Two-dimensional Individually Addressible Electrowetting Micro-Lens Array

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2022 IEEE Photonics Conference (IPC) | 978-1-6654-3487-4/22/$31.00 ©2022 IEEE | DOI: 10.1109/IPC53466.2022.9975536

***Abstract*— In this work we present a two-dimensional micro-scale array of individually addressable, focal length tunable, electrowetting lenses fabricated using standard microfabrication techniques. The compact, transmissive nature of these arrays opens the possibility for integration into miniature optical systems involving wavefront shaping and beam steering.**

I. Introduction

Electrowetting lenses are based on the electrowetting-on-dielectric (EWOD) effect in which an applied electric field is used to tune the surface tension of a solid-liquid interface [1]. Our devices utilize this effect using cylindrical glass cavities containing an electrode and dielectric layer attached to a base optical window with a ground electrode. The glass cavities are filled with two immiscible liquids: DI water and 1-phenyl-1-cyclohexene (PCH). A voltage is then applied between the electrodes on the bottom window and sidewalls of the cavity. As the effective contact angle of the polar droplet changes with an applied voltage, the curvature of the meniscus at the liquid-liquid interface has a corresponding change. If there is an index of refraction contrast between the two liquids, the liquid interface behaves like a lens and the change in meniscus curvature results in a change in effective focal length.

Fluidic single lens devices based on the EWOD effect have recently been demonstrated in applications such as beam-steering [2], aberration control [3,4], and biomedical imaging [5]. These devices are particularly attractive due to their transmissive nature, low power consumption, and large range of tunability [6]. In this work, we present an individually addressable, micro-scale array of electrowetting lenses. Since each lens can be addressed individually, these arrays open the possibility for further applications in transmissive wavefront shaping as well as fast, tunable phase arrays for optical encryption.

II. Methods

Our array design utilizes three separately fabricated chips: a bottom glass chip containing electrical contacts needed for individual actuation, a photo-patternable glass chip (Schott Foturan II®) used as both the vertical cylindrical cavities and sidewall electrodes at equipotential, and a top glass chip for sealing the liquids in our device. A cross section of a 1.5 mm thick array design with 500 μm diameter lenses is shown in Fig. 1. Individual actuation is achieved by applying a potential between the electrodes on the bottom glass chip and the electrodes on the sidewalls of the etched cavities in the Foturan glass chip. Crucially, this design is fabricated using standard microfabrication techniques and enables individual actuation for each micro-scale lens in the array, in contrast to previous work [7, 8].

Each cylindrical cavity is filled with approximately equal volumes of a polar liquid, DI water, and a nonpolar liquid, 1-phenyl-1-cyclohexene (PCH) using a micro-drop dispenser head (Microdrop Tech®). This liquid combination results in a 173° initial contact angle inside each lens cavity [7]. To address each individual lens, we wire bond our patterned bottom electrode chip to a custom-designed PCB connected to an 8-channel amplifier.

III. Results & Conclusion

Individual actuation of a single lens in a 3×3 500 µm diameter lens array is shown in Fig. 2a. The effective focal length of each lens changes with an applied voltage, demonstrated as an example by the underlying “CU” text taken at two voltages, 0 and 60 V. We observe that 60 V actuation results in the text no longer being in focus underneath the actuated lens.

To characterize the focal length tunability of our micro-lens array, we set up a 4f imaging system for our lens array which is translated to minimize focal spot size of a 635 nm wavelength collimated laser source. As increasing voltage is uniformly applied to each lens in our array, the change in contact angle of the meniscus results in a change of effective focal length and a corresponding change in the optimized position of our imaging system. The distance from our 4f system to the top of our electrowetting arrays is subtracted from the back focal length of the first lens to obtain an approximation for the effective focal length of each electrowetting lens as a function of applied voltage, shown in Fig. 2b. Our devices show theoretical focal length tuning (shown in blue on Fig. 2b.) from approximately -2 mm to -14 mm with an applied voltage of 0 V and 83 V, respectively. We have found good agreement with this fit through device actuation up to 55 V (shown in red on Fig. 2b.). Beyond 55 V applied, the device experiences dielectric breakdown, thus indicating that further optimization of fabrication parameters is necessary. At approximately 90 V actuation, corresponding to 90° liquid meniscus contact angle, the effective focal length of our array approaches infinity.

