Research Article
SU-8 as Hydrophobic and Dielectric Thin Film in Electrowetting-on-Dielectric Based Microfluidics Device

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1. Introduction

Microfluidics is the technology of miniaturized analysis system for chemical and biological applications [1, 2]. Many microfluidic devices have been studied and developed to handle fluids on the microscale [3]. In these devices, numerous actuation methods [4] like electrowetting, electrohoresis, electroosmosis, and thermocapillary have been reported to manipulate fluids in microdomains. EWOD has drawn much attention as a promising microfluidic actuation mechanism in micro total analysis system. Electrowetting (EWOD) has as excellent reversibility and it possesses a number of advantages over continuous flow system such as the ability to control each droplet independently, minimize the usage of fluidics, and reduce the mixing time. EWOD-based microfluidics devices, are used to manipulate droplet for splitting, mixing, and transporting [4, 5]. Electrowetting system has advantage of low power consumption and fast operation. It has wide application not only in the Lab-on-chip system [6] but also in the display and liquid sensor [7, 8].

In 1875 Lippmann [9] had shown the electrocapillary action to modify the shape of liquid droplet placed on the surface by application of voltage. Significant research since Lippmann has focused on understanding and optimizing the droplet actuation and contact angle behaviour. The focus of research in EWOD is towards reduction of power consumption, use of different dielectric materials, and optimization of device dimension. Existing EWOD microfluidics flow microchannel normally has Teflon coat as a hydrophobic layer [5–10]. The cost of Teflon is very high and its breakdown voltage is low. It is therefore desirable to deposit another dielectric material which can endure high voltage in conjunction with Teflon. Microchannels with Teflon have shown very good hydrophobicity with contact angle 120° [10] and enabled microfluidic flow with
application of voltage in the order of tens of volts at dielectric thickness of 1 µm [2]. A major issue in microfluidics flow-based electrowetting is high voltage which may cause excessive heating and evaporation of fluids in transport. The lower of voltage requires reduction of Teflon thickness, but with thickness reduction of Teflon coat the possibility of breakdown occurs. To avoid such breakdowns, Teflon needs to combine with other dielectrics.

In the present work, actuation of fluid using EWOD is demonstrated in SU-8 channels of size 100 µm wide and 10 µm deep. The present design does not have Teflon coat on SU-8 layer. Moreover, in the present design the size of electrodes and gaps between electrodes is smaller than those reported in literature. Optimization of design in this work shows low applied voltage for fluid flow in bare SU-8 channel, that is, without Teflon coating. The advantage of using bare SU-8 in microchannel is lowering the cost because of reduction of process steps, ease and wide range of bonding for capping of channel, and biocompatibility even at temperature above 260°C (temperature above which Teflon decomposes) [11].

The present work is organized in three more sections. Section 2 gives design and simulation of the device and is followed by section of fabrication and testing of the device. The last section gives conclusions and future scope of present work.

2. Design and Simulation

EWOD-based microchannel has been designed in CoventorWare Mask module. The complete die has the dimension of 5.6 × 5.6 mm². Microchannel design consists of six electrodes over which hydrophobic layer of SU-8 is coated. The design details are given in Table 1.

<table>
<thead>
<tr>
<th>Die sizes</th>
<th>5.6 × 5.6 mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir size</td>
<td>1.5 × 1.5 mm²</td>
</tr>
<tr>
<td>Electrode size</td>
<td>1000 × 100 µm²</td>
</tr>
<tr>
<td>Channel width (W_c)</td>
<td>100 µm</td>
</tr>
<tr>
<td>Channel length (L_c)</td>
<td>1800 µm</td>
</tr>
<tr>
<td>Channel height (h)</td>
<td>10 µm</td>
</tr>
<tr>
<td>Number of electrodes</td>
<td>6</td>
</tr>
</tbody>
</table>

The SU-8 layer act as dielectric and solve the purpose of hydrophobic layer of SU-8 is coated. The design details are given in Table 1.

