Patterned Photoalignment for Vertically Aligned LCDs

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Abstract

Photoalignment of liquid crystals is evaluated as a method of achieving patterned alignment for vertically aligned LCDs suitable for LCTV and other applications. The performance of photoalignment is demonstrated to be equivalent to rubbed alignment, with the considerable advantage of easy patterning of the alignment direction. Photoalignment is found currently to have some limitation on its long-term stability, however schemes for overcoming this limitation are discussed.

Introduction

Vertically aligned (VA) LCDs[1)2)] are an attractive option for flat screen displays and particularly for LCTVs because the very low transmission dark state results in an excellent contrast ratio. However in order to achieve a large, symmetrical viewing angle it is necessary to induce multi-domain switching of the liquid crystal within each pixel of the LCD. In this paper we investigate photoalignment as a method of inducing multi-domain switching in VA LCDs. We assess the advantages of photoalignment compared to conventional alignment by mechanical rubbing of polymer alignment layers.

The key advantage of photoalignment over rubbed alignment is that the liquid crystal alignment direction can be freely patterned. To obtain the required symmetric viewing angle in VA LCDs it is necessary to pattern the liquid crystal alignment in four, mutually perpendicular, directions. This is not possible by rubbed alignment, although at Sharp Laboratories of Europe a technique has been developed for two direction patterning by rubbed alignment[3)].

Other known methods of inducing multi-domain switching in VA LCDs are:

・Patterning the pixel electrodes to induce a fringe effect in the electric field[2)].
・Introducing structure into the surface of the LCD substrate[4)].

Both these approaches share the drawback that away from the features which induce multi-domain switching, the surface structures or the edge of the patterned electrodes, the effect of the features on the switching of the vertically aligned liquid crystal is weak. This can lead to the formation of random detects lines in the liquid crystal which slow switching. Fast switching of the liquid crystal is a key requirement for LCTVs since to avoid blurring the image must update faster than the 16 ms frame time. Photoalignment can avoid the formation of random defect lines by inducing a slightly tilted (88°) alignment over the whole of the pixel. This small tilt angle does not significantly degrade the contrast of the VA LCD.

1. Photoalignment

Photoalignment of liquid crystals is the technique by which exposure of an alignment layer to light, normally ultra violet (UV) light, generates an anisotropy in the layer which induces a particular alignment direction in the liquid crystal. Since the exposure can be carried out by using photolithographic masks it is relatively easy to pattern the resulting alignment. In addition the photoalignment technique is a non-contact process. This is a key advantage for some types of display, such as Plasma Addressed LCDs (PALC)[5], in which one of the substrates is thin and fragile. Non-contact processing is also an advantage for conventional TFT LCDs where photoalignment avoids the production of dust and the static damage to the TFTs which can be caused by rubbed alignment.

Photoalignment of liquid crystals can be broadly divided into three main types:

- Photoisomerisation[6].
- Photodimerisation[7].
- Photodecomposition[8].

Photoisomerisation involves a reversible conformation change in molecular constituents of the alignment layer (e.g. azo groups). Therefore, without further chemical processing, the resulting photoalignment has poor long-term stability. Photodimerisation involves a permanent change to the structure of the alignment layer, however the materials used (cinnimates, coumarins, chalcones) are not commonly used as liquid crystal alignment layers. The advantage of the photodecomposition method is that conventional polyimide materials, which have established reliability, can be used as alignment layers. Therefore this study has concentrated on applying photodecomposition photoalignment to VA LCDs.

1･1 Photoalignment Mechanism

The mechanism of photodecomposition photoalignment is that a polyimide alignment layer is exposed to short wavelength, normally less than 300 nm, UV light. At this wavelength the UV light has sufficient energy to break organic bonds within the polyimide molecules. The photochemistry of this reaction is complex. Some researchers have proposed that the UV light breaks the alkyl side chains which are present in VA type polyimides[9]. However, based on studies of polyimide photoresists, a more likely mechanism is photooxidation of the main polyimide chain[10][11]. These studies have shown that the imide linkage is subject to photooxidation. However , it is possible to increase the sensitivity of polyimides for photoalignment by including groups which undergo photooxidation at lower UV exposures than the imide groups. Cyclobutane has been found to be an effective group for increasing the sensitivity and uniformity of photoalignment[12].

