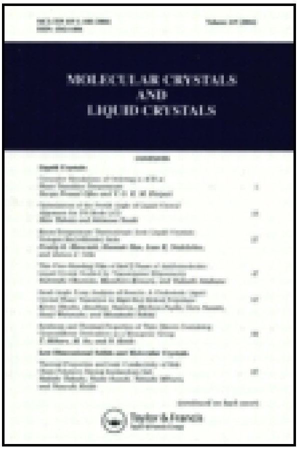


Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Optical Properties of Homogeneously- and Hibrid-Aligned Liquid Crystal Microlenses

Alexey Gvozdarev [a] & Galina Nevskaya [a]

[a] Novosibirsk State Technical University, K. Marxprosp. 20, Novosibirsk, 630092, Russia E-mail:

Version of record first published: 24 Sep 2006

Mol. Cryst. Liq. Cryst., 1999, Vol. 329, pp. 81-88
Reprints available directly from the publisher
Photocopying permitted by license only

Optical Properties of Homogeneously- and Hibrid-Aligned Liquid Crystal Microlenses

ALEXEY GVOZDAREV and GALINA NEVSKAYA

Russia, 630092, Novosibirsk, K. Marx prosp. 20, Novosibirsk State Technical University; E-mail: nevskaya@ref.nstu.ru

Optical properties of homogeneously- and hibrid-aligned liquid crystal (LC) microlenses with positive dielectric anisotropy have been researched. Focal distance-voltage dependencies have been obtained. When voltage is low the microlenses possess focusing optical properties. The focal distance is decreased with voltage increasing then it reaches a minimal value and is increased. At higher voltage defocusing optical properties are observed. The microlens focal distance decreases approximating asimptotically to the certain value. The focal length increase with microlens diameter and it is longer for hibrid-aligned LC-microlens compared to homogeneously-aligned one. The results of experiments agree qualitatively with the results of [1–3].

Keywords: liquid crystal microlens

INTRODUCTION

The construction of hibrid- and homogeneously-aligned liquid crystal microlens was offered by Japanise reseachers [1, 2]. They studied their electrooptical properties and showed that optical properties of both microlens types changed from focusing to defocusing when applied voltage increased (for LC with positive dielectric anisotropy). This effect is based on appearing nonuniform nematic director distribution at nonuniform electric field of LC-microlens (see the Figure1) Due to this nematic deformation there appears refractive index profile quadratically dependent on radial coordinate which is usual for lens. This phase profile can be varied by voltage applied to LC-microlens.

However there is no sufficient information about focal length-voltage dependencies. The presented paper is devoted to this problem.

EXPERIMENT

Liquid crystal microlens-cell has been manufactured by using a hole-patterned electrode and an In_2O_3 – coated counter electrode (see the Figure1). The hole-patterned electrode was made of thin chrome films deposited on a glass substrate and the hole-patterns were produced by means of photolithography. The diameters of holes L were 170, 370, 570 and 780 μm.

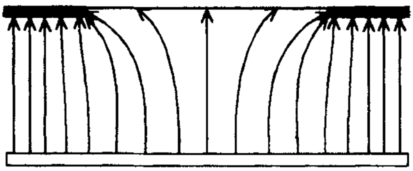


FIGURE 1. The non-uniform electrical field at the LC-microlens

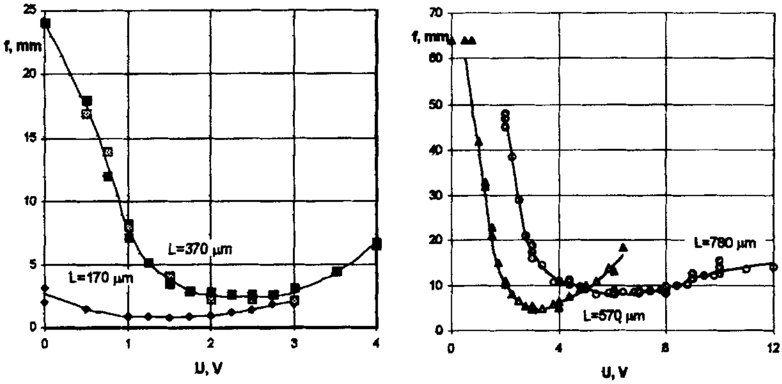
Microlenses with hibrid and homogeneous alignment were investigated. The homogeneous alignment was attained by rubbing polimer layer coated on the electrode surface. The thickness of LC-layer d was 120 μm for this experiment.The liquid crystal used for homogeneously-aligned LC-microlens possesses the following parameters:$\Delta\varepsilon$ = 9.8 (25 °C), Δn = 0.167 (20 °C).

