Flexible, Refractive Fresnel Liquid-Crystal (RFLC) Lens for Low-Power Autofocusing Smart Contact Lens Systems

Chayanjit Ghosh, *[1] Adwait Deshpande, *[1] Aishwaryadev Banerjee,[1] Mohit U. Karkhanis,[1] Erfan Pourshaban,[1] Hanseup Kim,[1] and Carlos H. Mastrangelo[1]

[1]*Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT, 84102, USA*
*Corresponding author: chayanjit.ghosh@utah.edu   *Equal contributing authors*

Abstract: We demonstrate fabrication of tunable flexible refractive Fresnel liquid-crystal lens using PET for Smart Contact Lens System. We show focus tunability of 1.9D at 1.1V_{RMS} using voltage and pulse width modulation lens tuning techniques.

1. Introduction

With progressing age, the biomechanical properties of the crystalline lens within the eye change, which cause the lens to lose its elasticity. This causes the eye to lose its accommodative abilities and results in a refractive error called presbyopia, which currently afflicts 2.1 billion people worldwide [1]. Traditional methods of vision correction, like multifocal/ progressive eyeglasses and contact lenses only provide a fixed offset, but do not reintroduce accommodation within the human eye. Therefore, tunable-focus liquid-crystal contact lenses are being considered as a solution for the correction of presbyopia. We chose a Fresnel based geometry for our tunable-focus liquid-crystal lens in order to reduce the thickness of the lens, as the liquid crystal is a scattering medium [2]. Such innovative lens provides similar optical properties as a conventional solid lens yet, offers a much thinner alternative. This lens is meant to be controlled with a low-power, 1.8V control electronics, integrated within a Smart Autofocusing Contact Lens System alongside other sub-systems such as low-power oculometers, and innovative power scavenging technologies, connected with flexible wires and mounted on a flexible substrate with soft, flex packaging [3]–[7]. It is crucially important for the tunable-focus liquid-crystal lens to be flexible to some degree for seamless integration with the flexible Kapton substrate.

2. Fabrication

Here we report the fabrication of a flexible refractive Fresnel liquid lens chamber filled with 5CB liquid crystal. The aperture of the lens system is 5 mm and comprises of ~25 µm grove thickness. We used PET film sourced from Toyobo (Cosmoshine A4100) as a substrate and used the PET substrate as a rigid frame to make a reverse mold using PDMS. The Fresnel mold was coated with a thin layer of Fluoropel 800 to facilitate easy release of the cured reverse mold. The other side of the lens cavity is fabricated by coating a thin layer of polyimide (PI2555) on the PET film. We make two holes on the polyimide coated PET substrate for filling the lens cavity with liquid crystal. Both the PDMS reverse mold and the PI coated substrate is buffed using a rayon cloth and sealed using a ~3.5 µm double sided tape (Nitto Denko NO. 5600).

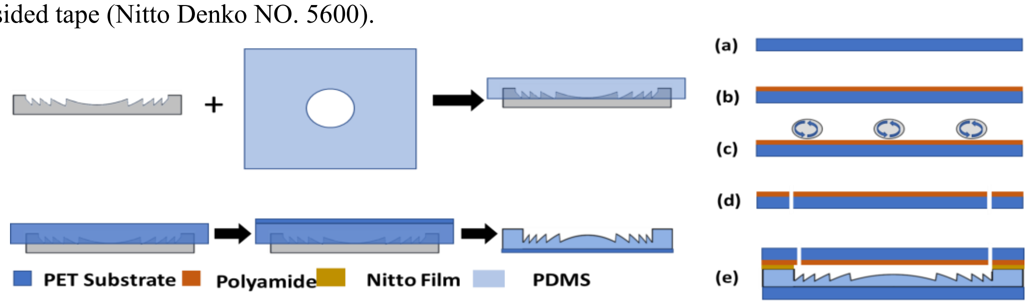

Fig 1: Schematic of the fabrication steps.

We also fabricate a Twisted Nematic Cell (TNC) to change the polarization of the incoming light. The TNC is comprised of two thin ITO coated glass substrates, that are then coated with polyimide (PI2555). We make two holes using laser to make an inlet for liquid crystal to be filled using capillary forces under vacuum. The PI coated glasses are buffed in a particular direction using a rayon cloth, arranged orthogonally, and sealed using double sided Nitto tape. Both the lens and the TNC are then vacuum filled with 5CB liquid crystal. Figure (1) shows the schematic of the fabrication steps of the lens and TNC [2].

