ACOUSTOFLUIDIC OPTICAL SWITCH

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ABSTRACT

Merging acoustofluidic mixing with optofluidic integration, we have developed a mechanism for optical switching in fiberoptic networks. The switching is achieved by changing the reflectivity of the sidewall of a microfluidic channel, via modification of the refractive index of fluids in the microchannel. To change the refractive index of fluids, two fluids are mixed by a microbubble mixer which was acoustically excited by a piezoelectric transducer. The device was found to have a switching speed of more than 5 Hz, an insertion loss of 6.02 dB, and extinction ratio of 28.48 dB. The low cost could lead to a line of inexpensive optical switches available at a fraction of the cost of a typical optical switch

KEYWORDS

Optofluidics, optical switch, oscillating microbubble

INTRODUCTION

In recent years, great effort has been devoted to the development of low-cost, disposable optofluidic switches for "low-end" optical switching and lab-on-a-chip applications based on flow rate [1,2] and pneumatic pressure [3,4]. In this work, we demonstrate an acoustofluidic-based optical switch that is affordable, easy to fabricate, and operate with less dependence on high flow rates and expensive external equipment.

EXPERIMENT

Figure 1 schematically shows the design of the acoustofluidic optical switch. This device was fabricated using standard soft lithography and included a single microchannel with two inlets and one outlet, pre-designed cavities on the sidewall of microchannel to trap bubbles for mixing, two channels for inserting and aligning the optical fibers and two air-PDMS lenses to collimate the light. A piezoelectric transducer, used to oscillate the sidewall-trapped microbubbles, was bonded using epoxy onto the glass slide, and the piezoelectric transducer was driven by a function generator. Two fluids, DI water (Q_1, n_1 = 1.333) and 4 M solution of $CaCl_2$ (Q_2, n_2 = 1.423) were injected at the fluid inputs.

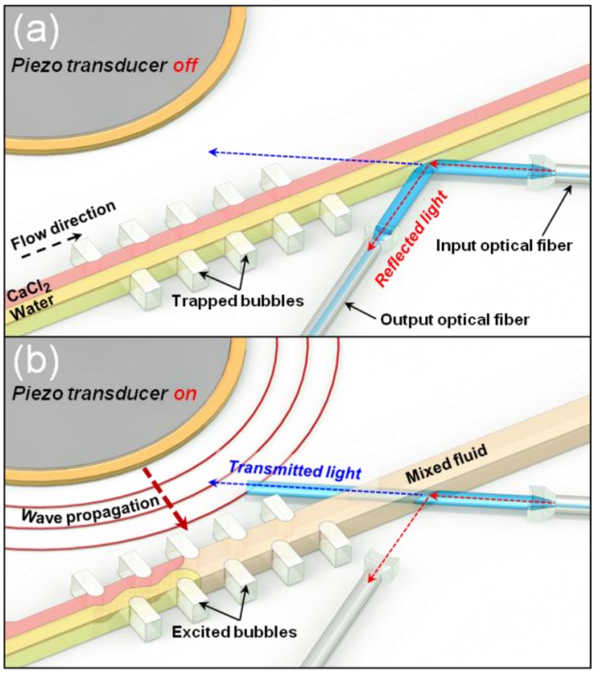

Figure 1: A schematic showing the design and working principle of the acoustofluidic optical switch.

When the piezoelectric transducer was inactive, the sidewall-trapped microbubbles neither oscillated nor mixed the two fluids. As a result, the majority of the incident laser beam was reflected and recorded by the output fiber, this condition is referred to as the switch "on" mode [Fig. 2(a)]. Once the piezoelectric transducer was activated, oscillating bubbles induced strong acoustic microstreaming which mixed the two fluids and decreased the reflectivity of the interface. Thus, most of the incident laser beam will pass through the microchannel, and only a small amount of beam will be reflected and recorded, referring to the switch "off" mode [Fig. 2(b)].

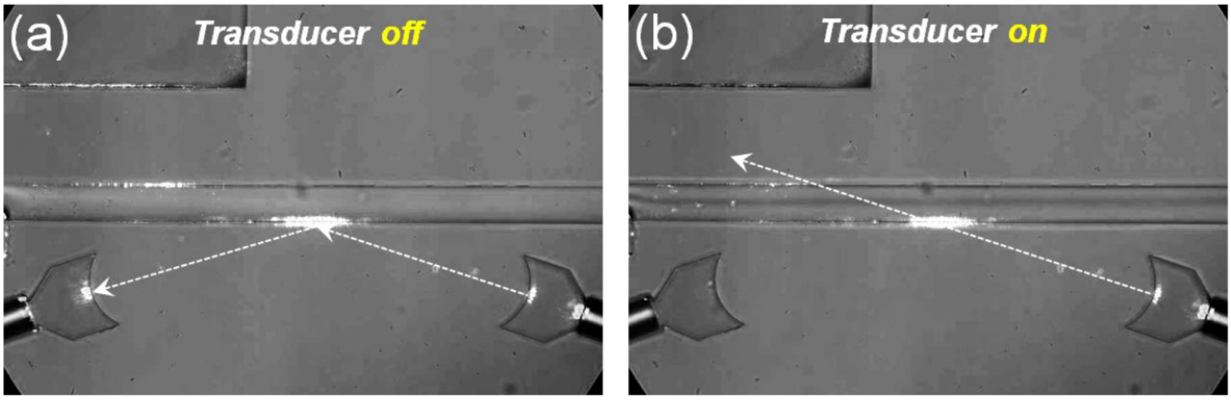

Figure 2: Experimental images of the optical switch. (a) The device without acoustic excitation. (b) The device under acoustic excitation. The dotted arrow represents the light path.

