Fast Response No-Bias-Bend LCD

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ABSTRACT

Fast response No-Bias-Bend (NBB) Liquid Crystal Displays using nano-textured high pretilt angle alignment surfaces has been demonstrated. Such alignment surfaces allow high pretilt angles of over 45º to be fabricated reliably. This NBB-LCD has a rise time of 1.8ms and a fall time of 80μs. The average response time is less than 1ms.

1. INTRODUCTION

Recently, high pretilt angles of near 45^o were achieved reliably by using nano-textured alignment surfaces. One application of such high pretilt angles is in making π-cells with no bias voltage [1-4]. It is also called the no-bias bend (NBB) cell.

The NBB cell is similar to the optically compensated bend (OCB) cell [5]. OCB is essentially a π-cell with film compensations for improved viewing angles and contrast ratio. This π-cell operates between the bend deformation (B-state) and the near homeotropic state at high voltage. Many studies have been devoted to the study of this interesting LCD mode for fast switching applications [6-10]. Its response time can be very fast since there is no backflow involved in its switching. On-off response times of less than 1ms have been achieved.

However, as is well known, this normal OCB cell is actually stable in splay deformation (S-state) as shown in Fig. 1. A critical voltage is needed to transform the splay cell into a bend cell. [11-12] However, if the pretilt angle is large enough, π-cells can be stable in the bend deformation without a bias voltage as shown in Figure 1b. This is the termed No-Bias-Bend (NBB) LCDs.

OCB cell has to be converted to bend state first by applying a high voltage, and then a holding voltage is needed to maintain the LCD in the bend state. The transformation of a splay cell to the bend state is nontrivial. Since the splay state and the bend state are topologically inequivalent, nucleation has to be initiated. For a large multiplexed display, it is quite difficult to convert the inter-pixel areas to the bend state since there is no voltage across the cell. As a result, the optical performance of the LCD is greatly degraded.

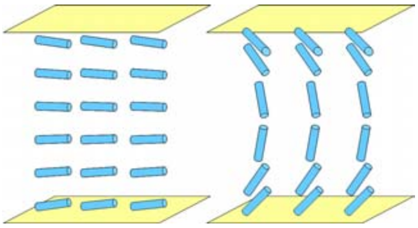

(a) (b)

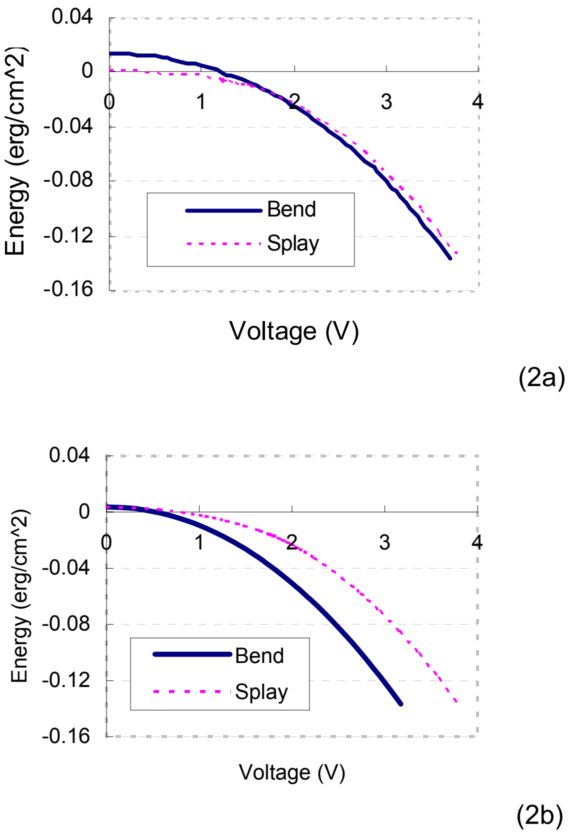
Fig. 1 (a) Splay cell (b) No-bias-bend cell

Uchida et al. [16] introduced an approach for OCB mode such that polymer wall is used to stabilized the twisted state of nematic liquid. Since the twist state is topologically equivalent to bend state, nucleation can be avoided. There are several studies and publications base on this idea. However, according to the TVC of the polymer stabilized cell, much higher driving voltage is required. Also the typical respond time of such OCB cell is increased up around 10ms.

