

## P-157: A Single Cell-gap Transflective VA LCD using Positive Liquid Crystal Materials

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### Abstract

*We propose a single cell gap vertical-alignment transflective LCD with patterned electrodes using a positive dielectric anisotropic liquid crystal. As compared to prior attempts using a positive LC in VA configurations, our new design significantly reduces the threshold and on-state voltages to a range reachable by portable electronic displays. In addition, the light efficiency is also enhanced and it only requires a single gamma curve for both transmissive and reflective modes.*

### 1. Introduction

The rapid development of portable electronics, such as mobile phones, e-books, and personal digital assistants (PDAs), generates a growing demand for displays with low power consumption, good outdoor readability, and compact size. Among various display technologies, transflective liquid crystal display (LCD) [1,2] seems a good candidate owing to its capability to meet these requirements. It can obtain high image quality under low ambient environment by using the transmissive (T) mode; and show good readability under strong ambient light conditions and low power consumption when operating in reflective (R) mode.

Most of the transflective LCDs use dual cell gap configuration [1,2] to optimize the optical efficiency. But the need for accurate control of the cell gaps results in complicated fabrication process and low yield and, thus, increases the cost. Therefore, transflective LCDs using a single cell gap would be highly desirable. The main drawback of a single cell gap LCD is the difficulty of obtaining both high T and R light efficiency simultaneously, if same liquid crystal cell configuration is

employed. However, in reality the T mode shows better image quality and is used more frequently than the R mode, which is mainly for outdoor ambient. Therefore, we follow this strategy to optimize the T mode for transflective LCDs.

Vertical alignment (VA) mode is widely employed in the single cell gap transflective LCDs because of its high contrast ratio and simple optical configuration. Negative dielectric anisotropy ( $\Delta\epsilon$ ) LC materials are often employed in VA transflective LCDs, but they usually have a higher viscosity, smaller  $\Delta\epsilon$  value, and are more expensive than the positive  $\Delta\epsilon$  LCs. Recently, a VA transflective LCD using a positive  $\Delta\epsilon$  LC material in the VA-IPS structure [3] was attempted [4]. However, for the transflective LCD shown in Ref. 4, it is rather difficult to lower the threshold voltage and the driving voltage simultaneously. Even using a large  $\Delta\epsilon$  LC mixture ( $\Delta\epsilon = 22.4$ ), the observed threshold voltages for T and R modes are around  $4V_{\text{rms}}$  and  $2.5V_{\text{rms}}$ , respectively. And the on-state voltage is  $\sim 4.5V_{\text{rms}}$  for both T and R modes. Besides, this transflective device shows a low light efficiency (T<60% and R<15% with maximum possible efficiency of 100%). Therefore, further adoption of this structure with positive  $\Delta\epsilon$  LC materials is prohibited.

In this paper, we propose a new VA transflective LCD using a positive  $\Delta\epsilon$  LC material with patterned electrodes. The threshold voltage is reduced to around  $2.0V_{\text{rms}}$  and on-state voltage is around  $4.8V_{\text{rms}}$  for both T and R modes. A TFT-grade MLC-6686 LC with  $\Delta\epsilon \sim 10$  is used in the design. The maximum light efficiency of T and R modes is enhanced to 90% and 32%, respectively. Moreover, in our design an inherently two-domain structure results in a good viewing angle. Thus, our transflective LCD design has potential for practical applications.

## 2. Device Configuration

Figure 1 shows the device configuration of our new transfective LCD. The VA cell interposed between two glass substrates is sandwiched between two circular polarizers, which is composed of a linear polarizer and a broadband quarter wave plate (QWP). Each broadband QWP is comprised of a narrow-band half wave film and quarter wave film with their optic axes inclined at  $60^\circ$  [5]. To compensate the dark state viewed at off-axis, a negative C plate [6,7] is laminated between the broadband QWP and the top substrate.

