REVERSIBLE LOW VOLTAGE ELECTROWETTING WITH SiO_2 CAPILLARY WINDOW FOR OPTICAL IMAGING

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ABSTRACT

This work reports the reversible low voltage electrowetting and liquid oscillation with SiO_2 capillary window for optical imaging. The optical window with and without Grycerol liquid penetration into SiO_2 capillaries has been demonstrated. The reversible electrowetting phenomenon has been achieved with low voltage supply of 8 V. The controlled liquid oscillation by pulse source has been observed. Additionally, the predicting response of switching speed between two states with and without liquid penetration into capillaries has been investigated by a fluidic numerical simulation.

INTRODUCTION

Image-sensing applications have been the focus of attention recently [1-4] for the support for safety and assurance, detection of moving objects and pedestrian, fields of security, medicine, and computer graphics, etc.

To capture light field information, a camera system that uses arrays of electronic photo-detectors (image sensor) have been employed. A microlens array is used to focus and placed in front of the sensor [5-6]. However, there is the trade-off in angle and spatial resolution when using microlens arrays [7]. In such situations, devices capable of the integration of the image sensor for the high resolution light field information are still urgent requirements for functional image sensing applications.

Electrowetting can be studied for many applications [8-12] such as electronic display, energy harvesting and adjustable lenses, etc. Generally, the electrowetting is performed on a dielectric film (EWOD). When a voltage is applied between a liquid droplet and counter electrode, the contact angle of liquid-solid surface is changed. The merit of EWOD is ability to electrically manipulate liquid droplets without movable mechanical parts. It exhibits, therefore, low power consumption. However, a high voltage supply and low switching speed still face problems for its applications. Electrowetting on liquid-infused film (EWOLF) have been presented recently in [5] for fast optical imaging. Nevertheless, the EWOLF still require a very high voltage of 500 V. Most published works regarded to the electrowetting reversibility and liquid oscillation are just demonstrated by liquid droplets.

In this work, the optical window with capillary structures with and without liquid penetration is demonstrated as an optical modulator device. The reversible electrowetting and liquid oscillation by using the SiO_2 capillary window is presented.

OPTICAL MODOLATOR DEVICE

Device structure and working principle

Device structure basically consists of the SiO_2 capillary window, aluminum-doped ZnO (AZO) films as electrodes, Cytop as hydrophobic layer and Grycerol liquid, etc. (Fig. 1).

Without voltage supply to electrodes, the Grycerol liquid is kept in the liquid reservoir due to the hydrophobic surface of Cytop (Asahi glass Co., Ltd., Japan). The light transmission is low due to the light reflection or scattering by capillary sidewalls. With voltage supply, the liquid penetrates into capillary and the light transmission is high because of an eliminated light reflection and scattering.

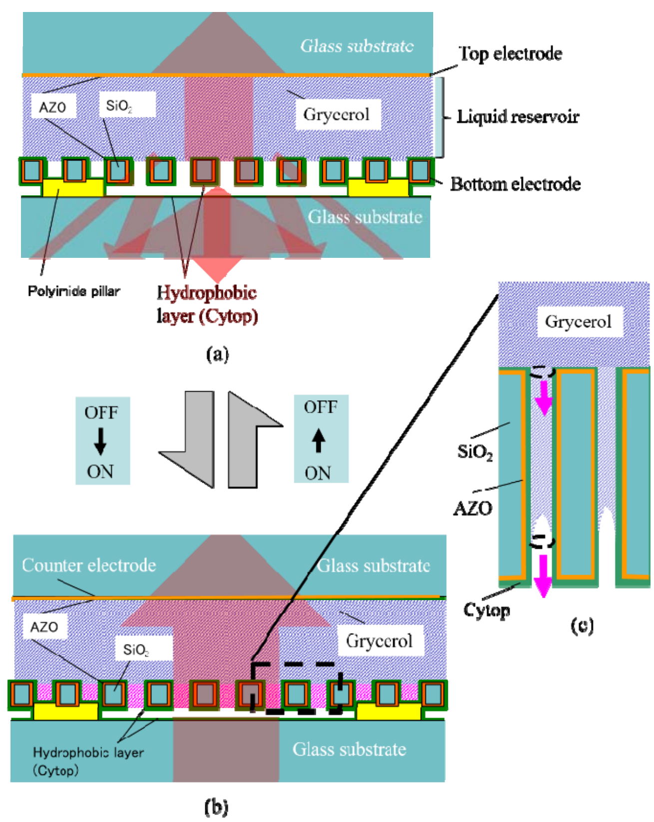

Figure. 1. Device structure. (a) Low optical transmission state. (b) High optical transmission state. (c) Liquid penetration state.

