ISSN : 2393-8188 (print)
2393-8196 (online)
www.milliyasrcollege.org.journal.php

ELECTRICALLY TUNABLE LIQUID CRYSTAL LENSES

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ABSTRACT

Electrically controlled Liquid Crystal (LC) lens cell having variable focusing properties is demonstrated by sandwiching a homogeneous LC layer between a parallel electrode structure. MBBA, a Nematic LC is used as lens material. The lens has large tunable range of focal length. Cell geometry, experimental setup and optical performance of the lens cell are discussed.

Keywords: Liquid crystals, director, liquid crystal lens, variable focusing.

1. INTRODUCTION

Liquid crystals (lcs) typically consisting of elongated, rod-like organic molecules with a size of a few nanometres are mesophases between crystalline solids and isotropic liquids, and shares properties of the both. LCs are materials with unique physical, optical and electro-optical properties. Applications of LCs is a well matured and developed area, but there are many other exciting possibilities are yet to be explored and remains as a challenge in the basic science and engineering. Depending on the phenomenon exhibited, LCs are categorized as Thermotropic, Smectic, Nematic or cholesteric. Smectic phases are distinguished by their stratified molecular arrangement in one dimension.[1,2,3]. Nematic liquid crystals are fluid phases found by anisometric molecules which, though free to rotate as in ordinary liquids, are preferentially aligned along a common axis, called director. When an incident plane wave propagates in LC experiences lens like phase difference due to the distribution of orientations of LC directors. The wave front of the incident plane wave is then bent as a converging or a diverging spherical wave.

Liquid-crystal lenses have long been considered as potential candidate for replacing or simplifying bulky conventional optics. Their advantages include tunable power, small size, low cost, low power consumption, and high-speed switching. Such lenses are likely to have a tremendous impact on future optical system designs. Tunability of LC lens is achieved electrically without any mechanical movement. The major technical challenge of LC lens is to create a smooth gradient refractive index distribution. Homogeneous and in-homogeneous LC-lens can generate a great index distribution by fabricated lens profile in the LC cell. However, the complex structure becomes an issue for practical application. Low power consumption and the thinness of LC lenses are promising features to be exploited for applying in portable devices

2. PRINCIPLE OF LC LENS

LCs have rod like structure. Figures 1(a-c) show the electrically tuneable refractive indices of the LC cell. The application of electric field (E) results in a torque to the induced dipole moment of the LC molecules and change the orientations of LCs, as shown in Fig. 1(b). The LC molecules remain parallel to the electric field at a high electric field, as shown in Fig. 1(c).

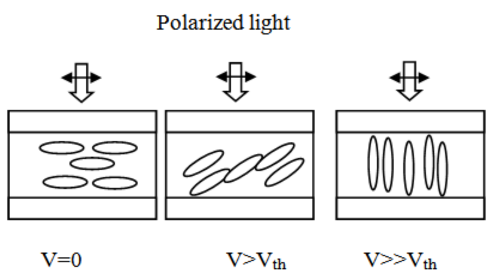

***Fig.* 1** *Electrically tunaable refractive indices of LCs*

When the polarization of incident light is x-linearly polarized, the effective refractive index (η_{eff}) can be expressed as[4,5]

$$\eta_{eff} = n_e n_o /(n_o^2 \cos^2\theta + n_e^2 \sin^2\theta)^{1/2} \quad (1)$$

where θ is the tilt angle between the LC directors and the polarization of the incident light, n_e and n_o are the extraordinary and the ordinary refractive indices of LCs respectively. The effective refractive index changes from n_e to n_o as the tilt angle increases by applying electric fields. The focal length (f) of converging and diverging lenses are easily shown to be given by

$$f^{-1} = \Delta n\, q^2 dA(1-V_{th}^2/V^2) \quad (2)$$

where q is the wave vector for periodic distortion along x axis, Δn the birefringence, d the sample thickness and A is the material constant . Hence the focal power f^{-1} is expressed to vary as the dimensionless control parameter

$$\varepsilon = (V^2-V_{th}^2)/V^2. \quad (3)$$

3. DESIGN OF LC BASED LENS

There are various methods for preparing liquid crystal lens cells. Different types of electrodes designs e.g., curved electrode, hole patterned etc. have been reported. Figure 2 shows the structure of the LC lens with parallel electrodes.

