Electro-Optical and Switching Behavior of In-plane Switching Twisted Nematic Liquid Crystal Display

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Abstract

*A driving mechanism and excellent features for an in-plane switching twisted nematic liquid crystal mode (IT mode) that could possibly improve the viewing-angle and color shift characteristics and the cell gap error tolerance is proposed. .It is important that the surface azimuthal anchoring strength of the liquid crystal cell differs at the upper and lower substrates. Furthermore, as a rubbing-free LCD, amorphously aligned in-plane switching twisted nematic mode (**a**-IT mode) is also demonstrated.*

1. Introduction

In regard to the many display application, replacing Cathode Ray Tube by Liquid Crystal Display (LCD) became a general trend because of its small size, lightweight and low electric power consumption. Needless to say, the most common type is the twisted nematic (TN) mode LCD, which is now spread over the market of the electric devices. However, TN LCD also has some weak points, such as a limited viewing angle, slow response speed, and high manufacturing cost, especially in case of active matrix driving type LCD. With regard to the visibility from an oblique direction to the LCD, serious problems such as reversal of the gray scale, decrease in contrast ratio, and color shift have been pointed out. In order to solve these problem of TN mode, various kind of techniques have been proposed, *e.g.*, retardation film compensated TN LCD [1], multidomain TN LCD [2], amorphous TN LCD [3], and so on. On the other hand, some novel driving mode have been proposed such as In-plane Switching (IPS) nematic mode [4,5], Vertically Aligned (VA) mode [6,7], and Optically Compensated Birefringence (OCB) mode [8]. The remarkable features of these modes are of these wide-viewing angle characteristics. However, IPS LCD still has weak points such as the large color shift and narrow cell gap error tolerance. VA LCD and OCB LCD have weak points such as complicated cell structure and driving scheme.

During the first half of the 1970's, the fundamental electro-optical (EO) effects of IPS mode with homogeneous and/or twisted nematic LCD have been investigated experimentally [9,10]. Then, based on a simplified numerical calculation, Baur *et al.* predicted that IPS mode have a potential to solve the viewing angle problem [11]. Since then, however, real product of IPS LCD has not been seen for many years, because, it was difficult to fabricate the interdigitated electrodes precisely. In 1995, Oh-e *et al.* described threshold voltage characteristics and viewing angle quality of a homogeneously aligned nematic driven by IPS mode [4,5]. Soon after these paper published, the real product of IPS LCD was marketed by Hitachi, Japan. From their paper, however, it was also pointed out that any inaccuracy in the cell gap results in poor quality EO performance, *i.e.*, the cell gap error tolerance should be small. Furthermore, IPS mode cannot be an essential solution to the color shift problem. Recently, to suppress the color shift in IPS mode, a multidomain structure with zigzag electrode was proposed [12]. However, the usual advantage of LCD as such the structure and manufacturing process is simple might be loss.

Baur *et al.* also noted that the homogeneously aligned nematic LCD driven by IPS mode is superior in viewing angle quality to the twisted nematic LCD driven by IPS mode [11]. Later, however, it was shown that their conclusion is mistaken [13]. From our calculation based on strict continuum theory, in-plane switching twisted nematic mode (IT mode) LCD can perform the desirable features both of the wide viewing angle characteristics and the preferable cell gap error tolerance [13,14,15,16,17]. It is important that the surface azimuthal anchoring strength of the liquid crystal cell differs at the upper and lower substrates, unlike a conventional TN mode. Furthermore, as a subspecies of the IT mode, amorphously aligned in-plane switching twisted nematic mode (*a*-IT mode) was also demonstrated [18]. The aim of *a*-IT is to simplify the manufacturing process, especially the rubbing process. Here, the basic concept and excellent EO performance of IT- and a-IT mode is reported.

