Wide Viewing Angle Technologies of TFT-LCDs

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Abstract

Recently, the viewing angle of TFT-LCDs has been drastically improved. The wide viewing angle technologies are classified into the modifications of molecular orientation and switching in nematic LC, the utilization of smectic LC, the application of optical compensation film, the photo-luminescent method, etc. This paper reviews these wide viewing angle technologies.

Introduction

The application of liquid crystal displays (LCDs) has expanded to include various areas such as electronic calculators, word processors, video cameras, laptop PCs, desktop PCs, and TVs. This great expansion is attributed to not only rapid cost reduction but also rapid improvement of the display quality in LCDs. Especially, a rapid improvement of the viewing angle, as well as improvements in contrast ratio, brightness, information content, and display size, played a big role to popularize the liquid crystal display.

LCDs essentially show viewing angle dependence because they utilize the transmission change induced by the switching of molecular orientation of anisotropic liquid crystal molecules with rod. For example, when TFT LCDs were first commercialized in the latter half of 1980's, they utilized TN (Twisted Nematic) mode[1)], but the viewing angle was very narrow with display image conversion. In the 1990's, however, various methods for achieving a wide viewing angle were proposed and developed, thus greatly improving the viewing angle characteristics.

The reason why the viewing angle of TN display mode is narrow will be explained in paragraph 1. Several wide viewing angle technologies are reviewed in paragraph 2.

1. The reason for the narrow viewing angle of the TN display mode

The TN display mode utilizes a 90˚ twisted alignment, where liquid crystal molecules are twisted in bulk and parallel to substrates. The liquid crystal molecules are switched perpendicular to substrates when an electric field is applied. (**Fig. 1**). Usually, the polarizers are set in cross nicol position (normally white mode), giving a bright state under no electric field (OFF state) and a dark state under application of electric field (ON state).

When no voltage is applied as shown in **Fig. 1(a)**, a polarizing plane of linearly polarized light passes through the first polarizer and rotates according to the twisted orientation of the liquid crystal molecules. This is called optical rotation. The optical rotational behavior is maintained even if the incident direction of light is tilted.

On the other hand, when the voltage is applied enough (**Fig. 1 (c)**), the twisted orientation disappears and the liquid crystal becomes a medium with an uniaxial birefringence. In

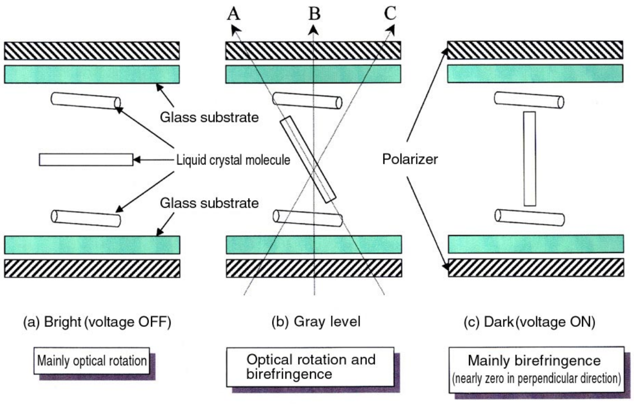

Fig. 1 The principle of TN mode.

this case, when the display is observed from a vertical direction to the substrate, the display shows a dark state, because the optical axis of liquid crystal is perpendicular to the substrate. However, when the display is observed from the tilted direction, the display does not show completely a dark state because light leaks due to the birefringence.

In the gray level as shown (b) in **Fig. 1**, optical rotation exists together with birefringence. The birefringence becomes predominant with an increase in the voltage. For example, if the views from each of the directions, ABC, are compared, the birefringence in the direction A the highest and the transmission is different in each direction.

2. Wide viewing angle technologies

Various wide viewing angle technologies have been developed so far. Some of them are reviewed in the following paragraphs.

2.1 Improvement of molecular orientation and switching in nematic liquid crystal.

2.1.1 Multi-domain method

The multi-domain method gives each pixel two or more domains with a different orientational state. For example, Kobayashi et al. have proposed the amorphous TN method with multi- domain using an aligning film without rubbing (**Fig. 2**)[2]. In this method, the rubbing process of conventional TN mode was omitted. The molecular long axis of liquid crystal molecules are parallel to the substrate and the direction of the molecular long axis is different in each domain. Therefore, the difference of the viewing direction can be reduced since the standing up direction of the molecule is random when the electric field is applied.

