PACKAGING TECHNIQUE FOR A TUNABLE MINIATURE LIQUID IRIS OPERATED BY ELECTROWETTING ACTUATION

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ABSTRACT

This paper presents a simple ultraviolet (UV) chemical sealant aided packaging technique for a tunable liquid iris actuated by electrowetting-on-dielectric (EWOD) principle. To evaluate the proposed UV chemical sealant aided packaging technique, a large number of tunable liquid iris samples (9×9×2 mm^3) are prepared by standard MEMS fabrication processes. The optical functionality of the microfabricated tunable iris is firstly tested. When an electrical voltage is sequentially applied to patterned ITO electrodes inside the tunable iris, opaque liquid initially covering only in the rim of the iris shifts to the center of the iris, resulting that the aperture diameter of the iris is modified from 4.2 mm to 0.85 mm. To improve the packaging of the iris the optimum chemical sealant (TB3124M UV sealant, ThreeBond Inc.) is selected through heavy field tests of various chemical sealants. To verify the proposed packaging technique, the high thermal test of the iris with the UV chemical sealant aided packaging is conducted using a temperature chamber. The result shows that the iris with the UV chemical sealant aided packaging shows no liquid leakage and remains as it was, while the iris only with a mechanical packaging shows severe liquid leakage through the joint area of the iris. The proposed packaging is easy to use but provides reliable liquid packaging, which can be applied to various microfluidic devices without additional complicated microfabrication processes.

INTRODUCTION

As the demands of miniature cameras with high optical performances for mobile devices such as smart phones and pads strongly increase, the development of micro tunable optical systems for controlling light path and modulating light intensity becomes important [1]. The tunable optical systems can be used not only for the mobile devices but also endoscope, optical coherence tomography (OCT), and various other industrial applications [2].

Typical optical systems of miniature cameras have been made up of solid lenses made of glass or plastic, an actuator to adjust the location of the lenses, an IR filter to block the remaining light other than a visible light, an image sensor, electric circuits, etc. Especially, the actuator consisting of tiny mechanical and electrical components has the largest volume with the highest electric power consumption among the components, which limits the capability for the miniaturization of the optical systems [2, 3].

Hence, numerous research groups have made considerable efforts to develop a new type of tunable optical system to reduce its size and power consumption with improving its response speed [4-6]. One of the most feasible methods is a liquid based tunable optical system where the liquid-liquid interface is used for an optical lens. Instead of controlling the location of solid lenses in a conventional optical system, the curvature of the interface is controlled by external actuation for image focus and zoom in the liquid based optical system.

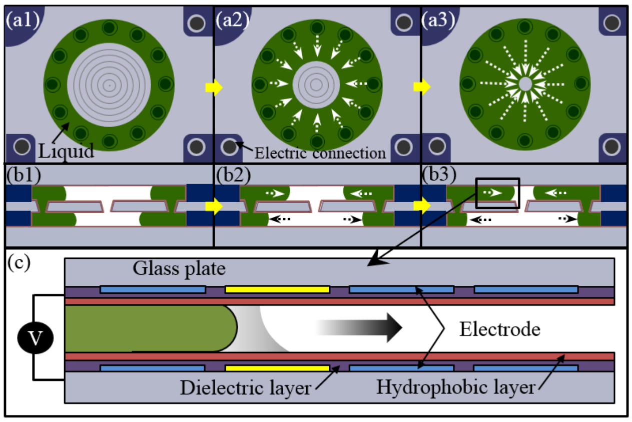


Figure 1: Schematic diagram of the operation of the proposed tunable liquid iris. When an electrical voltage is sequentially applied to patterned ITO electrodes inside the liquid iris, opaque liquid initially covering only in the rim of the iris shifts to the center of the iris, resulting that the aperture of the iris is modified: (a) Top view; (b) Side view; (c) Description of EWOD actuation on the liquid inside a confined channel.

Recently, electrowetting-on-dielectric (EWOD) driven optical systems such as EW liquid lens and liquid iris have drawn substantial attention from optical societies owing to their outstanding advantages such as small size, low power consumption, and fast response time [7-9]. EWOD actuation induces the modification of the wetting properties of a surface from hydrophobic to hydrophilic with an applied electric field. Various EWOD driven applications have been developed such as lab-on-a-chip, micro prism arrays, variable focus liquid lens, tunable iris, and reflective display [10].

