Limits of Adaptive Liquid Lens

Joy Johnson, Electrical & Computer Engineering, North Carolina State University
NNIN REU Site: Cornell NanoScale Science and Technology Facility, Cornell University

NNIN REU Principal Investigator: Prof. Sandip Tiwari,
Director of NNIN; Electrical & Computer Engineering, Cornell University
NNIN REU Mentor: Jay S. Van Delden, Visiting Scientist, Electrical and Computer Engr, Cornell University
Contact: jmjohns4@ncsu.edu, st222@cornell.edu

Abstract:

Practical limitations of a variable liquid lens using a electrowetting effect are investigated. Electrowetting, the change in contact angle at a solid-liquid interface as a result of an applied voltage, can be used to control the focal length of a liquid lens. SU8 chambers are prepared on a fused silica substrate with TiN electrodes, an Al mask layer, $Si0_2$ dielectric layer and FOTS hydrophobic monolayer. Excitation of the resulting chambers causes variations in the observed far-field diffraction patterns thus verifying electrically-induced changes in refractive power. Such changes to μm-sized lenses could be used for spatial light modulators, CCD cameras, and 3D displays in adaptive optics.

Introduction:

In order to investigate the practical size limits of the electrowetting effect, we had to define a process in which we could create variable-size liquid chambers on the micron scale. Initially, experimental procedures were performed on microscope slides to determine which films to use, as well as their respective thicknesses, in order to successfully show the electrowetting effect. Applying the knowledge gained in this preliminary setup, we fabricated arrays of micro lenses on a quartz substrate and performed tests using both a microscopic and laser setup.

Experimental Procedure:

For the preliminary setup, we characterized the materials and thicknesses for the electrodes (31nm of titanium nitride, TiN), dielectric layer (500 nm of silicon dioxide, SiO_2), and hydrophobic monolayer (Flourooctyl Tricholorosilane, FOTS) on microscope slides. A droplet of salt water (0.5M) was placed on the microscope slide and a voltage applied to the electrodes to show proof of principle.

For the wafer embodiment, we used the following procedure: First, we patterned the quartz substrate using our first mask, processing SPR 220-7.0 resist approximately 10 μm thick for etching. After the soft bake, the wafer was exposed to UV light using the EV620 at 12 mW/cm^2. Next, the quartz was dry etched approximately 3.6 μm deep using a $CHF_3/0_2$ recipe. To create the bottom electrode, a thin conductive layer of TiN was sputtered onto the quartz substrate at a thickness of approximately 30 nm. The aluminum mask was then evaporated on top of the TiN layer approximately 250 nm thick.

Next, a thick layer of SPR 1075 photoresist, approximately 11 μm, was spun on as a "planarization agent." After the softbake, the resist was baked for 180 minutes in a 90°C oven in order to get the resist as hard as possible. In order to planarize the resist we used a Strasbaugh Chemical Mechanical Polisher (CMP), with an oxide recipe, in intervals of 5 seconds, in order to planarize the resist to be flush with the top of the wells, until the aluminum was visible. Following planarization, the substrate was flood exposed to allow any solvents to escape, avoiding reactions between the photoresist and the SU8. Then, to dehydrate the surface, the substrate was baked 90 minutes in a 90°C oven and oxygen plasma cleaned to optimize surface adhesion prior to further resist processing.

Next, the SU8 was processed and patterned with the second mask to form liquid chambers. The SU8, at a thickness of approximately 50 μm, was exposed to UV light using a contact aligner (EV620). After the SU8 was developed, the planarizing agent, SPR 1075 photoresist, was cleared completely using an oxide etch.

Finally, for the top electrode, another thin, conductive layer of TIN was sputtered onto the substrate at a thickness of approximately 31 nm. SiO_2 was deposited as the dielectric layer using evaporation at a film thickness of approximately 500 nm. Lastly, we deposited a hydrophobic monolayer of FOTS. Our completed devices are shown in the SEM images in Figures 1 & 2.