The SU-8 layer act as dielectric and solve the purpose of hydrophobic layer. The contact angle was measured in goniometer GBX DIGIDROP and was found to be 84 ± 3°. The contact angle was measured for 15 µL Droplet of DI water.

To verify the design, the modelling and simulation microfluidic flow have been carried out in CoventorWare. Liquid considered as DI water and the surface boundary conditions, solid volume, and fluid volume boundary condition used in simulation are shown in Figure 1. Electric potential at all electrodes was varied from 20 V to 150 V. The liquid showed no movement below 70 volts and changes to vapour phase above 90 V. Various combinations of shape, amplitude, and phase difference of pulse for actuation of fluid were applied and tested. An optimal trapezoidal pulse phased out on consecutive electrodes triggered droplet movement at 75 volts. The pulse specifications as applied in simulations are shown in Table 2.

### Table 2: Working voltage for combination of different dielectric in EWOD.

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Dielectric 1</th>
<th>Dielectric 2</th>
<th>Voltage</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Parlyene</td>
<td>Teflon</td>
<td>30–100 V</td>
<td>[2]</td>
</tr>
<tr>
<td>2</td>
<td>PECVD Oxide</td>
<td>Teflon</td>
<td>100 V</td>
<td>[12]</td>
</tr>
<tr>
<td>3</td>
<td>SiO₂</td>
<td>Cytop</td>
<td>85 Vac</td>
<td>[13]</td>
</tr>
<tr>
<td>4</td>
<td>Parlyene</td>
<td>Teflon</td>
<td>80 V</td>
<td>[14]</td>
</tr>
<tr>
<td>5</td>
<td>Parlyene</td>
<td>Teflon</td>
<td>110 Vrms</td>
<td>[15]</td>
</tr>
<tr>
<td>6</td>
<td>SiO₂</td>
<td>Teflon</td>
<td>25–100 V</td>
<td>[16]</td>
</tr>
<tr>
<td>7</td>
<td>SiO₂</td>
<td>Teflon</td>
<td>45 V</td>
<td>[17]</td>
</tr>
<tr>
<td>8</td>
<td>Parlyene</td>
<td>Teflon</td>
<td>80–150 V</td>
<td>[18]</td>
</tr>
<tr>
<td>9</td>
<td>SiO₂</td>
<td>Teflon</td>
<td>50–200 V</td>
<td>[19]</td>
</tr>
<tr>
<td>10</td>
<td>SU-8</td>
<td>—</td>
<td>70</td>
<td>Present design</td>
</tr>
</tbody>
</table>

3. Fabrication and Testing

Microchannels for EWOD actuation are fabricated using Si (100) substrate. A P type silicon wafer of 2 inch diameter and <100> orientation was used in the fabrication. The resistivity of the wafer was 1–10 ohms-cm. The major fabrication steps are shown in Figure 4. Prior to loading sample for thermal oxidation, the standard cleaning of wafers RCA1 and RCA2 was performed.

Sample was loaded for thermal oxidation at 1100°C with a flow of nitrogen at atmospheric pressure. Initially, dry oxidation was performed for 15 minutes to realize the better contact or interface. Next, the wet thermal oxidation was performed at 100°C for 3 hours. Finally, again dry oxidation was performed for 15 minutes. All the wafers were unloaded at 500°C in nitrogen flow. Oxide thickness of sample was measured using ellipsometer followed by surface profile verification. Thickness of SiO₂ layer has been found 495 ± 3 nm. The deposition of Cr/Au was carried out in e-beam evaporation unit in high vacuum. A 99.9999% pure Gold 2 cm wire is used for evaporation. During the Evaporation the vacuum chamber of the order of 1.7e-6 mbar was maintained. The estimated thickness of Cr/Au was 20/200 nm. The electrode having length of 1000 ×
100 µm was delineated using optical photolithography. The S1813 positive photoresist was used for patterning the metal electrode. The photoresist was spin on 3000 rpm for 30 sec followed by baking at 70°C for 15 minutes. After exposure and development, the unwanted metal was etched out in Electronics grade Cr/Au etchant. Refer to Figures 3(a) and 3(b).