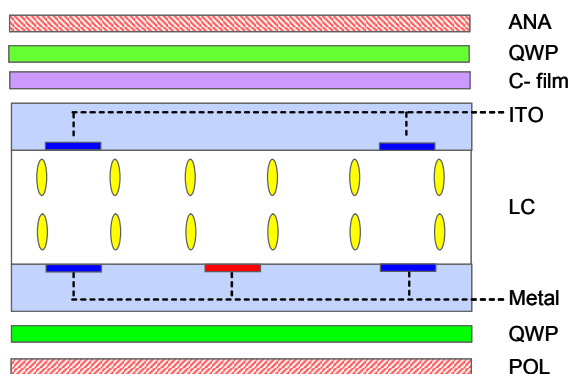


Fig. 1. Configuration of the transfective VA LCD with patterned electrodes.

Figure 2 shows a detailed view of a single repetitive unit of the VA cell at the voltage-on state with calculated directors included. The electrodes 1 and 2 on the bottom substrate are made of metal to work as reflectors, while the electrode 3 on the top substrate is made of transparent ITO. The electrodes 1 and 3 are both grounded, and electrode 2 has an applied voltage. From Fig. 2, if the top ITO electrode 3 is removed, this structure is reduced into the Hyundai's VA IPS configuration, where the potential difference between electrodes 1 and 2 generates horizontal electric fields to reorient the positive  $\Delta\epsilon$  LC directors. However, because the LC directors near two edges of each electrode tilt down toward different orientations, two symmetric centers will form in the center regions between electrodes and above electrode surface in that structure [3]. Therefore, those LC directors there will stay unperturbed by the balanced torques, unless a high voltage ( $V > 10V_{rms}$ ) is applied. This is one of the key reasons why the VA-IPS shows both high threshold voltage and on-state voltage, and low light efficiency. Thus its application in transfective LCDs is limited.

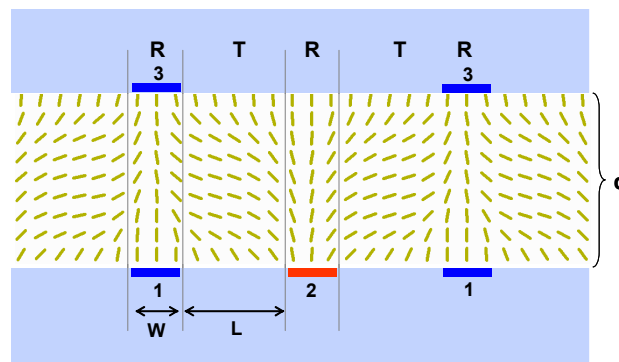


Fig. 2. LC director distribution at a voltage-on state.

In our design, a common electrode 3 on the top substrate is introduced. The potential difference between electrodes 2 and 3 removes the symmetric center between bottom electrodes 1 and 2. It makes the LC directors in the T region easy to tilt. As a result, both threshold and on-state voltages are greatly reduced and transmittance is enhanced. In addition, a 2-domain LC director profile is automatically formed both in the T and R regions. In the regions above electrode surfaces, the LC directors are not as much tilted as those in the T regions. Since the light in the R mode experiences double optical path, these regions are taken as R mode to gain additional light efficiency.

## 3. Results

We have investigated the effects of electrode width  $W$ , electrode gap  $L$ , and LC cell gap  $d$  on the electro-optic performance by using the 2dimMOS software [8]. Merck MLC-6686 is selected in our calculations and its parameters are:  $K_{11} = 8.8$  pN,  $K_{33} = 14.6$  pN,  $\epsilon_{//} = 14.5$ ,  $\epsilon_{\perp} = 4.5$ ,  $\gamma = 0.102$  Pa·s,  $n_o = 1.4824$  and  $n_e = 1.5774$  at  $\lambda = 589$ nm. The LC molecules in the cell are initially vertically aligned without rubbing.

The threshold voltage and on-state voltage are first studied to confine them into the TFT driving regime. Since in our design as shown in Fig. 2, the bottom electrode configuration is similar to an IPS structure, in which the threshold voltage and on-state voltage is proportional to the  $L/d$  ratio. We first fix the cell gap  $d$ , and investigate the impact of gap  $L$  and electrode width  $W$  on the electro-optic performance. The cell gap  $d$  is fixed at  $6.2\mu\text{m}$ , and  $W$  and  $L$  is changed from  $(4\mu\text{m}, 8\mu\text{m})$  to  $(4\mu\text{m}, 10\mu\text{m})$  and  $(6\mu\text{m}, 8\mu\text{m})$ . The calculated V-T and V-R curves at  $\lambda = 550$ nm are plotted in Fig. 3. It confirms the driving voltage tendency.