Nematic liquid crystal *5CB* was placed in the cell with hibrid alignment. The homeotropical alignment was attained by means of coating the electrode surface by layer of $Cr(OH)Cl_2C_{17}H_{35}COOH$. The homogeneous alignment was attained by rubbing method. The thickness of LC-layer at LC-cell was 50 μm.

The ac voltage (2 kHz) was applied to electrodes. The investigations were carried out by means of a polarization microscope similar to [4]. The focal length was measured by using displacement of the microscope objective to obtain a clear image of a focal point.

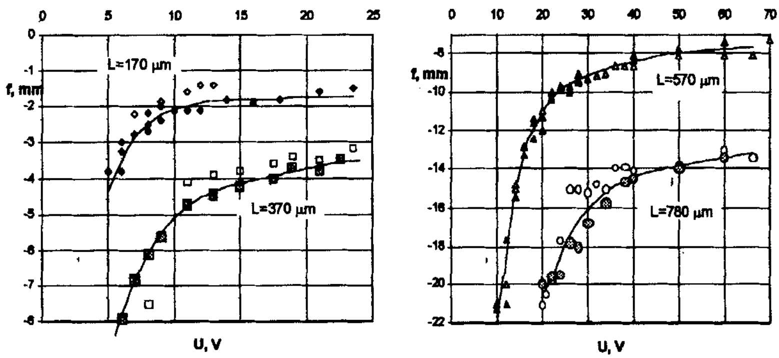
HOMOGENEOUSLY-ALIGNED LIQUID CRYSTAL MICROLENS

The experiments show that the optical properties of homogeneously-aligned liquid crystal microlens is varied from focusing properties to defocusing properties with voltage increasing.



a b

FIGURE 2 The dependence of homogeneously-aligned LC-microlens focal length on the voltage (the focusing properties): a – L=170, 370 µm, b – L=570, 780 µm.



a b

FIGURE 3 The dependence of homogeneously-aligned LC-microlens focal length on the voltage (the defocusing properties) : a – L=170, 370 µm, b – L=570, 780 µm.

When the voltage is low the LC-microlens possesses focusing properties for incoming light polarized parallel to rubbing direction. The dependencies of LC-microlens focal length on the voltage is shown on the Figure 2a-b. When the voltage increases the focal length decreases reaching a minimal value at certain voltage and then it increases. The focal length is longer for LC-microlens with large diameter.

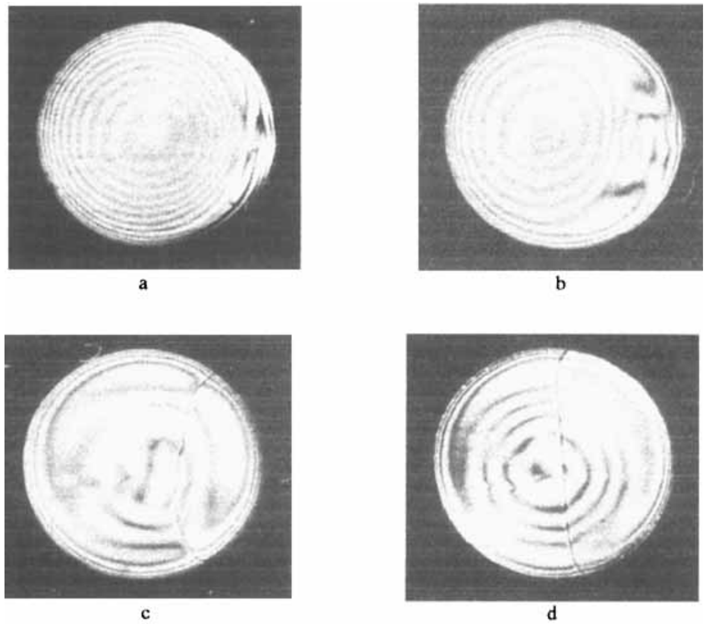


FIGURE 4 The interference pattern of homogeneously-aligned LC-microlens (L=370 μm) observed through polarization microscope at various voltages: a – 3V, b – 4V, c – 8V, d – 30V.