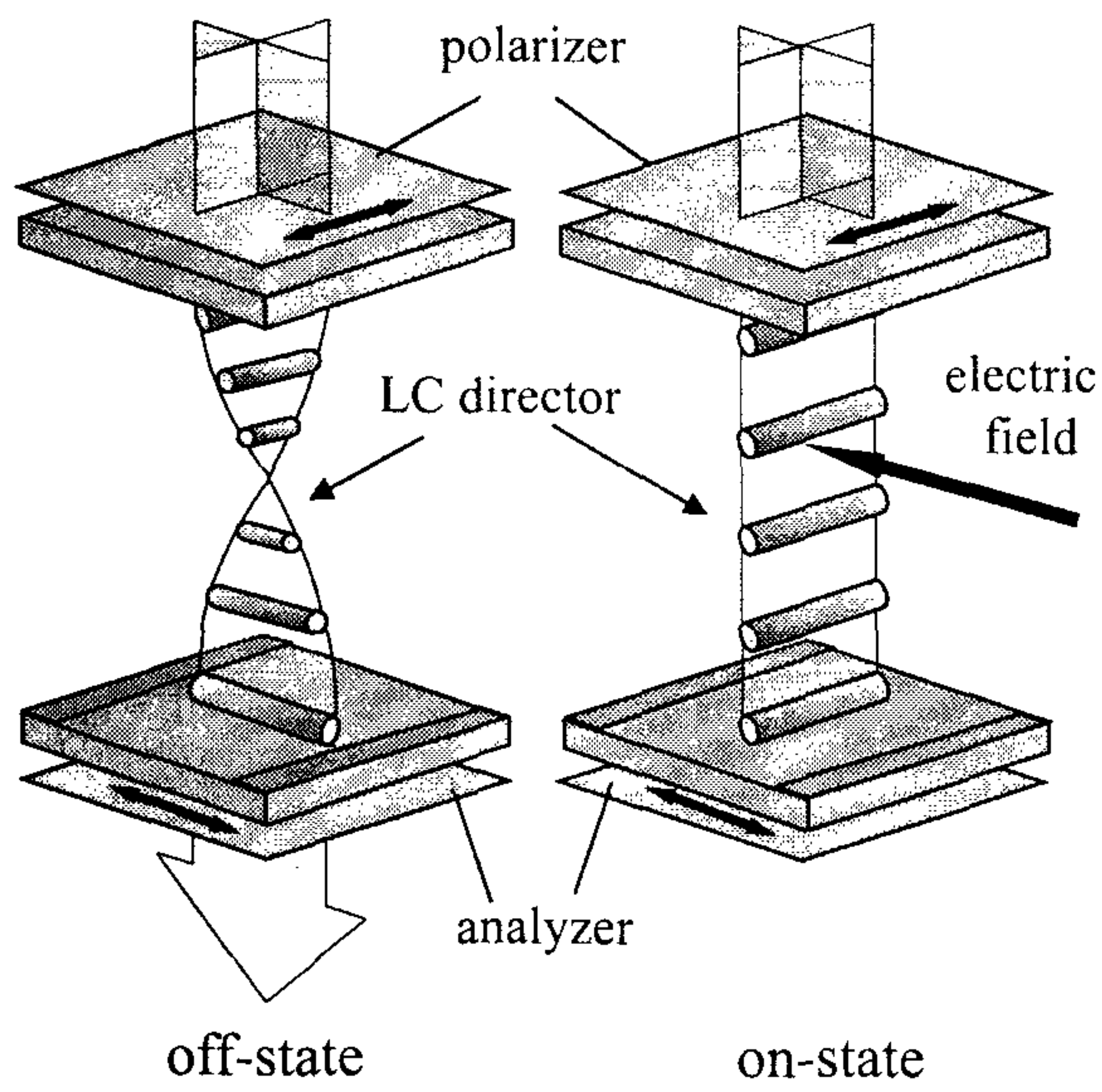

Figure 1 Schematic diagram of off and on states with IT mode.