To reduce the driving voltage to less than  $5.0V_{rms}$ ,  $L$  should be kept below  $10\mu m$  for the selected cell gap. For the same  $L = 8\mu m$ , the change of  $W$  from  $4\mu m$  to  $6\mu m$  only reduces the driving voltage a little. But since the overall R/T area ratio changes substantially from  $1/2$  to  $3/4$ , further increasing of  $W$  will reduce the overall light efficiency greatly. For  $W = 4\mu m$  and  $L = 8\mu m$ , the overall light efficiency is  $\sim 71\%$ , as the R/T area ratio is equal to  $1/2$ .

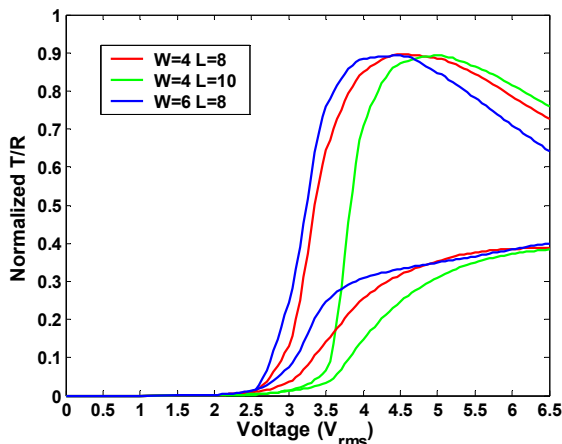


Fig. 3. V-T and V-R curves at different  $W$  and  $L$ .

We further studied the cell gap effect on the electro-optical performance. We fix  $W = 4\mu m$  and  $L = 8\mu m$ , while changing the cell gap  $d$  from  $5.0\mu m$  to  $6.8\mu m$  at a step of  $0.6\mu m$ . Figure 4 shows the corresponding V-T and V-R curves at different cell gaps. The increasing of cell gap reduces the threshold and driving voltage evidently. To maintain a driving voltage less than  $5.0V_{rms}$ , the cell gap should be kept greater than  $5.6\mu m$ . In addition, we find that a larger cell gap has a lower transmittance peak. This is because the overall transmittance is averaged throughout the T region, where the LC directors at different positions respond differently to the applied voltage, i.e., the transmittance at some positions changes faster than at others with respect to the applied voltage. For a thicker cell gap, this non-uniformity becomes more severe than in a thinner cell gap cell, thus results in a reduced overall transmittance.

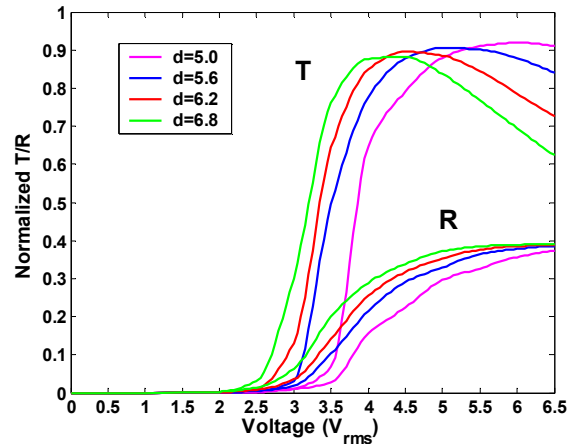


Fig. 4. V-T and V-R curves at different  $d$ .

We also investigated the tolerance for the top and bottom electrode misalignment. The V-T and V-R curves in red solid line in Fig. 5 represent the case that the top electrode 3 and the bottom electrode 1 are well aligned in the horizontal direction. And the V-T and V-R curves in blue dash-dot lines occur when the top electrode 3 is misaligned by  $1\mu m$  with respect to the bottom electrode 1 in the horizontal direction. The tolerance is good since the change in threshold voltage and on-state driving voltage is fairly small.

