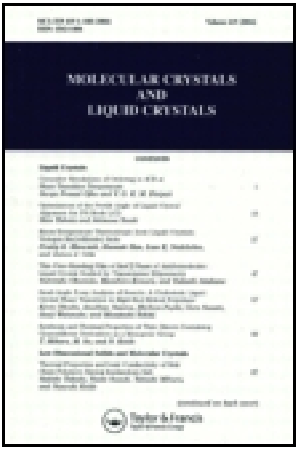

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

# Transient Properties During Positive-Negative Switching of Liquid Crystal Lens

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Version of record first published: 22 Sep 2010

*Mol. Cryst. Liq. Cryst.*, Vol. 480, pp. 44–48, 2008

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701821531



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*The properties of a liquid crystal lens with two thin liquid crystal layers are studied. By using two-voltage driving approach, the focus range is expanded by driving the liquid crystal cell working as not only a positive lens but also a negative lens. The evolution of the lens power during the switching between the positive and negative lenses is observed. The switching becomes fast when thin liquid crystal layers are used.*

**Keywords:** liquid crystal lens; stacked structure; transient property

Liquid crystal (LC) materials have large electrical and optical anisotropies, and they are widely used to fabricate electro-optic devices the optical properties of which are controllable electrically. LC lenses are made using LC materials. They have focal lengths tunable by applied voltages [1–10]. Recently, an LC lens driven by two voltages has been proposed [11]. The new drive method makes it possible to build fast LC lenses with stacked structure of thin LC layers [12], and lenses with both positive and negative power [13]. In this article, we report a two-LC-layer lens driven by two voltages via a new electrode structure. The lens power changing with applied voltages are measured. The power evolution of the lens during positive-negative switching is examined, and the switching times are measured.

The structure of the LC lens is shown in Figure 1(a). The cell consists of two LC (Merck E44) layers of 20-μm thickness. The two LC layers are separated by thin glass substrate 2 of 70-μm thickness.

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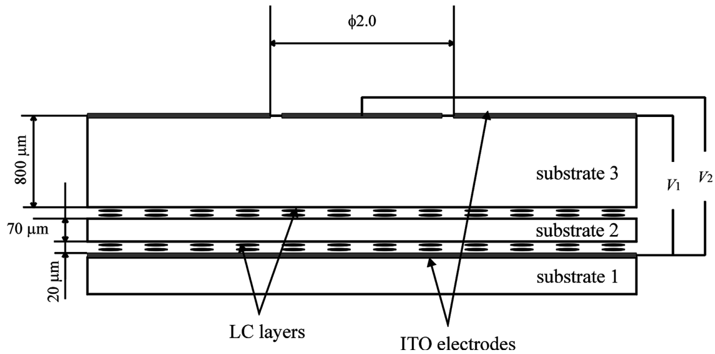


**FIGURE 1** Structure of LC lens cell.



The surfaces of the glass substrates confining the LC layers are coated with polyimide films that are rubbed with cloth to let the LC directors homogeneously align initially. The directors in the two layers pre-tilt to opposite directions. There are two transparent indium tin oxide (ITO) electrodes sputtered on glass substrates 1 and 3. The thickness of substrate 3 is 800 μm. The bottom ITO electrode is a uniform one, while the top one is patterned [14]. The patterned electrode consists of outer and inner parts. In the center of the outer part of the patterned electrode, there is a circular hole of 2.0-mm diameter. The inner part of circular shape of 1.92-mm diameter is concentric with the circular hole. A thin ITO line of 50-μm width lead the inner part to outside through a narrow slit of 130-μm width left in the outer part. One voltage $V_1$ across the outer part of the patterned ITO electrode and the bottom ITO electrode, and another voltage $V_2$ across the inner part and the bottom ITO electrode are applied on the cell.

The two voltages set up axially symmetrical but spatially nonuniform electric fields in the LC layers, which control the reorientations of the LC directors. When $V_1 > V_2$, the electric field in the LC layers decreases gradually from the edge to the center, and so does the reorientation of the LC directors. The refractive index seen by an incident light beam linearly polarized in the rubbing direction increases from the edge to the center and the wave-front of the light beam turns from plane to a bell-like form. The bell-like phase retardation at the center is the largest. With the geometrical structure of the cell and the voltage ranges in this work, the form of the phase retardation is close to the phase transformation of an optical positive lens, and the LC cell then behaves as a positive lens. When $V_1 < V_2$, on the other hand, the electric field increases from the edge to the center, and so does the reorientation of the LC directors. The light beam experiences a phase retardation that is the smallest at the center. The LC cell then behaves as a negative lens. So by adjusting $V_1$ and $V_2$, the LC cell can work as an LC lens with both positive and negative powers.

