Photonics 2014: 12th International Conference on Fiber Optics and Photonics © OSA 2014

Realization of an Electrically-Controlled Optical Switch Using Nematic Liquid Crystal Core Waveguide

Mukesh Sharma, Aloka Sinha, M.R. Shenoy

Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110 016, INDIA
Author email address: (mukeshnice@gmail.com, aloka@ physics.iitd.ac.in, mrshenoy@physics.iitd.ac.in)

Abstract: We report fabrication and characterization of a nematic liquid crystal waveguide on an ITO coated glass substrate, which behaves as an electrically-controlled optical switch with a small threshold voltage of 1 V.

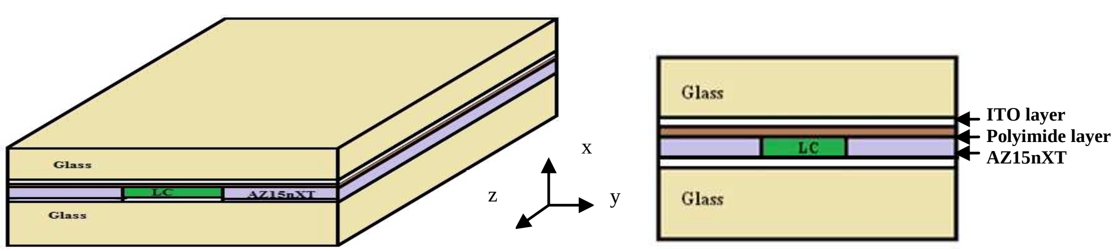
OCIS codes: (230.3720) Liquid-crystal devices, (130.4815) Optical switching devices, (230.2090) Electro-optical devices.

1. Introduction

Liquid crystals (LCs) are widely used in display technology [1]. Several properties of LCs such as high birefringence, high transmission and low absorption in the visible and near infrared wavelength region, and large electrooptic effect, low driving power and low power consumption also make them a promising material to fabricate many integrated optical devices like planar and channel waveguides, optical switches, attenuators and polarization controllers which are useful in fiber optic communication systems [2]. LC based optical switches do not need mechanical moving components and therefore they have longer lifetime, less power consumption and lower cost. Donisi *et al.* [3] proposed an optical switch by infiltrating the LC E7 in to an optical waveguide on silicon substrate. However, the waveguide requires high threshold voltage for light propagation, and exhibits higher coupling losses. Maksimochkin *et al.* [4] reported electrically-controlled switching of light beams in the plane of liquid crystal layer. These structures were complex in shape and their fabrication process was at high cost, and guidance of wave inside the liquid crystal required high voltages, and also showed lower switching response in terms of light intensity. In this paper, we demonstrate an optical switch using light guidance in a simple electro-optically controlled LC core waveguide geometry, fabricated on a glass substrate. The design, fabrication process and the effect of applied electric field on light propagation are presented.

2. Design and Fabrication

Schematic diagram of the proposed waveguide device structure and the transverse section are shown in Figs. 1(a) and (b), respectively. The nematic liquid crystal 5CB (4-Cyano-4'-pentylbiphenyl), obtained from Sigma-Aldrich, USA, is used as waveguide core material and indium tin oxide (ITO) coated glass plates are used as upper and lower substrate materials. The ordinary (n_o) and extraordinary (n_e) refractive indices of the LC (at wavelength of 633 nm) are 1.53 and 1.71, respectively; the design parameters for the LC waveguide are $n_{ucl} = n_{lcl} = 1.51$, where n_{ucl} and n_{lcl} are the refractive indices of the upper and lower ITO coated glass plates [1]. The fabricated waveguide structure is a rectangular waveguide with a guiding layer of thickness 4.8µm and width 2mm, respectively. For fabrication of the rectangular core region, a negative photoresist, AZ 15nXT (Microchemicals, Germany) is first spin-coated on the bottom ITO glass substrate, which is followed by UV exposure and then developed to realize the rectangular channel. The photoresist layer determines the thickness of the waveguide.



