A Microfluidic Device to Acquire Gaseous Samples Via Surface Tension Held Gas-Liquid Interface

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Abstract—We present a relatively simple and effective method for acquiring gaseous samples into microfluidic channels. Hydrophobic polymers are photopatterned on hydrophilic substrates. Due to surface tension, aqueous liquid is confined by the hydrophobic polymers, but not completely blocked by a physical wall, thus allowing an interface for gas-liquid interaction. Here, the mechanism is demonstrated by using hydrophobic (poly)iso-borynl acrylate polymer patterns on hydrophilic glass substrates, and through a Nessler’s reagent-ammonia reaction that exhibits changes in color and electrical resistance.

Index Terms—Gaseous sample acquisition, hydrophobic patterning, microfluidics, surface tension.

I. INTRODUCTION

RecenTlY, there has been an interest to realize systems which support gas-liquid interactions, especially in microfluidic environments [1], [2]. In addition to performing routine liquid manipulation, such systems can potentially be a part of chemical/biological sensors—for example, to acquire toxic bacterial spores by dissolving them in a liquid [3], or in the diagnosis of certain diseases—for example, by observing ammonia levels in air exhaled by the patient [2]. Capillary action [1] and surface chemistry [4] have been used previously, but require relatively complicated fabrication processes.

Here, we present a relatively simple technique to enable gas-liquid interactions in microfluidic devices using a gas-liquid interface held by surface tension. We demonstrate it using gaseous ammonia (NH$_3$) and aqueous Nessler’s reagent (NR) model. We chose this model since it is routinely used in ammonia detection, which finds application in disease diagnosis [2].

II. PRINCIPLE OF OPERATION

The principle of operation and structure of the microfluidic gas-liquid interaction system is shown in Fig. 1. Aqueous liquid is confined to the region between two hydrophobic polymer patterns on two hydrophobic glass substrates. Surface tension at the interface of the liquid and the polymer prevents the liquid from crossing this interface. Thus, a physical side wall is not required to confine the liquid, and the lateral area of the device is available for gas-liquid interaction.

The gas-liquid interaction is detected by monitoring the change in color and electrical resistance of NR (liquid) in the presence of ammonia (gas), by using indium tin oxide (ITO) coated glass substrates. The thickness of the air gap along with the pattern of the microchannel determines the surface area available for gas-liquid interaction.

III. FABRICATION

Liquid-phase photopolymerization (LP$^3$) [5] is used to fabricate the device. A 125 $\mu$m thick cavity is formed between a hydrophilic glass substrate and a film photomask. A prepolymer solution [5], [6] consisting of a monomer: isobornyl acrylate (IBA), crosslinker: tetraethylene glycol dimethacrylate, photoinitiator: 2,2-dimethoxy-2-phenylacetophenone is flowed into the cavity. Ultraviolet exposure cross-links the IBA monomer to form the hydrophobic polymer [p(IBA)] patterns. Next, the microfluidic channels are formed by aligning the polymer patterns on the two substrates, and an air gap is created by separating the substrates using 375-$\mu$m thick adhesive spacers (3M acrylic adhesive transfer tape, 468 MP). The electrically conductive ITO slides make direct contact with the liquid in the channel.

IV. EXPERIMENTS AND RESULTS

The contact angle of water was found to be 59° on ITO glass and 95° on p(IBA). The maximum pressure that can be sustained within the microfluidic channel is estimated by the Young–Laplace equation [7] to be $P = 100.5$ Nm$^{-2}$ with water as liquid. Based on this, the maximum possible flow rate is estimated to be 3.17 mL/min, using $P = f \times R$, $f$ = flow rate, $R$ = channel resistance.
NR solution is introduced into the microchannel and the device is exposed to NH₃ generated by evaporating NH₄OH (10% w/w) at room temperature. The solution is kept stagnant during experiments. The optical images and electrical resistance of NR are recorded concurrently. Fig. 2(a)–(d) shows optical images of NR in the microfluidic channel at different instants of time. Although the device is capable of interacting with gas on either side of the microfluidic channel, here, we infuse gas from only one side [arrows in Fig. 2(a)–(d)] and use the other side as a control interface (not exposed to gas).

NH₃ diffuses into the solution in the direction shown and causes a change in the color, as well as electrical resistance of NR. Fig. 2(e) is a 2-D profile plot of the grayscale values of NR in the microfluidic channel along the line X-X’ [Fig. 2(c)], and gives a quantitative representation of the progress of the reaction. Low grayscale values represent dark regions (reaction has occurred) and vice-versa. The quantity of NR that has reacted with NH₃ increases with time. The interface between the reacted NR (low grayscale value) and unreacted NR (high grayscale value) penetrates towards the unreacted NR. Fig. 3 shows a plot of the electrical resistance of NR as a function of time. The resistance drops by a factor of ~6 (from 21.9 MΩ to 3.6 MΩ) in the presence of NH₃ due to the formation of NH₄⁺ ions. The initial resistance is measured just before the introduction of NH₃, while the final resistance is measured after the color and resistance stabilize.

V. CONCLUSION

A relatively simple scheme to acquire gas samples into liquid is demonstrated. By calibrating the device using resistance-time plots, the concentration of NH₃ can be estimated. Automation could be achieved by integrating with other microfluidic components and microelectronics [6]. It can be used to collect aerosols into aqueous streams for downstream analysis, thus finding potential applications in medical diagnostics and detection of chemical and biological warfare agents.

ACKNOWLEDGMENT

The authors cordially thank Prof. D. J. Beebe, University of Wisconsin-Madison, and his research group for discussions and access to their facilities. They also acknowledge Dr. L. Dong, Prof. N. L. Abbott, and M. Frisk for technical discussions and assistance.

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