A new TN-ECB mode reflective liquid crystal display with large cell gap and low operating voltage

F. H. Yu, J. Chen, H. C. Huang and H. S. Kwok *

Department of Electrical and Electronic Engineering, The Hong Kong University of Science & Technology, Clear Water Bay, Kowloon, Hong Kong

Abstract

A new TN-ECB mode liquid crystal display is developed for reflective liquid crystal displays (RLCDs). This new TN-ECB mode has a larger cell gap and lower operating voltage than most recently developed RLCDs. It also has a small wavelength dispersion and has a good dark state at the low operating voltage. It is particularly suitable for reflective crystallineSi backplane CMOSAMLCDs.

Key Words: TN-ECB; RLCD.

Introduction

Conventional reflective TN & STN LCDs[1] use 2 polarizers which leads to a loss of brightness. Moreover, they have intrinsic problems such as slow response speed, difficult grayscaling, low brightness and large parallax. Since the early years of LCD research, various schemes have been attempted to eliminate the rear polarizer [2-9] and to increase the response speed[10,11,12]. There is a recent push again for designing fast reflective LCDs (RLCDs) and LCLV [13-18]. In particular, for the case of reflective displays based on CMOS on crystalline silicon, RLCD modes with good efficiency and low voltage operation are needed.

RLCDs can be divided into two basic modes: the electrically-controlled birefringence (ECB) mode [19] and the hybrid twisted nematic ECB (TN-ECB) mode. For the ECB mode, there is no twist in the cell. It may be in a tilted parallel alignment, homeotropic alignment (DAP), hybrid alignment (HAN), or bend alignment (π-cell)[15]. For the TN-ECB mode, it may be in the 45° hybrid-field-effect (HFE) mode [4], the 63° TN-ECB [5-6], the mixed TN (MTN) mode [13-14], and the self-compensated twisted nematic (SCTN) mode[20]. There is also the 52° RLCD[17] mode which is capable of direct view applications. These RLCDs only need a single polarizer or a polarization beam splitter (PBS) for their operation. They are therefore ideal for silicon backplane CMOS LCD.

Among the various TN type RLCD modes, the HFE and TN-ECB modes are hampered by large chromatic dispersions. The MTN mode is attractive in terms of chromaticity, but is disadvantaged by a relatively high operating voltage and small $d\Delta n$. The value of $d\Delta n$ ranges from 0.24μm for the 90° MTN cell to about 0.18μm for the 60° MTN cell. When the twist angle gets smaller, the operation voltage becomes higher as well. For the 60°, 70°, 80° and 90° MTN cells, through numerical simulation, we found that when the dark state operating voltage is 4V, their white light contrast ratio will be 15, 21, 32 and 65 respectively. These values are too small. In order to increase the contrast ratio, the dark state voltage has to increase. For example, at 6V, the white light contrast ratio will become 37, 53, 78 and 116 respectively. Such thin cell gaps (normally about 2-3 μm) in combination with such high operating voltages are undesirable.

Recently, Yang proposed a new SCTN mode [20]. In this SCTN mode, a low operating voltage is possible for the dark state. However, this SCTN cell has quite large color dispersion. Actually, this SCTN is the same as the MTN mode except that the second order TN-ECB maximum point is used as the cell static operating point. It is the purpose of this study to find a RLCD mode that has good chromaticity and low operating voltages.

Optimization of the new TN-ECB

We make use of the parameter space[16-18, 21] of the RLCD in optimizing the MTN/SCTN/TN-ECB mode to achieve a low chromatic dispersion/low operating voltage combination. Actually, from the parameter space, the TN-ECB, the MTN and the SCTN modes are indistinguishable. They are simply variations of each other as the polarizer angle is changed. We shall refer to them simply as the TN-ECB mode.

The configuration of the new RLCD is the same as before. There is only the front polarizer, the LC cell and the rear reflector. Fig. 1 shows the 2D parameter space diagrams [21] of reflectance vs $(d\Delta n,\ a)$ for twist angles from 60° to 90°. From Fig. 1, we find that

* Author to whom correspondence should be addressed

with an increase of the twist angle f, the second TN-ECB maxima with larger $d\Delta n$ (A) and the first TN-ECB maxima with smaller $d\Delta n$ (B) approach each other. When the twist angle is near $90°$, these 2 TN-ECB modes combine into one point.