(a) (b)

Fig.1 (a) Schematic of the LC waveguide (b) Transverse section of the LC waveguide

A polyimide layer is spin-coated over the upper ITO coated glass substrate and is rubbed along the direction of the channel for homogeneous alignment of the liquid crystal. It is then placed on the photoresist layer and the channel is filled with the liquid crystal. The top and bottom ITO glass substrates are used as electrodes to apply electric field to the waveguiding liquid crystal layer. The voltage applied to the electrodes is in the transverse direction to the aligned LC layer. Since the width of the waveguide is much longer than the thickness, the structure essentially behaves like a planar waveguide. The number of modes supported by the waveguide depends on the V-parameter of the waveguide. The V-parameter of a symmetric planar waveguide is given by [5]

$$V = \frac{2\pi d}{\lambda}(n_1^2 - n_2^2)^{1/2} \quad (1)$$

Where 'd' is the thickness of the waveguide, λ is the operating wavelength, 'n_1'and 'n_2' are the refractive indices of the LC core and the glass plate cladding, respectively. Nematic LCs are uniaxial crystals and hence they have two refractive indices, $n_x = n_y = n_o$ and $n_z = n_e$; $n_e \equiv n_e(\theta)$, where θ is the orientation angle with respect to the direction of propagation of light. The orientations of the LCs can be controlled by applying voltage [1]. The V-parameter value, using eq. (1), are calculated as $V \approx 2.52$ for n_o and $V \approx 8.22$ for n_e. Thus, the LC waveguide supports only single mode propagation when the light sees ordinary refractive index and supports three modes when the light sees extraordinary refractive index, the implications of which is discussed in Sec.4.

3. Experiment

The schematic of the experimental setup is shown in Fig. 2. In the experiment, a He-Ne laser is used as the light source at the wavelength of 632.8 nm; a single mode fiber (SM600, NA=0.13,4.3/125 µm, length =12 cm) is used to couple light into the LC optical waveguide by the butt-coupling technique. The output of the waveguide was collected by a 20 X microscopic objective and focused on to a CCD Camera (Lumenera Infinity 2.0, 1616x1216 pixels) which is interfaced with a computer for mode field analysis. To measure the output power, the CCD camera was replaced by a photodetector connected to an optical power meter. In order to observe the light propagation inside the waveguide, the CCD camera was setup above the LC waveguide. A square voltage signal of frequency 1 kHz is applied across the upper and lower electrodes of the waveguide.

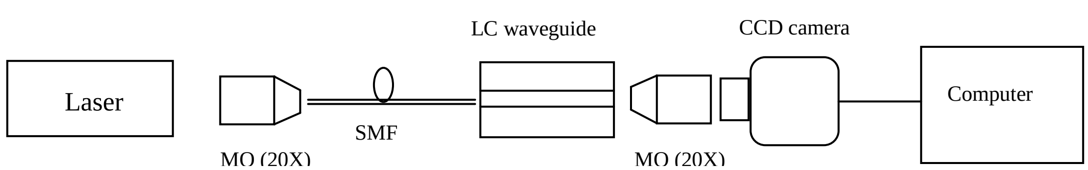
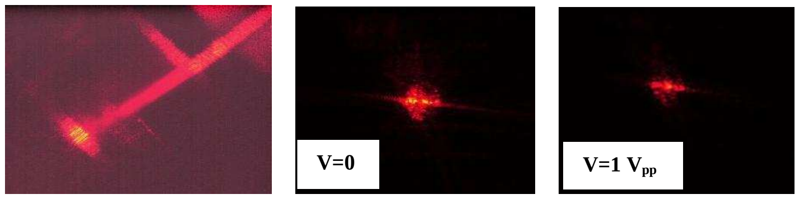


Fig.2. Schematic diagram of the experimental setup; SMF: single mode fiber; MO: microscope objective

4. Results and Discussions

In the experiment, the light guidance and switching properties due to an applied electric field are studied. Initially, the light is guided inside the liquid crystal core waveguide as can be seen in Fig. 3(a) because n_o of the core layer is more than the top and bottom glass plates. In this case the output power of the waveguide is maximum, since the fundamental mode of the optical fiber excites the TE_0/TM_0 modes with good coupling efficiency. But in the presence of electric field, the LC molecules re-orient in the direction of the field. The vertically polarized input light would see the extraordinary refractive index, and the resultant V-parameter increases to 8.22. This waveguide then supports three TE/TM modes, while the horizontally polarized light would continue to see the ordinary refractive index, and therefore would support only one mode.

