# P-125: Sequential Color LCD Using No-Bias Bend Mode

**Fion S. Y. Yeung, Yuet-Wing Li, Li Tan, Jacob Y. L. Ho, Kuen-Kuen Li, Wai-Shan Cheung, and Hoi-Sing Kwok**

Center for Display Research, Department of Electronic and Computer Engineering,

Hong Kong University of Science and Technology,

Clear Water Bay, Hong Kong

## Abstract

*A field sequential color (FSC) LCD is made using the no-bias bend (NBB) mode. This NBB mode is made possible using a nano-structured alignment layer which is capable of producing any pretilt angles. This NBB pi-cell has a total response time less than 1.3ms which is needed for FSC.*

## 1. Introduction

Previous studies clearly stated that optically compensated bend (OCB) mode liquid crystal display (LCD) is capable of fast response time [1-6]. OCB is a pi-cell which operates from bend to bend states with a critical holding voltage. However, such a critical voltage degraded the optical performance of the LCD. In particular the spacing between pixels remains in the splay state since no voltage can be applied there. A systematic experimental study of the critical voltage has been reported previously [7]. A stable bend state of the LC cell can be obtained if the pretilt angles are high enough. The response time of such No-Bias-Bend (NBB) pi-cell is potentially faster than OCB cell. The major application of such mode is fast response color-filterless field sequential LCDs.

## 2. Nanostructured Alignment Layer

The fabrication of LC cells with any value of pretilt angle has been discussed previously. It is based on a nano-structured alignment layer [8-11]. This alignment layer consists of a random distribution of nano-scale domains of homogeneous and vertical alignment materials as shown in Figure 1. Uniform pretilt angle is obtained at a short distance above the alignment layer due to elastic energy minimization. Such fabrication process is very controllable and repeatable.

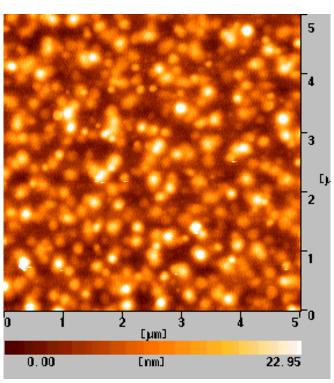



**Figure 1** An example of nano-structured alignment layer.

## 3. Working Principle of Sequential Color LCD

The principle of a sequential color LCD is based on a field sequential LED backlight. The backlight is switching time sequentially from red to green, green to blue and blue to red as shown in Figure 2.

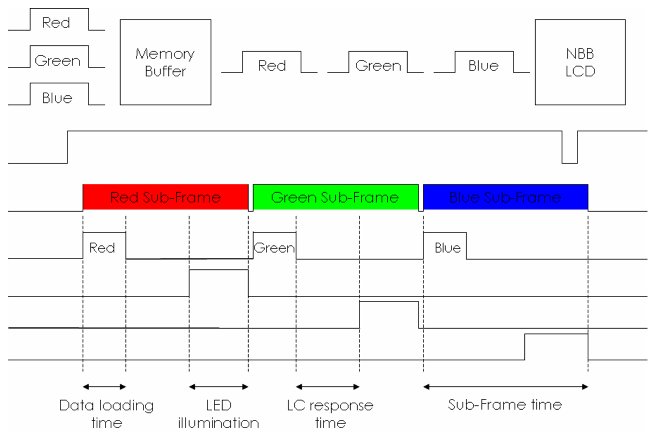



**Figure 2** Driving principle of sequential color NBB LCD.

For a QVGA display with 60Hz frame rate, each frame can have approximately 16.5ms. Each frame contains three sub-frames which will have a duration of 5.5ms. During this time limit, data has to be loaded onto the pixels, LC needs to finish their response and finally the LED needs to turn on. The minimum data loading time for a QVGA display is 1.3ms and the minimum LED illumination time is around 2ms in order to obtain the best contrast. Therefore, only around 2.2ms is left for the LC to response. It is obvious that NBB mode can fit the requirement of sequential color display as its worst-case response time is only 1.18ms with a 4μm cell gap.

Color mixing can be obtained if we carefully control the switching on and off time of the LCD. White color can be obtained when the LCD is off in all three sub-frames. Black color can be obtained when the LCD is on in all three sub-frames. Figure 3 shows an example of color mixing in NBB LCD. If we want to have a yellow color, the LCD is set to be in the off state when both of the red LED and green LED are on, and the LCD is set to be in the on state when the blue LED is on.

