P-109: Fast Response Reflective NBB Display and its Application to LCOS

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Abstract

A reflective LCD using high pretilt angle No-Bias-Bend (NBB) mode is designed. The pretilt angle and cell gap is optimized for high reflectivity display, at low driving voltage. The contrast ratio is improved by film compensation. Nano-structured alignment surface is utilized for preparing high pretilt angles. The experimental result shows a high reflectivity and fast response time around 0.7ms, which makes it possible for the use of color-filter-less microdisplay.

1. Introduction

Optically compensated bend (OCB) mode responses fast since there is no backflow involved during switching [1-6]. At the same time, it offers wide viewing angle because of the symmetric configuration of the pi-cell. The main difficulty of the conventional OCB mode is the need for transformation from the splay state to the band state. Fortunately, if the pretilt angle of liquid crystal is high enough, the splay state can be eliminated and No-bias-bend (NBB) mode can be obtained [7].

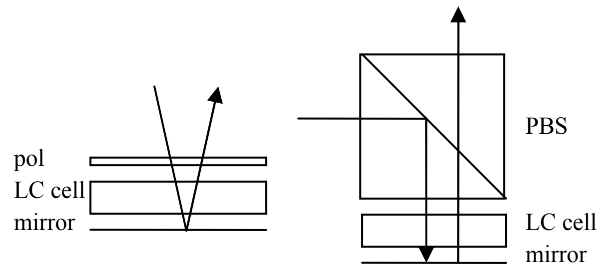
The pi-cell is basically an electrically controlled birefringence (ECB) mode. That is, with the voltage applied, the overall retardation value changes. So the large pretilt angle will cause a relative small birefringence. Such decrease of retardation can be compensated by either increasing the cell gap or using a LC with larger birefringence.

For reflective LCD, the equivalent retardation is two times the transmissive LCD with the same cell gap. High reflectivity is therefore achieved at small cell gap. In this paper, we apply the NBB mode for the use of reflective LCD. At the same time, in order to meet the driving requirement of liquid crystal on silicon (LCOS), our design is optimized for the voltage between 0V and 5V. The optimization of the design is to implement both fast response time and high reflectivity at the same time. Film compensation is also applied to improvement the display contrast.

2. Device configurations

For a truly reflective mode display without the rear polarizer, there are two possible configurations, as shown in Figure 1. One is with only one sheet polarizer on the top of LC cell, the other is with polarizing beam-splitter (PBS), which is a configuration used for micro-display. For both cases, the rubbing direction of NBB mode is at 45^{o} to the transmission axis of polarizer.

If no additional retardation film attached, the off state (no voltage applied) is designed to be the dark state for structure a; while for structure b, the on state (with voltage applied) is the dark state.



(a) (b)

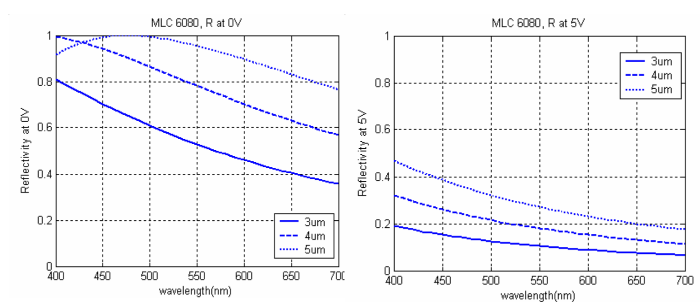
Figure 1 (a) One sheet polarizer reflective mode (normally black) (b). LCOS (normally white)

3. LCD optimization

For both configurations, residual retardation for the dark state exists. Since for configuration (a), the retardation of LC cell cannot be exactly equals to $\pi/4$ for all wavelengths, so some of the light will still pass through the polarizer after going through LC cell. For configuration (b), if the voltage is not high enough, the LC directors will not be completely tilted, thus there is some residual retardation.

The optimization was done to obtain a high contrast ratio and high reflectivity LCD at the same time. The residual retardation need to be compensated by retardation films. This will also influence the reflectivity of bright state. So, the retardation difference between the bright state and the dark state is an important reference. In order to meet the requirement of LCOS driving, 5V is chosen to be the on-state voltage when doing the optimization and PBS structure is applied when doing calculation and experiments.