3. Results and Conclusion

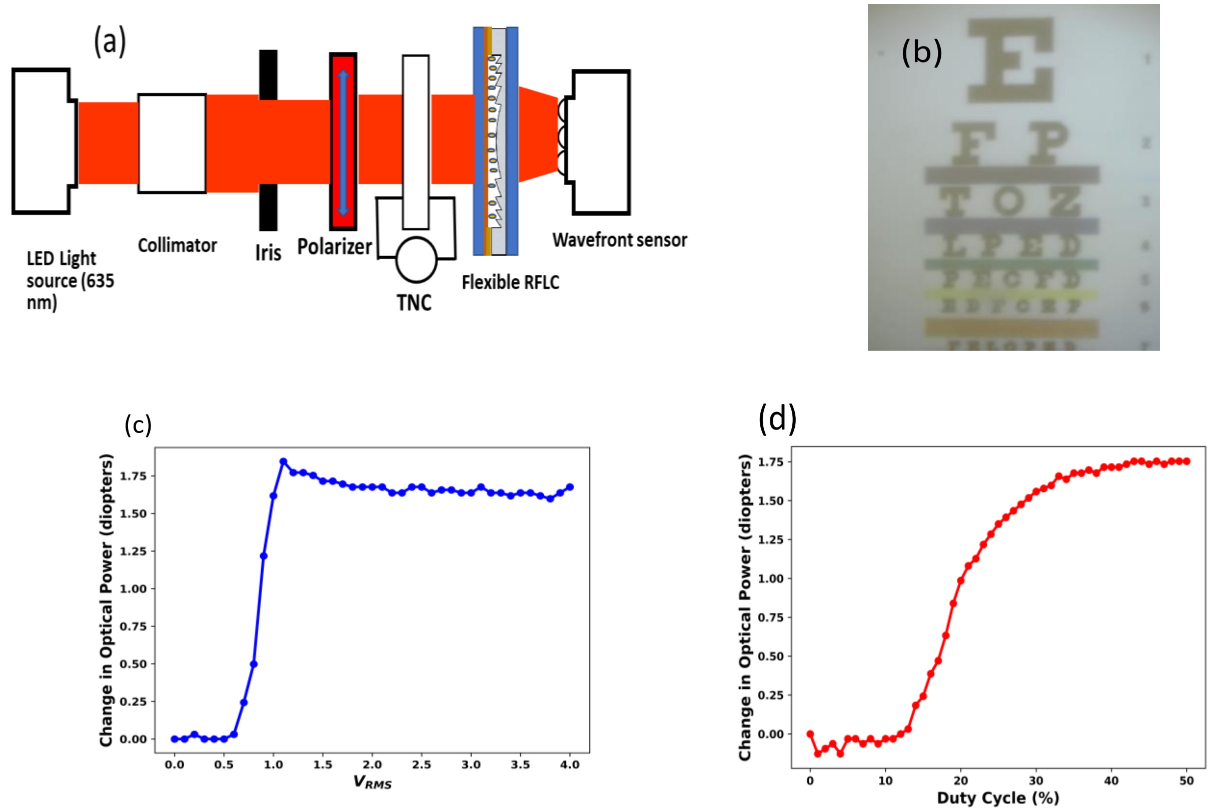

Fig 2 (a) Schematic of Shack Hartmann wavefront test setup, (b) Image taken through flexible RFLC lens, (c) Voltage vs Optical power of RFLC lens, (d) Duty cycle vs Optical power of RFLC lens.

Figure (2a) shows the Shack Hartmann wavefront sensor setup. Figure (2c,d) shows the optical tunability with respect to the voltage and pulse width modulation techniques. Figure (2b) shows the image taken through the lens, using a commercial DSLR camera (Canon 1200D). As shown in the plot, the maximum change in optical power observed in 1.9D by using only 1.1 V_{RMS} across the TNC, hence making this lens compatible with low voltage, low power 1.8 V control electronics in the smart contact lens system.

4. References

[1] R. R. A. Bourne *et al.*, “Trends in prevalence of blindness and distance and near vision impairment over 30 years: An analysis for the Global Burden of Disease Study,” *Lancet Glob. Heal.*, vol. 9, no. 2, pp. e130–e143, Feb. 2021, doi: 10.1016/S2214-109X(20)30425-3.

[2] A. Banerjee *et al.*, “Microfabricated Low-Profile Tunable LC-Refractive Fresnel (LCRF) Lens for Smart Contacts,” *Conf. Lasers Electro-Optics (2022), Pap. AW4C.3*, p. AW4C.3, May 2022, doi: 10.1364/CLEO_AT.2022.AW4C.3.

[3] A. Deshpande, E. Pourshaban, C. Ghosh, A. Banerjee, H. Kim, and C. Mastrangelo, “Adhesion Strength of PDMS to Polyimide Bonding with Thin-film Silicon Dioxide,” Jun. 2021, doi: 10.1109/FLEPS51544.2021.9469779.

[4] A. Deshpande *et al.*, “High-Toughness Aluminum-N-Doped Polysilicon Wiring for Flexible Electronics,” Jun. 2022, doi: 10.1109/FLEPS53764.2022.9781554.

[5] C. Ghosh *et al.*, “Low-Profile Induced-Voltage Distance Ranger for Smart Contact Lenses,” *IEEE Trans. Biomed. Eng.*, 2020, doi: 10.1109/TBME.2020.3040161.

[6] E. Pourshaban *et al.*, “Flexible and Semi-Transparent Silicon Solar Cells as a Power Supply to Smart Contact Lenses,” *ACS Appl. Electron. Mater.*, Aug. 2022, doi: 10.1021/acsaelm.2c00665.

[7] E. Pourshaban *et al.*, “Eye Tear Activated Mg-Air Battery Driven by Natural Eye Blinking for Smart Contact Lenses,” *Adv. Mater. Technol.*, p. 2200518, Sep. 2022, doi: 10.1002/admt.202200518.