ISSN/007-0966X/07/3801-0677-$1.00 © 2007 SID

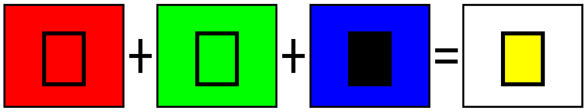


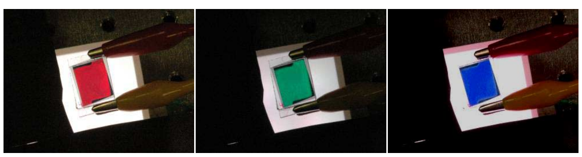
**Figure 3** An example of color mixing in NBB LCD.

## 4. Experimental Results

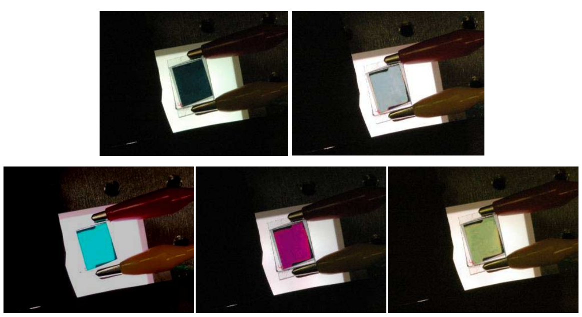
A sample color-sequential NBB LCD is successfully fabricated using nano-structured surfaces. A pretilt angle of 53 degrees is required for a stable bend configuration without a critical holding voltage.

### 4.1 Color Generation

By applying the color mixing scheme discussed above, three primary colors are obtained in a NBB test cell as shown in Figure 4a. Figure 4b shows some examples of mixed color such as black, white, cyan, magenta and yellow. Full color display can be obtained by controlling the gray-level of LCD.



(a)



(b)

**Figure 4** (a) A NBB test cell shows three primary colors on a color-sequential backlight. (b) other mixed colors

The measured corresponding color co-ordinates of the above colors are shown in Figure 5. It can be seen that all three primary colors can be obtained. Additionally, mixed colors can also be made by using the sequential color scheme. The full color gamut of the LED backlight can also be reproduced.

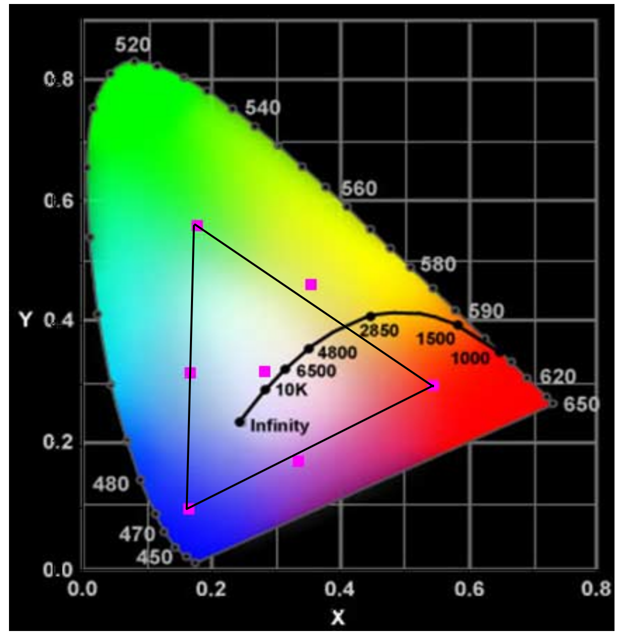



**Figure 5** Measured color coordinates of NBB LCD.

### 4.2 Gray-level Response time

Liquid crystal response should be fast enough in order to implement the sequential color scheme. NBB mode is proven to be fast enough. In our case, STN LC with $\Delta n$=0.2024 is used. Since the frame time is short, STN LC can be used without worrying the VHR. With a 4µm cell gap, the worst case measured rise time is 1.18ms while the fall time is only 255µs. Figure 6 shows the gray-to-gray response time data of NBB cell. It includes response time between 11 different grayscale levels. This NBB operates in a normally white mode. Level 1 indicates a black state and level 11 indicates a white state.

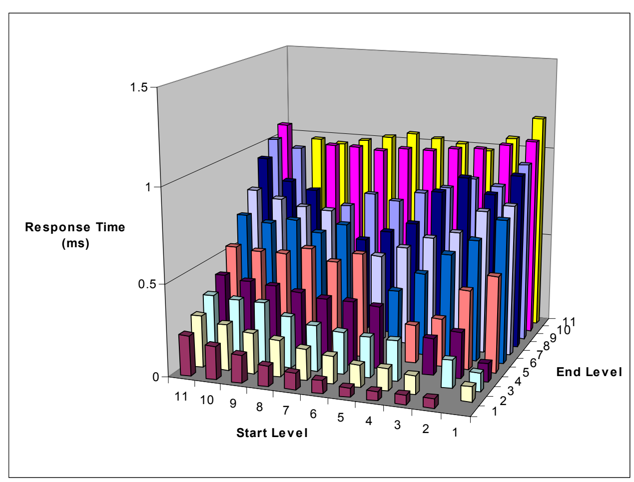



**Figure 6** Gray-to-gray response time of NBB LCD.

### 4.3 Application to TFT panels

The NBB mode is implemented into a TFT active matrix display panel. This active matrix backplane was fabricated at HKUST using metal based low temperature polycrystalline process [12]. It is a QVGA resolution display. Defects are due to open data and gate lines. The result of this sequential color active matrix LCD is shown in Figure 7. Good color is obviously shown on the panel with reasonable contrast ratio.