Results and Conclusions:

In order to observe and investigate the electrowetting effect in our SU8 wells, we used an optical setup in which a HeNe laser beam was reflected by two mirrors

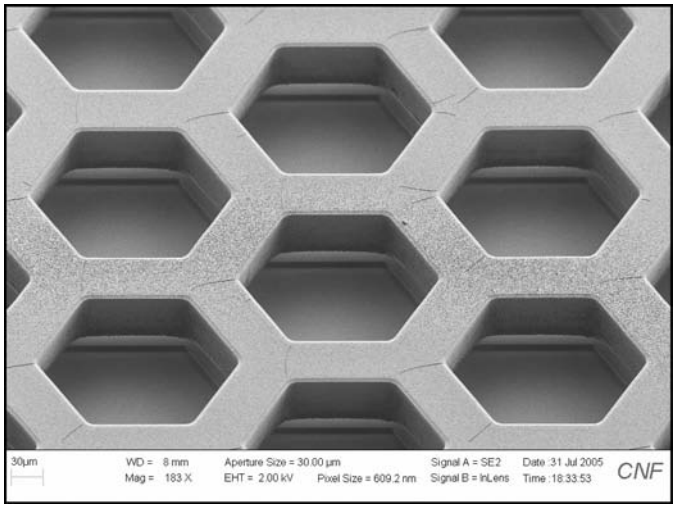

Figure 1: Hexagonal arrays apertures.

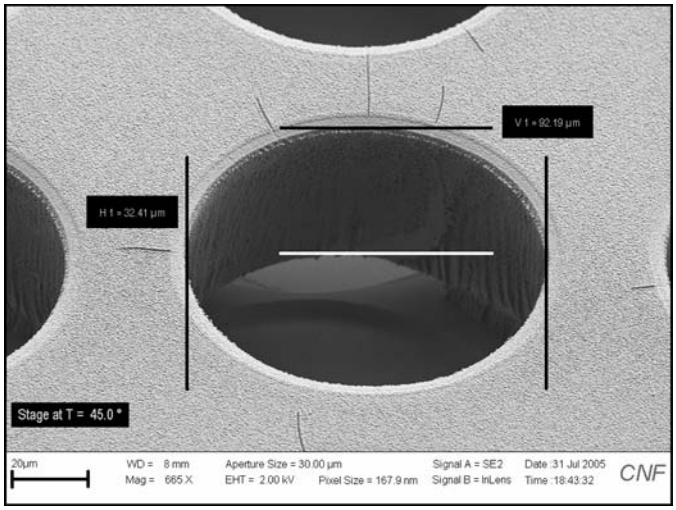

Figure 2: Circular array apertures.

and then through the apertures on our wafer. The apertures were filled with a polar liquid (salt water of 0.5M) and increasing voltages were applied to the top and bottom electrodes from 0 to 100 volts. Using the laser, we were able to observe the diffraction patterns created by the aperture before, during, and after voltage application; the diffraction pattern allowed us to observe electrically induced changes taking place on the microscale (Figures 3 & 4). The 200 μm leg hexagonal aperture was the microlens in which we observed definitive effects taking place. We also performed a test using microscopy, observing changes in focal length with the application of a voltage. The results obtained using microscopy were less definitive than those yielded by the observation of diffraction patterns.

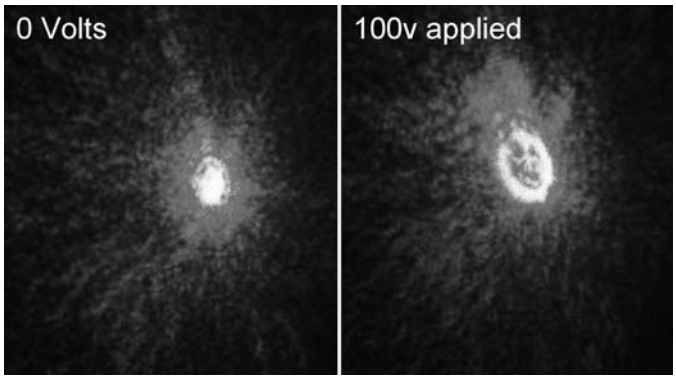

Figure 3, left: Diffraction pattern prior to voltage. Figure 4, right: Diffraction pattern after 100V applied.

Future Work:

In order to optimize our device, we would like to make some changes to our mask design in order to create a more distinct separation between the top and bottom electrodes during processing to solve the problem of shorts in the wafer. In addition, we would also like to isolate the arrays such that each array can be probed and excited individually as opposed to the excitation of the entire wafer. In the future, we would like to perform software simulations to investigate wave propagation through the arrays of apertures due to the electrowetting effect.

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References:

[1] Lazar, Paul PhD. Dissertation Seminar, Max Plank Institute. Contact angle and wetting films. July 30, 2004. URL http://www.mpikg-golm.mpg.de/gf/1 Accessed August 21, 2004.

[2] M. Vallet, M. Vallade et B. Berge, "Limiting phenomena for the spreading of water on polymer films by electrowetting", Eur. Phys. J. B11 (1999) 583-591.

[3] C. Quilliet , Bruno Berge, " Investigation of effective interface potentials by electrowetting " Eurphysics letter, 1 October 2002, PP 99-105.

[4] Duke University; www.ee.duke.edu/Research/microfluidics/