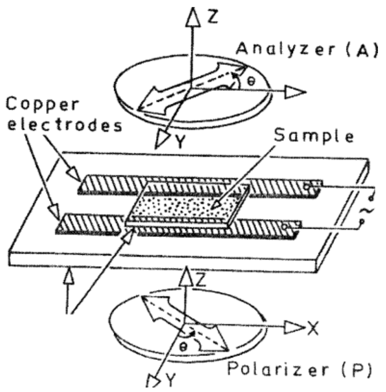

Fig. 2 *LC lens geometry*

Two copper electrodes pasted with adhesive on glass plate with thickness appx 100 µm and separated by a distance of 1 mm are used. A thin layer of Liquid crystal (MBBA) placed in between two electrodes and thin cover slip gently placed on it as shown in fig. 2.

4. EXPERIMENTAL SETUP

Setup to study the optical performance of the LC lens consists of optical polarizing microscope with a special objective of 10X is illuminated with mercury lamp. It has rotating , ceramic-coated stage and 3-gear focus drive with individual torque adjustment and stage height stop. Leica camera is fitted at the top to take the photographs. Primarily, optical polarizing microscopy enables the identification of the type of the liquid crystal and other mesophases from the optical texture that is generated[4]. However, the technique is also essential when evaluating the physical properties of liquid crystals in certain phases and its applications.

5. RESULT AND DISCUSSION

An ac electric field was applied across the cell and the observations were made in transmitted light using Leica polarizing microscope. For interferometric studies, the sample was placed between crossed polarizer in diagonal position and was viewed in mercury green light for ac fields at 50 Hz. For the distorted convective LC here, we measured the focal length corresponding to virtual images as a function of the electric field intensity, using the Vernier on the vertical stage of the microscope.

The experiment results of focal power and its controlling parameter is shown in Fig. 3. It shows a non linear scalling of f^{-1} with control parameter. For lower values of control parameter, f^{-1} changes almost linearly[6,7].

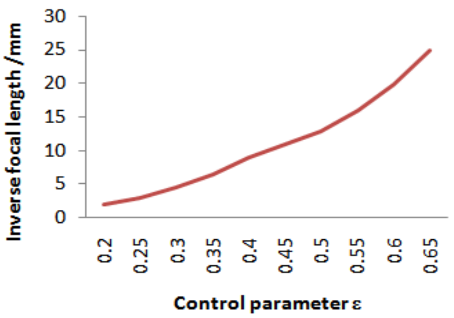

Fig. 3 *Focal power as function of control parameter for virtual images.*

The micro texture of different focusing which was taken with leica make CCD camera are shown in fig. 4. Virtual lines are even finer with rise in voltage. Similar phenomena were observed for real ones but not uniformly.

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(a)

(b)

(c)

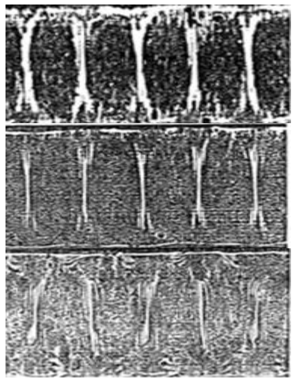

Fig. 4 *Focal lines produced by the LC lenses in electrically distorted homeotropic regions of MBBA in the transverse geometry. Virtual images (a-c). Voltages and focal lengths are (a) 57 V,600 µm (b) 62 V, 275 µm (c) 72 V, 70 µm.*

CONCLUSION

With the advantages of variable power, small size and weight, low cost and power consumption, liquid-crystal lenses will be very useful in portable devices, requiring variable focus or zoom within a limited space. Stacking of several layers of these cells is possible to achieve high optical power and for polarization independence. In many photonic applications like electrically tunable focusing pico projection system, the electrically tunable optical zoom system can be achieved by LC lenses. A new type of lens could make the batteries in smartphone and tablet last longer, and it's based on liquid crystal. It could be used in all applications that need a small lens, like endoscopy and beam shaping for lasers where it can be changed the shape of the laser beam by tuning the lens. Another example is fibre optic communications. To put light in an optical fibre, it needs to focus the light on the end of the fibre, so it can be useful to have a small tunable lens that can be used to redirect the light. However a lot of research is yet to be done to make the design commercially viable.

ACKNOWLEDGEMENT

The Authors acknowledge the Commandant, College of Military Engineering, Pune for constant encouragement in research work.

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