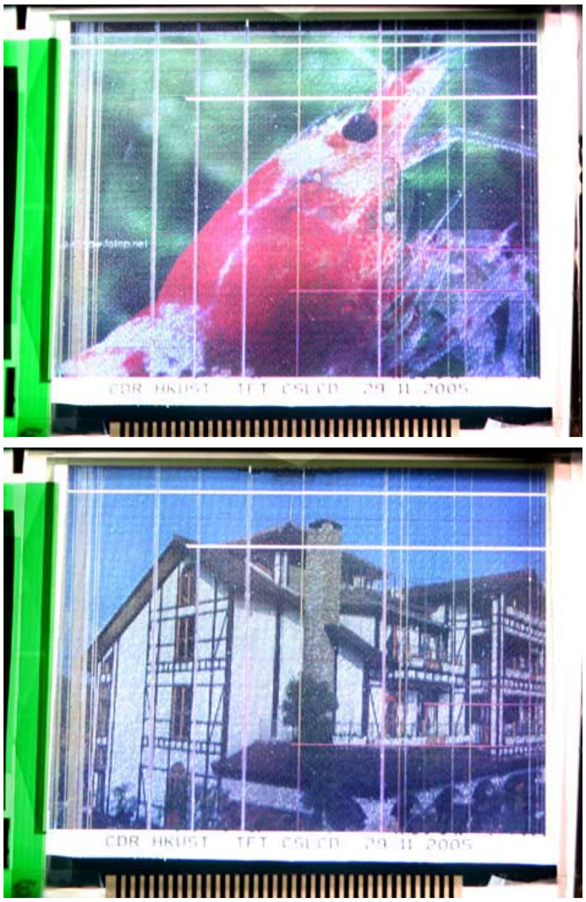


**Figure 7** A sample of NBB TFT LCD.

## 5. Conclusion

In summary, a color-filterless NBB LCD is successfully fabricated using large pretilt angles. Color coordinates and gray-level response time is also studied. Such NBB mode is successfully integrated in a TFT LCD. This application is important for future fast response LC-TV applications.

## 6. Acknowledgements

This research was supported by the Hong Kong Government Innovation and Technology Fund and the Research Grants Council.

## 7. References

[1] P. J. Bos, K. R. Koehler-Beran, *Mol. Cryst. And Liq. Cryst.* **113**, 329 (1984).

[2] C. L. Kuo, T. Miyashita, M. Suzuki and T. Uchida, *Appl. Phys. Lett.*, **68**, 1461 (1996).

[3] H. Mori and P. Bos, *Japn J. Appl. Phys.*, **38**, 2837 (1999).

[4] H. G. Walton and M. J. Towler, *Liquid crystals*, **27**, 1329 (2000).

[5] S. T. Wu and A. M. Lackner, *Appl. Phys. Lett.*, **64**, 2047 (1994).

[6] J E Anderson, C. Chen and A. Lien, U. S. Patent No. 6,067,142 (2000).

[7] F. S. Yeung, Y. W. Li and H. S. Kwok, *Appl. Phys. Lett.*, **88**, 041108 (2006).

[8] F. S. Yeung, F. C. Xie, H. S. Kwok, J. T. Wan, O. K. Tsui and P. Sheng, Society for Info. Disp. Symp. Digest, vol. **36**, p. 1080 (2005).

[9] F. S. Yeung, J. Y. Ho, Y. W. Li, F. C. Xie, O. Tsui, P. Sheng and H. S. Kwok, *Appl. Phys. Lett.*, **88**, 051910 (2006).

[10] F. S. Yeung, F. C. Xie, J. T. K. Wan, F. K. Lee, O. K. C. Tsui, P. Sheng and H. S. Kwok, *J. Appl. Phys*., **99**, 124506 (2006).

[11] J. T. Wan, O. K. Tsui, H. S. Kwok and P. Sheng, *Phys. Rev. E.*, **72**, 021711-1-021711-4 (2005).

[12] Z. Meng and M. Wong, *IEEE Trans. Elec. Dev.*, Vol. **49**, No. 6, 991 (2002).

[13] Z. Meng, M. Wang and M. Wong, *IEEE Trans. Elec. Dev.*, Vol. **47**, No. 2, 404 (2000).