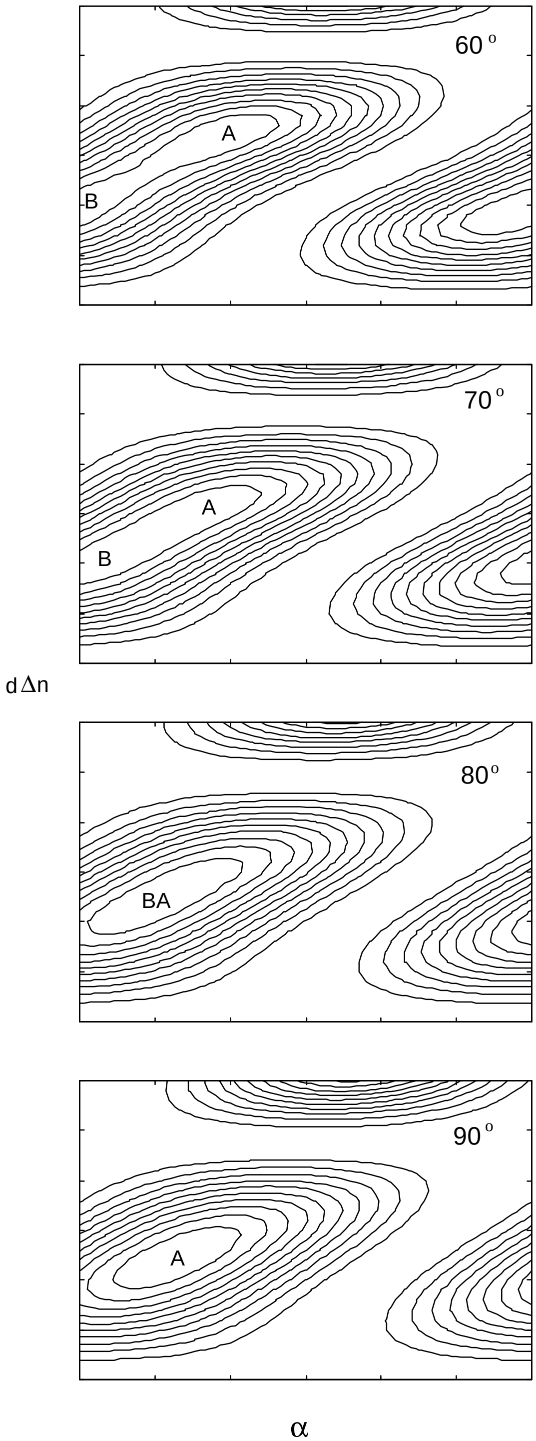

Fig. 1 Parameter spaces for the TN-ECB under different twist angles

The $d\Delta n$ of point B and point A are about 0.20μm and 0.35μm respectively in the $70°$ twist cell. Therefore, one can select any $d\Delta n$ between 0.20 and 0.35μm for the TN-ECB. For example, if we select point A as the static work point, then a large cell gap with low operation voltage can be obtained. However, as mentioned earlier, a larger $d\Delta n$ will cause greater color dispersion. Therefore a compromise in f and *dDn* has to be found.

We calculated the wavelength dispersion and reflectance-voltage characteristics of all of these combinations in order to obtain the best RLCD cell. In the optimization, for each f value, a has to be varied as well. Fig. 2 shows the dependence of the reflectance on the wavelength for the 70°, 80° and 90° TN-ECB/MTN cells. From Fig. 2, we find that at the voltage-off state the reflectance-wavelength curve for the 70° cell has an acceptable color dispersion. Its operating parameters are (70°, 30°, 0.31μm). This new TN-ECB with larger twist angle also has lower color dispersion than that of the SCTN mode.

