Paper No: PZT-based transmissive liquid crystal lens approach

Oliver Willekens*, John George*, Kristiaan Neyts*, Jeroen Beeckman*
***Ghent University, dept. ELIS, Belgium; email: oliver.willekens@elis.ugent.be**

Abstract
We report the design and fabrication of an electro-optical tunable liquid-crystal-based lens and analysis of its performance. The lens obtains its GRIN profile from multi-electrode addressing using a layer with high dielectric constant to extend and smoothen out the horizontal electric field between the large interelectrode distances.

1. Introduction
Since their first report in 1979, many novel electrically tunable liquid crystal (LC) lenses have been proposed [1]. Most are plagued by the inherent polarization-dependence of the LC to induce the optical path differences required for a parabolic phase profile, but with the advent of blue phase LC (BPLC) this problem could also be addressed [2]. The structures can be categorized as either dual-electrode or multi-electrode designs. While the latter is more versatile, as defects can be compensated, the driving is more complex. To avoid fringe fields between the electrodes, several designs use a conductive material between the electrodes to generate a gradual potential drop. However, such devices draw a considerable current.

In this paper, we introduce an alternative technique for inducing a gradual voltage drop, by using a layer with a high dielectric constant, $\varepsilon_{\parallel}$, over the substrate containing the addressing electrodes. Such a structure has been proposed earlier [2], but, to our knowledge, this is the first report on its successful fabrication. This structure can be manufactured without using the relatively costly transparent conductor ITO and the power consumption is small.

2. Design and fabrication
LC-based electro-optic devices apply a non-uniform electric field over the liquid crystal to obtain a desired optical path length (OPL) profile. For a lens, the OPL profile should be parabolic. Such a profile could be obtained by using multiple electrodes in a vertical-field-switching (VFS) configuration. However, when the distance between these electrodes becomes large, the OPL deviates strongly from the desired profile. Our simulations show that these effects can be diminished by applying a layer of high dielectric constant over the electrodes.

Lead zirconate titanate (PZT) is an appropriate material and we have developed a deposition process by spincoating and annealing, which yields a dielectric constant of $\varepsilon_{\parallel}$ ~500 [3]. We deposited a PZT layer on top of an electrode design made by liftoff. The design consists of 8 metallic concentric rings that are separately addressable. After spincoating the PZT-layer over the electrode pattern, the substrate is pretreated with nylon and subsequently rubbed to set a preferential alignment direction for the LC. This substrate is glued together with another pre-treated glass substrate, with a homogeneous ITO layer acting as reference electrode. Both substrates are separated by 5.5µm spacers and the cavity is filled with the nematic LC mixture E7.

3. Results
Polarizing optical microscopy (POM) is used to analyze the effect of the PZT layer on the electric field distribution indirectly. **Figure 1** shows the observed POM images for the device with ring electrodes, with and without the PZT layer, using a green LED light source to simplify the analysis.

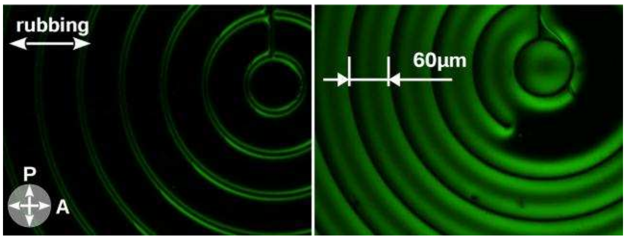

Figure 1: microscope images with crossed polarizers of a reference device (left) and a device with electrodes covered by 0.84µm PZT (right). The electrodes are all 3µm wide and spaced 60 µm apart; they are all at 5.1 V_{rms}.

The concentric electrodes are all at the same potential with respect to the ground electrode. The rubbing direction is parallel to the analyzer. Because of the mismatch between the rubbing direction and the radial fringe fields, the director does not only tilt with increasing voltage, but also twists, which is the reason why light is transmitted in this configuration.

A series of images was taken for the reference cell and PZT cell at different voltages. These images were then processed to obtain the radial intensity profile between two neighboring electrodes, as a function of the applied voltage, as shown in **Figure 2**. The comparison shows that PZT is able to bring the applied voltage difference across the gap: even halfway between two electrodes, the LC molecules are reoriented.

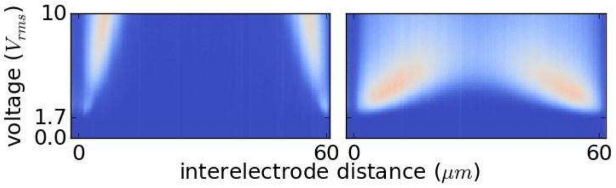

Figure 1: intensity profile between two neighboring electrodes for the reference lens (left) and the lens with PZT layer (right) at different voltages.

A smaller interelectrode distance, a thicker PZT layer or using a layer with an even higher dielectric constant would improve the homogeneity of the electric field and the light transmission.

4. Acknowledgements
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5. References
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