2.1 Reflectivity



(a) (b)

Figure 2 (a) Calculated reflectivity of bright state. (b) Calculated reflectivity of dark state.

Figure 2 (a) shows the reflection spectrum at 0V for 3µm, 4µm and 5µm NBB cells. MLC-6080 is used for the calculation. The

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Δn value is 0.2024. As expected, the reflection at 5V is not small enough, shown in Figure 2 (b). This will cause a low contrast ratio. The contrast performance needs to be improved by film compensation.

2.2 Parameters optimization

It is noted that the reflection increases for both the on-state and off-state with increasing cell gap. The neutralization of dark state reflection would decrease the reflection of bright state at the same time. In order to optimize the cell parameters to achieve high contrast ratio and high reflectivity at the same time, the reflectivity after dark state compensation is studied.

Figure 3 shows the calculated reflectivity as a function of pretilt angle for 3 different cell gaps. The reflectivity is calculated using retardation difference between 0V and 5V. Pretilt angle should be larger than 50^{o} to make the cell stable at bend state.

Larger cell gap will induce higher response time. However, it would also slower the response time. In order to compromise the response time and reflectivity, 4 to 5μm 52^{o} pretilt is the most suitable configuration. And 50% reflection is still high enough, if it is used as color sequential display.

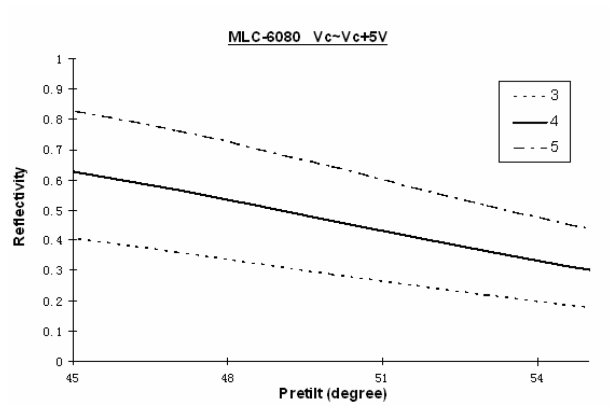

Figure 3 Reflectivity after dark state compensation as a function of pretilt angle, for different cell gaps.

2.3 Film compensation

The dark state reflection can be reduced by film compensation. We can use an a-plate with certain retardation value attached on the top of LC-cell. This is the simplest compensation configuration, as show in Figure 4. The fast axis of compensation film is along rubbing direction of LC cell.

However, this configuration requires the film retardation to be equal to the residual retardation of LC dark state. While, the retardation values of commercial retardation films are fixed to be some certain values, such as 140nm and 270nm.

Another method is to use quarter-wave-plate (QWP) attached at certain angle to LC cell. The angle depends on residual retardation need to be compensated. Figure 5 shows the result after film compensation. Obviously, the contrast ratio is increased after compensation.

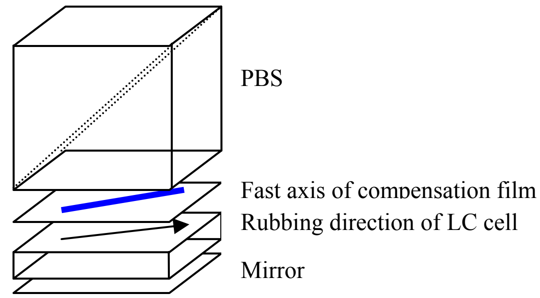

Figure 4 Optical configuration of film compensation.

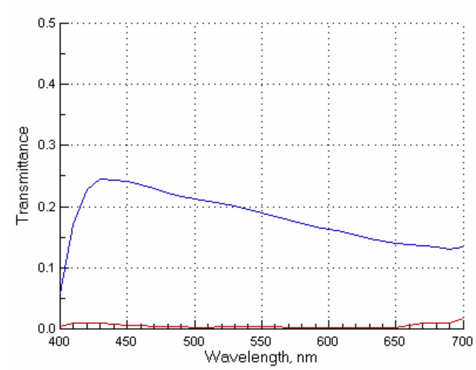

Figure 5 Calculated reflectivity at on and off state, after residual retardation compensation.