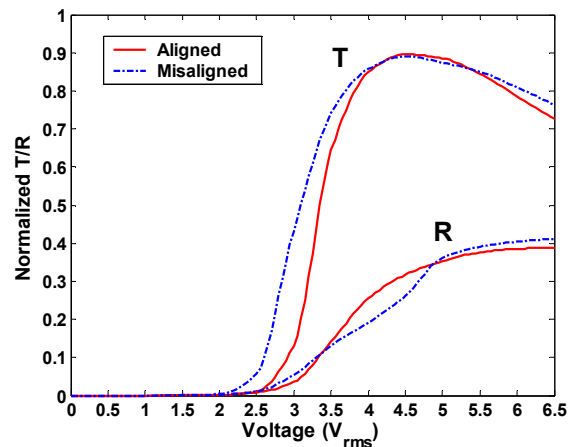


Fig. 5. V-T and V-R curves with top electrode well aligned or misaligned by  $1\mu m$ .

Figure 6 shows the viewing angle for the T mode in the proposed device with  $d = 6.2\mu m$ ,  $W = 4\mu m$ , and  $L = 8\mu m$ . To enhance the off-axis contrast ratio, a negative C plate [6,7] with effective  $d\Delta n \sim 365\text{ nm}$  is employed. Due to the 2-domain

structure in the T regions, the viewing angle of the T mode seems more symmetrical in the azimuthal directions than a single-domain VA cell. As shown in Fig. 6, for the T mode the CR>10:1 viewing cone is between  $\pm 40^\circ$  and  $\pm 65^\circ$ .

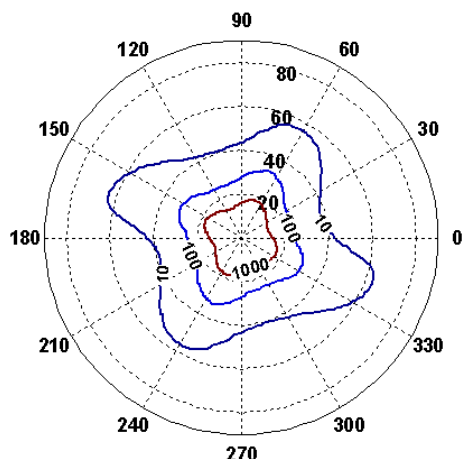


Fig. 6. Iso-contrast plot for the T mode with a C-plate.

Figure 7 shows the calculated optical response time using a 6.2- $\mu\text{m}$ -thick MLC-6686 mixture in a VA cell. The rise time from 10% to 90% transmittance is around 22ms, and the decay time from 90% to 10% is around 20ms.

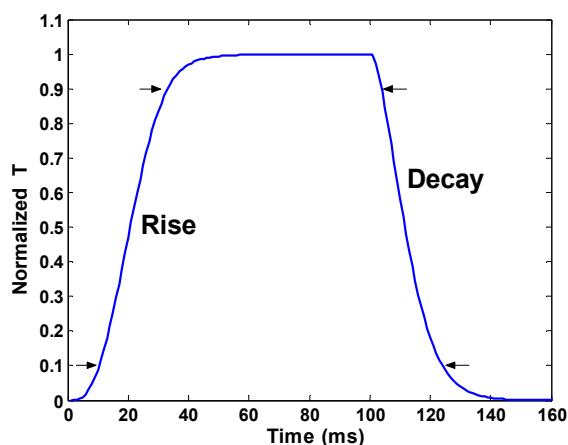


Fig. 7. Simulated optical response time of the VA cell with  $d = 6.2 \mu\text{m}$ ,  $W = 4 \mu\text{m}$ , and  $L = 8 \mu\text{m}$ , and LC: MLC-6686.

#### 4. Conclusion

We have designed a new transfective VA LCD with patterned electrodes using a commercially available positive  $\Delta\epsilon$  TFT-

grade LC mixture. Our design reduces the threshold voltage and on-state voltage to meet the requirements for low-power portable electronics. The normally black transfective VA LCD has a large cell gap tolerance for high contrast ratio and a very simple optical configuration without any in-cell patterned phase retarders, such as the in-cell quarter wave plate for reflective regions. Furthermore, it is single cell gap and rubbing free, which greatly facilitates the manufacturing process. Although the R mode has a low light efficiency, the T mode in this design which occupies a larger area ratio shows excellent transmittance and good viewing angle. In addition, the R and T modes could share one single gray-scale gamma curve.

#### 5. Acknowledgement

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#### 6. References

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