2. Principle

A schematic diagram of off and on states with IT mode is illustrated in Fig.1, where a nematic LC (NLC) with negative dielectric anisotropy was supposed to be employed. The director arrangement of the LC molecules in the cell is controlled to have 90 degree twist, and the optical axes of the polarizer and analyzer are set parallel to the director at the upper- and lower-substrate surfaces. This is the same as in conventional TN mode in normally white geometry. In order to realize uniform twist alignment and to improve the response time for the driving voltage, a small amount of chiral dopant is mixed with the host NLC. Without an applied field, the incident light can pass through the analyzer (viz. off state), provided that it satisfies the Mauguin's condition [19],

$$\Delta nd = \lambda\sqrt{m^2 - \left(\frac{\Phi_t}{\pi}\right)} \qquad (m=1,2,...), \qquad (1)$$

where Δn is the birefringence, d is the cell gap, and Φ_t is the initial twist angle, λ is wavelength of the incident light. Here we suppose m=1.

To give the director reorientation, in the case of employing LC material with negative dielectric anisotropy (N_nLC), a transverse electric field parallel to the analyzer axis is applied in the plane of the lower substrate's surface. In the case of the employing positive dielectric anisotropy (N_pLC), the electric field should be applied perpendicular to the analyzer's axis. Similar to standard IPS mode, in order to suppress the splayed alignment near the electrode, N_nLC are more preferable than N_pLC [10]. Because, the director of N_pLC tends to align parallel to the electric field vector $\boldsymbol{E}$. Under a high electric field, $\boldsymbol{E}$ diverges near the edges of the electrode, as a result, the director near the substrate surface incline from the substrate surface and splayed alignment would be induced [20]. However, the N_nLC has significant disadvantageous such as high viscosity and small dielectric anisotropy. At a certain electric field, the director arrangement can change and exhibit quasihomogeneous alignment with no light passing through (on-state). The direction of rotation of each director throughout the cell is restricted to parallel to the substrates, thus the viewing-angle limitation of the IT mode LCD should be wider than that of the conventional TN LCD. Furthermore, an on-state can be obtained since the cell behaves as a uniaxial medium, therefore, deviation of the cell gap from the nominal cell gap will not affect the optical transmittance, and the color shift problem may also be solved without adopting any optical compensation films.