1･2 Photoalignment Method

Two VA-type polyimide alignment layer materials have been investigated, JALS-2026 (JSR Corporation) and RN-1338 (Nissan Chemical Industries, Ltd). Both types of alignment layer were spun coated onto ITO coated glass plates and cured under a nitrogen atmosphere at 180℃.

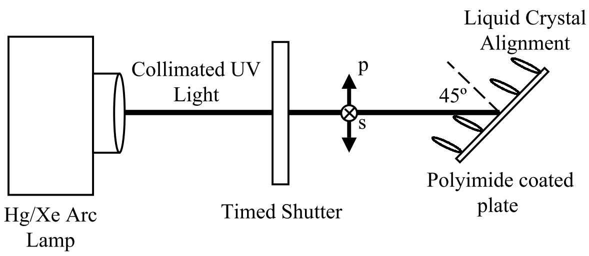

Fig. 1 UV exposure system.

UV exposures were carried out with a 200 W Mercury/Xenon high pressure arc lamp. As shown in Figure 1 the polyimide coated glass plates were exposed to the collimated output of the lamp at a 45° angle of incidence. Figure 1 illustrates that exposure with unpolarised UV light gave tilted alignment of the liquid crystal within the plane of incidence of the beam. By the geometry of the exposure, the component of the UV intensity in the plane of incidence (p-polarised) was less than the component perpendicular to the plane of incidence (s-polarised). Therefore more bonds were photodecomposed in the polyimide chains which were oriented perpendicular to the plane of incidence. The liquid crystal was aligned by the undecomposed polyimide chains orientated within the plane of incidence.

UV intensity was measured at 250 nm wavelength by a calibrated Newport 835 Optical Power Meter. For intensity measurements a 10 nm bandpass filter was used to select the 250 nm wavelength, but for alignment layer exposures the arc lamp output was unfiltered. Total exposure energy was controlled by varying the exposure duration.

After exposure the polyimide coated glass plates were assembled into test LCDs. Unless stated otherwise these test LCDs were filled with the negative dielectric anisotropy liquid material MJ 97174 (Merck KGaA). Filling was carried out with the liquid crystal in its isotropic phase, followed by slow cooling into the nematic phase.

2. Tilted Alignment

Glass plates coated with the polyimide alignment layers JALS-2026 and RN-1338 were exposed to unpolarised deep UV light as described above. The glass plates were assembled into 50 µm test cells to measure the resulting pretilt angles. The crystal rotation technique[13] was used to measure pretilt in the ranges 0°-10°, 70°-90° and the conoscopic technique[14] to measure the intermediate pretilt range.

Fig. 2 demonstrates that the full range of pretilt angles, from 90° down to 0° can be obtained with increasing UV exposure. However, as with rubbed alignment, it is difficult to achieve reproducible alignment in the pretilt range between 20° and 80°. For VA LCDs a pretilt angle of approximately 88° is required. This can be achieved with a UV exposure of approximately 1 Jcm^{-2} for both the alignment layers investigated.

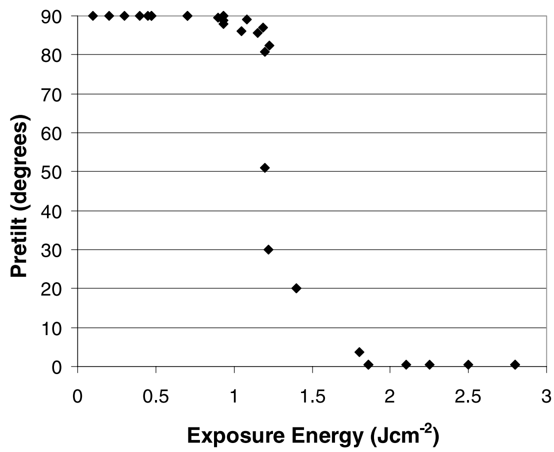

Fig. 2 Pretilt as a function of exposure energy at 250 nm for JALS-2026.

3. Performance Comparison

To assess the quality of a Vertically Aligned Nematic (VAN) LCD made using photoalignment, RN-1338 coated glass plates were exposed to obtain 88° pretilt. These plates were assembled into 5µm test LCDs with antiparallel alignment directions. For comparison test LCDs were also made using rubbed alignment. **Fig. 3** demonstrates that similar transmission/voltage curves were obtained for photoaligned and rubbed VAN

Table 1 Response times for switching of VAN LCDs (0-90% of Transmission Change).