Fluidic numerical simulation

The liquid dynamic in single capillary has been studied by fluidic numerical simulation. Figure 2 illustrates the geometry of single capillary with a diameter and length of 1 μm and 10 μm, respectively. A liquid reservoir is set on the top on the capillary. The simulation result shows that the switching speed of liquid is 10 μsec (Fig. 2). Thus, a fast response can be expected.

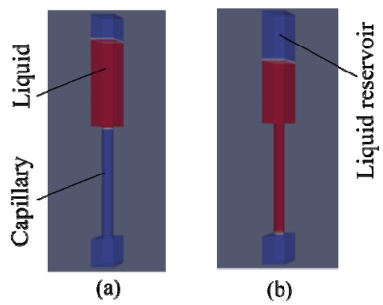

Figure 2. Dynamics in single capillary. (a) Static state. (b) Dynamic state.

EXPERIMENTS AND DISCUSSIONS

Fabrication process

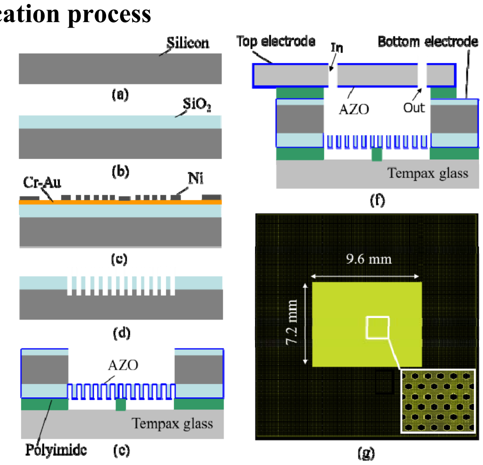

Figure. 3. Fabrication process. (a) Silicon wafer. (b) Thick SiO_2 deposition. (c) Ni electroplating. (d) RIE. (d) Transferring process. (f) Bonding with liquid reservoir. (g). Layout of SiO_2 patterning.

The details of the fabrication process are shown in Fig. 3. It starts with a n-type silicon wafer with a thickness of 300 μm (Fig. 3 (a)). After cleaning, a 15 μm-thick SiO_2 layer is deposited by plasma enhanced chemical vapor deposition (PECVD) using TEOS (TetraEthOxySilane $Si(OC_2H_5)_4$) (Fig. 3 (b)). Next, Cr and Au layers with thicknesses of 10 nm and 100 nm, respectively, are deposited on above wafer by sputtering. A 3 μm-thick positive photoresist is coated on the Au surface of the wafer and patterned via conventional lithography process. A 1 μm-thick pure nickel film is formed via photoresist patterns by electroplating using a direct current (Fig. 3 (c)). The photoresist is then removed by acetone. The thick SiO_2 layer is etched out by the reactive ion etching (RIE) process using a mixture of SF_6 and O_2 gases. The electroplated nickel and Cr-Au layers are then removed by wet chemical etching (Fig. 3 (d)).

Transferring process is proposed to enhance the mechanical strength of the optical window with a large size of the membrane (7.2 mm x 9.6 mm). A 300 μm-thick Tempax glass with 10 μm-height polyimide pillar structures has been prepared for this process. The silicon wafer with SiO_2 structures and Tempax glass are bonded together at 350ºC for 30 min. The back side silicon wafer is then patterned by deep RIE until exposing SiO_2 and AZO structures (Fig. 3 (e)). AZO membranes on capillaries is etched out by ion beam milling. The 1 μm-thick Cytop is deposited on the wafer by dip-coating. This wafer is then sealed (Fig. 3 (f)). Finally, the Grycerol liquid is inserted through in/outlet holes. Figure 3 (g) shows the top view of the optical window.

