

## Abstract

In this paper, we describe a simple approach to the fabrication of a switchable multifocal lens for smart contact lenses or other compact devices. A combination of a multi-zone static multifocal lens with a liquid crystal based zone selector yields the desired optical behavior.

## 1. Introduction

Tunable lenses without moving parts have received a lot of attention in the last decade [1], with applications ranging from endoscopy [2] over smart phones to corrective eyewear [3]. Existing implementations include Fresnel-like or other circular grating-like diffractive optical elements in combination with a layer of liquid crystal (LC). The electrical tunability of the refractive index of the liquid crystal is used to generate a lens with tunable optical power. Although proven, the concept has a number of drawbacks. First of all, the tunability only works for one polarization of the light. That means that either a polarizer has to be added, thereby reducing the light transmission and increasing the thickness of the whole system, or a second component, whose preferred polarization is oriented perpendicularly to that of the first one, has to be stacked on top of it, also adding to the thickness as well as to the complexity of the system. Secondly, both the operating voltage and the response time of this type of components are higher than desired, due to the non-uniform LC layer thickness and the voltage drop across the thickest parts of the circular grating. Finally, the diffractive nature of the component can lead to severe color dispersion and the vertices of the Fresnel-like structures lead to scattering of light, manifesting itself as haze.

Other implementations are based on the so-called electrowetting effect or on piezo electric actuators. These approaches also work, but require very high voltage levels [4].

In this paper a much simpler implementation is proposed that can be used in active multifocal contact lenses.

## 2. Multi-zone lens

It is known from optics theory that a fragment of a broken lens still has the same functionality as the complete lens. We can use this to our advantage by composing a new lens from fragments of lenses with different optical power. In the simplest case, we can cut two lenses in half along a diameter and then combine one half of one lens with one half of the other, to come to a combined lens with 2 powers. Such a lens will have two focal lengths at the same

time, and when used in an imaging system, it will superimpose the images of both lenses. Passive multifocal contact lenses use this approach to help presbyopia patients. The brain filters out the unwanted image. Unfortunately, only 40% of all patients are able to get used to this type of lenses.

## 3. Zone selector

By integrating into the lens described in section 2 a light modulating liquid crystal device (2-pixel display in the simplest case) whose pixels coincide with the

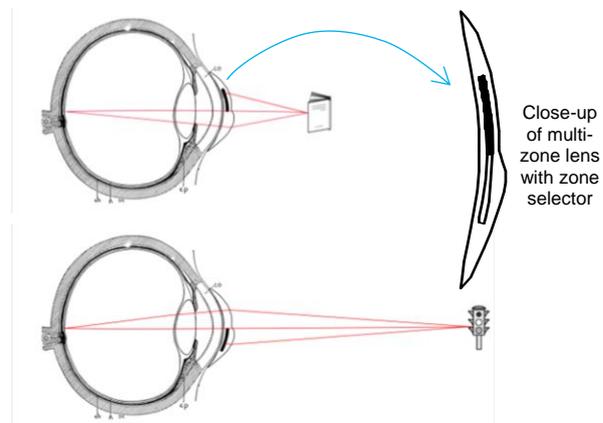


Figure 1: Bifocal contact lens with zone selector

different lens zones, it becomes possible to actively block the light crossing the undesired lens region. That way, the resulting image will only be formed by the 'correct' part of the lens. The system can be extended by having three or more lens zones with different power. To avoid the need for a polarizer, the guest-host liquid crystal mode can be used for the zone selector. This LC mode combines a moderate driving voltage with a sufficient modulation contrast, compatible with contact lens integration.

## 4. References

- [1] H-C Lin *et al.*, "A Review of Electrically Tunable Focusing Liquid Crystal Lenses" *Trans. Electr. Electron. Mater.*, 12(6), pp. 234-240 (2011)
- [2] T. Afentakis *et al.*, "Miniature adjustable-focus endoscope with a solid electrically tunable lens" *Optics Express* 23(16), pp. 20582-20592 (2015)
- [3] H-S Chen *et al.*, "Electrically Tunable Ophthalmic Lenses for Myopia and Presbyopia Using Liquid Crystals", *J. Mol. Cryst. and Liq. Cryst.* 596(1), pp. 88-96 (2014)
- [4] K. Mishra *et al.* "Optofluidic lens with tunable focal length and asphericity", *Scientific Reports* 4(6378) (2014)