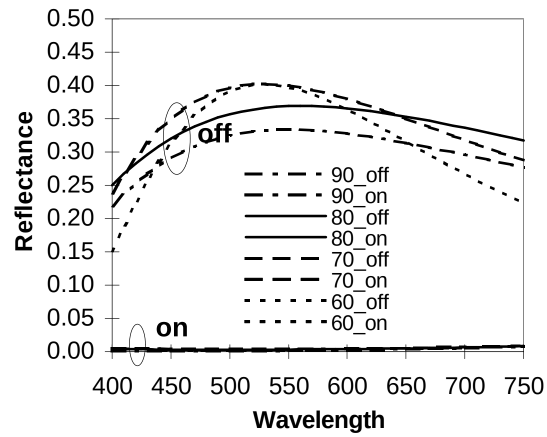

Fig. 2 Reflectance-wavelength curves at the voltage-off and on states for $f = 60°$, $70°$, $80°$ and $90°$.

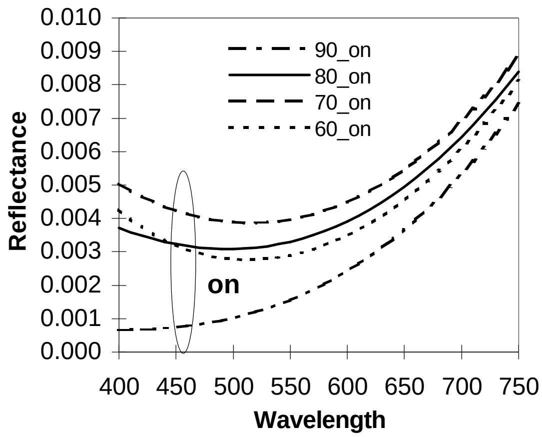

Fig. 3 Reflectance-wavelength curve at the voltage-on state for $f = 60°,\ 70°,\ 80°$ and $90°$.

In Fig. 2, both the voltage-off and voltage-on states are calculated. The on voltage is fixed at 4V for comparison. Details of the voltage-on state are shown in Fig. 3. For MTN cells, the voltage-on state is near homeotropic and corresponds to the dark state. It therefore requires cross polarizers. From Fig. 3, we find that again the cell with $70°$ twist angle has an acceptable dark state with an operating voltage of 4V. Its contrast ratio is about 74. The calculated contrast ratios are summarized in Table 1 for various operating conditions. The contrast ratios are 96 and 106 for operating voltages of 5V and 6V. So 5V is an appropriate operating voltage for this new TN-ECB cell.

Fig. 4 shows the reflectance vs voltage curve of the new TN-ECB at the wavelengths of 450 nm, 550nm, and 650 nm (RGB) respectively. Table 1 shows the contrast ratio of several different cells under operating voltage of 4 V, 5 V, and 6 V respectively. Considering both the contrast and the dispersion, the TN-ECB cell with parameters (70^o, 30^o, 0.31μm) can be seen as the optimal choice.

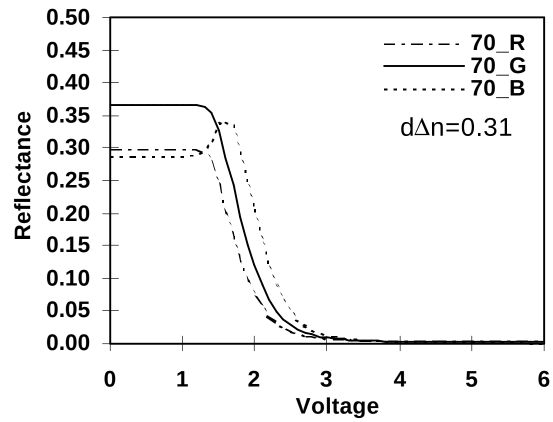

Fig. 4 Reflectance-voltage curve of the new-TN-ECB.

Table 1. Contrast ratio of different cells under different operating voltages.