2. NBB CELL PRINCIPLES

In this paper, we propose and demonstrate another way to obtain bend configuration, which does not require any holding voltage. Fig. 2 shows the calculated free energies of the bend and splay configurations against different applied voltage in the π-cells with different pretilt angles. The parameters of liquid crystal MDA01-4679 is dielectric anisotropy is $\Delta\varepsilon$ = 12.7, and the Frank elastic constant are K_{11}=14.5pN, K_{33}=15.3pN. The cell gap is 5um. From Fig. 2a, if there is no bias voltage applied, splay configuration has lower free energy than bend configuration. The bend state can be obtained only when there is a bias voltage higher than 1.85V, which is the critical voltage.

In Fig. 2b shows the same calculation at a higher pretilt angle. Here it can be seen that the bend and splay configuration have the same free energy. No bias voltage is required for splay to bend transition anymore.



(2a)

(2b)

Fig. 2 Free energy of Splay and Bend configuration against different bias voltage at pretlt angles of 5° upper and 45.5° lower.

Once the critical voltage becomes zero, the driving and operation of this NBB LCD can be greatly simplified. Our NBB cell is made possible by using a special alignment layer to induce a high pretilt angle near 50° in the LC cell. The exact value of this critical pretilt angle requirement depends on the elastic constants of the LC materials.

3. CONSTRUCTION OF NBB CELLS

The major issue of achieving a NBB cell is high pretilt angles [13]. In this paper, we use nano-textured surfaces [14,15] as the alignment layer of NBB cell. The basic idea of the new alignment layer is to form very small surface domains of homogeneous and vertical alignment layers. If these domains are small enough, the liquid crystal molecules will realign themselves to achieve a uniform pretilt angle near the alignment surface. This pretilt angle is formed due to the elastic interaction of the individual alignment domains. It has been shown that such surfaces can have excellent anchoring energies as well as good thermal stability [15].

In order to evaluate the simulation result, several NBB and OCB cell with different pretilt angle is fabricated. The cell gap of them is 5um. Fig. 3 shows the critical voltages for different pretilt angle OCB is measured. It is found that if the OCB cell with pretilt angle higher than 45.5 degree, it becomes NBB cell such that the critical voltage is zero.

However, It should be noted that if the NBB cell has pretilt angle larger than 60°, the retardation of the cell will become too small to produce good enough contrast. Thus a balance has to be obtained for high optical efficiency and fast response times.

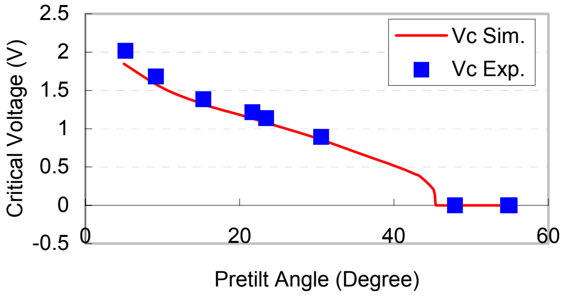


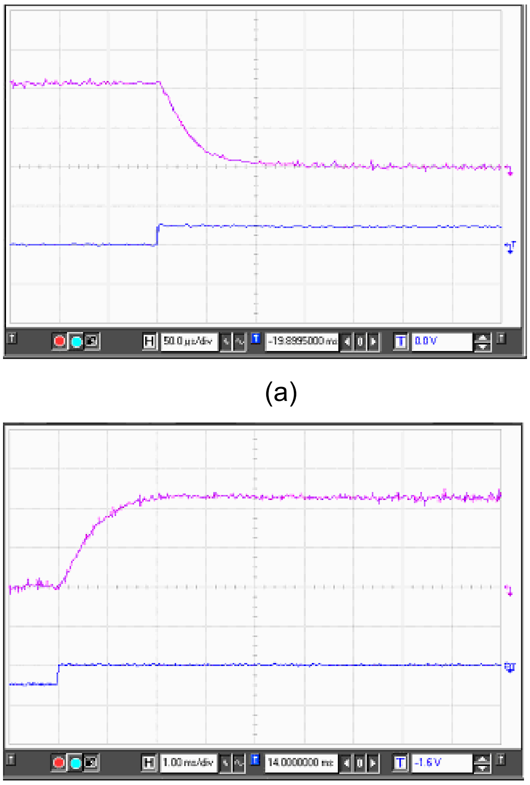
Fig. 3 The critical voltage against pretilt angle. Simulation (line), measured data (dot)