Nevertheless, any EWOD driven applications have not been successfully launched in the market mainly due to the reliability issues of the liquid based optical devices. One of the most significant issues is the packaging of the liquid system. When a liquid system has been undergone in a high temperature condition, the inside pressure of the liquid system increases due to the volume of the liquid is proportional to the surrounding temperature. As a result, the working liquid inside the liquid system with a simple mechanical packaging leak out and it does not work properly because a small amount of liquid in the liquid system brings the significant change of the optical

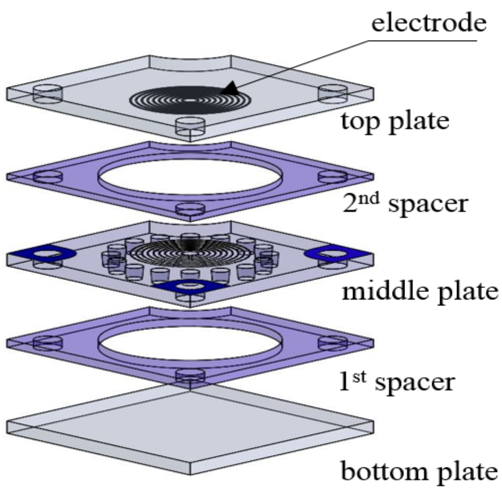


Figure 2: Schematic exploded diagram of iris.

performance. To resolve these issues, Krogmann et al. applied the anodic bonding of silicon and Pyrex wafers for the hermetic packaging of the liquid lens [1]. Recently, Okayama et al. proposed the bonding-in-liquid technique (BiLT) for the encapsulation of liquid in MEMS devices [11, 12]. And Lee et al. also suggested the hermetic sealing of liquid based on Laplace pressure disparity induced by heterogeneous surface energy [13].

In this work, we propose a simple but reliable ultraviolet (UV) chemical sealant aided packaging technique for a liquid system in which an UV chemical sealant selected through multiple reliability and repeatability tests is used to seal the outer surface of the mechanical joint area of the liquid system. Its sealing performance is experimentally verified through the high thermal test of microfabricated liquid irises. The proposed packaging is easy to use but provides reliable liquid packaging, which can be applied to various microfluidic devices without additional complicated microfabrication processes. Figure 1 shows the schematic diagram of the operation of the proposed tunable liquid iris. When an electrical voltage is sequentially applied to patterned ITO electrodes covered with a hydrophobic dielectric layer inside the liquid iris, opaque liquid initially covering only in the rim of the iris shifts to the center of the iris, resulting that the aperture diameter of the iris is modified.

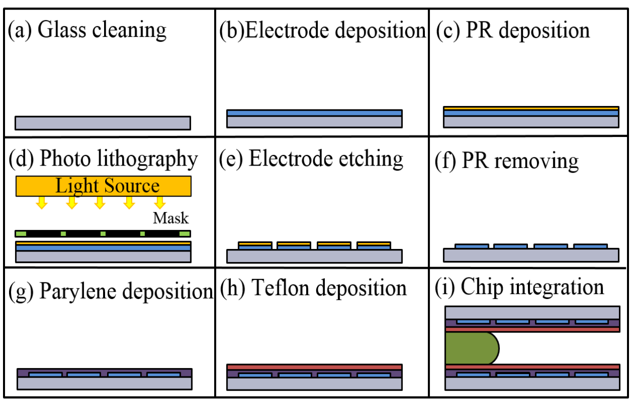


Figure 3: Schematic diagram of microfabrication.