	Response Time (ms)		
Voltage Change	Modelled	Rubbed	Photoaligned
5 to 2 V	33	30	32
2 to 5 V	37	29	39

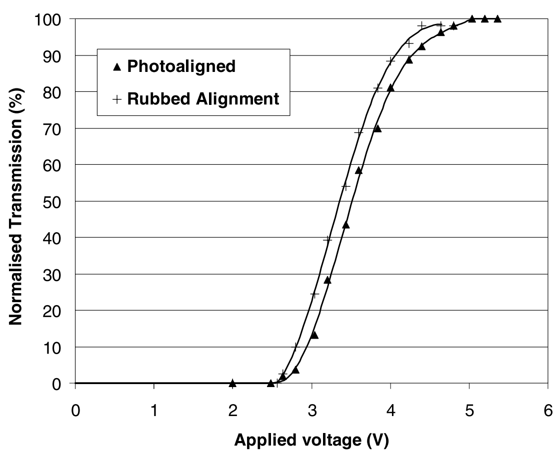

Fig. 3 Transmission/voltage curves for photoaligned and rubbed VAN LCDs.

displays. The response times are compared in **Table 1**, together with values obtained by numerical modelling[15] using realistic cell and material parameters. (Response times in **Table 1** are longer than 16 ms because the cell and material parameters were not optimised for video rate switching). These results demonstrate that VAN LCDs fabricated by photoalignment have the same performance as those fabricated by rubbed alignment.

4. Voltage Holding Ratio

The effect of the UV exposure required for photoalignment on the Voltage Holding Ratio (VHR) is an important issue which must be addressed when considering the practical use of photoalignment for TFT addressed LCDs. The VHR is a measure of how much of the charge applied to a pixel leaks away over a frame time due to conduction in the liquid crystal. The VHR should be 0.98 to 1.0 to avoid image flicker. Photoproducts from the UV decomposition could increase the conductivity of the liquid crystal material and so degrade the VHR for photoaligned LCDs.

The VHR was checked for the RN-1338 alignment layer using a VHRM 105 system (autronic-Melchers GmbH). VHR measurements were made on 5mm thick test cells at 70℃ for a simulated frame frequency of 30 Hz. The TFT compatible LC material ZLI 4792 was used for this study. **Fig. 4** shows that, contrary to expectation, the UV exposure need not significantly reduce the VHR. This means that photoalignment can be used to fabricate TFT addressed LCDs.

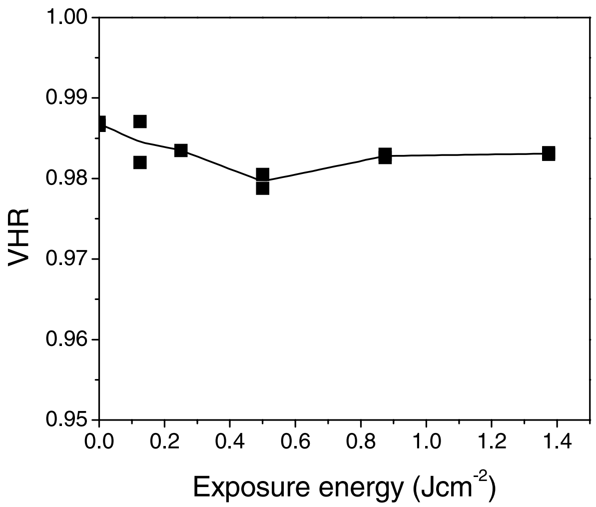

Fig. 4 Voltage holding ratio for ZLI 4792 and photoaligned RN-1338.

5. Stability

Another important consideration for photoalignment is the long-term stability of the alignment. This was tested for both alignment layers by monitoring the value of the pretilt of photoaligned test LCDs subjected to accelerated ageing by storage at 60℃. **Fig. 5** shows that both the alignment layers evaluated in this study did show a reduction of pretilt under these conditions. The initial ~88° pretilt values dropping continuously over the duration of the test. This level of variation is not acceptable for an LCD product. However, there is clearly a strong dependence of stability on the alignment layer material. Therefore further material development could overcome the stability problem.

