Microfabricated Low-Profile Tunable LC-Refractive Fresnel (LCRF) Lens for Smart Contacts

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Abstract: Using high-performance LC (E7) filled microfabricated refractive Fresnel chambers, we experimentally demonstrate a thin low-profile adaptive optical system with high analog tunability (2.1 D) that can be integrated with an adaptive contact-lens system. © 2022 The Author(s)

1. 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 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, Merck E7. The aperture of the lens system is 5mm and comprises of a ~25 µm groove-thickness Fresnel mold cavity and one ~3 µm thick, ITO coated, twisted nematic cell (TNC) cavity, both filled with Merck E7. The TNC acts as a tunable polarizer which changes 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 switching speeds and require low actuation voltage, while maintaining optical clarity. Preliminary results show that the power of the lens stack can be continuously tuned by 2.1 D, by application of only 11 V_{RMS}. 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.

2. 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 5mm, consisting of PDMS cavity mold, bonded with a PI coated glass substrate. The chamber of the mold is filled with a high-performance nematic LC: Merck E7. The TNC is an ITO coated 3 µm thick glass chamber with PI2555 coated in the inner walls and filled with E7. 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 LC within the Fresnel cavity leads to a change in power of the lens system.

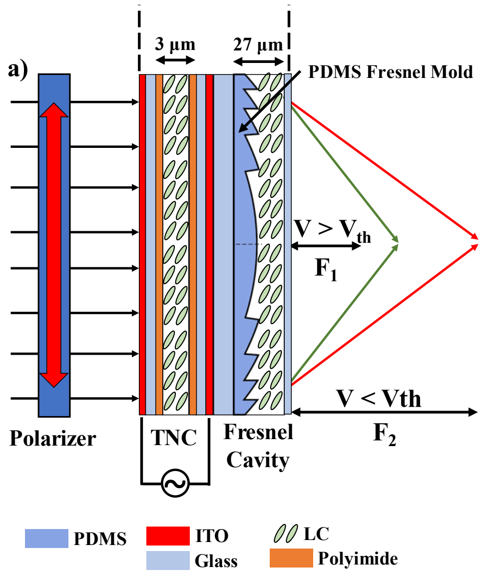

Figure 1a: Working principle and schematic of the refractive Fresnel LC lens.

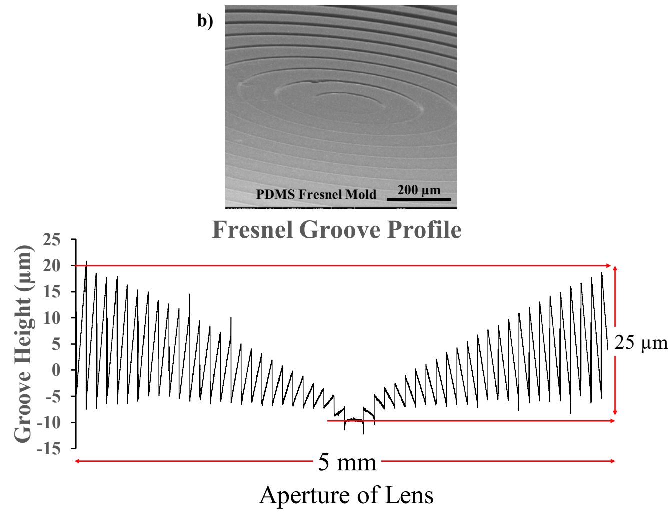

Figure 1b: SEM image and height profile of the Fresnel mold.

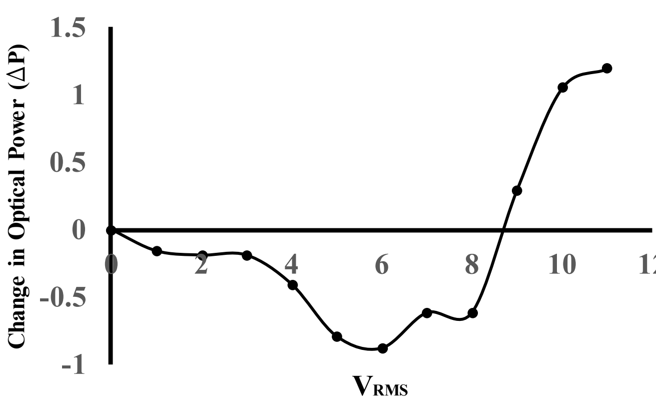

Figure 2: Change in optical power vs. voltage.

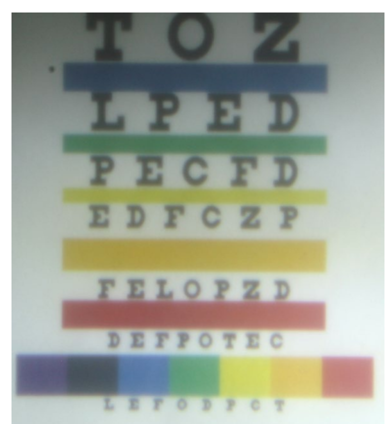

Figure 3: Imaging through the Fresnel LC lens.

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 ~2.1D was achieved by using only by applying 11 V_{rms} across the TNC. Figure 3 shows the clear imaging of a multi-colored target through the LC Fresnel lens, thereby demonstrating high optical clarity.

3. References

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