The Movement of Micro Droplet with the Effects of Dielectric Layer and Hydrophobic Surface Treatment with R.F. Atmospheric Plasma in EWOD Structure

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Abstract. This study is about how to lower the driving voltage that enables to move the micro droplet by the EWOD (Electro Wetting On Dielectric) mechanism. EWOD is well known that it is used μ-TAS digital micro fluidics system. As voltages are applied to the device which is fabricated with dielectric layer between electrode and micro droplet, the hydrophobic surface is changed into the hydrophilic surface by its electrical property. EWOD induces the movement of micro droplet with reducing contact angle of micro droplet. Because the driving voltage depends on the dielectric constant of dielectric layer, it can be reduced by increase of dielectric constant. Typically, driving voltage of these devices was 30V~100V and Teflon film was coated to provide hydrophobic surface. This high voltage induces many problems. In previous study, we used Ta₂O₅ as the dielectric layer and driving voltage was 23V that reduced 24 percent compared with SiO₂. In this study, we used BZN (Bi₂O₃-ZnO-Nb₂O₅) layer which had high dielectric constant. It operated the just on 12V. And micro droplet was moved within 1s on 14V. It reduced the voltage until 35 percents compared with Ta₂O₅ and 50 percents compared with SiO₂. The movement of micro droplet within 1s was achieved with BZN (ferroelectrics) just on 14V. Teflon film which is coated to provide hydrophobic surface is a very difficult to control accurate concentration, and unnecessary processes which uses metal as a protect layer in patterning should be added. So instead of Teflon coating, surface was treated to hydrophobic with R.F. atmospheric plasma.

1. Introduction

In recent years, μ-TAS (Micro Total Analysis System) have been much investigated, because it consist of a system, which is movement, reaction, separation and analysis of sample, in just one chip [1-3]. In these systems, the control of micro droplets using the principle of electro wetting is very important to move the sample from the reservoir to reaction zone and outlet.

So, much attention has been concentrated on the control of micro droplets that can change the contact angle of micro droplets as electric potential applied to the electrode [3-5]. Fig. 1 showed the
movement of micro droplet by contact angle reduction in EWOD (Electro Wetting On Dielectric) structure. In previous reports, electro wetting requires high driving voltage more than 100V [6]. To lower the driving voltage, wetting was performed with the surrounding silicone-oil or electrolyte. However, micro droplet was contaminated [7]. On the other hands, EWOD was operated in air and covered with a thin dielectric layer [3]. EWOD is a mechanism that can change the contact angle of a micro droplet on dielectric layer using electric potential. SiO₂ and Fluoropolymer have been used as the dielectric layers. The driving voltage in this case was also required more than 30V.

According to Lippmann-Young’s equation, the driving voltage was inversely proportional to a dielectric constant of dielectric layer. Therefore, the driving voltage can be reduced by increasing the dielectric constant. If the dielectric layer has bigger dielectric constant than that of SiO₂ is used, the micro droplet can be moved under less than 30V. In previous study [9], we used Ta₂O₅ as the dielectric layer and driving voltage was 23V that reduced 24 percent compared with SiO₂. In this study, we used BZN (Bi₂O₃-ZnO-Nb₂O₅) as the dielectric layer and compared with SiO₂, Si₃N₄, and Ta₂O₅.

Also, Teflon was very difficult to control accurate concentration, and unnecessary processes which uses metal as a protect layer in patterning should be added. So surface was treated to hydrophobic with R.F. atmospheric plasma and then compared with Teflon coating surface.

![Fig. 1: The movement of micro droplet by contact angle reduction in EWOD structure](image)

2. EWOD(Electro Wetting On Dielectric)

2.1. Dielectric Constant

EWOD is well-known as it is used m-TAS digital micro fluidics system. As voltages are applied to the device which is fabricated with dielectric layer between electrode and micro droplet, the hydrophobic surface is changed into the hydrophilic surface by its electrical property. Therefore, EWOD induces the movement of micro droplet with reducing contact angle of micro droplet.