SU-8 2000 series was used as insulating dielectric layer. SU-8 2000 is a high contrast epoxy-based photo resist designed for micromachining and other microelectronic applications, and it is used where a thick chemically and thermally stable pattern is desired. SU-8 2000 is an improved formulation of SU-8, which is widely used in MEMS for many years now. SU-8 resists have high functionality, high optical transparency, and are sensitive to UV radiation. SU-8 (2000.5) and SU-8 (2010) were used for fabrication of the microchannel. The SU-8 (2000.5) is used for thin film applications ≈ (0.5–1 µm) while SU-8 2010 is used for thick films ≈ (10–20 µm). The electrode arrays of gold and aluminium were fabricated over layer of SiO₂. (refer to Figures 3(a) and 3(b)). The major fabrication steps are shown in Figure 4. SU-8 is used as insulating dielectric layer. The thinnest available grade of SU-8 (MicroChem SU-8 2000.5) was deposited on electrodes by spin coating at 500 RPM for 5s followed by 3000 RPM for 30 s and then soft-baking on a hot plate at 70°C for 2 min and 90°C for 2 min. Following exposure for 17 sec, the device is postbaked at 70°C for 2 minutes and 90°C for 4 minutes. This is then developed in SU-8 developer for 30 s, rinsed with IPA and blow dried with nitrogen gas shown in Figure 4(c). Finally, the thick layer of SU-8 (MicroChem SU-8 2010) is subjected to photolithography for opening the channels with width of 100 µm. SU-8(2000.5) is not only used as dielectric layer but also used as hydrophobic Layer over the electrode.

Arrays of electrodes of different materials, namely, Gold, aluminium, and copper over silicon were examined for the microfluidics actuation with hydrophobic layer of bare SU-8. Water droplet, in the order of microliter of spherical shape over the surface, moves by changing contact angle on application of voltage in the range of 60–80 volts. The droplet movement was captured with optical microscope fitted with a digital camera and is shown in Figure 5. The net motion due to electrowetting was observed from initial placement with boundaries over first electrode (refer
Figure 2: Trapezoidal pulse details used in simulation for triggering smooth droplet movement.

Figure 3: (a) Gold electrode in SU-8 (2010), (b) aluminium electrode in SU-8 (2010).

Figure 4: Process flow of EWOD device.
to Figure 5 (a)). The final spread causing movement in droplet reached to the third electrode which corresponds to a movement of ∼300 µm. The change of contact angles resulting into spread of droplet in microchannel was observed when a voltage of 70 volts was applied with gold electrode. The applied voltage validates with simulated values mentioned in previous section.

No change or flow was observed when copper or aluminium was used as electrode even when the applied voltage was increased up to 220 volt. This may be attributed to higher resistivity of copper and aluminium leading to lesser strength of lines of electric field responsible for contact angle change of droplet. The exact reason needs to be further investigated.

The thickness of SU-8 was varied from 0.5 µm to 5 µm. The droplet movement was observed with gold electrodes only but required higher voltage (>100 V) and show pinholes in SU-8 below 0.5 µm thickness. The SEM graph of microchannel with gold electrodes embedded below SU-8 is shown in Figure 6.

4. Conclusions

The EWOD-based microfluidic flow with SU-8 as dielectric and as hydrophobic layer is designed, simulated, and fabricated using MEMS technology. The simulations were carried out in CoventorWare. The fabricated device is tested and the experimental results validate the simulation results. It has been shown that the device works well in comparable voltage range with those of Teflon coated microchannels. Teflon is costly and therefore present fabricated device suggests lowering of cost of EWOD-based microfluidic device by avoiding Teflon coating. The movement of the droplets in a controlled manner from the one electrode to another of the device is demonstrated.

The present work gives a low cost, robust, and biocompatible material in the form of SU-8 which can be used in devices with EWOD. The method of EWOD micropumping is very useful in transport of fluid digitally in Lab-on-a-chip kind of devices with metered quantity of fluid in microdomains. Currently, the authors are using the outcome of present work for development of Lab-on-a-chip device for testing for urinary tract infecting pathogens.

Acknowledgment

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References


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