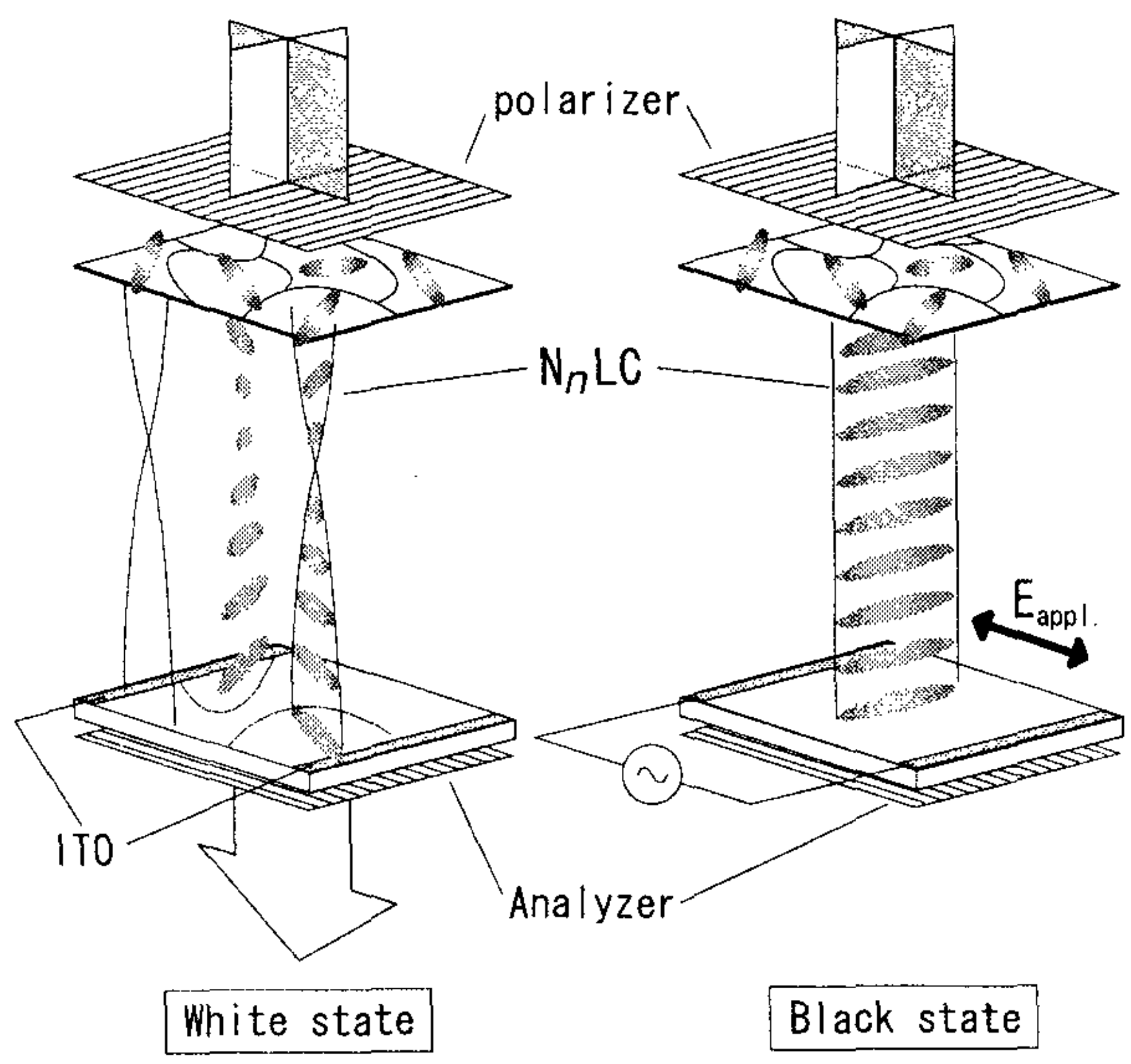

Figure 2 Schematic diagram of off and on states with a-IT mode.

The *a*-IT mode is hybrid between the *a*-TN mode [3] and the IT mode. The schematics are illustrated in Fig.2. The cell structure is similar to IT mode, whereas the inside of the glass substrates are not prerubbed. Therefore, no uniform alignment can be obtained and multidomain texture is revealed. In order to realize 90 degree twist alignment inside the each domains when an electric field is not applied, chiral dopant is mixed with the host LC. As a result, the incident light can pass through the cell and analyzer (off state) regardless of the random amorphous texture. Under an appropriate electric field, the helical structure inside the domain is unwound, and finally quasihomogeneous alignment appears (on state). As a result, the incident light can not pass through the analyzer (Black state).

3. Results and discussion

Figure 3 shows the EO response typically observed by applying an electric field. The LC material used in this experiment was 5CB (4-cyano-4'-pentylbiphenyl), whose dielectric anisotropy $\Delta\varepsilon$ =9.9 (RT, 1 kHz). This experimental result exhibits a continuous change in EO response with applied electric voltage. Furthermore, these result demonstrated the excellent viewing angle characteristics.