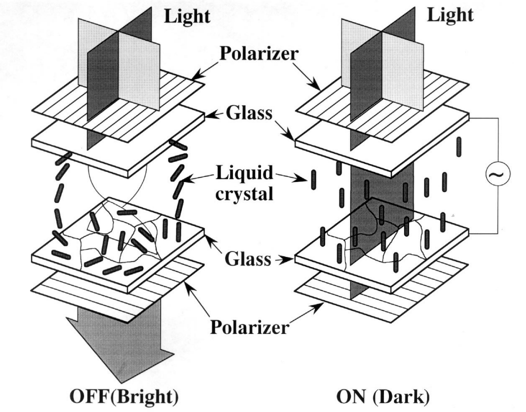

Fig. 2 The amorphous TN method.[2]

Sumiyoshi et al. have proposed C-TN method[3] which changes the standing up direction of the molecule by dividing the display pixel in orientation (**Fig. 3**). In this method, a low pre-tilt aligning film is coated on one substrate. A high pre-tilt aligning film is coated on the other substrate and each pixel is divided into two different areas with different pre-tilt directions. When the voltage is applied, the direction of the molecule standing up direction is opposite between the two domains and the viewing angle dependence of the TN mode is compensated.

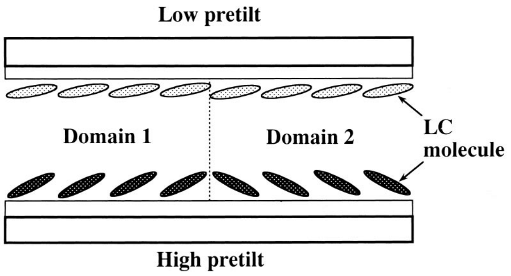

Fig. 3 The C-TN method.[3]

Recently, a method of making four domain areas of the TN orientation in one pixel has also been reported. The schematic explanation is shown in **Fig. 4**. Several methods that realize four domains have been reported. For example, a LC cell with very low pre-tilt aligning film and no chiral compound is cooled from isotropic liquid, giving four domains[4]. The polymer stabilization method[5] has also been reported, which expose light on an LC cell while applying an electric field in order to polymerize the monomers.

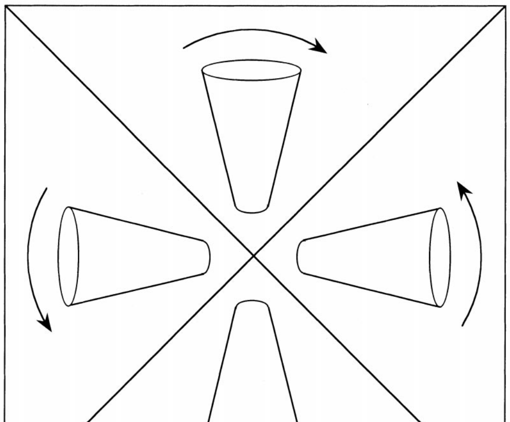
Fig. 4 The 4-domain method.[4)5)]

Yoshida et al. have reported the PDN-LCD[6] method, which combines polarizers with a polymer dispersion liquid crystal (**Fig. 5**). A phase separation occurs by exposing light to a mixture of liquid crystal and monomer, giving a polymer dispersion LCD. When no electric field is applied, the incident polarized light changes in LC cell because the directions of liquid crystal molecules are random. When the electric field is applied, the direction of the molecular long axis of the liquid crystal molecules turns perpendicular to the substrate, giving no change in the incident polarized light. As for this method, the viewing angle is expanded because the molecular orientation and the standing up direction of the molecules are random.

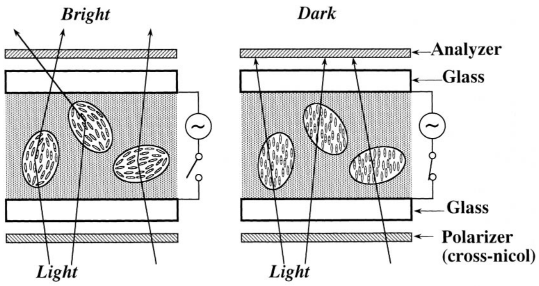

Fig. 5 The PDN-LCD.[6)]

2.1.2 ASM

Yamada et al. have reported the axis symmetry micro-cell (ASM: Axial Symmetric Micro-Cell) method[7)], in which nematic liquid crystal is surrounded by polymer walls. Axis symmetry micro-cell (ASM) are fabricated by phase separation of liquid crystal and polymer. The polymer wall is fabricated by UV exposure. **Fig 6** shows the structure and the molecular orientation of the ASM cell. The chiral compound is added to nematic liquid crystal to realize a twisted orientation of 90˚. The ASM method not only has the advantage of a wide viewing angle due to the axis symmetry orientation but also no disclination due to mono-domain orientation. Figure 7 shows the viewing angle dependence of conventional TN and ASM modes. Using the ASM method, a wide viewing angle with high contrast is obtained and the direction dependence is eliminated.

