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DEVELOPMENT OF A MICROFLUIDIC GAS GENERATOR FROM AN EFFICIENT FILM-BASED MICROFABRICATION METHOD

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Recently, tape&film based microfabrication method has been studied for rapid prototyping of microfluidic devices due to its low cost and ease of fabrication [1]. But most of the reported film-based microfluidic devices are simple single-layer patterned 2D designs, whose potential applications are limited. In this paper, we present the design, fabrication and testing results of a 3D structured microfluidic gas generator prototype. This gas generator is used as an example to introduce our new approach of film-based fabrication method towards lab-use microfluidic research, which usually requires constant change of design and prefers low fabrication cost and short fabrication period. The prototype is a film-based comprehensive microfluidic gas generator which integrates self-circulation, self-regulation, catalytic reaction and gas/liquid separation. Time and economy efficiency are the biggest merit of this method. The only required facility during the whole process is a digital craft-cutter.

The working principle of the device is illustrated in Fig.1. The film-based prototype is an alternate version of a silicon-based self-circulating self-regulating gas generator developed by Zhu and Meng [2]. Fig.2 shows the schematic of the film-based prototype, it consists of 15 layers of films, tapes, glass slide, tubing connectors and cube supporting. As shown in Fig.3, the prototype device is obtained by sequentially aligning and stacking multiple layers of patterned polystyrene (PS) films (50 µm thick) (Goodfellow, Coraopolis, PA), polycarbonate (PC) films (125 µm) (McMaster, Chicago, IL) and double-sided kapton tape (70 µm) (Grainger, Lake Forest, IL). The patterns are obtained by a digital craft-cutter (CE5000-40-CRP, Graphtec, Santa Ana, CA) from CAD drawing. The complicated 3D structure is made from both the pattern and the thickness of the layer material, as shown in Fig.4. Besides, functional features can be easily added into the device, Pt-black is partially sprayed on the tape layer for catalytic reaction using a shadow mask, and nanoporous membrane is cut in desired shape and stack-placed in position as a gas/liquid separator. The self-circulating and self-regulating functions are achieved by surface energy difference of the channel interior as shown in Fig.4. This can be achieved by treating the surface of certain layer (PS) of the device into hydrophilic and leave the untreated film surface hydrophobic as it is the natural property of certain film. The treatment for PS film can be achieved by spraying Lotus Leaf® hydrophilic coating or using oxygen plasma machine [3], the treatment result is shown in Fig.5.

After gluing tubing connectors and cube supporting with epoxy, the prototype was fabricated. We tested the device with 3% H_2O_2 solution and successfully achieved O_2 generation rate of 0.024 SCCM (Fig.6) measured by a gas flow meter (FMA-2600A, Omega, Stamford, CT), and liquid pumping rate of 0.05 µl/s measured by monitoring the movement of a liquid/gas meniscus in the serpentine microchannel (Fig.7). The fluctuation of gas generation rate is due to the pulsative pumping of this self-pumping mechanism. It is expected that designs with multiple parallel channels can make the gas generation profile smooth due to the interactions among the channels.

We have completed a complex microfluidic gas generator with short fabrication period and low cost. This method can easily embed functional features such as hydrophilicity difference, gas/liquid separation, catalytic reaction (noted that high quality catalyst layer can be achieved by electroplating), etc. Besides, if material uniformity or high quality bonding is required, hot press bonding of PS films without tape can be considered [1]. In conclusion, this new method is capable of providing a fast and cheap approach for lab-use microfluidic researches in a variety of applications.

Word Count: 583

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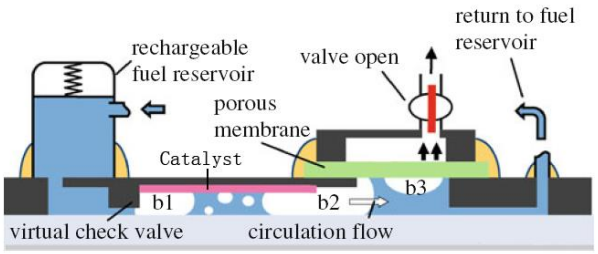

***Figure 1**: **Schematic of the device working principle**.* **[2]**
When reactant solution come into contact with the catalyst, the generated gas bubble (b1) will be pushed rightward due to the check valve, thus pushing everything in the reaction channel rightward. When the bubble (b2) reaches the hydrophobic porous membrane, it will be dragged rightward due to hydrophilicity difference and be vented out (b3) and collected. Therefore, self-circulation in the device is achieved and new reactant solution will be pumped into the reaction channel to react until the valve is closed which will cause a self-regulation.

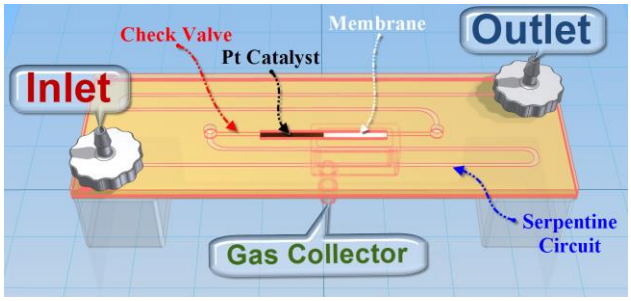

Figure 2. Schematic of film-based microfluidic gas generator.
The device is made by aligning and stacking multiple layers of patterned films and tapes, thus 3D structured channels are achieved. The serpentine circuit on the top layer is specially designed to visually measure the self pumping rate of this single-channel gas generator. Pt catalyst layer and hydrophobic nanoporous membrane are imbedded in the device as well.