Equation (1) is Lippmann-Young’s equation, which shows the relationship between electric potential (V) and dielectric constant (ε). The driving voltage (V) depends on the dielectric constant (ε) of dielectric layer, so it can be reduced by increase of dielectric constant.

\[
\cos \theta - \cos \theta_0 = \frac{\varepsilon_0 e V^2}{2d \gamma_{LG}}
\]

\(\cos \theta \): Contact angle non applied voltage
\(\cos \theta_0 \): Contact angle applied voltage
\(\varepsilon_0 \): Dielectric constant in vacuum
\(\varepsilon \): Dielectric constant of layer
\(d \): Thickness of dielectric layer
\(\gamma_{LG} \): Liquid-Gas surface tension
2.2. BZN (Bismuth Zinc Niobate)

It is necessary to have a high-k dielectric layer to reduce the driving voltage in EWOD structure. According to Lippmann-Young’s equation, the driving voltage is proportional to thickness of dielectric layer. Ferroelectric BST (Ba,Sr)TiO₃ has been widely researched because it has very high dielectric constant of 200–600. But it is difficult to control the composition and has dielectric loss in thin film deposition [10-11]. It has many problems in EWOD. On the other hands, non-ferroelectric BZN (Bi₂O₃-ZnO-Nb₂O₅) has low dielectric loss. BZN is crystallized at 600°C ~ 800°C, and annealed BZN at 700°C [12] has low loss as shown Fig. 2.

![Fig. 2: Dielectric constant and loss tangent of BZN films annealed at different temperatures as a function of O₂/Ar ratio [12]. The dielectric constant of BZN was higher than 600°C and 800°C in 700°C annealing process](image)

3. Experiment

3.1. EWOD Structure

All movements of micro droplet were confined between two parallel electrode plates. The top electrode was fabricated with IZO on the glass plate and bottom electrode was Pt, which was fabricated under dielectric layer to make the EWOD structure. SiO₂ and Si₃N₄ were deposited by PECVD and, Ta₂O₅ and BZN were deposited by R.F. sputtering as dielectric layer with similar thickness respectively. Both of the top electrode and the dielectric layer, which were contacted with micro droplet, were treated with plasma or coated 400Å of Teflon film to provide hydrophobic surface. The THB 430 of 60 μm were patterned as spacers to maintain the space between top electrode and bottom electrode.
3.2. BZN

In previous study, we confirmed the relation of dielectric constant and driving voltage when SiO$_2$ and Si$_3$N$_4$ were used as dielectric layer. In this study, Ta$_2$O$_5$ and Bi$_2$O$_3$-ZnO-Nb$_2$O$_5$ (BZN) were used to confirm the driving voltage. Non-ferroelectric BZN has dielectric constant of ferroelectric material level. 700ºC crystallization annealing can reduce the dielectric loss compared with ferroelectric materials.

3.3. Hydrophobic surface treatment with R.F. atmospheric plasma

Instead of Teflon coating, surface was treated to hydrophobic with R.F. atmospheric plasma, as shown Fig. 3. Both of the top electrode and the dielectric layer, which were contacted with micro droplet, were treated with R.F. atmospheric plasma to provide hydrophobic surface. Argon (Ar) was used as a carrier gas and Methane (CH$_4$) was used as reactive gas. It didn’t consume toxic gas nor generate any chemical liquid wastes [13] and the process of hydrophobic surface coating became very simple.

![Fig. 3: R.F. Atmospheric Plasma](image)

4. Results

The voltage which started the movement of micro droplet were 12V (BZN), 15V (Ta$_2$O$_5$), 17V (Si$_3$N$_4$), and 21V (SiO$_2$). The driving voltages on which moves micro droplet within 1sec were 14V (BZN), 23V (Ta$_2$O$_5$), 24V (Si$_3$N$_4$), and 30V (SiO$_2$) respectively. BZN, which had the biggest dielectric constant of four dielectric layers, was operated under lower voltage than others, as shown Fig. 4. It was confirmed that this result corresponded to Lippmann-Young’s equation which means driving voltage can be lowered by a higher dielectric constant of a dielectric layer.

| Table.1 Dielectric Constants (thickness 1000 Å) and Driving Voltages |
|-----------------------------------------------|
| SiO$_2$ | Si$_3$N$_4$ | Ta$_2$O$_5$ | BZN |
| Driving Voltage | 30 | 24 | 23 | 14 |
| Dielectric Constant | 2.3 | 7.8 | 8.5 | 12 |
Fig. 4: Required time for complete movement versus applied voltage. BZN, which had the biggest dielectric constant among four dielectric layers, was operated under lower voltage than others.

And R.F. atmospheric plasma treatment for hydrophobic surface had similar contact angle with Teflon. But micro droplet didn’t move continuously on the surface, because it had not good reversibility (from hydrophobic to hydrophilic or from hydrophilic to hydrophobic). So the future work will be the solution of these problems.

5. Conclusion

The micro droplet was moved just on 12V, and the fast movement within 1sec was achieved just on 14V with BZN dielectric layer. This driving voltage was reduced 50 percent compared with SiO₂. It is possible that the digital micro fluidic system is materialized on low driving voltage.

Fig. 5: The movement of micro droplet, which followed the electrodes.

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