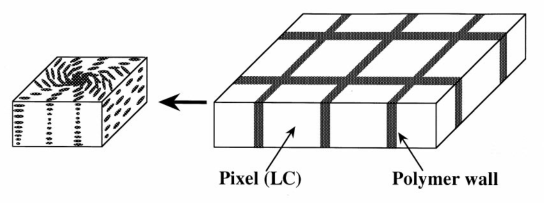

Fig. 6 The ASM method.[7)]

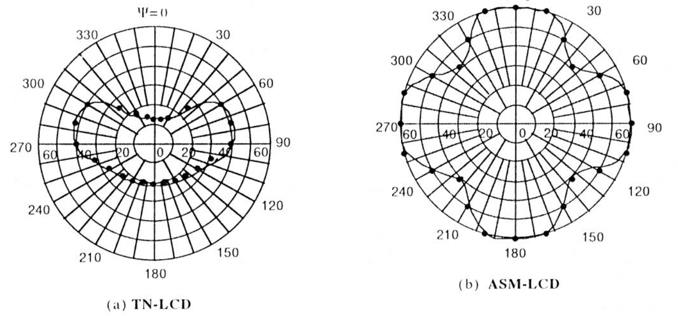

Fig. 7 The viewing angles of normal TN and ASM mode.[7)]

2.1.3 IPS

The IPS (In-Plane Switching) method[8)] is a method to switch the liquid crystal molecules by using lateral electric field (**Fig. 8**). Because the liquid crystal molecules do not stand up diagonally the dependence of the viewing angle on optical characteristics is small, thus realizing a wide viewing angle.

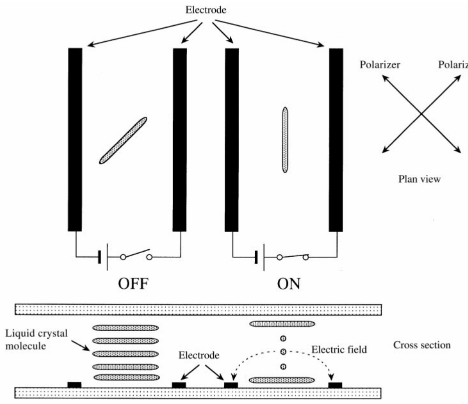

Fig. 8 The IPS mode.[8)]

2.1.4 OCB

The OCB (Optically Compensated Birefringence) mode consists of orientation and optical compensation film as shown in **Fig. 9**. In order to obtain the orientation as shown in Fig. 9, it is required to apply an electric field to a homogeneous orientation with a pre-tilt angle. The OCB cell has a fast response speed in addition to a wide viewing angle. In the case of a TN cell, the response speed is usually 10 - 20 ms and it reaches speeds of nearly 200 ms between different gray levels. On the other hand, in the case of an OCB cell, the response speed is about 2 ms and the response speed between different gray levels is less than 10 ms.

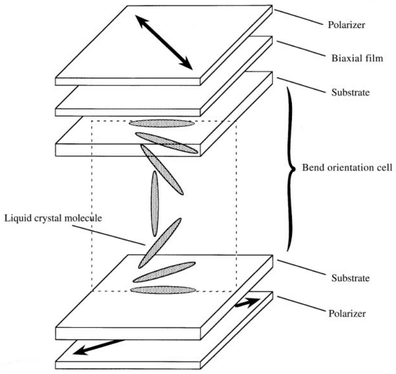

Fig. 9 The OCB mode.[9)]

2.1.5 VA

The VA (Vertically Aligned) method combines the vertical aligning film and nematic liquid crystal with negative dielectric anisotropy

(**Fig. 10**). Contrary to the conventional TN method, a very high contrast ratio can be obtained because the molecular long axis of liquid crystal molecule is almost perpendicular to the substrate and the black level is comparable with the characteristics of cross nicol polarizer when no electric field is applied. Omuro et al. have reported a wide viewing angle of 140° in the top and bottom and the right and left directions by combining this method with the orientation dividing technology. The capability to obtain high contrast (300:1) and high response speed (25 ms) simultaneously is another feature of this method.
Moreover, recently the Electrically-induced Optical Compensation mode,[11)12)] which uses nematic liquid crystal with positive dielectric anisotropy and a lateral electric field (**Fig. 11**), has also been reported.

