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Hiap L. Ong [a]

[a] Kopin Corporation, 125 North Drive, Westborough, MA, 01581, USA

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Improvement of LCD Viewing Angles by Negative Birefringence Compensation Films

HIAP L. ONG
Kopin Corporation. 125 North Drive. Westborough, MA 01581. USA

The negative birefringence optical compensation films can be used to significantly improve the viewing angles of single-domain and multi-domain LCDs. We review the major applications of the applications of negative birefringence compensation to TN, STN, vertically aligned LCDs, and parallel aligned LCDs. Most recently, there are three TFT/LCD panels with improved large viewing cone being commercialized with the use of the negative birefringence optical compensation films. These panels include: (1). US TFT/LCD vendors compensated single domain TFT/TN panels; (2). Sharp compensated 2-domain Super-V TFT/TN panels; and (3). Fujitsu super-wide compensated 4-domain vertical aligned TFT/VA panels.

Keywords: LCD, viewing angle; negative birefringence compensation film

INTRODUCTION

The limited viewing angle cone and asymmetrical viewing angle are two of the major limitations of present liquid crystal displays (LCDs). Various LCD structures have been developed to improve the LCD viewing angle cone and to change the asymmetrical viewing to symmetrical viewing angle[1]. The use of an external optical compensation film provides one of the simplest methods to improve the LCD viewing angle cone. The compensation film can enlarge the viewing angle cone, but can not improve the asymmetrical viewing angle to a symmetrical viewing angle. In addition, the optical

compensation can be combined with various improved LCD geometries having symmetrical viewing angle to further enlarge the LCD viewing angle cone of the symmetrical viewing LCDs. In this paper, we will review the major applications of the negative birefringence optical compensation films to LCD viewing angle improvment[2].

The application of the negative birefringence compensation film was first considered by Clerc for to improve the vertically aligned nematic LCDs; the new LCDs were called color-super-homeotropic (CSH) LCDs[3,4]. In 1992, we applied this negative birefringence optical film to TN/LCDs and showed that the viewing angle for the normally white TN/LCDs can be improved significantly with the use of a negative birefringence compensation film[5]. This technique provides the simplest method to improve the conventional single domain LCD viewing angle without any modification of the LC fabrication process. The negative birefringence film compensated TN/LCD gives the largest reported viewing angle performance for a single domain TN/LCD. Mori et al have further improved the vertical oriented negative birefringence optical film to negative birefringence discotic compound film to further improve the viewing angle.[6,7].

Besides the CSH and conventional single domain TN LCDs, the negative birefringence optical films have been applied to other major types of LCDs. The application of the negative birefringence film is summarized in TABLE I.

SINGLE-DOMAIN AND MULTI-DOMAIN TN/LCDs

Single-Domain TN/LCDs

For the NW TN/LCDs, we showed that the light leakage in the off-axis viewing angle in the black state is significantly reduced by the use of a negative birefringence compensation film. The negative birefringence film is used to compensate the black state and reduce the light leakage in the off-viewing angle in the field-on state. The new NW negative birefringence film

TABLE I. Summary of the application of negative compensation film in major LCD geometry's and the end products.

LCD Geometry	Inventor	End Product
1. TN/LCDs		
a. Single-domain TN/LCDs	Ong (IBM) Hatoh (Toshiba) Muri (Fuji)	US vendors
b. Two-domain TN/LCDs	Ong (IBM) Muri (Fuji) Hirata (Sharp)	Sharp
c. Four-domain TN/LCDs	Ong (IBM)	
2. Vertical aligned LCD (VA, CSH)		
a. Single-domain VA/LCDs	Yamauchi (Stanley) Wu (Hughes)	
b. Four-domain CSH/LCDs		
(1). + structure	Clerc (Stanley) Ong (IBM) Koike (Fujitsu)	Fujitsu
(2). X structure	Lien (IBM) Ong (IBM)	
c. Two-domain VA with grating surface	Ong (IBM)	
3. Parallel aligned nematic (CSP) LCD	Ong (IBM)	
4. IPS nematic LCDs	Ong (Kopin)	
5. pi-cell LCDs	Mori (Fuji)	
6. STN/LCDs	Mori (Fuji)	

compensated TN/LCD gives the largest reported viewing performance for a single domain TN/LCDs. We use a negative birefringence with a vertical optical axis orientation film directly for this application[5], whereas Hatoh et al. proposed to use a thick layer of cholesteric LC film as the negative birefringence film[8]. The same method was used by Eblen et. al. in their film compensated TN/LCDs[9].

We also worked with Japanese polarizer and optical film manufacturer Nitto Denko to fabricate this kind of special compensation film. At present such kind of optical compensation films are being commercialized by Nitto Denko and are also available from a few major polarizer and optical film manufacturers[6,10,11].

In our negative birefringence compensation film, the optical axis is in vertical alignment. The negative birefringence film is used to compensate the field-on black state. Recently low voltage LC materials are available and make this type of compensation work even more effective with same operation field-on voltage.

Muri showed that with the use of a negative birefringence discotic compound film, the viewing angle can be further improved. This discotic compound film has a hybrid alignment structure of negative birefringence and has similar orientation structure to that of the field-on state LC. In addition, two identical films with a similar structure to that of the half LC cell are placed on the both sides of the cell. This compensation results in uniform black in all directions in the field-on state[6,7].