3. Experimental results

A sample reflective NBB LCD is fabricated using nano-structured surfaces [8-9]. A pretilt angle of 52^{o} is required for a stable bend configuration without a critical holding voltage. The LC used is MLC-6080.

3.1 Measured reflectivity

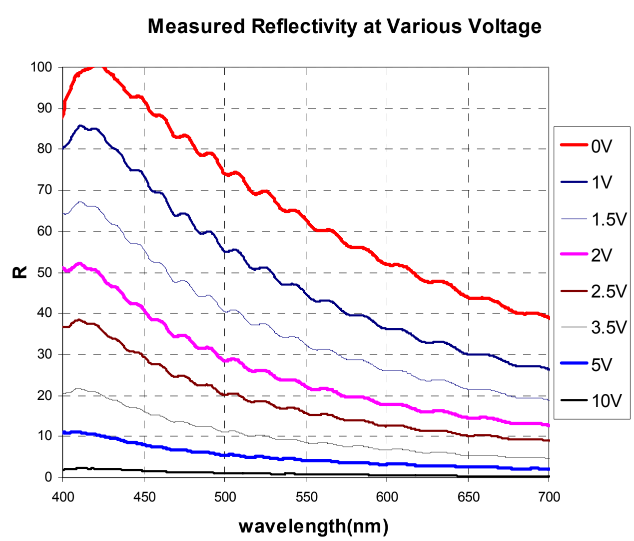

Figure 6 Measured reflectivity at various voltages.

By applying different voltage, the reflective spectrum was measured. PBS was used during the measurement. Figure 6 shows the measured reflectivity at various voltages. As expected, completely dark state was difficult to obtain, even at the voltage of 10V. The reflectivity as a function of voltage is showed in Figure 7. The residual reflection at 5V can be neutralized by film compensation method discussed above.

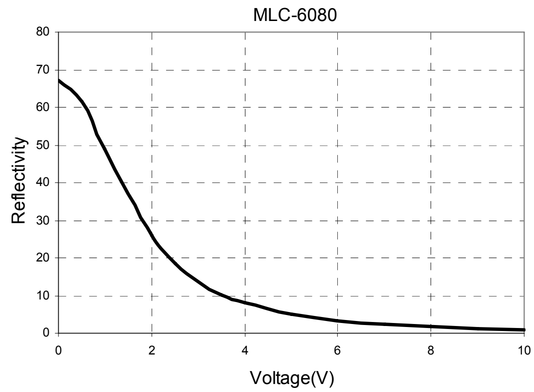

Figure 7 Reflectivity as a function of voltage.

3.2 Response time

Response time is an important reference for evaluating LCD performance. NBB mode is proven to have fast switching time. Figure 8 shows the response time of such reflective NBB LCD, at driving voltage between 0V and 5V. The relaxation time is 1.18ms and the switch on time is 255µs. Average switching time is around 0.7ms.

Figure 8 Measured response time of a 4µm NBB test cell.

3.3 Application to LCOS panels

One of the applications of reflective NBB mode is the micro-display. Figure 9 shows a sample of micro-display using NBB mode. Moreover, because of the fast response time of NBB mode, the color-filter-less LCOS is possible. Since the driver is not ready, we could not see the pictures on the panel yet. This result will be reported in the future.

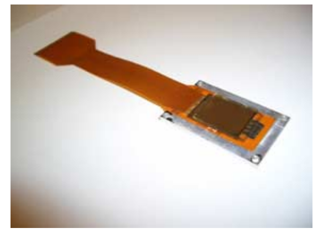

Figure 9 A sample of microdisplay using NBB mode.

4. Conclusion

In summary, reflective NBB mode is studied. The optimization and film compensation are discussed in detail. High contrast and high reflectivity reflective LCD is obtained under low driving voltage theoretically. Experimental NBB test cell with the optimized cell parameters was obtained by using nano-structured alignment layer. The experimental results agree with the calculations well. Moreover, the response of NBB mode is very fast. Such reflective NBB LCD can be applied for color-filter-less microdisplay.

5. Acknowledgements

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6. References

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