A HIGHLY EFFICIENT BUBBLE TRAP FOR CONTINUOUS REMOVAL OF GAS BUBBLES FROM MICROFLUIDIC DEVICES

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ABSTRACT

We have fabricated a novel bubble trap based on polydimethylsiloxane (PDMS) featuring arrays of microposts with gradually decreasing but uniform sizes in the microfluidic chamber that could retain gas bubbles of various sizes up to 15 µL. Meanwhile, a vacuum chamber was constructed on top across a thin PDMS membrane to continuously remove the trapped bubbles when negative pressure is applied, due to the gas permeability of PDMS. The bubble trap showed high efficiency in preventing bubbles from passing through, and the bubble removal rate was dependent on the size of the bubble as well as the negative pressure applied.

KEYWORDS: Bubble trap, microposts, continuous removal, organs-on-a-chip

INTRODUCTION

The application of microfluidic technologies in biomedicine has greatly expedited the field through utilization of miniaturized devices for high-throughput screening. For example, the organs-on-a-chip platforms seek to recapitulate human organ functions at microscale by integrating microfluidic networks with three-dimensional tissue models, which are expected to provide robust and accurate predictions of drug/toxin effects in human bodies [1]. However, the complex microfluidic networks often introduce and/or generate gas bubbles with different sizes, which may affect the overall performance of the devices. Therefore, it is critical to enclose a trapping module into the microfludic system from which it can efficiently collect and remove gas bubbles [2]. To this end, we have developed a novel bubble trapping system that could efficiently retain and continuously remove gas bubbles generated in microfluidic devices.

EXPERIMENTAL

The bubble trap featured a 10-mm single-chamber containing posts with a series of uniform diameters of 1000, 500, and 250 µm (with spacing identical to post diameter), and a height of 200 µm, leading to a total chamber volume of approximately 20 µL (Fig. 1a). The aligned posts in the bubble trap are expected to prevent the bubbles from flowing downstream. We further added a vacuum chamber (depth: 100 µm) on top of the fluidic chamber. Fig. 1b shows a schematic of the device, where each vacuum chamber and the fluidic chamber are bonded *via* a thin PDMS membrane (20-µm thick), so that when vacuum is applied the bubbles entrapped in the fluidic chamber can be continuously eliminated due to the gas permeability of PDMS. SU-8 molds were fabricated by standard lithography techniques, and used for replicating PDMS blocks (SYLGARD® 184 Silicone Elastomer Kit, Dow Corning). The thin PDMS membrane was obtained by spin coating at a rate of 5000 rpm on the cap of a petri dish. PDMS pieces were then permanently bonded after air plasma treatment for 1 min, with the bonding further strengthened by heating at 80 °C in an oven for 1 h. Poly(methyl methacrylate) (PMMA) clamps were cut with a laser cutter (VLS 2.30 Desktop Laser System, Universal Laser Systems) and tightened together to sandwich the bubble trap with screw/bolt sets.

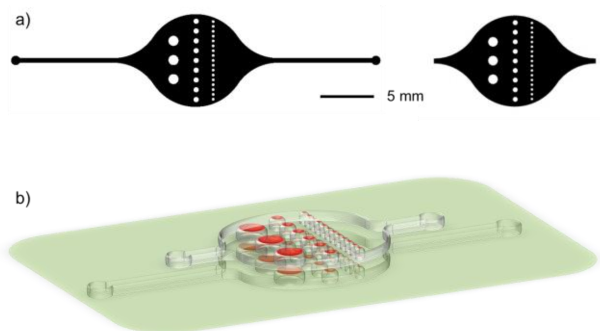

Figure 1: Design of bubble trapping system. a) Layouts of fluid chamber and vacuum chamber of the bubble trap. b) Schematic showing the assembly of the bubble trap.

RESULTS AND DISCUSSION

Photographs of the bubble trap are shown in Fig. 2a and 2b. The PDMS-based device was sandwiched in between a pair of PMMA clamps, so that when the vacuum is applied, only the entrapped air bubbles within the fluid chamber can be removed but not the atmospheric air from the other side. Negative pressure was realized simply by the utilization of syringes (Fig. 2c), or connection to vacuum lines to achieve long-term operation.