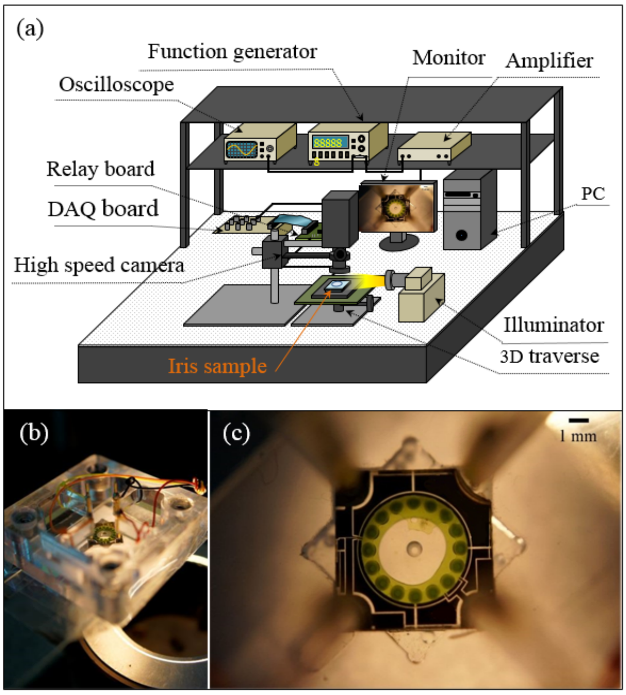
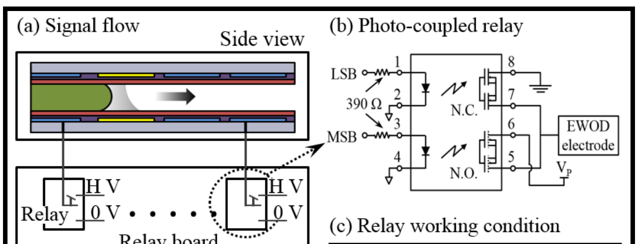


Figure 4: (a) Schematic diagram of experimental setups (b-c) Images of an iris placed in a test bed.

FABRICATION OF IRIS AND EXPERIMENTAL SETUPS

To evaluate the proposed UV chemical sealant aided packaging technique, a large number of tunable liquid iris samples (9×9×2 mm^3) operated by EWOD actuation are prepared by standard MEMS fabrication processes. Figure 2 shows the schematic exploded diagram of the tunable iris consisting of three square-shaped glass plates and two spacers made of polyimide silicone adhesive tapes (PIT-10050S-D50S-FL50, Isoflex), which form two connected circular microchannel. The middle plate has a center hole and 16 edge holes (diameter: 600 µm) for transparent air and opaque liquid passage. For sequential EWOD actuation, concentric patterned electrodes made of indium tin oxide (ITO) were microfabricated on both surfaces of the main channel, as shown in Fig. 3(a-f). For a dielectric layer, Parylene C was deposited on the entire surface of the patterned electrodes by chemical



MSB	LSB	STATUS
0	0	GROUND
0	1	FLOAT
1	0	SHORT
1	1	HIGH

Figure 5: Schematic diagram of chip integration; (a) Signal flow (b) Configuration of photo-coupled relay (c) Relay working condition.

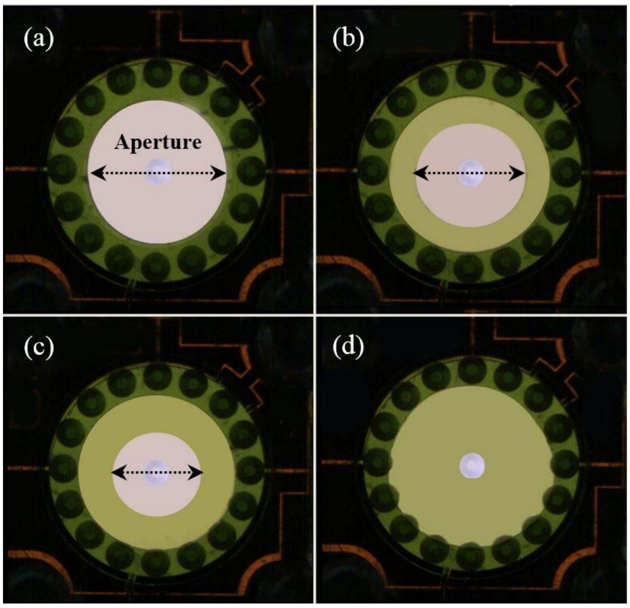


Figure 6: Operation test of a microfabricated iris: (a) Initial state; (b-d) When a voltage is applied to patterned electrodes inside the iris, the aperture of the iris sequentially changes.

vapor deposition (CVD) in Fig. 3(g). For a hydrophobic layer, Teflon AF 1600 (Dupont) was spin-coated on top of the dielectric layer in Fig. 3(h). For opaque working liquid, aqueous dye solution (10 µL) was injected on the microchannels.