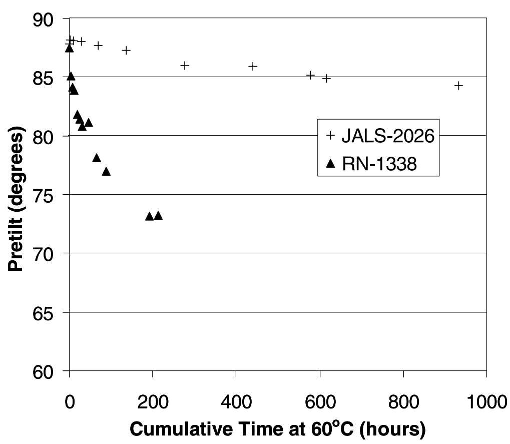

Fig. 5 Long term stability of pretilt for JALS-2026 and RN-1338 using the liquid crystal MJ 97174.

6. Stable Photoalignment Scheme

The problem of pretilt stability identified in **Fig. 5** shows that further investigation would be required before this alignment technique could be used in the active (i.e. visible) area of an LCD pixel. We have recognised however that such photoalignment might still be used if pretilt variation could be confined to non-active (i.e. non-visible) areas of a pixel. We therefore proposed the alignment method shown in **Fig. 6**. Photoaligned areas are arranged surrounding a non-photoaligned visible pixel area. The purpose of the photoaligned areas is to influence, via the elastic forces present in the bulk liquid crystal, the switching in the 90° aligned visible area. The black matrix surrounding the pixel can hide the photoaligned areas. Variation in the pretilt of the photoaligned areas does not effect the optical properties of the visible area of the pixel which has stable 90° alignment.

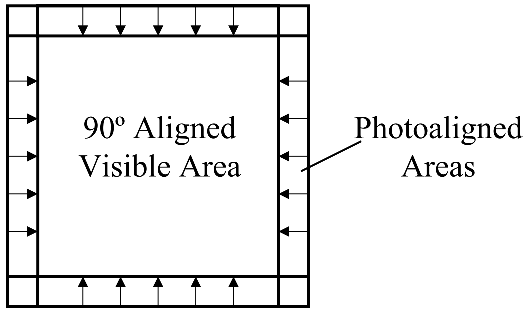

Fig. 6 Layout of photoaligned areas to induce uniform switching (arrows show direction of the titled alignment).

This scheme was evaluated by fabricating a test LCD with four low pretilt (~1°) photoaligned areas surrounding 100μm square pixels. Both substrates of the test LCD were identically patterned (although a variation of the scheme is possible for which only one substrate is patterned and the other substrate has uniform 90° alignment). For this test device the liquid crystal alignment direction was parallel in all of the photoaligned areas (**Fig. 7a**). The thickness of the liquid crystal layer was 5μm. **Fig. 7b** shows a typical pixel with 0 V applied. The 90° aligned visible pixel area is black between crossed polarisers.

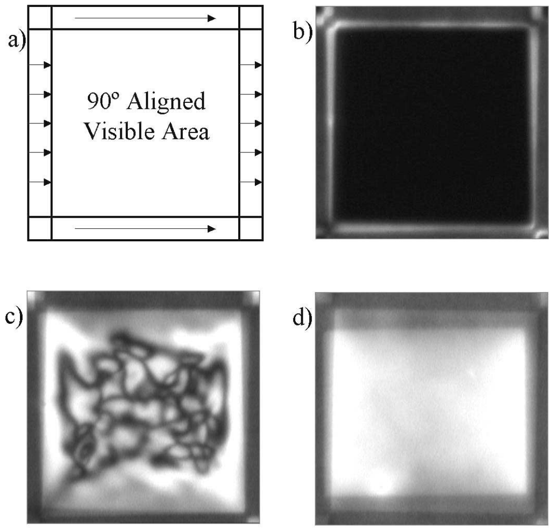

Fig. 7 90° aligned pixel with surrounding photoaligned areas.
a) Liquid crystal alignment directions.
b) No field applied. c) 20 ms after a 5.6 V is applied, no polymer network.
d) 20 ms after a 5.6 V is applied, weak polymer network.

The effectiveness of the photoaligned areas in controlling the switching of the 90° aligned visible area was evaluated by applying 5.6 V across the liquid crystal layer. The field was applied both to the visible pixel area and the surrounding photoaligned areas. An image of the pixel 20 ms after the field was applied was acquired by an image capture system (**Fig. 7c**) to test the video rate switching capability of the scheme. It can be seen that while the areas of the pixel within approximately 20μm of the photoaligned areas have switched uniformly the liquid crystal orientation in the centre of the pixel has many random defect lines. The influence of the photoaligned areas propagates by elastic interactions approximately 20 μm into the 90° aligned visible area within 20 ms. Therefore, to achieve uniform switching at video rate, the photoaligned areas should to be spaced by 40-50μm. Pixels of this size are used in small, mobile LCDs and so for this application the photoaligned areas could still be located at the edges of the pixels. For large area LCTVs, such as the 20" Aquos, the pixel size is approximately 200μm by 600 μm. In this case photoaligned areas need to be provided within the area of the visible pixel. These small photoaligned areas could be hidden by additional areas of black matrix, fabricated during the same processing step as the conventional black matrix.