Light from an unpolarized laser is coupled through the single mode fiber to the LC waveguide. Figs.3 (b) and (c) show the output power variation with respect to applied voltage when input (unpolarized) laser light is coupled from the fiber to the LC waveguide. The output light intensity is reduced significantly for an applied voltage of $V=1\ V_{pp}$ as shown in Fig 3 (c). The unpolarized light has both horizontal and vertical polarization components. At $V=1V_{pp}$, the waveguide still propagates single mode for horizontal polarization, while it becomes multimoded for vertical polarization. The two polarization components see two different refractive indices, one polarization component will couple strongly and the other polarization component is weakly coupled. The coupled power in the vertical polarization is distributed among the three modes, and the resultant overlap would be lower and the output power of the LC waveguide is also reduced. The output power variation with applied voltage is shown in Fig.4. As can be seen from the figure output drops sharply when the applied voltage exceeds 1 $V_{pp.}$ Thus, optical switching is possible in this LC waveguide at low applied threshold voltage of 1 V_{pp}.



(a) (b) (c)

Fig .3 (a) Light guidance inside the LC waveguide, output power (b) when applied voltage is zero (c) when applied voltage V=1V_{pp}

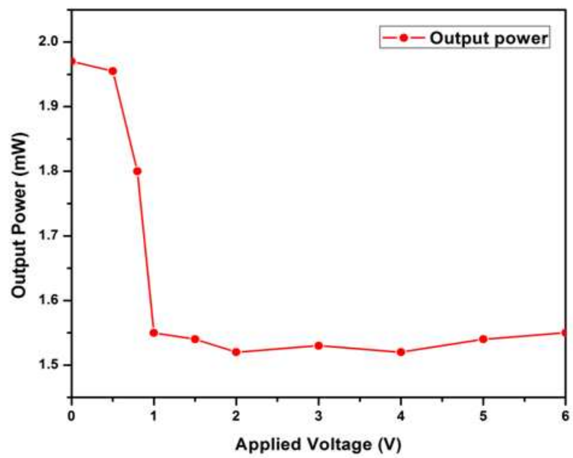


Fig.4. Output power variation of LC waveguide when input light is unpolarized light; at V=1V_{pp} waveguide works as optical switch

5. Conclusion

An optical switch in nematic LC core waveguide geometry on glass substrate is demonstrated using a simple fabrication process. It is experimentally shown that with the application of voltage up to 1$V_{pp,}$ the refractive index distribution of the LC changes due to the reorientation of LC molecules. This results in a change in the V-parameter of the waveguide, and the single mode waveguide becomes a multimode waveguide. The proposed structure has advantages of simple fabrication process at lower cost and low operating voltage of 1V_{pp} which are useful in the future for mass production of LC waveguide based devices for fiber optic communication applications.

References

[1] I. C. Khoo, “Liquid Crystals,” ed. (Wiley and Sons, New York. 2007).

[2] D. C. Zografopoulos, R. Asquini, E. E. Kriezis, A. d’Alessandro and R. Beccherelli, “Guided wave liquid crystal photonics,” Lab Chip **12**, 3598-3610 (2012).

[3] D. Donisi, B. Bellini, R. Beccherelli, R. Asquini, G. Gilardi, M. Trotta and A. d’Alessandro, “A switchable liquid crystals optical channel waveguide on silicon,” IEEE J. Quantum Electron., **46** (5), 762-768 (2010).

[4] A. G. Maksimochkin, S. V. Pasechnik, G. I. Maksimochkin and V. G. Chigrinov, “Electrically controlled waveguide mode in LC layer for fiber optic applications,” Opt. Comm., **283**, 3136-3141(2010).

[5] A. K. Ghatak and K. Thyagarajan, “Optical Electronics,” (Cambridge University Press, Cambridge. 2011).