After the NBB is obtained, lets come to investigate the optical properties of such kind of display. A 5μm parallel rubbed NBB π-cell filled with commercial TFT liquid crystal is fabricated.

4. RESPONSE TIMES

Fig. 4 shows the measured response of the

NBB cell for voltage on and voltage off situations. Obviously the response time depends on the voltage pulse applied and the gray levels of the starting and ending states. Fig. 5 and 6 show the gray-to-gray response time data of ordinary OCB cell and NBB cells. It includes response time between 8 different grayscale levels. Both LCDs operate in a normally white mode. Level 1 indicates a black state and level 8 indicates a white state. Figure 7 shows the gray-to-gray response time of ordinary OCB π-cell with pretilt angle 8^0



(a)

(b)

Fig. 4 Transmission (top curves) vs driving electrical pulse (bottom curves) for voltage on (a) and voltage off (b) situations.

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Fig. 5 shows the gray-to-gray response time of NBB cell with pretilt angle 53^0. Fig. 6 is that of an OCB cell. It clearly shows that the response time of NBB cell is faster than π-cell. The worst case of NBB cell is only 1.8ms while the worst case of ordinary π-cell is more than 3.5ms.

Indeed, since we can make OCB cells with arbitrary pretilt angles, we can study the response time of OCB cells as a function of the pretilt angle. Fig. 7 summarized the results for the worst case (total on to total off switching). It can be seen that there is a systematic decrease of the total response time as the pretilt angle is increased. This is evidently due to the less deformation of the on state so that less time is needed to relax back to the no voltage state.

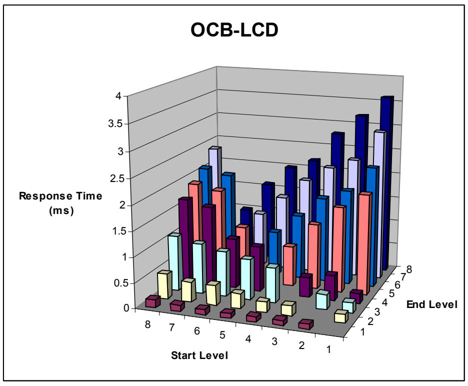

Fig. 5 Response characteristics between gray levels of a OCB cell.

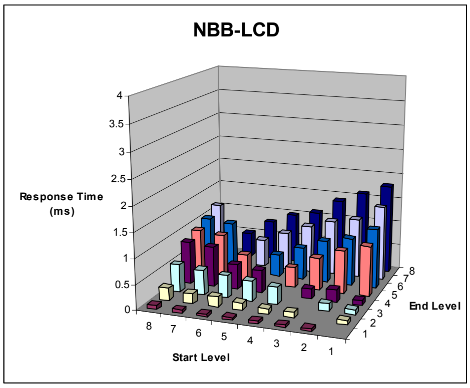

Fig. 6 Response characteristics between gray levels of a NBB cell.

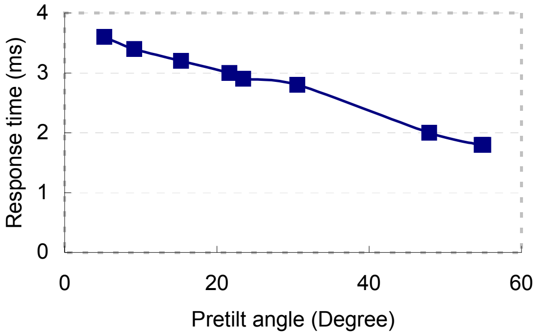

Fig. 7 Total response time of switching as a function of the pretilt angle for the OCB cell. The last two data points are those of an NBB cell.