7. Polymer Network Scheme

A disadvantage of the scheme described in section 6 is that it reduces the aperture ratio of the pixels. Therefore an alternative scheme has also been investigated. As before the areas at the edges of the pixels were photoaligned. However a small amount, 0.36% by weight, of a diacrylate monomer plus 0.04% of photoinitiator were mixed with the liquid crystal before filling. This monomer concentration is less than that required for a conventional polymer stabilised LCD. When polymerised this concentration forms a weak network which is sufficient to bias the switching of the liquid crystal in the 90° aligned visible area, without degrading other display properties, such as contrast or switching speed.

To evaluate this alternative scheme another test LCD panel was fabricated, identical to the one already described in section 6, with the monomer and photoinitiator added to the liquid crystal mixture. When a voltage was first applied to the pixels of the LCD it showed similar behaviour to that in **Fig. 7c**. However after 1 second a uniform liquid crystal orientation was achieved. With the voltage continuously applied the test LCD was exposed to near UV light to polymerise the diacrylate monomer. Once the polymer network had formed the voltage was removed. Due to the low concentration of the polymer network the 0 V transmission of the LCD was unchanged. However **Fig. 7d** shows that when the 5.6V was applied again the presence of the network induced defect free switching of the 90° aligned visible area within 20 ms. Therefore this technique can be applied to achieve video rate switching in LCTVs

Conclusions

Photoalignment by the photodecomposition method has been evaluated as a technique for achieving multi-domain switching in VA LCDs. The required 88° pretilt angle could readily be achieved for the alignment layers studied. The properties of photoaligned VAN LCDs were found to be equivalent to those with rubbed alignment. Contrary to expectation UV exposure of the alignment layer did not significantly degrade the VHR for the materials tested in this study.

However the long term stability of the VA-type photoalignment has been found to need further improvement before the alignment technique could be used in the visible area of a pixel. The results suggest that this improvement could be achieved by further materials development. In addition two new schemes have been proposed and evaluated for overcoming the current limitation on the long term stability of VA-type photoalignment. Both of these schemes offer the potential of video rate switching in vertically aligned LCDs, and so are suitable for LCTVs.

Acknowledgements

The authors wish to thank Nissan Chemical Industries, Ltd. and JSR Corporation for the supply of alignment layer materials and for discussions relating to this work.

References

1) M. F. Schiekel and K. Fahrenchon, Applied Physics Letters, vol. 19 (1971) p391.
2) J. F. Clerc, SID 1991 Digest (1991) p758.
3) J. Harrold, A. Jacobs et al., Sharp Technical Journal, vol. 6 (1999) p24.

4) K. Ohumuro, S. Kataoka et al., SID 97 Digest (1997) p845.
5) N. Yamada, T. Akai et al., International Display Workshop 98 (1998) p143.
6) W. M. Gibbons, P. J. Shannon et al., Nature, vol. 351 (1991) p49.
7) M. Schadt, K. Schmitt et al., Japanese Journal of Applied Physics Part 1, vol. 31 (1992) p2155.
8) M. Hasegawa and Y. Taira, International Display Research Conference 94 (1994) p213.
9) Y. Iimura and S. Kobayashi, SID 97 Digest (1997) p311.
10) C. E. Hoyle, E. T. Anzures et al., Macromolecules, vol. 25 (1992) p6651.
11) H. Okitani, A. Tsuchida et al., Macromol. Chem. Phys., vol. 197 (1998) p2493.
12) H. Endo, Y. Miyama et al., International Display Workshop 2000 (2000) p439.
13) T. J. Scheffer and J. Nehring, Journal of Applied Physics, vol. 48 (1977) p1783.
14) W. A. Crossland, J. H. Morrissy et al., Journal of Physics D, vol. 9 (1976) p2001.
15) autronic-Melchers GmbH, DIMOS.

（received Jan. 20, 2003）