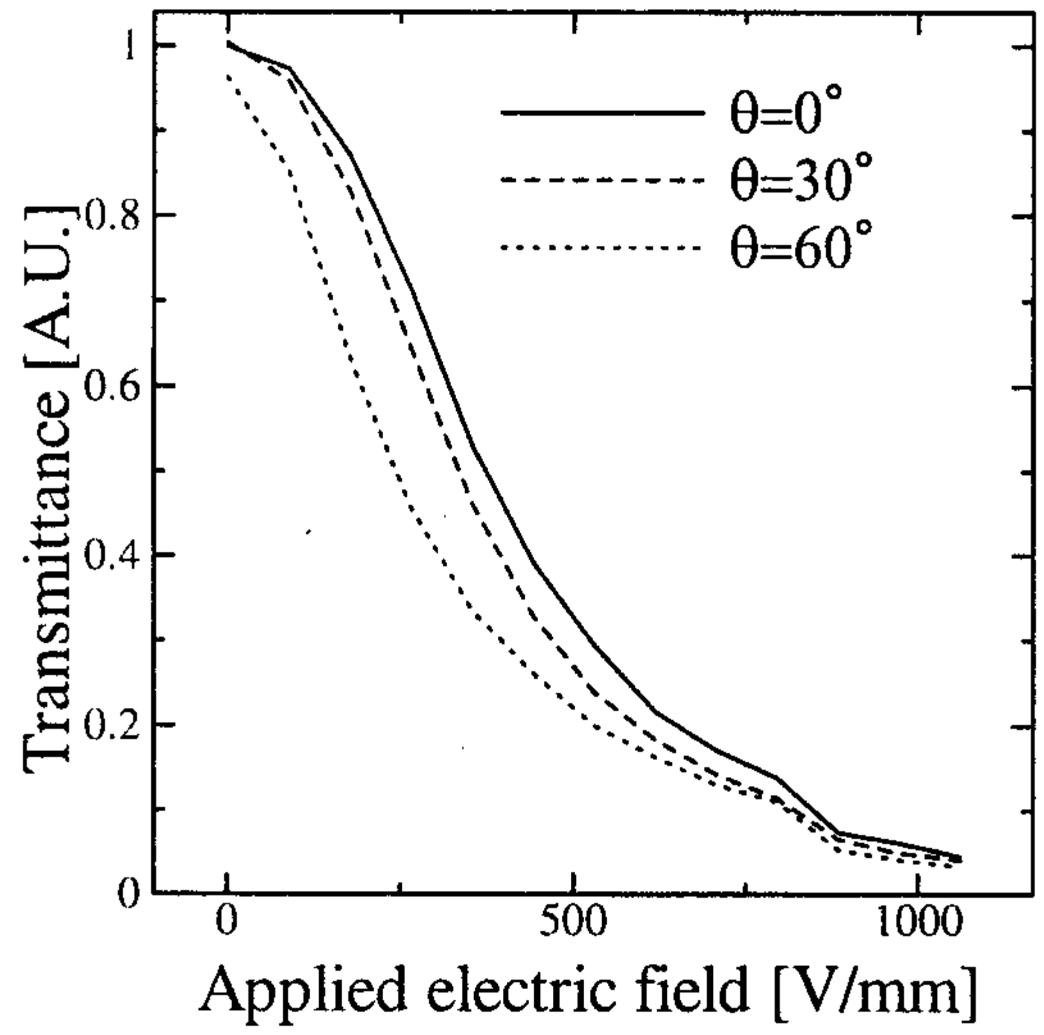

Figure 3 Typical voltage-dependent optical transmittance curves. The light angles incident θ to the cell are 0, 30, 60 degree, respectively. The LC material used was 5CB.