Fabricated results

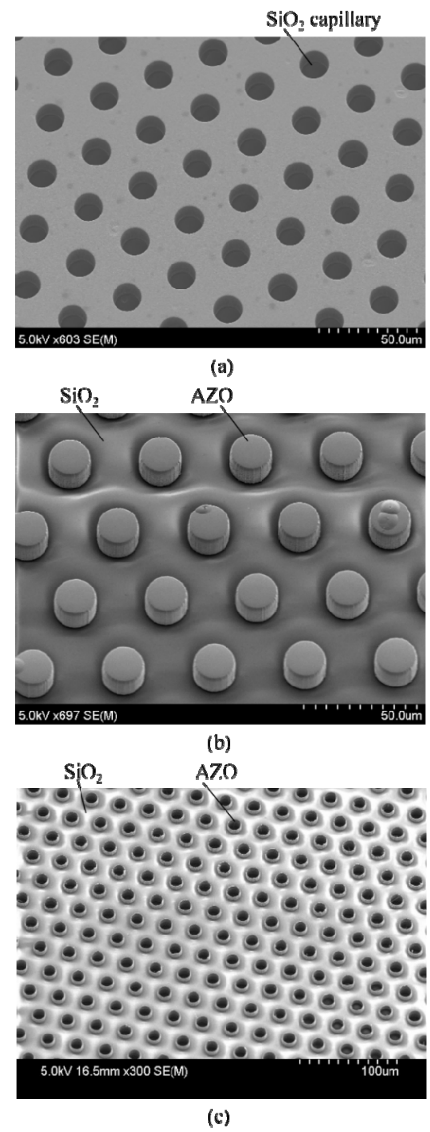

Figure. 4. Fabricated results. (a) SiO_2 capillaries after RIE. (b) After backside deep RIE. (c) After ion beam milling.

The fabricated results are shown in Fig. 4. 15 µm-thick SiO_2 capillary structures have been successfully etched with smooth etched surfaces, and vertical shapes (Fig. 4 (a)). Figure 4 (b) shows the SiO_2 layer and AZO structures after back side deep RIE of silicon wafer. The capillary structures are exposed after etching AZO membranes, as shown in Fig. 4 (c).

Evaluation setup

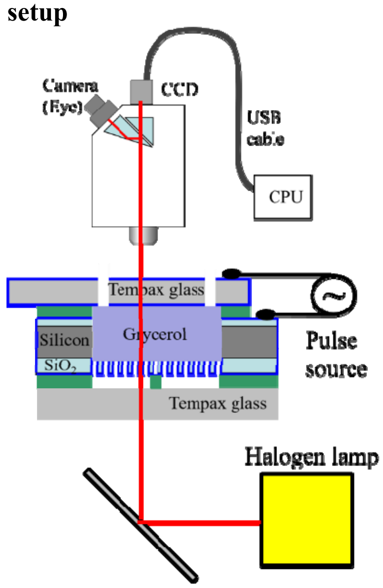

Figure 5. Evaluation setup.

Evaluation Result

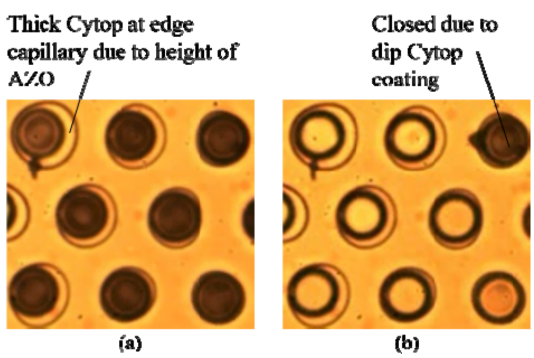

Figure 6. Optical image. (a) Without voltage supply. (b) With voltage supply.

