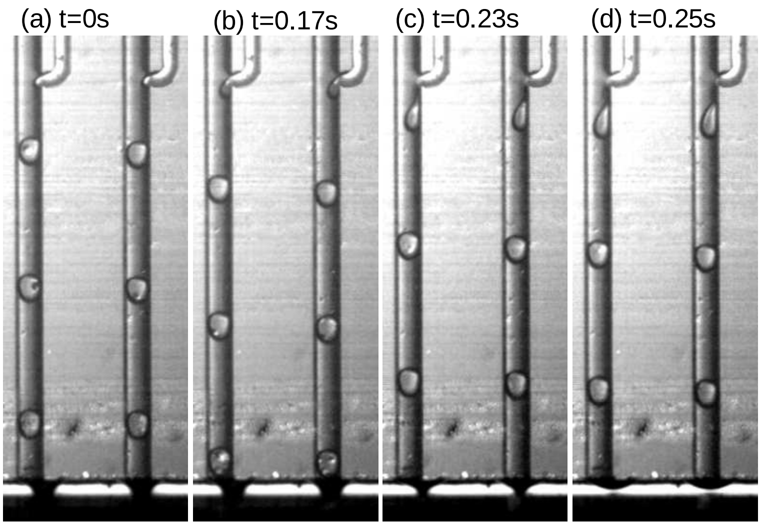

Figure 4 The sequential visualization pictures demonstrate the front view of multichannel air-bubble coating results. During the coating process, pairs of bubbles are generated to segment the coating fluid. Meanwhile, (a)-(b) the segmented coating fluid flow out of the channels to coat on the rolling roller and then (c)-(d) the liquid bridges are cut off by pairs of synchronized bubbles to leave pairs of liquid patches on the roller.

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