Figure 3 shows the normalized reflectivity waveforms from the photomultiplier tube (PMT), in which two standard references (blue and red curves) are shown with the signals, and the signals were normalized to these references. The standard reference for maximum reflection (blue curve) was produced by recording data while the channel was filled only with DI water (attenuation of 0 dB). The standard for minimum reflection (red curve) was produced by recording data while the channel was filled only with a 4 M solution of $CaCl_2$ (attenuation of –30 dB). When the device was operated under a proper different total flow rates ($Q_T = Q_1 + Q_2$) which was high enough to avoid premixing, the switching signal was very clear and strong and the reflectivity at the "on" mode almost exactly matches with the standard reference for maximum reflection. Once Q_T was high enough to avoid premixing, If Q_T was further increased, both the high and low parts of the signal were far from the standards.

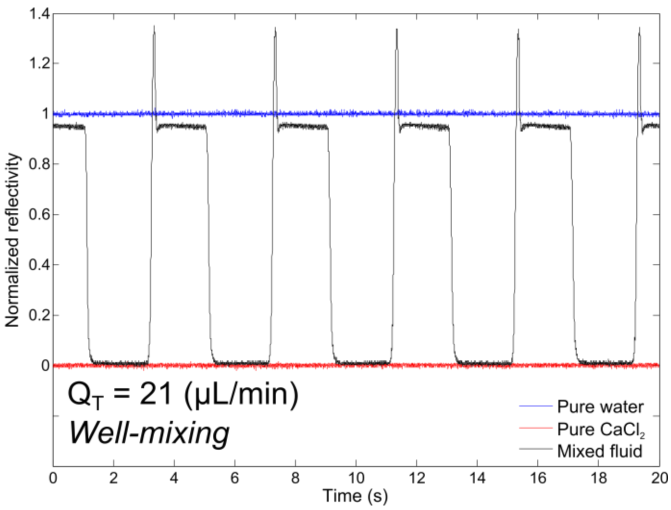

Figure 3: The normalized signal waveforms under Q_T = 21 μl/min ($Q_T = Q_1 + Q_2$).

Figure 4 displays several characterizes of interest (rising time, falling time, and extinction ratio) as a function of Q_T. As the Q_T of the mixed solution increased, the rising and falling time decreased, improving the switching speed; however, the extinction ratio was only acceptable over a range of flow rates. A working range between 15 and 30 μl/min of Q_T was defined for this device. The maximum extinction ratio of 28.48 was observed, yielding a switching time of ~200 ms corresponding to a 5.03 Hz of switching frequency.

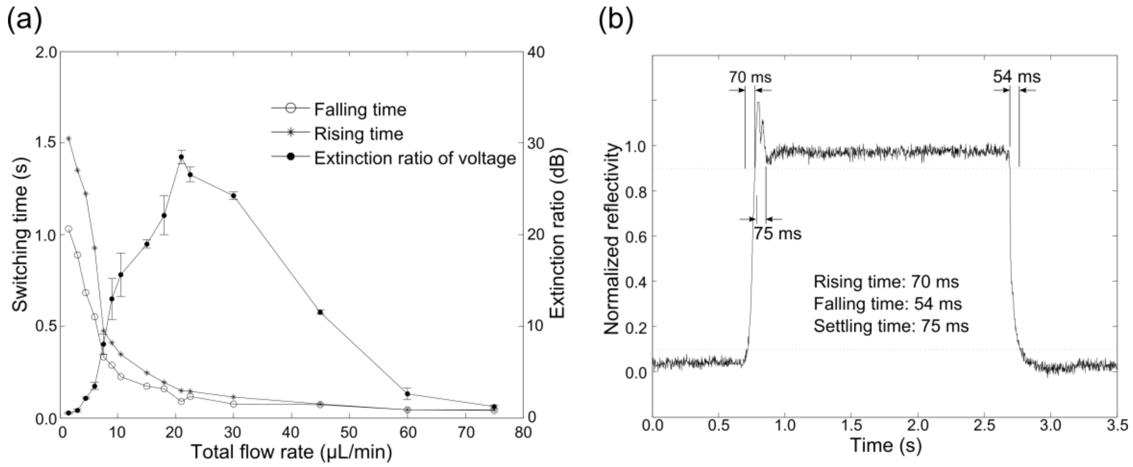

Figure 4: (a) Switching performance in response to total flow rate. (b) Analysis of the dynamic response of the device.

In conclusion, we fabricated and tested an acoustofluidic optical switch that operates by oscillating microbubbles to produce the microstreaming effects which mixed two fluids, thus altering the refractive index of a PDMS/fluid interface. This device offers low-cost fabrication, simple operation, high extinction ratios, and switching times comparable to other optofluidic switches.

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