In summary, we have demonstrated an individually addressable electrowetting micro lens array fabricated using standard microfabrication techniques capable of focal length tuning. Due to their compact and transmissive nature, these arrays have promising applications for integration into miniature imaging systems and optical phase arrays.

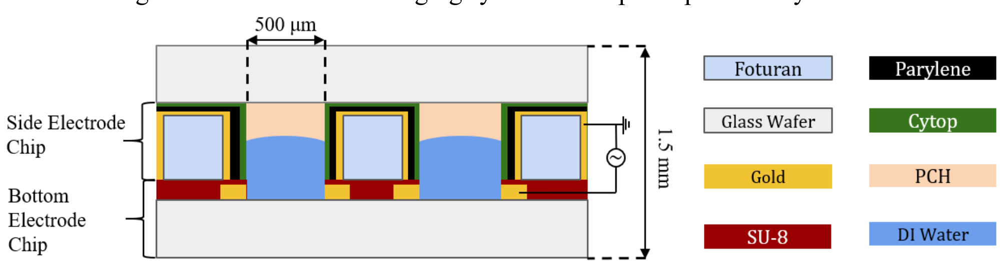

Fig. 1. A cross-section view of a fabricated 500 µm diameter electrowetting microlens array. The side and bottom electrode chips are fabricated separately then bonded together. The device is filled with DI water and PCH and a potential is applied between the side and bottom electrodes to actuate each lens individually. The final device is approximately 1.5 mm thick.

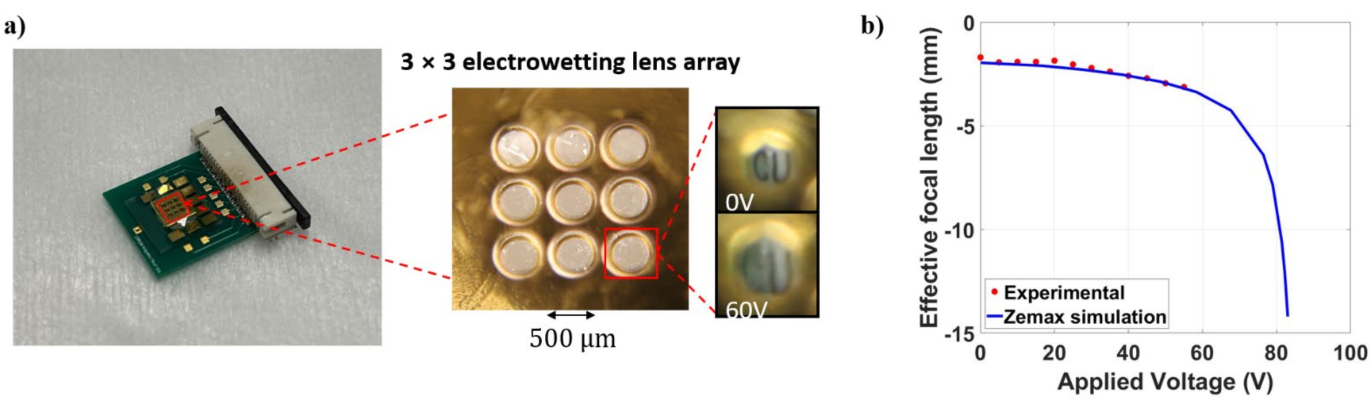

Fig. 2. (a) A fully assembled electrowetting micro lens array and a magnified view of actuation of a 500 µm diameter 3×3 array. Note that the “CU” text imaged by the array is no longer in focus when actuating at 60 V. (b) Focal length tunability obtained experimentally by actuating a 500 µm lens from 0 to 55 V (red points). We compare these results with a theoretical focal length fit found by modeling our device in Zemax OpticStudio (blue curve).

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