Voltage / Cell parameters	4V	5V	6V
$70°$,0.31,$30°$	74	96	106
$80°$ **MTN**	32	61	78
$90°$ **MTN**	65	103	115
$60°$ **SCTN**	76	100	111

Experiment

To verify our theoretical simulations, sample cells were made and tested. The cell parameters are (70^o, 30^o, 0.31μm). We used liquid crystal number ZLI-1695 from E. Merck with a low Δn of 0.0625. The cell gaps were 5 μm. Standard rubbed polyimide films were used to aligned the LC molecule to form the $70°$ twist cell. The LC cell has indium-tin-oxide as the transparent electrodes on one side and aluminum coated glass as the reflective electrode.

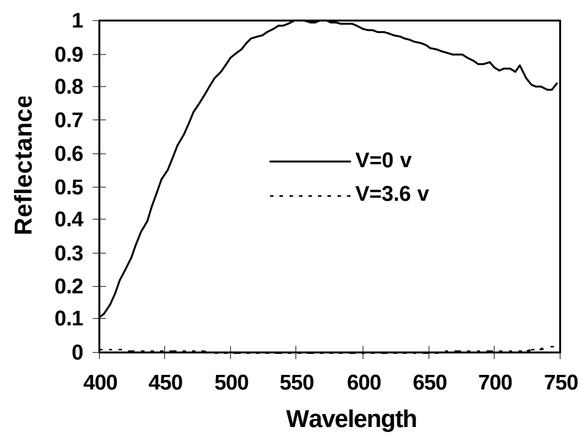

Fig. 5 Reflectance vs wavelength for the (70°, 30°, 0.31) *display.*

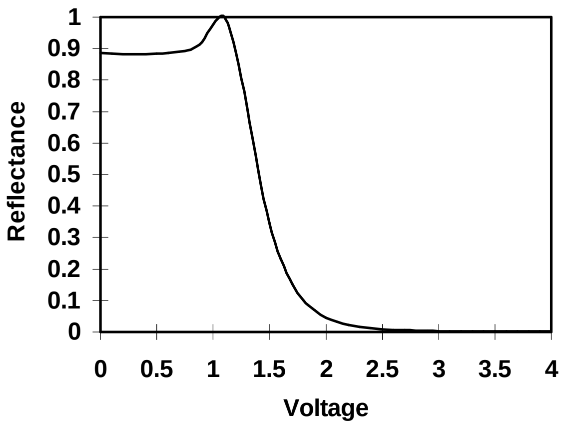

Fig. 6 Reflectance vs voltage for the (70°, 30°, 0.31) *display.*

Fig 5 shows the experimental reflectance vs wavelength of the new TN-ECB. It can be seen that at long wavelengths, the reflectance agrees with the theoretical simulation quite well. At short wavelengths, however, there is some deviation from the theory. This is because the PBS used in the experiment has poor optical characteristics in this wavelength range. Another reason is that the cell thickness was not exactly 5 μm. The actual cell thickness was measured to be about 5.2 μm. So its real $d\Delta n$ was about 0.325μm.

Fig. 6 shows the experimental reflectance vs voltage curve of the new TN-ECB under white light illumination. From Fig. 6, we can find that there is a good dark state at 3.6V. There is also a slight increase in the reflectance at 1.2V as predicted. The operation voltage for the dark state is only 2.5V which is well suited for CMOS AMLCD applications.

In addition to the low operating voltage, the 5 μm cell gap is also a comfortable value for cell fabrication. In particular, it is suitable for crystalline silicon based CMOS LCD. The uniformity requirement should also be easy to satisfy for such large cell gaps. Further experiment will focus on the cell thickness of about 4.5 μm. We believe that this smaller cell gap will further lower the cell color dispersion and operating voltage.

Conclusions

In this study, we performed an optimization of the TN-ECB/MTN/SCTN modes in terms of low voltage operation and low color dispersion. Such features are important for reflective displays. In particular, it is suitable for CMOS driven LCD on x-Si, because the reflective light valve no longer requires a transparent substrate. Additionally, the new TN-ECB would be useful for optically addressed spatial light modulators. We showed that it is possible to use a low voltage of 4V to obtain excellent contrasts of over 70 with minimal color dispersion.

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