Figure 4 shows the schematic diagram of experiment setups and the images of an iris placed in a test bed. For EWOD actuation, a sinusoidal wave voltage was generated by a function generator (33210A, Agilent Co.), and amplified up to 70 V by a voltage amplifier (PZD700, Trek Co.). The amplified voltage signal was transmitted to the EWOD electrodes through photo-coupled relays (PhotoMos®, AQW614EH, Aromat Co.) controlled by a digital I/O board (DAQpad-6229 BNC, NI Co.) along with a programmed LabVIEW code. Note that the diagram of the signal flow and configuration of the photo-coupled relay are described in Fig. 5. All experiment images were captured by a charge coupled device (CCD) camera (EO-1312C, Edmund Optics) as well as a high-speed camera (Phantom Miro eX2, Vision Research) integrated with a zoom lens (VZMTM 450i eo, Edmund Optics) and saved on a PC.

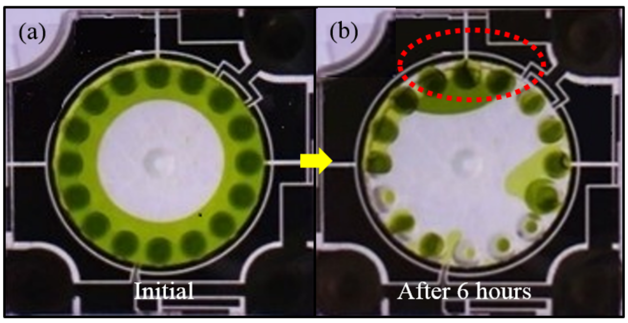


Figure 7: High thermal test: (a) Initial state; (b) After 6 hours. Note that most operating liquid inside the iris leaks through the spacer and glass plates within a few hours.

EXPERIMENTAL RESULTS AND DISCUSSIONS

The optical functionality of the proposed tunable iris is firstly tested, as shown in Fig. 6. In the initial state, opaque liquid inside the iris is in a relaxed state, so the iris shows the largest aperture (4.2 mm). When an electrical signal (70 V and 1 kHz) is applied to a patterned electrode, the liquid, which is initially placed on the rim of the iris, is actuated and pulled toward the activated electrode by electrowetting-on-dielectric (EWOD) principle.

To reduce the aperture of the iris, an electrode adjacent to the liquid is activated. Then the liquid is immediately pulled to the activated electrode. By shifting and repeating this procedure to the most inner electrode, the smallest aperture of the iris is achieved, as shown in Fig. 6(d). The tunable aperture diameter of the iris ranges from 4.2 mm to 0.85 mm.

Although the tunable iris satisfies the specifications of optical and mechanical functions such as light intensity modulation and fast response speed, it should be also guaranteed for the iris to pass the same reliability tests as mobile smart devices for turning it into a product and being used for these applications. Among various reliability tests, we focus on the high thermal test, because it has been known as the most critical problem for microfluidic optical systems such as liquid lens and liquid iris. Figure 7 shows the result of the high thermal test (85 °C, 30 hours) for the iris only with a mechanical packaging based on a polyimide tape (PIT-10050S-D50S-FL50, Isoflex), which is widely used in the MEMS field because of convenience for use and excellent heat resistance and withstand voltage. Most of the liquid initially filled in the iris leaks and only a small amount of the liquid remain after 6 hours. It is found from multiple tests that the liquid in the iris starts to leak around the joint area between the spacers and glass plates within a few hours, and the iris only with a mechanical packaging cannot resist in the high-temperature environmental condition.