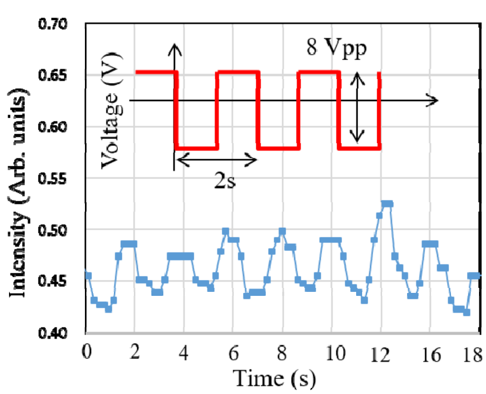

Figure 7. Controlled liquid oscillation

Evaluation setup is shown in Fig. 5. A charge-coupled device (CCD) detector and halogen lamp are employed. Top and bottom electrodes of the fabricated device are connected to the pulse source. With 8 V supply to the electrodes, the capillary areas become clear due to the liquid penetration into capillaries which reduce the light reflection or scattering at capillary sidewalls (Fig. 6). In order to demonstrate for the liquid oscillation, the pulse voltages have been applied with a cycle of 2 sec. The liquid oscillation has been observed from the light intensity change, as shown in Fig. 7.

CONCLUSION

The reversible low voltage electrowetting and controlled liquid oscillation with SiO_2 capillary window have been successfully demonstrated. The predicting response of switching speed for the liquid penetration into the capillaries has been investigated by a fluidic numerical simulation. We believe that optimum versions of this device is one of promising options for optical focusing with low voltage supply and fast response which can replace microlens array in the current digital cameras.

ACKNOWLEDGEMENTS

Part of this work was performed in the Micro/Nanomachining Research Education Center (MNC), and the Micro System Integration Center (µSIC) of Tohoku University. This work was supported in part by a Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Culture, Sports, Science and Technology of Japan, also supported by Special Coordination Funds for Promoting Science and Technology, Formation of Innovation Center for Fusion of Advanced Technologies.

REFERENCES

[1] G.D. Antoio, L.P. Jose, N. Manuel, P. Antonio, R. Santiago and O. Luis, "Locating moving object in car-driving sequences", *J. Image and video processing*, 24, 1-23, 2014.

[2] F. Liang, S.Tang, Y. Zhang, Z. Xu and J. Li, "Pedestrian detection based on sparse coding and transfer learning", *J. Machine Vision and applications*, 25, 1697-1709, 2014.

[3] H. Karaoguz, O. Erkent and H. I. Bozma, "RGB-D based place representation in topological maps", *J. Machine Vision and applications*, 25, 1913-1927, 2014.

[4] J. Han, D. Wang, L. Shao, X. Qian, G. Cheng and J. Han, "Image visual attention computation and application via the learning of object attributes", *J. Machine Vision and applications*, 25, 1671-1683, 2014.

[5] Ng. Ren, L. Marc, B. Mathieu, D. Gene, H. Mark, H. Pat, D. Duval, "Light field photography with a hand held plenoptic camera", *Stanford Tech Report CTSR* 2005-2.

[6] Ph. Nussbaum, R. Volkel, M. Eisner and S. Haselbeck, “Design, fabrication and testing of microlens arrays for sensors and microsystems“, *Pure and applied optics: Journal of the European optical society part A*, 6, 617-636, 1997.

[7] A. Levin, R. Fergus, F. Durand and W.T. Freeman, “Image and depth from a conventional camera with a coded aperture”, *ACM Transaction on Graphics*, 26, 701-709, 2007.

[8] S. Arscott, “Electrowetting and semiconductors”, *RSC Advances*, 4, 29223, 2014.

[9] L. Chen, E. Bonaccurso, “Electrowetting – from statics to dynamics”, *Adv. Colloid Interface Sc.,* 210, 2-12, 2014.

[10] S.K. Cho, H. Moon, C.J. Kim, “Creating, transporting, cutting and merging liquid droplets by electrowetting based actuation for digital microfluidic circuits”, *Journal of microelectromechanical systems*, 12, 70-80, 2003.

[11] R.A. Hayes, B.J. Feenstra, “Video speed electronic paper based on electrowetting”, *Nature*, 425, 383-385, 2003.

[12] C. Hao, Y. Liu, X. Chen, Y. He, Q. Li, K.Y. Li, Z. Wang, “Electrowetting on liquid-infused film (EWOLF): complete reversibility and controlled droplet oscillation suppression for fast optical imaging”, *Science reports*, 4, 6846, 2014.