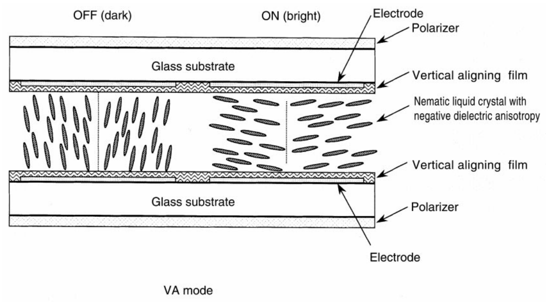

Fig. 10 The VA mode.[10)]

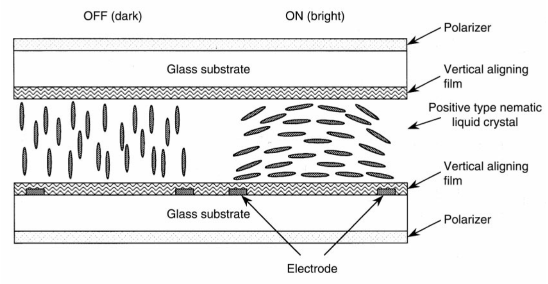

Fig. 11 The EOC mode.[11)]

2.2 Utilization of smectic liquid crystal

The viewing angle of Ferroelectric Liquid Crystal (FLC)[13)] is wide because the switching of FLC is basically in-plain switching. Chiral smectic C liquid crystal is injected into an LC cell with a thin cell thickness of about 2μm m and the resultant unwound orientational state is utilized. Due to spontaneous polarization, FLC can realize a very fast response speed of μs order. Nito et al. have reported a prototype of 0.7" poly-Si TFT FLC with full gray scale, utilizing monostable FLC.[14)] In this panel the position of the molecular long axis of FLC is controlled by the electric field (**Fig. 12**). Terada el al. have reported a prototype of a video-rate full-color a-Si TFT FLC panel by developing monostable FLC with the INC phase sequence.[15)]
An active-matrix DHF (Deformed Helix Ferroelectric) mode has been reported[16)]. In this mode the helical pitch of smectic C phase is shorter than visible light. Therefore, the helical axis, which is usually consistent with the rubbing direction, is consistent with the extinction position under no electric field, though the liquid crystal molecules show a helical structure in the cell. When an electric voltage is applied, a full gray scale could be obtained by an active-matrix drive because the transmission can be controlled by the electric field.
Active-matrix AFLC (Anti-Ferroelectric Liquid Crystal) is also being investigated because it also features a fast response speed and wide viewing angle (In-plane switching) similar to that of FLC. AFLC is switched by interaction between the spontaneous polarization and the electric field, which is similar to switching of FLC. Certain kind of AFLC materials show a smooth voltage-transmission characteristic (**Fig. 13**).[17)] Utilizing such behavior, some prototypes a-Si-TFT AFLC have been reported.[18)19)]

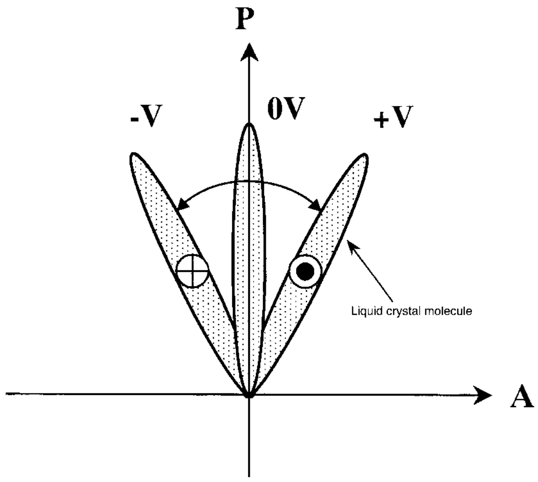

Fig. 12 The principle of monostable FLC showing full gray scale.[14)]