To resolve the problem, the proposed UV chemical sealant aided packaging technique is applied to the tunable iris for improving the packaging of the iris. The most important mission for successful packaging in the technique finds the optimum chemical sealant. For the task, numerous chemical sealants were tested, and only a few

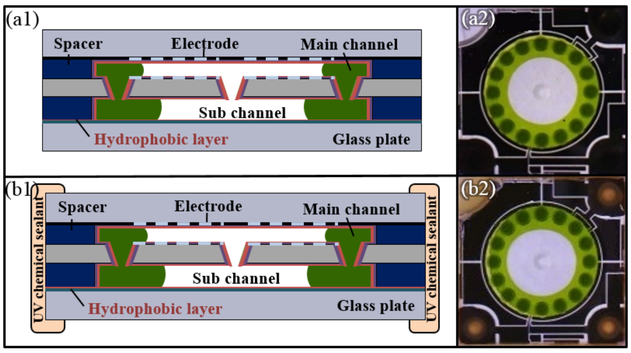


Figure 8: Tunable liquid iris only with mechanical packaging vs. tunable liquid iris with UV chemical sealant aided packaging: (a1) and (b1) Cross section views; (a2) and (b2) Top views.

chemical sealants satisfied the high thermal test of the iris. In this work, the TB3124M UV sealant from ThreeBond Inc. is used because the product does not require a high temperature during the curing process. For the enhancement of the packaging, the selected sealant is dispensed on the outer joint area of the iris where the liquid leaks using a high-precision dispenser (SBD-A101N, SEBA Co.). And the sealant on the iris is cured by a four-spot UV curing equipment (SP9-250W, USHIO Co.) for 24 seconds in a custom-made UV chamber. Figure 8 shows the comparison of the iris with or without UV chemical sealant aided packaging.

To verify the proposed packaging technique, the high thermal test (85 °C, 30 hours) is conducted using the iris only with a mechanical packaging and another iris with the proposed UV chemical sealant aided packaging in a temperature chamber (SH-VDO-30NG, Samheung Energy Co.), as shown in Fig. 9. The result shows that the iris with the UV chemical sealant aided packaging shows no liquid leakage and remains as it was, while the iris only with a mechanical packaging shows severe liquid leakage through the joint area of the iris. Note that five iris samples are prepared and tested for each test.

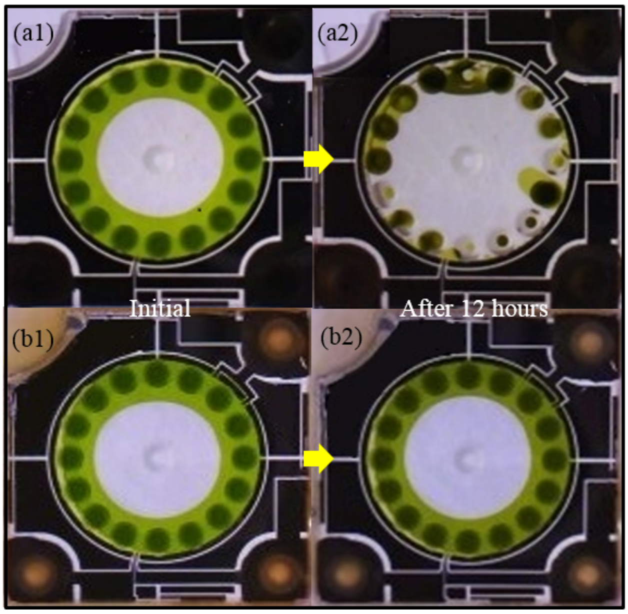


Figure 9: High thermal test (85 °C for 30 hours): (a) Tunable liquid iris only with mechanical packaging; (b) Tunable liquid iris with the UV chemical sealant aided packaging.

CONCLUSION

This paper describes a reliable ultraviolet (UV) chemical sealant aided packaging technique for an electrowetting-on-dielectric (EWOD) driven tunable liquid iris. First, a large number of tunable liquid irises (9×9×2 mm^3) are manufactured by standard MEMS fabrication processes to evaluate the proposed UV chemical sealant aided packaging technique. Second, the optical functionality of the microfabricated iris is carried out using photo-coupled relays and a digital I/O board along with a programmed LabVIEW code. Third, the optimum chemical sealant is selected through heavy field tests of various chemical sealants to satisfy the high thermal test of the iris. Fourth, the high thermal test of the iris is carried out using a temperature chamber to verify the proposed packaging technique. It is found that the UV chemical sealant aided packaging technique is simple but reliable for miniature liquid systems.

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