Fig. 10 shows the simulated and measured transmission spectra of the NBB cell when no voltage is applied.

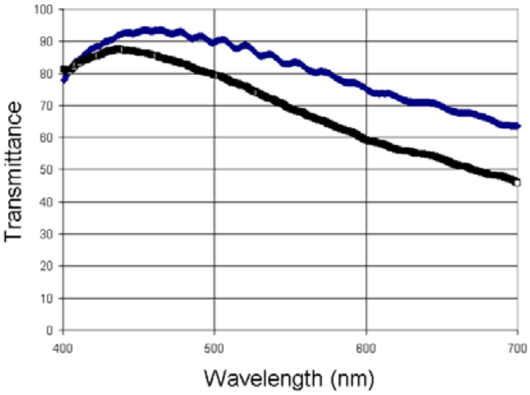

Fig. 10 Measured transmission spectra of the NBB and the OCB cell.

5. CONCLUSION

In this paper, the NBB cell is studied. It is a no bias π-cell. As a π-cell, it has a fast response time less than 2ms. It is made possible with the nano-textured alignment layers reported earlier [14]. This alignment layer does not involve any untested new materials and is compatible with existing manufacturing techniques.

With the ability to make OCB cells with arbitrary pretilt angles, we performed a systematic study of this cell, in terms of the response time, the critical voltage needed to transform from the splay to the bend state. As expected, the critical voltage decreased from 2V to zero as the pretilt angel is decreased. It is also interesting to note that the total response time of the OCB decreases steadily as the pretilt angle is increased. Unfortunately, the cell retardation also decreases as the pretilt angle is increased, making the optical efficiency less than ideal. Thus some compromise has to be reached, unless LC materials with higher birefringence and low viscosity can be found.

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REFERENCES

[1] H. G. Walton and M. J. Towler, Liquid Crystals, 27, 1329 (2000).
[2] S. T. Wu and A. M. Lackner, Appl. Phys. Lett., 64, 2047 (1994).
[3] C. L. Kuo, T. Miyashita, M Suzuki and T. Uchida, Appl. Phys. Lett., 68, 1461 (1996).
[4] H. Mori and P. Bos, Japan J. Appl. Phys., 38, 2837 (1999).
[5] K. Kumagawa and A. Takimoto, SID Digest, 33, 1288 (2002).
[6] H. G. Walton and M. J. Towler, Liquid Crystals, 27, 1329 (2000).
[7] E. J. Acosta, M. J. Towler and H. G. Walton, Liquid Crystals, 27, 977 (2000).
[8] J. E. Anderson, C. Chen and A. Lien, U. S. Patent No. 6,067,142 (2000).
[9] S. T. Wu and A. M. Lackner, Appl. Phys. Lett., 64, 2047 (1994).
[10] C. L. Kuo, T. Miyashita, M. Suzuki and T. Uchida, Appl. Phys. Lett., 68, 1461 (1996).
[11] E. J. Acosta, M. J. Towler and H. G. Walton, Liquid Crystals, 27, 977 (2000).
[12] M. D. Tillen, E. P. Raynes, M. J. Towler, U. S. Patent No. 6,222,605 (2001).
[13] T. Uchida, M. Ohgawara and M. Wada, Japan J. Appl. Phys., 19, 2127 (1980).
[14] F. S. Y. Yeung, F. C. Xie, J. Wan, O. Tsui, P. Sheng and H. S. Kwok, SID Digest, 36, 1080 (2005)
[15] X. J. Yu and H. S. Kwok, Appl. Phys. Lett., 85, 3711 (2004)
[16] T. Kono, T. Miyashita and T. Uchida: Asia Display (1995) p. 581.