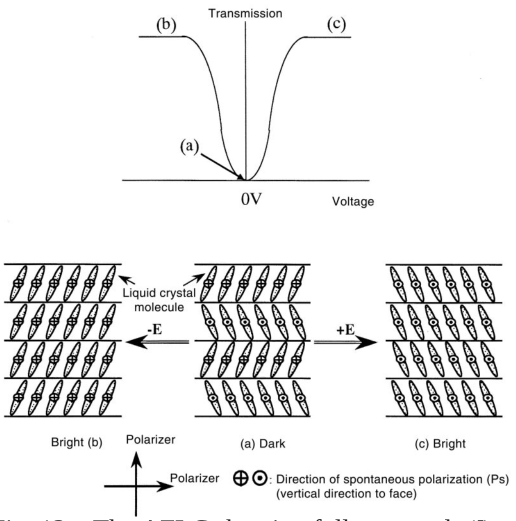

Fig. 13 The AFLC showing full gray scale.[17)]

2.3 Optical compensation method

Wide viewing angle technology utilizing optical compensation film is also being progressed.[20)21)] It is a method with a film in which the orientation angle of uniaxial material with negative optical anisotropy is changed continuously in the direction of the thickness as shown in **Fig. 14**. Such optical compensation film consists of an orientation film coated on the base film and an optically anisotropic layer with a hybrid orientation discotic compound. Discotic liquid crystals can be used for the discotic compound.

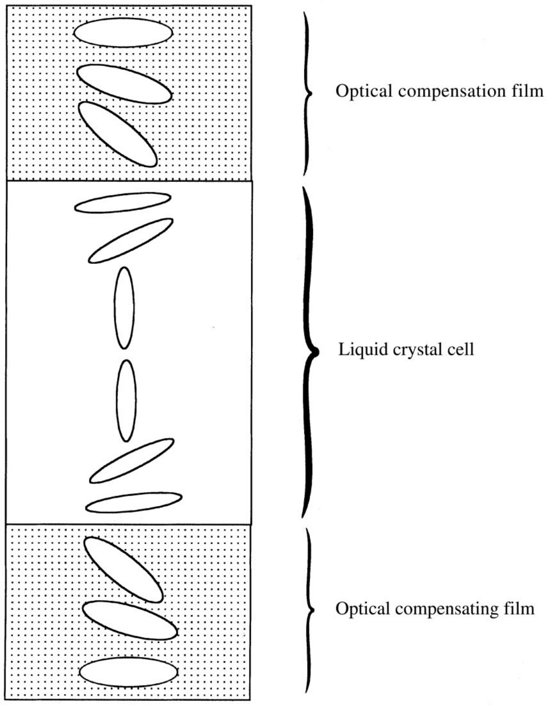

Fig. 14 The optically compensation method.[20)21)]

2.4 Photo-Luminescent LCD

The PL-LCD (Photo-Luminescent LCD)[22)] has been reported as a method for wide viewing angle LCD utilizing a fluorescent phosphor instead of a normal color filter. As shown in **Fig. 15**, the transmission of the UV light guided from the outside lamp is modulated by the liquid crystal layer, and the light which passes the liquid crystal layer reach the phosphor, giving fluorescence. Since the direction of irradiation of fluorescent light is isotropic, it is theoretically possible to give a wide viewing angle.

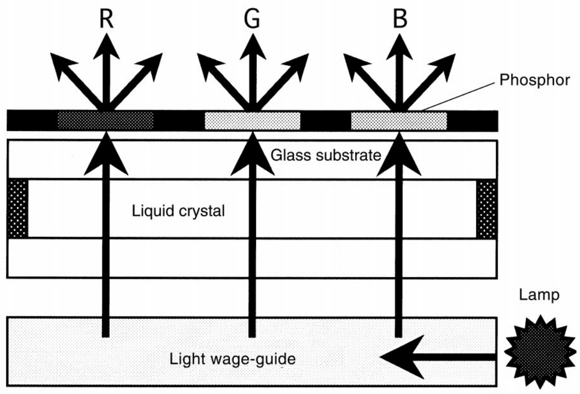

Fig. 15 The photo-Luminescent LCD.[22)]

Conclusion

In this paper, the recent trend of wide viewing angle technologies are reviewed.
Recently, the "Super-V" (SV) method,[23)] which utilizes optical compensation films and an orientation dividing method, has been developed. In addition, as the further improved version, the "Advanced Super-V" (ASV)[23)] method has been developed. The ASV technology can realize excellent characteristics such as a wide viewing angle of 160° (contrast 10:1 or more) in the top and bottom direction, and the right and left direction, a higher contrast ratio of 300:1 and a fast response speed of 25 ms.

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