The two driving voltages $V_1$ and $V_2$ play in different ways in the cases of positive lens and negative lens. When the cell is driven to operate as a positive lens, $V_1$ is maintained at 170 $V_{rms}$ and $V_2$ varies from 10 to 170 $V_{rms}$ to tune the lens power. When it is driven as a negative lens, on the other hand, $V_2$ is maintained to 190 $V_{rms}$ and $V_1$ varies from 40 to 190 $V_{rms}$ to tune the power.

The lens properties are observed by an interference method [11] using a He-Ne laser source of 633-nm wavelength. Figure 2 shows the lens powers as functions of applied voltages. The controlling voltage $V$ in the figure represents $V_2$ and $V_1$ in the cases of the positive and negative lenses, respectively. The lens powers vary with the controlling voltages. In both cases of positive and negative lenses, the absolute values of the lens powers decrease monotonically with controlling voltages. A total power range of approximate 10.5 D is covered.

The transient behaviors during the switching between the positive lens at its largest power and the negative lens at its largest power are very important in many applications. The motions of the interference fringes after voltage switching are observed, as shown in Figure 3. The first row represents the evolution of the fringe patterns during



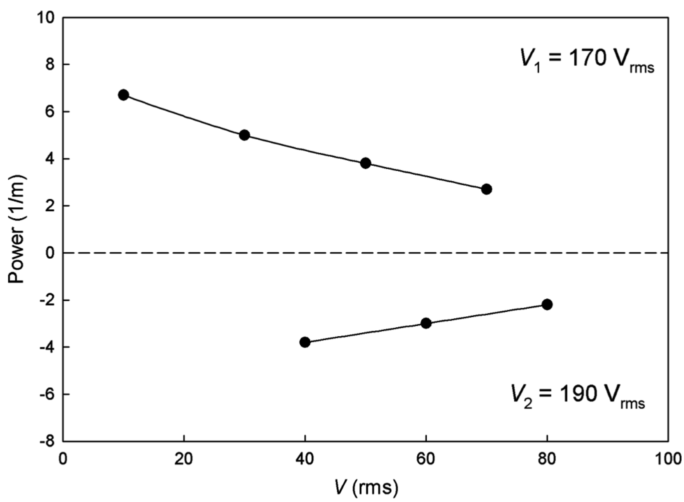


**FIGURE 2** Lens power changes with controlling voltage.

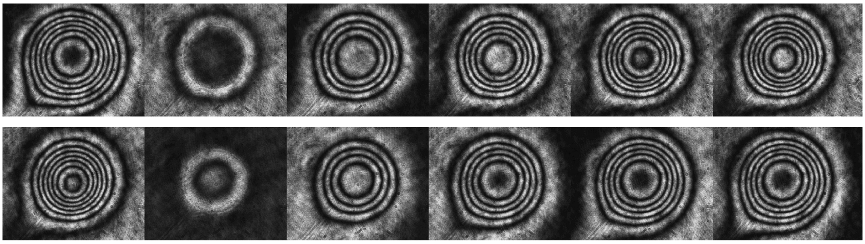


**FIGURE 3** Evolutions of fringe patterns.

the switching from the negative lens to the positive lens, and the second row that from the positive lens to the negative lens.

Figure 4 gives the power change during the switching. We define the switching time as the time needed to cover 90% of the total power range of 10.5 D. It is approximately 800 ms for the switching from negative lens to positive lens, and 300 ms for the switching from the positive lens to the negation lens.

In conclusion, an LC lens with stacked structure of thin LC layers is studied. A patterned electrode is designed for applying two voltages on the LC cell. The lens can be driven to work as both positive and negative lenses. The transient behaviors of the lens during the switching between positive and negative lenses are examined by observing evolution of the interference fringe pattern. The switching times are measured.

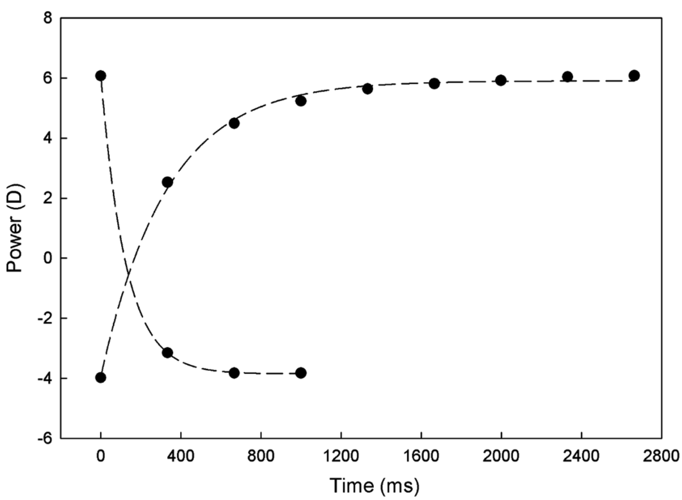


**FIGURE 4** Change of lens power with time during positive-negative switching.

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