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Low-Profile Stacked Digitally Tunable LC Fresnel Lens for Smart Contact Lens System

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***Abstract:* By stacking multiple thin, LC filled lenses based on refractive Fresnel geometry, we experimentally demonstrate a fast response, low-power, and low-profile adaptive optical system that is suitable for integration with a smart contact lens system.**

Keywords—smart contact lenses, tunable lens, Liquid Crystal.

I. Introduction

Smart contact lenses with tunable optical power are a potential solution for addressing vision deterioration. The main component of such a system is a tunable lens whose optical power can be adjusted. Although there are several technologies which can be utilized to realize an adaptive lens, LCs are an attractive option due to their low voltage actuation, low-profile realizations and low power requirements [1]. However, LCs also suffer from scattering, loss in optical transmission and slow response-time. Therefore, Fresnel implementations and Fresnel zone-plates have been previously used to achieve low-thickness LC lenses. Typical Fresnel LC (FLC) lenses are thin and light-weight but require complicated patterning of electrodes to realize the Fresnel phase profile within the LC [2,3]. Conventional ultra-thin diffractive Fresnel zone plates also suffer from significantly high chromatic aberration and are not suitable for applications which require broadband imaging.

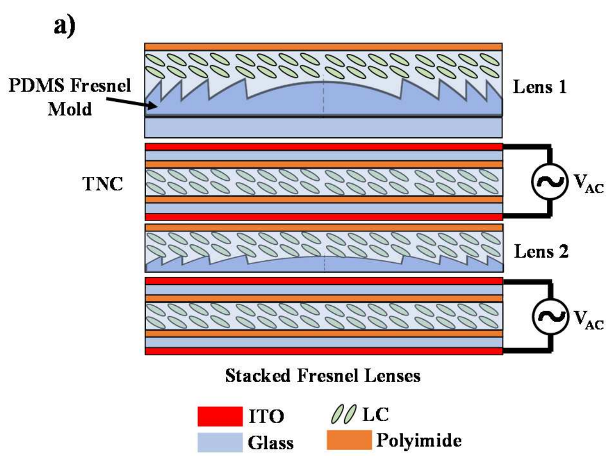

Figure 1a: 3D schematic of the stacked refractive Fresnel LC lens.

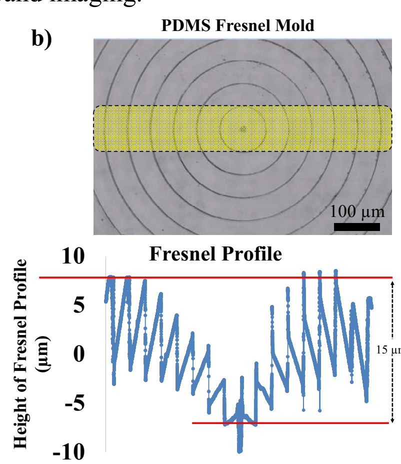

Figure 1b: Optical image and height profile of the Fresnel mold.

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Here, we report the fabrication and characterization of a digitally tunable lens system based on liquid-crystal technology implemented within a refractive Fresnel lens geometry. The aperture of the lens is 5mm and comprises of two 15 µm thick Fresnel mold cavities and two 10 µm thick, ITO coated, twisted nematic cell (TNC) cavities filled with a nematic LC: 5CB. Here, for the first time, it is demonstrated that refractive Fresnel PDMS molds, filled with an LC material can be used as a voltage controlled tunable lens which is simple to fabricate, is low-profile, requires low-voltage to operate, with a low switching-time and demonstrates negligible chromatic aberration. The lenses are operated at voltage greater than the threshold voltage of the LC and the net optical power of the lens stack can be tuned between four discrete states by selectively applying the same voltage. Preliminary results show that the power of the lens stack can be digitally tuned within 1 second, between ~10.7D – ~12D by applying a voltage of 17 V_{rms} across the TNC. The total thickness of the beam shaping elements within the system is ~110 µm. However, these are embedded within thicker glass frames which increase the final thickness of the entire stack. Such a stacked-lens system can be integrated with a tunable contact lens platform for presbyopia correction.

II. Result and Discussion

The detailed fabrication flow of the lens has been previously described [4]. Figure 1: (a) shows the working principle and schematic of the stacked FLC lenses and TNC. Each lens has an aperture of 5mm, consisting of PDMS cavity mold, bonded with a PI coated glass substrate. The chamber of the mold is filled with a nematic LC: 5CB. The TNC is an ITO coated 10 µm thick glass chamber with PI2555 coated in the inner walls and filled with 5CB. The entire assembly constitutes of two such lens/TNC assemblies. When a voltage greater than the threshold voltage of 5CB is applied across the TNC, the direction of polarization of the incident light changes. This, combined with the birefringence of the LC within the Fresnel cavity leads to a change in power of the lens system. First, confirm that you have the correct template for your paper size.

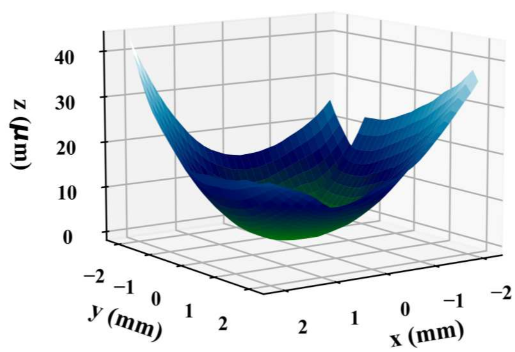

Figure 2: Parabolic wavefront of the Fresnel LC lens.

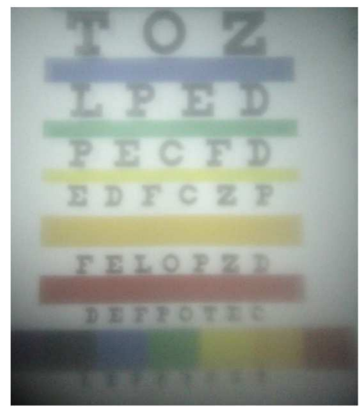

Figure 3: Imaging through the Fresnel LC lens.

Lens 1 (V_{rms})	Lens 2 (V_{rms})	Effective Optical Power (D)
0	0	~12
0	17	11.77
17	0	10.9
17	17	10.7

Figure 1: (b) shows optical images and height profile of the FLC mold. The maximum thickness of the Fresnel steps is ~15 µm. Figure 2 shows a near-perfect parabolic wavefront of one of the Fresnel lenses after filling with LC as measured by a Shack Hartmann Sensor. Figure 3 shows the clear imaging of a multi-colored target through the LC Fresnel lens. Table 1 shows the effective optical power of the lens stack for the four discrete states as a result of various combinations of voltage applied to the TNC. The optical power can be tuned between ~10.7D – ~12D by applying a voltage of 17 Vrms across the TNC.

III. References

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