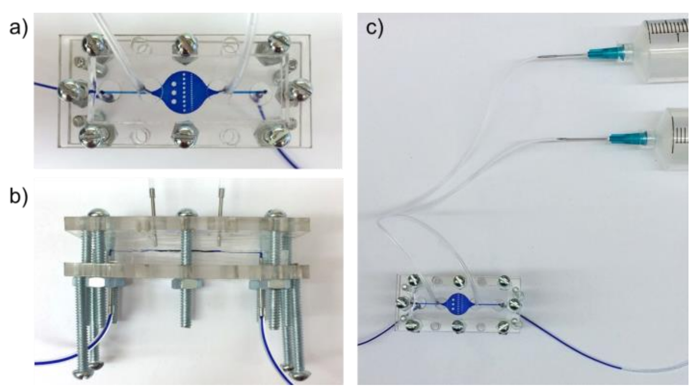

Figure 2: Photographs showing a, b) the bubble trap filled with an aqueous dye, and c) the application of negative pressure using two 60-mL syringes.

In a demonstration, one large air bubble with a volume of 10 μL was introduced into the bubble trap at a flow rate of 200 μL/h (Fig. 3). The bubble was effectively stopped by the posts and trapped in the fluidic chamber, which was then gradually removed through the PDMS membrane under the constant negative pressure from the vacuum chamber.

Bubble removal capability of the bubble traps was examined against different negative pressure applied (27, 22, and 19 psi). The bubble removal rate under each pressure followed an exponential decay over time, and the rate at each time point was proportional to the pressure.

We then recorded the flow rate of the fluid circulated in the tubing using a peristaltic pump (200 μL/h). The pulsatile movement of the pump generated a huge amount of bubbles with different sizes, shown as the pikes on the graph, when no bubble trap was present (Fig. 4a). In comparison, with the use of a bubble trap, the number of bubbles was significantly reduced (Fig. 4b).

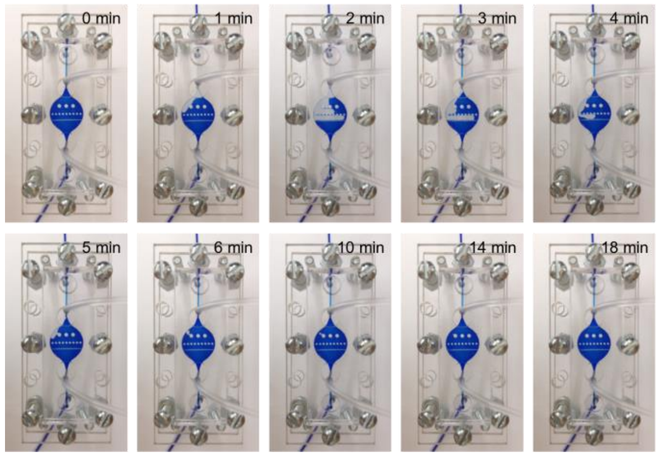

Figure 3: Photographs showing the introduction, stopping, and trapping of an air bubble with a volume of approximately 10 µL in the chamber, followed by the gradual removal of the bubble through the PDMS membrane under constant negative pressure applied in the vacuum chamber. The flow rate was 200 µL/h.

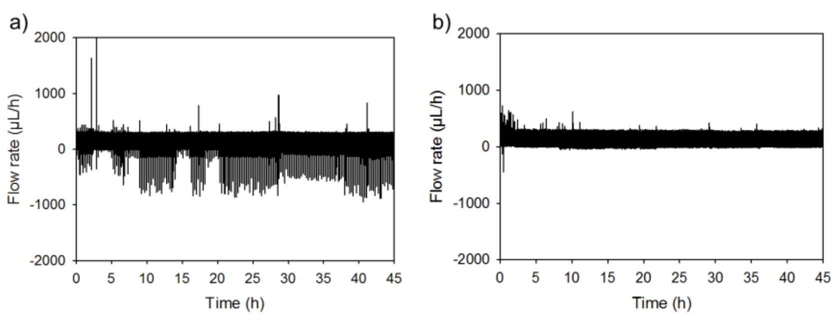

Figure 4: Flow rate data obtained from the fluid circulated in the tubing using a peristaltic pump at a flow rate of 200 µL/h: a) without a bubble trap and b) with an upstream bubble trap.

CONCLUSION

We have successfully fabricated a bubble trap based on arrayed microposts and a built-in vacuum chamber, which could efficiently retain bubbles and continuously remove them under negative pressure.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge funding by the Defense Threat Reduction Agency (DTRA). The content is solely the responsibility of the authors and does not necessarily represent the official views of the awarding agency.

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