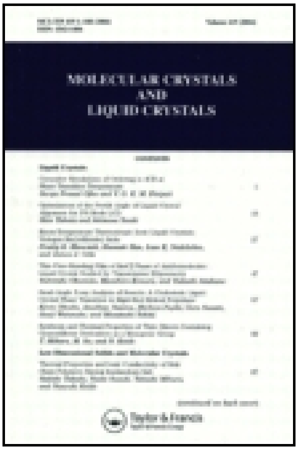

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Waveguide Based Liquid Crystal Display

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Waveguide Based Liquid Crystal Display

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Instead of using polarizers to control light intensity, high optical efficiency is obtained by using a liquid crystal to switch light out of a waveguide. Wide viewing angle is obtained by using a scattering screen.

Keywords: waveguide; liquid crystal; display

INTRODUCTION

Liquid crystal displays (LCDs) typically consist of a backlight, polarizers and a liquid crystal cell driven by an addressing matrix. LCDs have several advantages over other displays: they are compact, lightweight with low power consumption. However, in the past, their shortcomings included low brightness, limited viewing angles, low contrast and small display size. Progress has been made recently in a number of areas which enhance the LCD technology, such as in plane switching, compensation film and bistable, reflective technologies [1]. In this paper, we introduce a novel waveguide based LCD (WGLCD), which uses total internal reflection between the liquid crystal and one substrate rather than birefringence between crossed polarizers. In our scheme, the thickness of the LC cell is less critically important. A waveguide with edge-lighting is used both as a backlight and a substrate. Without polarizers, most of the unused light is retained in the waveguide, resulting in high optical efficiency. A second substrate is used as a scattering screen to give the display a wide viewing angle. Various liquid crystals and configurations can be used between the substrates to serve as an optical switch. Here we concentrate on nematic liquid crystals with twist or hybrid configurations. We present the results of numerical simulations and experiments, where contrast ratio of 174:1 has been achieved. Due to its simple structure, high optical efficiency and wide viewing angle, this scheme may be useful for display applications.

OVERVIEW OF WGLCD

Fig. 1 illustrates the structure of the WGLCD. It consists of 11 components. Without an applied voltage, the condition for total internal reflection is maintained at the LC and the waveguide substrate interface, and light propagates in the waveguide. When a selected pixel is turned ON by the applied voltage, there is no longer internal total reflection at this pixel, and light 'leaks' into the liquid crystal layer, from where it reaches the scattering layer and is scattered in different directions.

Liquid crystal materials and alignment

Various liquid crystals can be used in this type of display; here we consider only nematics. The nematic should have an ordinary refractive index n_o smaller than that of the substrates and an extraordinary index n_e near or a slightly greater than that of the substrates, so that the total internal reflection condition is maintained in the OFF-state. The alignment layers should provide a twist or hybrid configuration with the easy axis along the light propagation direction on the back substrate. The required thickness of LC layer should be much greater than the distance for the decay of the evanescent wave, which depends on the light propagation direction and the difference of the refractive index n_o of the LC and n_s of the waveguide substrate. The thickness is not critically important once it exceeds this required value, uniform thickness is therefore not a key requirement.

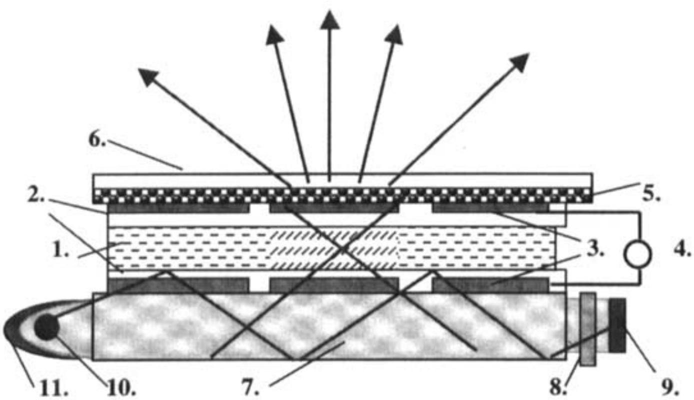


FIGURE 1. Components of WGLCD
1. LC layer. 2. Alignment layer. 3. Addressing layer.
4. Addressing circuit. 5. Scattering layer. 6. Top cover.
7. Waveguide substrate. 8. Quarter-wave plate. 9. Plane mirror
10. Light source. 11. Parabolic reflector

Light source and collimator

Nearly collimated light should be used for the WGLCD. The required dispersion angle, which is defined by the maximum angle of propagating beam in the waveguide, depends on the difference of the refractive indices n_o

of LC and n_g of waveguide substrate. LEDs or other collimated light sources are preferred. Fig. 1 shows a light source in which a thin, cold cathode light tube is placed near the focal point of a cylindrical parabolic reflector. The light coupled into the waveguide has a well defined dispersion angle, and can maintain in total internal reflection.

Waveguide and light recycle

To efficiently couple light into the waveguide, the waveguide thickness should be matched to the light source. A lossless, non scattering of waveguide is required high optical efficiency, while the birefringence is less important here than in substrates for conventional LCDs.

Both s- and p-polarized light will propagate in the waveguide. P-polarized light gives rise to the extra-ordinary wave used for the display, while s-polarized light always propagates inside the waveguide. One quarter-wave plate and one plane mirror are positioned at one edge of the waveguide substrate, serving as the light recycling elements. When the s-polarized light passes through the quarter wave plate and is reflected back into the waveguide, it changes to p-polarized light. This helps to maintain the p-polarized light intensity , which 'leaks' when a pixel is ON.

Only the selected pixels leak light, so the selected pixels will be very bright. Light is used more efficiently than in conventional displays, where the light is absorbed by polarizers.