The negative birefringence compensation film enlarged the TN/LCD viewing angle significantly. The negative birefringence compensation films have been used in several Asia and US TFT/LCD manufacturers and display system developers to improve the TN/LCD viewing angles. However, two major LCD viewing angle problems are still not completely eliminated by this type of negative birefringence compensation film. The first major problem is the color-shift in the oblique viewing angle and its dependent on temperature. The second major problem is the grayscale inversion in the upper viewing zone.

Multi-Domain TN/LCDs

Multi-domain TN/LCDs are developed to eliminate the asymmetrical viewing angle in the vertical viewing zone and consequently to have symmetrical viewing angle in both vertical and horizontal viewing zones[11]. The grayscale inversion in the upper viewing angle is significantly improved and therefore the viewing angle is enlarged. The negative birefringence compensation can also be used for the compensation of multi-domain TN/LCDs. The resulting LCDs offer an further enlarged viewing angles cones and symmetrical angle in both horizontal an vertical viewing zones[17]. Muri and Chen also studied the negative birefringence film compensation multi-domain TN/LCDs[6,7,18].

The negative birefringence compensation film have been used in the Sharp Super-V wide viewing angle TFT/LCD panels[13]. Watanabe found that by adjust the ratio of the two domain to 85 to 15, the negative birefringence film compensated two-domain TN/LCDs gives a wide viewing angle (70 degrees in left, right, and upper viewing angle, and 40 degree in the lower viewing angle) with no gray scale inversion.

SINGLE-DOMAIN AND MULTI-DOMAIN VERTICALLY ALIGNED NEMATIC LCDs

Single-Domain VA Nematic LCDs

The vertically aligned nematic (also called the electrically controlled birefringence, ECB) LCDs have a vertical alignment at the field-off state. Therefore it is natural to use the standard negative birefringence with a vertical axis structure to compensated the field-on black state. The method of adding the negative birefringence compensation film was first suggested by Clerc and Yamauchi[3,4]. The compensated panels showed significantly reduction of light leakage at all viewing angle at black field-off state and resulted in a large viewing cone[14,15]. But the viewing angle improvement is not large enough for large viewing application. Ohmura showed that the viewing angle can be further improved by the addition of a uniaxial positive birefringence film on a uniaxial negative birefringence compensation film[16].

Multi-Domain VA Nematic LCDs

The used of the negative birefringence compensation for LCD viewing angle improvement was first introduced by Clerc and Yamauchi, et al. for the multi-domain VA nematic LCD using a rectangular type + pattern[3,4]. The CSH was used to call this improved LCD with excellent viewing angle cone. We further improved the symmetrical property of this CSH to a full symmetrical and best transmission in all viewing angle by using a square-type + sub-pixel pattern[19]. That is, we decomposed the rectangular-type pixel into square-type sub-pixels to have best transmission under the cross polarizer or parallel polarizer geometry. In comparison to the +-pattern, a square X-pattern will offer higher fringe field effects, but the viewing angle is best the diagonal direciton[20,21]. By using the same method for the single-domain VA LCDs, Ohmura showed that the viewing angle of the +-pattern can be further improved by the addition of a uniaxial positive birefringence film on a uniaxial negative birefringence compensation film[16]. The viewing angle is larger than 70 degrees in all directions.

Most recently, Fujitsu has introduced a 15-in panel with full symmetry from all viewing angles[16]. With the use the +-pattern, the contrast ratio is more than 300 with a viewing angle cone of 140 degrees.

Ong also invented a two-domain VA/LCDs using grating surface to have symmetrical viewing angle performance, and applied the negative birefringence film to further enlarger the viewing angle[22].

PARALLEL ALIGNED NEMATIC, IPS, PI CELL AND STN/LCDs

Parallel Aligned Nematic LCDs

We showed that the viewing angle of a parallel aligned nematic LCD can be significantly enlarged by the use of a negative birefringence compensation film. The resulting LCDs are called color-super-parallel (CSP) LCDs[20]. Two types of the compensation films are used. For the NW CSP, where the field-off state is white, the negative birefringence compensation film has the standard vertical axis orientation to improve the field-on black state. For the

normally black (NB) CSP/LCD, where the field-off state is black, the negative birefringence compensation film has a special parallel axis orientation to improve the field-off black state.

A symmetrical viewing angle performance in all viewing zones can be obtained in CSP, with the use multi-domain method. The negative birefringence compensation film can also used to improve the viewing angle of the multi-domain CSP/LCDs[21].

In-Plane Switching Nematic LCDs

New in-plane switching (IPS) nematic LCDs with super wide viewing angle characteristics have been developed by Oh-e et al in Hitachi[21]. We showed that the viewing angle of certain IPS/LCDs can be further enlarged by the use of a negative birefringence compensation film[23].

Pi-Cell Nematic LCDs

Pi-cells were originally developed by Bos et. al. as a fast response and wide viewing angle LCD[21]. Later, Bos et. al. and Uchida et. al., independently showed that the viewing angle of a pi cell can be enlarged by the use of a negative birefringence compensation film[26,27]. With the use discotic negative birefringence optical film, the viewing angle can be further improved the resulting LCDs[29].

STN/LCDs

The direct application of the negative birefringence vertical orientated optical film is shown to not very effective to improve the STN viewing angle[28]. However, Muri showed that with the use discotic negative birefringence optical film, the viewing angle can be further improved[6,7,29].

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