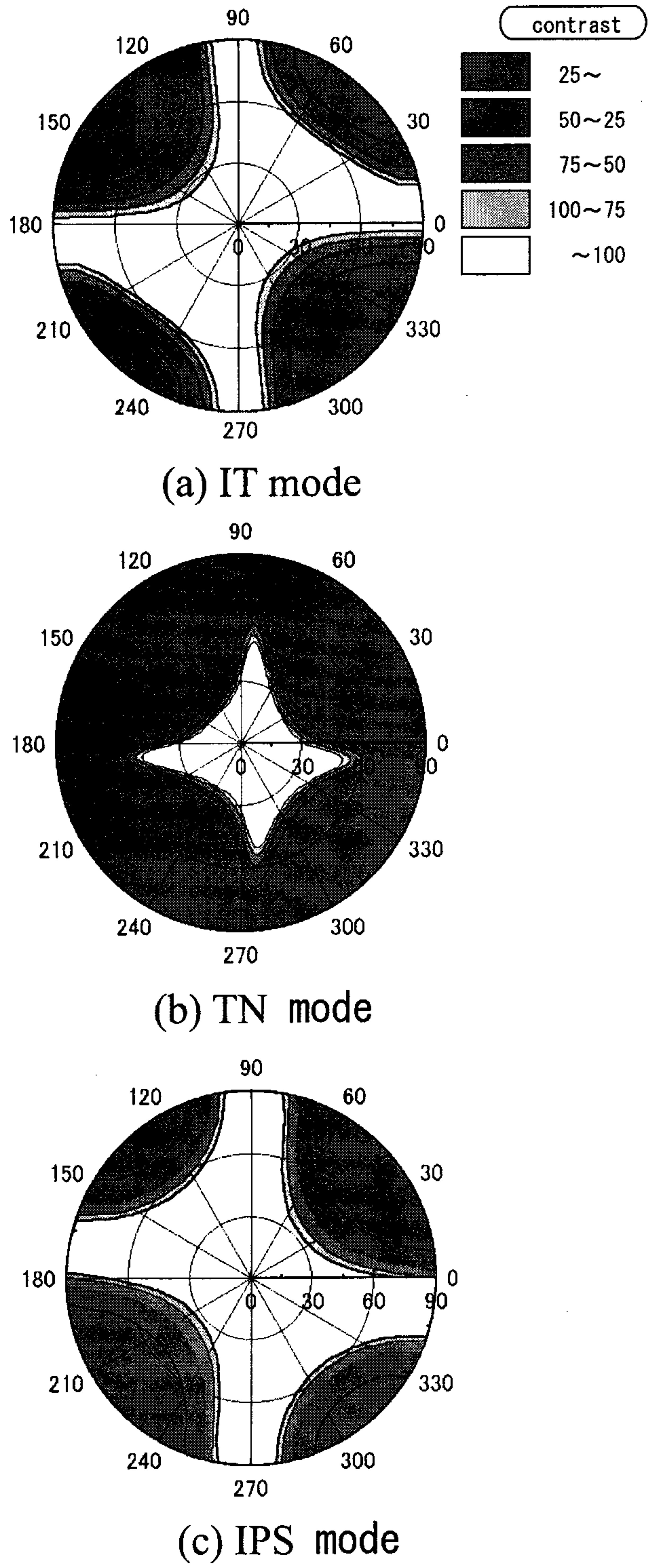

Figure 4 The iso-contrast ration diagrams obtained by numerical simulations.

In case of the a-IT mode, experimental and numerical simulation also demonstrated excellent EO performance, which is never inferior to IT mode.

To evanuate the viewing angle characteristics of the IT mode LCD, the iso-contrast ratio diagram was obtained by numerical simulations, as shown in Fig.4. To compare with IT mode, typical results of the TN mode and IPS mode are also shown, where the cell parameters were optimized for these mode. It is found that the IT mode has a fairly wide viewing angle compared with the TN mode, and the quality of the visibility from the oblique direction is the same as that of the IPS mode.

4. Conclusion

From the numerical and experimental studies, it was found that IT mode and a-IT mode can realize excellent EO performance without adopting any compensation film or structural contrivance. To optimize the EO performance, controlling the surface anchoring strength is one of the important key. In the past literature, nobody has described the importance of surface anchoring. The mathematical approximation such that the director arrangement maintains *uniform twist* seems to mislead them in their conclusion. Another important key is to control ration of the chiral pitch and cell gap to optimize the response speed. Introducing additional contrivance with these LCDs will realize a practical LCD.

Latest results will be presented by S.Oka in poster session.

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