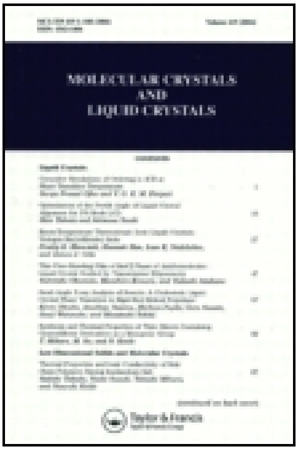

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Dynamic Behaviors of Directors in a Liquid Crystal Microlens

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Dynamic Behaviors of Directors in a Liquid Crystal Microlens

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A numerical simulation of the temporal evolution and spatial distribution of directors in a liquid crystal microlens with a hole-patterned electrode structure is given. We show that both splay and twist deformation initially start at the hole boundary, and at each side of the hole center in the rubbing direction the splay angle is opposite and the twist rotation at neighboring quadrant is in opposite direction

Keywords: liquid crystal microlens; splay angle; twist angle

1. INTRODUCTION

High-speed operations of liquid crystal (LC) optical devices are highly desired. Recently, responses or decays of LC microlenses[1] in only several milliseconds have been realized[2][3]. Until now, however, the knowledge of the process of molecular reorientation in a LC microlens is still not enough. A deep understanding of the dynamic behaviors of the directors is very necessary for fast LC microlenses' designs. In the present work the temporal evolution and spatial distribution of reorientation of the directors in a LC microlens when an external electrical field is turned on have been numerically worked out. The simulation technique is going to be applied to the development of new driving modes for high-speed operating LC microlenses.

2. Equations of Motion

The structure of a LC microlens is shown in Figure 1. There is a round hole on each of the two electrodes. The liquid crystal in the cell is initially homogeneously aligned. When an external voltage is applied, the directors in the hole region will be less rotated owing to the smaller electric field in the area. A quadratic bell-like phase profile will then develop, and the cell will therefore act as an optical lens.

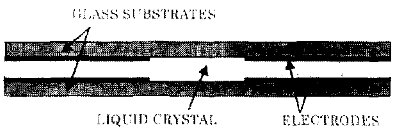

FIGURE 1. Structure of a LC microlens

The equations governing the motion of the director $\vec{n} = (n_x, n_y, n_z)$ and the distribution of electric field $\vec{E}$ are

$$-\frac{\partial f}{\partial n_\alpha} + \frac{\partial}{\partial \beta}\left[\frac{\partial f}{\partial(\frac{\partial n_\alpha}{\partial \beta})}\right] - \gamma_1 \frac{\partial n_\alpha}{\partial t} \qquad (1)$$

and

$$\nabla \cdot (\bar{\varepsilon} \cdot \vec{E}) = 0, \tag{2}$$

respectively, where α, β denote x, y, or z components, γ_1 one of the viscosity coefficients, and ε the dielectric constant. The free energy density

$$f = \frac{K}{2}[(\nabla \cdot \vec{n})^2 + (\vec{n} \cdot \nabla \times \vec{n})^2 + (\vec{n} \times \nabla \times \vec{n})^2] - \frac{1}{8\pi}(\bar{\varepsilon} \cdot \vec{E}) \cdot \vec{E}, \tag{3}$$

where K is the Frank elastic constant.

3. RESULTS

We apply these equations to the LC microlens and assume that the microlens has an infinite extension in the x and y directions. It is convenient to specify the director orientation by polar angles, defined by

$$\begin{aligned} n_x &= \cos\phi\cos\theta, \\ n_y &= \sin\phi\cos\theta, \\ n_z &= \sin\theta. \end{aligned} \tag{4}$$

where θ represents the splay deformation and ϕ the twist one. All quantities are expressed in natural units (Table 1), where d is the thickness of the cell and $\Delta\varepsilon$ the dielectric anisotropy. The applied voltage is $2V_c$ and the ratio of diameter and thickness is taken to be about 3. Material parameters of 5CB are used.

3.1. Splay deformation

Figure 2 shows the change of the reorientation splay angle θ of the directors in the central layer of a LC microlens. The directors at the hole boundary in the rubbing direction rotate first, and at each side of the hole center the directors rotate in opposite direction. The splay deformation in the area of hole boundary gradually spreads and finally fills the whole area of the cell. We can see that though the response of the directors far beyond the holes to the external electric field is rather slow, the expected distribution of reorientation in the hole region for lens operation is formed at comparatively early time stage. The lens effect takes place before the whole area of the cell becomes stable.

Quantity	**Unit**
Length	d
Time	$\tau = d^2\gamma_1/(\pi^2 K)$
Voltage	$V_c = (4\pi^3 K/\Delta\varepsilon)^{1/2}$

TABLE 1 Quantities and units

The above results can be understood physically. Due to the edge effect, there exist horizontal electrical components at the boundary of the holes, which drive the directors in this region rotating first. At the symmetrical positions with respect to the plane passing the centers of the holes and vertical to the rubbing direction, the electrical field distributes almost symmetrically. So the directors at each side are inclined to rotate in the opposite direction.

