Flexible Membrane Liquid Lens

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Abstract and Introduction:

Reconfigurable optical devices are important for optical system characterization, materials measurements, communications, and imaging. In particular, variable-focus lenses have potential in many adaptive optical systems. In this project, a lens whose focus could be varied by fluid pressure was designed, fabricated, and characterized. The lens consisted of an aluminum, liquid-filled cavity that is sealed with a flexible polydimethylsiloxane (PDMS) membrane on one side and glass on the other. Pressure changes in the liquid-filled cavity cause the membrane to curve inwards or outwards, resulting in lensing [1, 2]. The goal of this project was the fabrication of a lens that maximized focal length variability while minimizing aberrations. Several liquid lenses were fabricated and demonstrated focal length variability from 20 mm to 125 mm and an average spherical aberration of 5 mm. Current work focuses on optimization of design to increase possible focal lengths and minimize aberrations.

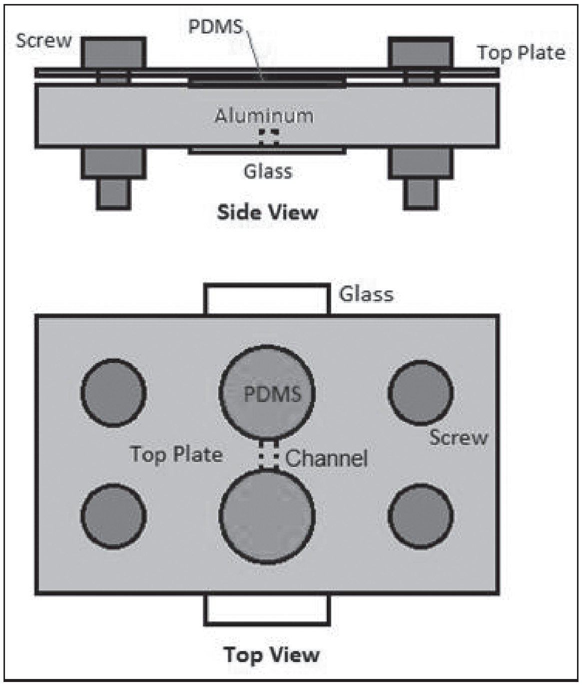

Figure 1: A top and side view of the lens design

Experimental Procedure:

The lens design is shown in Figure 1. Two cavities were drilled into an aluminum (Al) substrate. The Al substrate thickness was 1.5 ± 0.1 mm or 6.5 ± 0.1 mm. One cavity was for the lens and the other acted as a liquid reservoir. The lens aperture diameter was either 12.7 ± 0.1 mm or 19.1 ± 0.1 mm. The two cavities were connected by a shallow channel on one side of the Al. A Fisher Brand 25x75 glass microscope slide sealed the lens cavity and reservoir on the side containing the channel. The slide was attached using a UV curing adhesive to avoid outgassing. The other side was sealed using a thin, flexible polydimethylsiloxane (PDMS) membrane. The membrane was clamped onto the Al substrate with a similar Al top plate. The PDMS films were spun onto Corning 50x75 mm glass slides.

The process began by mixing the two part kit in a 1:10 ratio of curing agent to silicone elastomer. The mixture was put in a sonic dessicator for 30 minutes to remove bubbles. Cleaned slides were coated in a solution, 10% Dawn dish detergent and 90% DI water, that acted as a release layer for the PDMS [3]. The slides were spun with approximately 1.5 ml of PDMS mixture for 40 seconds. Spin speed was varied from 500 to 1900 rpm to produce a range of film thicknesses. The film thickness was measured using a DekTak contact profilometer on a low force setting of 1 mN. The resulting spin curve can be seen in Figure 2.

The PDMS was cured on a hot plate or at room temperature. The baked films were placed on a 150°C hot plate for

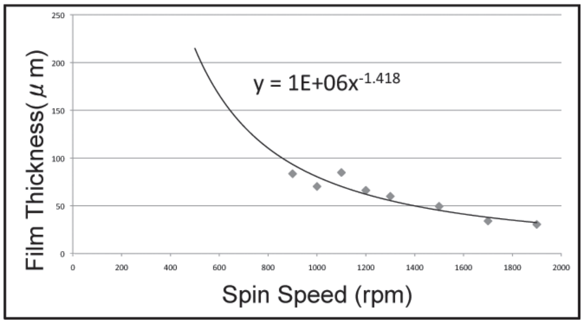

Figure 2: A spin curve for PDMS shows film thickness as a function of spin speed.

35 minutes. The films cured at room temperature took 36 hours. The surface roughness of the films was characterized for both the hot plate and room temperature cure using differential interference contrast (DIC) microscopy. The resulting films were removed from the glass slides and cut to the desired dimensions using a razor blade.

Results and Conclusions:

Several flexible membrane liquid lenses were designed, fabricated, and characterized. The lenses were tested for their focal length variability and spherical aberration. In addition, the PDMS films were characterized in thickness and surface roughness.

Focal length variability was tested for the different aperture diameters. The smaller aperture diameter (12.7 mm) had an effective focal range from 20 to 90 mm while that of the larger diameter (19.1 mm) was 30 to 125 mm.

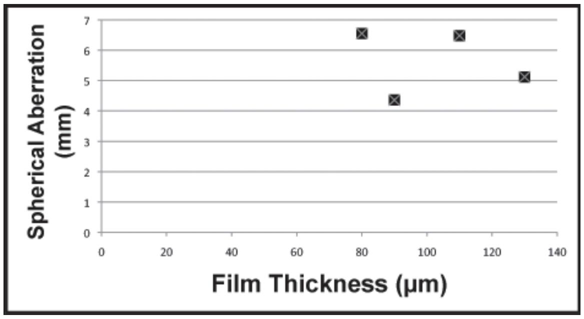

Figure 3: A plot of aberration as a function of film thickness. There was no apparent correlation

Spherical aberration was measured as the distance between the marginal focus and paraxial focus using a knife edge test [2]. The spherical aberration varied from 4.36 to 6.55 mm with an average of 5.6 mm. As can be seen in Figure 3, no correlation was found between spherical aberration and film thickness, indicating the large observed aberration was not due to the thickness of the PDMS film.

The PDMS film thickness was measured using a contact profilometer and varied from 30 to 200 μm. Surface

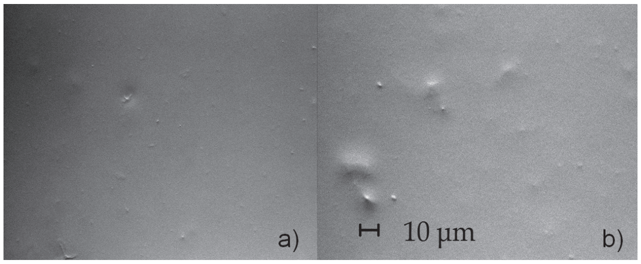

Figure 4: DIC microscope image of 100 µm PDMS film: a) left to cure at room temperature for 36 hours, and b) baked at 150°C for 35 minutes. Long cure times reduced the bubbles and nonuniformities in the PDMS.

roughness was measured using DIC microscopy. Films cured at room temperature for 36 hours had less surface roughness than those cured at 150°C for 35 minutes (Fig. 4).

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