Microfabricated Low-Profile High Tunable LC Fresnel Lens for Smart Contacts

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Abstract**—** Using high-performance LC (5CB) filled microfabricated refractive Fresnel chambers, we experimentally demonstrate a thin low-profile adaptive optical system with very high analog tunability (15.5 D) that can be integrated with an adaptive smart contact-lens system.

Keywords—*liquid-crystal, 5CB, refractive Fresnel, Smart Contact Lens*

I. Introduction

A next-generation solution aimed at presbyopia correction is a varifocal, smart contact lens platform. At the heart of such a system lies a tunable lens that needs to demonstrate a high degree of tunability, consume low electrical power and demonstrate excellent optical characteristics. Due to their low voltage actuation requirements, liquid-crystals (LCs) have always been considered as an attractive option for realizing tunable lenses [1], but they suffer from significant scattering at high thicknesses, leading to loss in optical transmission, poor imaging quality and slow response-time. Therefore, the commercial applications of liquid-crystal (LC) lenses have been limited to LCD pixels which are only ~1 µm thick. LC based lenses need to be significantly thin to maintain imaging clarity. However, this puts a fundamental limitation on the tunability of the lens. Therefore, it is necessary to utilize non-conventional optical lenses which can provide a high optical power while demonstrating reduced thickness. Previously, Fresnel Zone Plates (FZPs) and Fresnel implementations have been used to achieve low-thickness LC lenses. These are thin and light-weight but require complicated electrode structure to realize the Fresnel phase profile within the LC [2,3]. Furthermore, FZPs also suffer from severe chromatic aberration and are therefore not suitable for bio-optical imaging applications such as contact lenses. A compromise between conventional refractive lenses and diffractive FZPs lies refractive Fresnel geometries (RFGs), which are significantly thinner than bulky refractive optical elements but do not suffer from severe chromatic aberration like the zone-plates. The beam shaping elements are significantly larger than the wavelength of visible light, thereby utilizing refraction of light to achieve focusing. Literature suggests that there have been very limited attempts at utilizing RFGs with LC for building tunable lenses, with no demonstration of imaging through the lens [1]. This is primarily because of the complicated structure of the Fresnel grooves and difficulty in patterning conductive, transparent thin-films on these grooves, which are required for optical-switching of LC molecules.

We report the fabrication and characterization of a tunable lens system based on refractive Fresnel lens chamber filled with high performance LC, 5CB. The aperture of the lens system is ~4.5 mm and comprises of a ~25 µm groove-thickness Fresnel mold cavity and one ~3 µm thick, ITO coated, orthogonally aligned twisted nematic cell (TNC) cavity, both filled with nematic LC, 5CB. The TNC acts as a tunable polarization rotator which rotates the polarization of the incident rays upon application of external AC voltage and due to the birefringence property of LC materials, the optical power of the LC Fresnel lens also changes. Here, for the first time, using this novel driving scheme, we demonstrate that a refractive Fresnel geometry can be utilized to fabricate thin, tunable LC lenses which are simple to fabricate, demonstrate very high optical tunability, very low switching speeds and require extremely low actuation

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voltage, while maintaining optical clarity. Preliminary results show that the power of the lens stack can be continuously tuned by ~15.5 D, by application of only ~3.2 $V_{p\text{-}p}$. The switching time was lower than 1 second. The total thickness of the beam shaping elements within the system is ~30 µm. Such a tunable lens system can be easily integrated with a tunable contact lens platform for presbyopia correction.

II. Results and Discussion

Figure 1: (a) shows the working principle and schematic of an LC filled refractive Fresnel lens and a TNC. The detailed fabrication has been previously described [4]. The lens has an aperture of 4.5mm, 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 3 µm thick glass chamber with PI2555 coated in the inner walls and also filled with 5CB. The entire assembly constitutes of a lens/TNC pair. When an AC voltage is applied across the TNC, the direction of polarization of the incident light changes. This, combined with the birefringence of the Fresnel-LC geometry leads to a change in power of the lens system.

Figure 1: (b) shows high-resolution SEM images and height profile of the refractive Fresnel geometry. The maximum thickness of the Fresnel steps is ~25 µm. Figure 2 shows the optical power of the LC lens vs applied voltage. As shown in the plot, a maximum change in optical power of ~15.5D was achieved by using only by applying 3.2 $V_{p\text{-}p}$ (1 kHz) across the TNC. Figure 3 shows the clear imaging of a multi-colored target through the LC Fresnel lens before and after applying the threshold voltage, thereby demonstrating high optical clarity in both switching states.

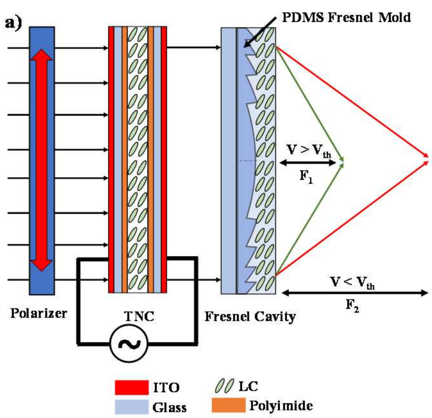

Figure 1a: Working principle and schematic of the refractive Fresnel LC lens system.

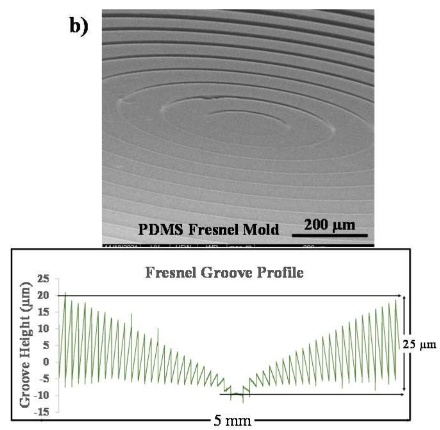

Figure 1b: SEM image and height profile of the Fresnel mold.

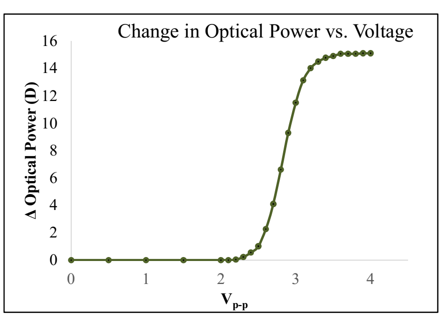

Figure 2: Optical power vs. applied Voltage.

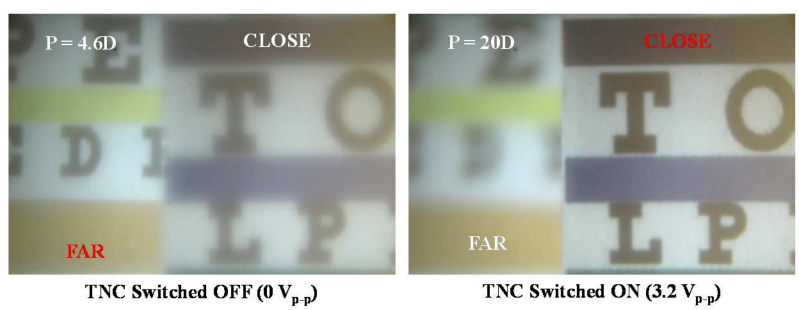

Figure 3: Tunable imaging through the Fresnel LC lens.

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