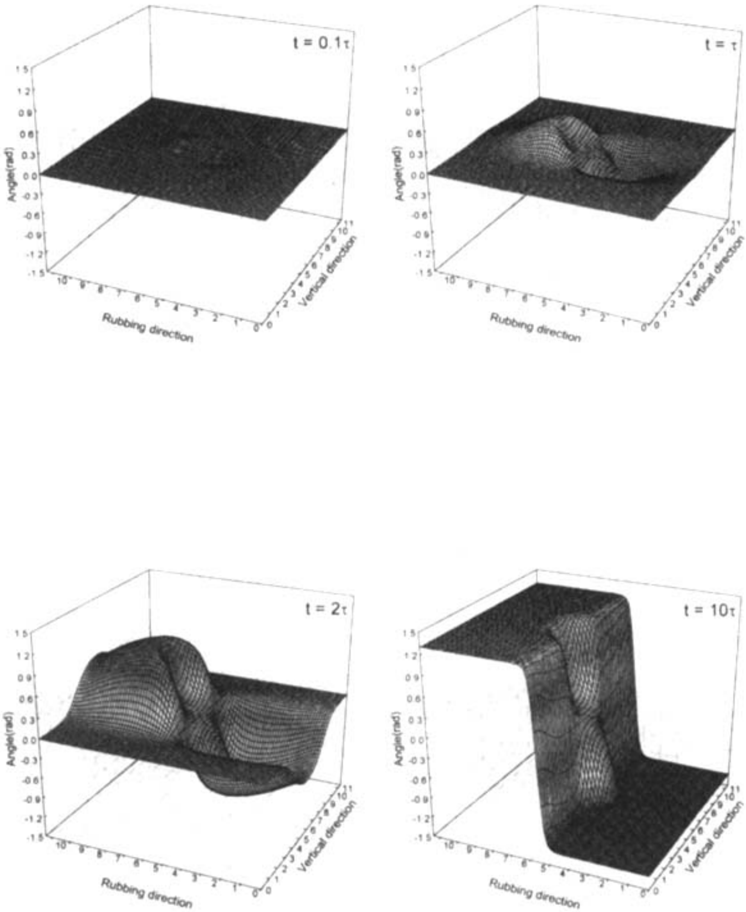

FIGURE 2. Time dependent distribution of splay angle

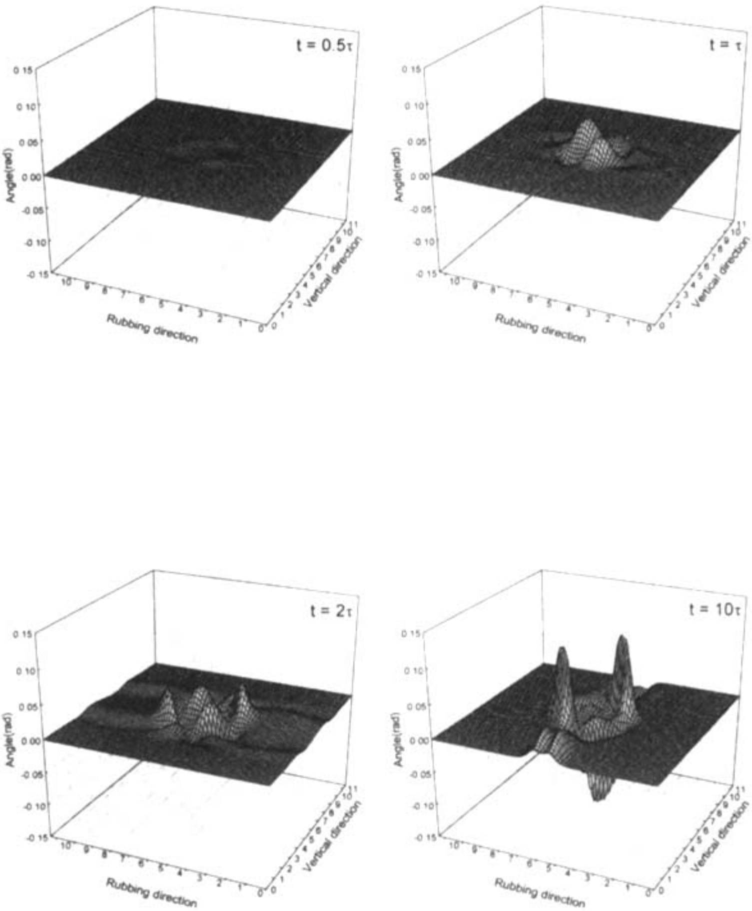

FIGURE 3. Time dependent distribution of twist angle

3.2. Twist deformation

The spatial distribution and temporal evolution of the angle ϕ of twist deformation are shown in Figure 3. The twist deformation first occurs also around the hole boundary, and is most active in the area. The directors at neighboring quadrant rotate in opposite direction.

The situation is similar to that in the splay deformation. There exist horizontal components of electric field only in area of the hole boundary and therefore the twist deformation is found largely in this area. The direction of twist rotation is clearly explained in Fig 4. The horizontal electrical field distributes almost symmetrically with respect to the hole center. The twist rotation tends to align the directors along the electrical field. So the directors in different quadrant rotate in the way shown in the Figure.

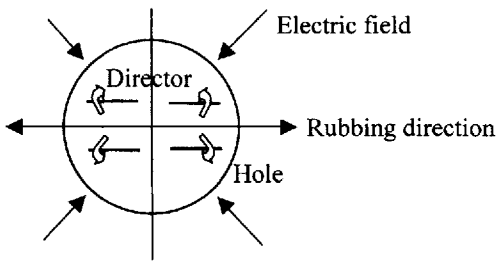

FIGURE 4. Direction of twist rotation

4. Conclusions

The splay deformation first occurs at the hole boundary in the rubbing direction. At each side the directors rotate in the opposite direction. The deformation gradually spreads from the hole boundary to the whole cell. The distribution of angle in the hole region for lens operation is formed before the whole area of the cell becomes stable. The twist deformation first occurs also around the hole boundary, and is most active in the area. The directors at neighboring quadrant rotate in the opposite direction.

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