When voltage is low the molecules of liquid crystal are reoriented only around the edge of the hole. The director deformation is magnified with voltage increasing and the phase profile depth grows also. However the molecules of LC at the hole center save the initial orientation. As a result a curvature of phase profile increases and the focal distanse decreases. The reorientation at the center of microlens appears at higher voltage. The focal distance start to increase and the phase profile depth is reduced.

The best optical properties are observed at the voltage corresponding to descending curve of focal length - voltage graph $f(U)$. The optical properties are worsed due to appearing "collapse" at the phase profile of microlens. This "collapse" can be seen on the right side of the interference patterns that are shown on the Figure 4 a–b. It can be seen that its influence is magnified with voltage increasing, the center of interference circles shifts from the microlens center and the depth of phase profile decreases.

A disclination line oriented perpendicularly to rubbing direction appeares in microlens at the voltage when optical properties of microlens transform from focusing properties to defocusing ones (see the Figure 4c). The voltage of disclination appearing depend on the microlens diameter and the quality of alignment at the microlens. This disclination line does not worse the focusing optical properties of LC-microlens despite of results obtained by Japanise researchers[2]. Furthemore the disclination line is not observed at the smallest LC-microlens (L=170 μm).

The defocusing properties of LC-microlens are observed at the more high voltages (see Figures 3, 4d). The focal length decreases with voltage increasing stabilizing at the high voltages. The voltage at which focusing properties change to defocusing properties is higher for LC-microlens with large value of L/d (where d is the thickness of LC-layer).

HIBRID-ALIGNED LIQUID CRYSTAL MICROLENS

The experiment shows that focal distance is decreased with voltage increasing then it reaches a minimal value and is increased. The Figure 5 shows this dependence. As it can be seen smaller optical strength is observed at microlens with greater diameter. It is caused by smaller nonuniformity of electrical field at these microlenses. The diameter of microlens is very small therefore the microlens properties are anologous to Fresnel plate with one Fresnel zone. Due to diffraction effects the microlens focuses (and defocuses) a light when the voltage isn't even applied. But optical quality is not too good in this case and it becomes much better when the voltage is applied.

The second focus is observed at microlenses with diameters equal to 570 and 780 μm when voltage exceeds certain value. The dependencies of its focal distance on voltage are shown on Figure 5 also by transparent triangles and circles. It is possible that the second focus is caused by microlens astigmatism appearing due to difference of nematic deformations at plane parallel to rubbing direction and across it. The deformation at the section along rubbing direction is different from deformation at the plane across this direction. Twist deformation is absent in the first case but it plays a important role in the second case. Twist deformation requires the lowest voltage to appear compared to other types of deformation. Therefore the deformation appeas first when electrical field is directed across rubbing direction.

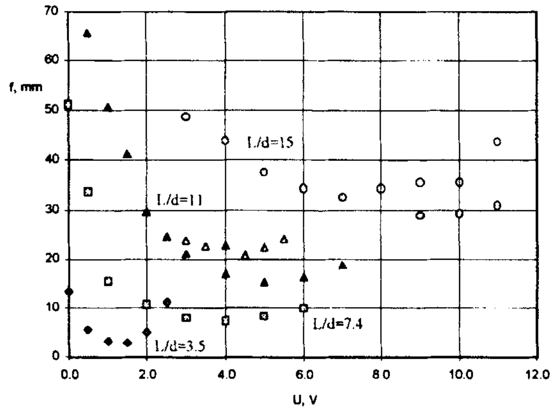


FIGURE 5 The dependencies of hibrid-aligned LC-microlens focal distance on the voltage.

Figure 6 shows interference pattern of microlens with diameter equal to 570 μm at different voltages. Nematic molecules reorientation starts at region where electric field is directed across the rubbing direction and then it expands to all edge of microlens (see Figure 6a). The phase profile depth increases and reorientation region extends to hole center and "collapse" is formed on interference picture near the hole edge when voltage reaches 2V (see Figure 6b). The similar phenomena were observed in the experiments of Nose et al [2]. The structure of beam passed through microlens is changed and the part of light begins to defocus. One of defocusing structures is caused by "collapse", other is connected to hole edge. The deformation begins at microlens center at voltage equal to 3V. The radius of interference rings becomes smaller and the depth of phase profile begins to decrease. The figure 6c shows the interference pattern at U=5V.

When voltage is high the microlens possesses defocusing properties. Figure 6d shows interference pattern at 30 V. The conoscopical cross usual for diverging lens appears at microlens. The phase profile is stabilized with voltage increasing. It is caused by the fact that molecules of LC being oriented significantly along electric field and configuration of it is slightly dependent on voltage. Experiments show that the point image quality is higher at the homogeneously-aligned LC-microlens. It is possible it is caused by small phase profile depth at the hibrid aligned LC-microlens.