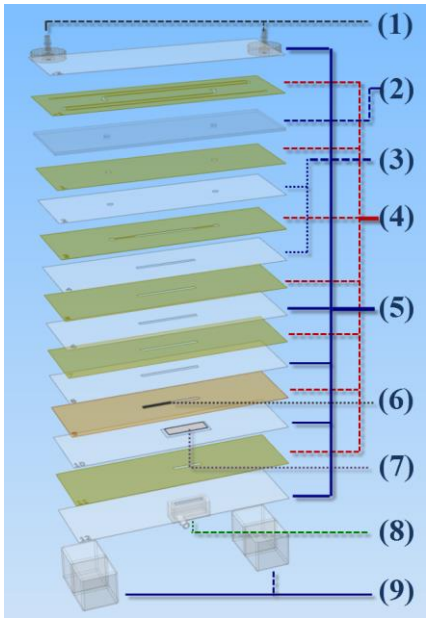

Figure 3. BOM view of the design.
(1)*Tubing connector for inlet and outlet.*
(2)*Glass slide with two drilled holes.*
(3)*PS film (50 μm).*
(4)*Double-sided tape (70 μm).*
(5)*PC film (125μm).*
(6)*Pt-black catalyst.*
(7)*Nanoporous hydrophobic membrane for gas/liquid separation.*
(8)*Gas collector.*
(9)*Tube supporting*

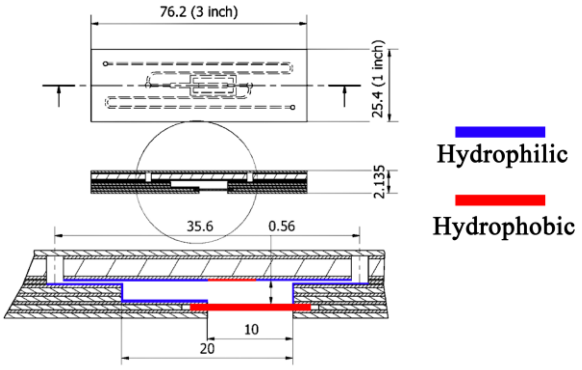

Figure 4. Sectional schematic of the device.
*The film-based device sits on a glass slide as rigid foundation. Overall dimension of the main body is 76.2*25.4*2.135 (mm). The interior of the reaction channel is specially treated to be partially hydrophilic and partially hydrophobic in order to achieve self-pumping.*

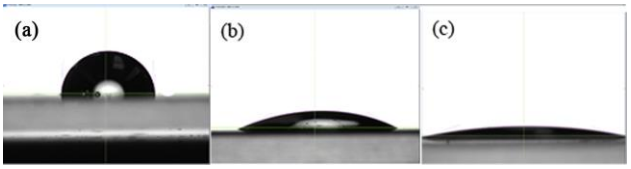

Figure 5. Hydrophilicity test on differently treated PS film.
Only PS film in the device has direct surface contact with reactant, thus it is specially treated to acquire different surface property.
(a) without treatment, contact angle=92 °
(b) PS film after oxygen plasma treatment, contact angel= 25 °
(c) PS film after hydrophilic coating, contact angle=17 °

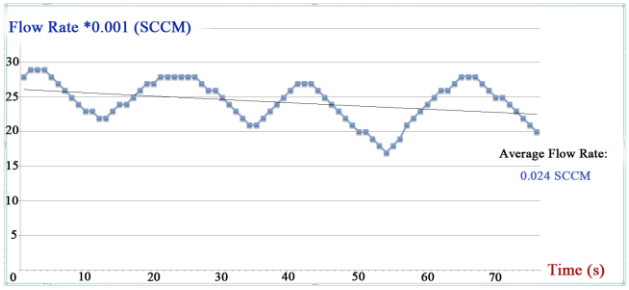

Figure 6. Gas (O_2) generation rate measurement by a flow meter. *The average flow rate in 75 seconds is recorded and calculated as 0.024 SCCM.*

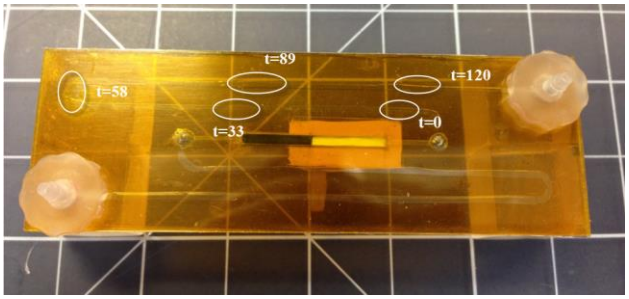

Figure 7. Self pumping rate measurement in the specially designed serpentine channel. *Using a video camera, a certain liquid/gas meniscus is observed during the reaction to have moved 100 mm in 120 s in the channel. Given that volume per length of the channel is 0.06 μl/mm, it is calculated that the pumping rate of the prototype is 0.05 μl/s.*