NUMERICAL SIMULATION

We have calculated the nematic director field as function of applied voltage for TN, hybrid and planar cells by a relaxation method[2]. With this data, we simulated the electro-optic response of WGLCDs by using a new 4×4 matrix method[3], which can describe the total internal reflection. In the simulations, all dispersion angles were considered and averaged. The simulated results, shown in Fig. 2, Fig. 3 and Fig. 4 corresponding to TN , hybrid and planar cells , use the same parameters : n_o =1.4673, n_e=1.5185, n_s=1.5, light source dispersion: 15° vertical , 45° horizontal , and LC thickness d=5 μm.

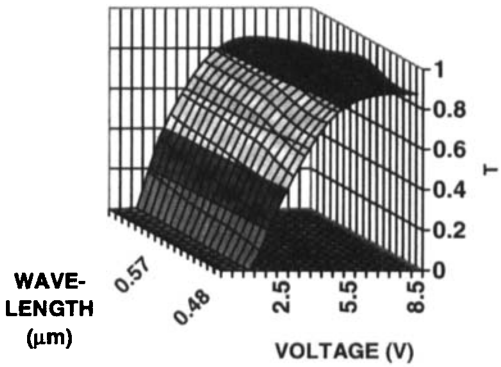


FIGURE 2. Numerical results for 90° TN WGLCD: transmittance versus applied voltage and wavelength.

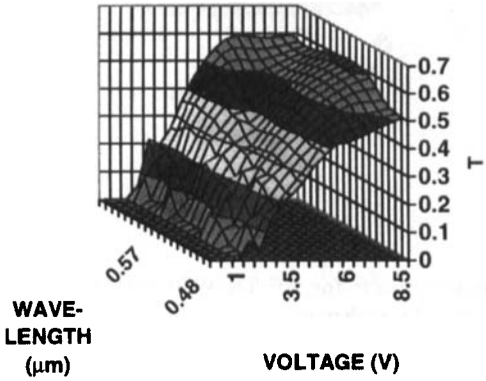


FIGURE 3. Numerical results for 90° hybrid WGLCD: transmittance versus applied voltage and wavelength.

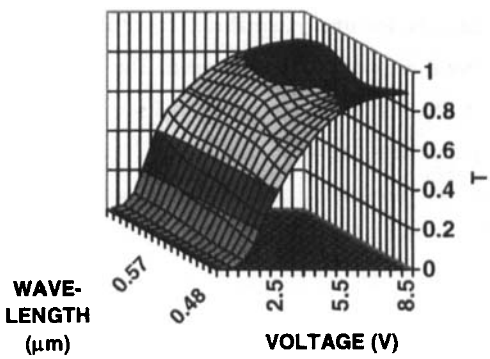


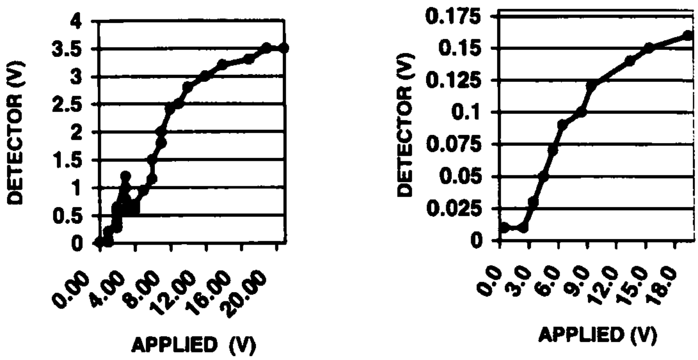
FIGURE 4. Numerical results for planar WGLCD: transmittance versus applied voltage and wavelength.

Comparing Fig.s 2 and 3, one finds that the TN cell provides the best electro-optic performance, with the hybrid cell next and the planar cell last. This can be understood as follows. Within the planar cell, near the two boundaries, the director is aligned parallel to the same easy axis even with an applied field, so the refractive index for the extraordinary wave increases from the back substrate to the mid-layer, but decreases again from the mid-layer to the front substrate. Consequently, the planar cell only can reach ~ 60% maximum transmittance. The other configurations don't have this problem; the hybrid cell has homeotropic alignment at the front surface while the TN cell causes rotation of the polarization.

EXPERIMENTAL RESULTS

We have made a series of cells and demonstrated proof of the WGLCD concept. The experiments showed the behavior as predicted by simulations. The cells with the highest contrast ratio used the TN configuration. A thick glass plate (5.8mm) was used as the waveguide substrate, while a thin glass plate (1.2mm), with paint as scatterer, was used as the front substrate. Both were coated with patterned ITO serving as addressing elements. A 10 kHz AC voltage was used as the driver. The cell was capillary filed with a nematic LC with n_o=1.4673 and n_e=1.5185. Several light sources, varying from He-Ne laser, cold cathode lamp to slide projector lamp, were used in the different experiments. Although the demonstration is simple, even with a low birefringence LC (Δn=0.05), the results are very promising.

Fig. 5 shows the experimentally obtained electro-optic response. A photodiode was placed close to the scattering screen to detect all light scattered from the pixel. The voltage from the photodiode measures the intensity of the transmitted light. Fig. 5a shows results when a Ne-He laser, followed by a cylindrical lens, was used to illuminate the edge. A contrast ratio of 174:1 was obtained in this experiment. Fig. 5b shows the results when a projector lamp with ~30° dispersion angle was used for illumination. Here the contrast ratio is lower , but the response still indicates useful performance.



a. b.

FIGURE 5. Electrooptic response of the WGLCD.

a. source: He-Ne laser b. source: slide projector lamp

Acknowledgments

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