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-bornyl 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 hydrophilic 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 interaction with a gas.
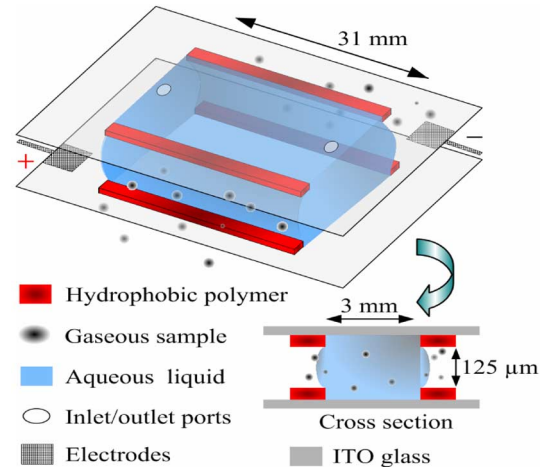
Fig. 1. Principle of operation. Hydrophobic polymers patterned on two hydrophilic glass substrates confine aqueous liquid by surface tension. A physical side wall is not required to confine the liquid which enables gas-liquid interaction on the lateral side of the device. Total area available for gas liquid interaction (without taking curvature into account) $= 8.6$ mm^2.

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 μm 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-μm 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 $=$ 109.5 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.
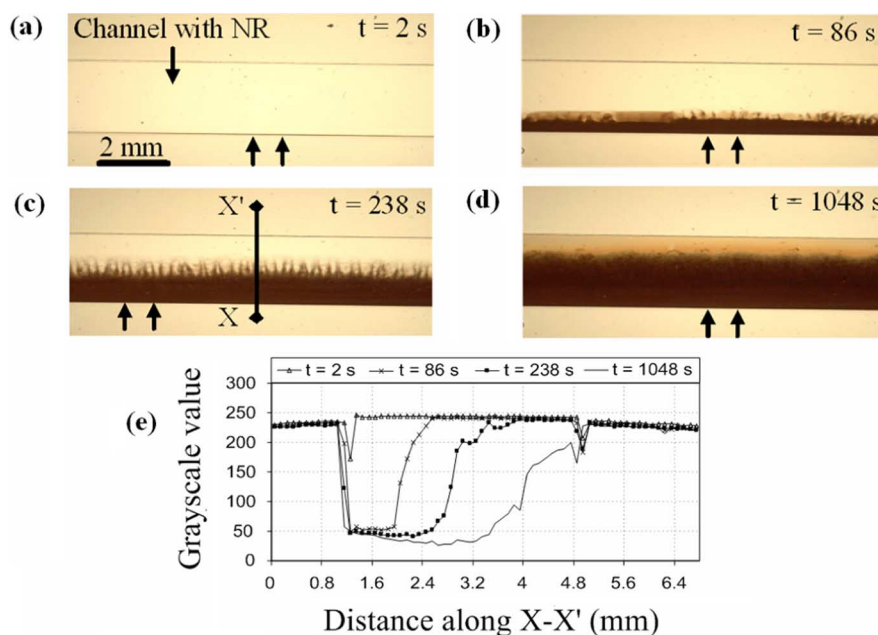
Fig. 2. (a)–(d) Optical response of NR to NH_3. Arrows indicate direction of entry of NH_3. (e) Gray scale plot of the color change along the X-X′ line. Low grayscale values indicate dark regions.
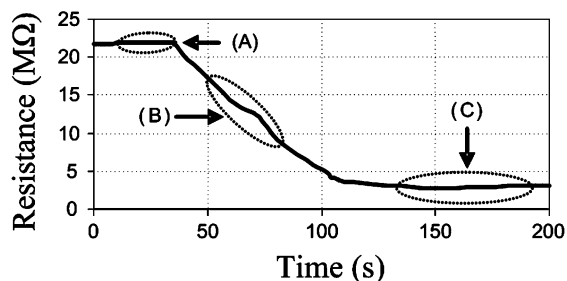

Fig. 3. Change in electrical resistance of NR in the microfluidic channel due to presence of NH_3. NH_4OH is introduced at $t = 0$ s. In (A), the reaction is yet to occur and the resistance is 21.9 MΩ. In (B), the resistance drops rapidly due to the reaction between NH_3 and NR. In (C), the resistance stabilizes at ~ 3.6 MΩ and the reaction is complete.

NR solution is introduced into the microchannel and the device is exposed to NH_3 generated by evaporating NH_4OH ($\sim 10\%$ 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).

NH_3 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 NH_3 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 NH_3 due to the formation of NH_4^+ ions. The ini-

tial resistance is measured just before the introduction of NH_3, 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 NH_3 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.

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