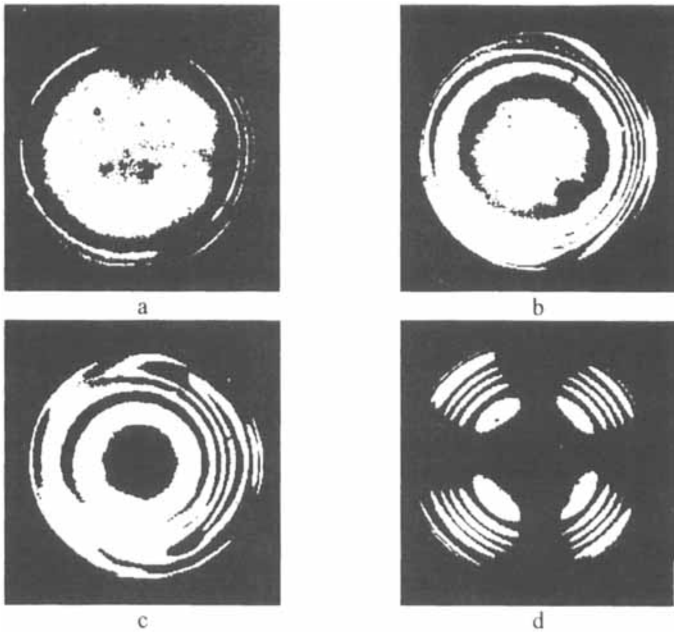


FIGURE 6 Interference patterns of hibrid-aligned LC-microlens at different voltages (L=570 μm, d=50 μm): a – 1V, b – 2V, c – 5V, d – 30V.

The similar interference pictures are observed at different microlenses and voltages at which similar pattern is observed depend on microlens diameter linearly. Consequently this voltage is defined by radial component of electric field.

The comparision of Figures 4 and 6 show that the transformation of interference pattern is similar for both microlens types but there is the disclination line at the homogeneously-aligned LC-microlens and the phase profile depth of hibrid aligment case is smaller.

SUMMARY

Our experiments confirm the results of Japanise researchers[1-3] qualitatively. It is shown that LC-microlens of both types with positive dielectric anisotropy possesses focusing properties at small voltages and defocusing ones at high voltages.

The focal length-voltage dependencies are similar for both types of LC-microlens. The focal distance decreases with voltage increasing then becomes minimal and increases. The inversion of optical properties is observed at the more high voltage. The focal distance of microlens increases with the diameter increasing also.

The dependence of defocusing properties on the voltage have been researched for the first time. The focal distance appeared to decrease with voltage increasing and approximate to constant value. The voltage when focusing properties changes to defocusing properties increases with lens diameter.

The conclusion can be made that optical properties of homogeneously-aligned LC-microlens is better compared to hibrid-aligned microlens. The numerical aperture of hibrid-aligned microlens doesn't exceed a value 0.06 (for microlens with L=170 μm). Such low value is caused by the fact that phase profile at this microlenses is formed by the part of LC-layer near the substrate with homogeneous alignment only. The numerical aperture of homogeneously-aligned LC-microlens reaches the value equal to 0.21. Note that this value exceeds slightly the numerical aperture maximal value of LC-microlens with holes at both substrates[5].

The disclination line does not worse the focusing optical properties of LC-microlens because it appeares in the microlens at the middle voltage when the optical properties of microlens transform from focusing properties to defocusing ones.

Furthemore our experiments show that the point image quality is higher at the homogeneously-aligned LC-microlens at the high voltage.

Thus the investigation of homogeneously-aligned LC-microlens properties can be perspective in the future.

References

[1] T. Nose, S. Sato, *Liquid Crystals,* **5,** 1425 (1989).
[2] T. Nose, S. Masuda, S. Sato, *Mol. Cryst. Liq. Cryst.,* **199,** 27–35, (1991).
[3] T. Nose, S. Sato, *Electronics and Communications in Japan,* part 2, **75,** No. 11, (1992).
[4] A. Gvozdarev, G. E. Nevskaya, *Mol. Cryst. Liq. Cryst.,* **304,** 423–428, (1997).
[5] S. Masuda, S. Fujioka, M. Honma, T. Nose, S. Sato, *Jpn. J. Appl. Phys.,* **31,** 4668–4672, (1996).