"Super-V" TFT-LCD Technology

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Abstract

The "Super-V LCD" (Super View LCD) is a high performance TFT-LCD using high aperture ratio technology "Super-HA(High Aperture)", wide viewing angle technology "Super-VA(Viewing Angle)", interface technology and so on. Super-VA technology has optimized optical parameters and has employed a new technique of alignment control structure of liquid crystal molecules. Super-VA technology obtained wide viewing angle without sacrificing the other important characteristics of conventional TFT-LCDs, such as high brightness, high contrast, and low electrical power consumption.

Introduction

The TFT-LCD has excellent performance of high brightness, high contrast, and low-power consumption. It is widely used for desk-top PCs, notebook-type PCs, TVs, in-car TVs/navigations, and movie cameras. Recently, higher performance is required to the TFT-LCD. As the CPU processing speed and the memory-capacity have been improved in notebook-type PCs as well as desk-top type PCs, additional features come into demand, such as full-color display and high-speed motion display. Now well-balanced display performance is required, ranging from high brightness, high contrast, wide viewing angle to rich color reproduction.

To meet these demands, we have developed the "Super-VA" technology. This has realized high brightness, high contrast, low-power consumption and wide viewing angle without any tradeoff, while other previously-reported technologies for wide-viewing angle had various shortcomings such as increased power consumption led by the low aperture ratio, degraded frontal display quality, and unfavorable production processes.

This paper reviews the very-wide-viewing angle technology, what we call, "Super-VA" technology.

1. Optimization of the Optical Compensating Layers [1)]

The TFT-LCD uses the twisted-nematic (TN) LC that shows the anisotropy, and its transmittance changes drastically according to the viewing angle. Therefore, The conventional TFT-LCD has a narrow viewing angle. As the **Figure 3** shows, the viewing angle of the conventional TFT-LCD is approximately 30 degrees at upper direction, 40 degrees at right/left direction and 15 degrees at lower direction. The contrast decrease at upper direction and the gray scale inversion at right/left and lower direction limit the viewing angle. To improve viewing angle properties, we attempted to compensate the anisotropy of LC molecules with the optical compensation layers and to optimize the optical parameters via computer simulation method. First, optimization was carried out to the conventional TFT-LCD with the optical compensation layers. The direction of LC molecules was calculated with the application of Flank's "Continuum Theory", and the transmittance was gained with the application of Berreman's 4 x 4 matrix method. **Figure 1** indicates the simulation parameter and flow implemented for the calculation. The followings are what we have discovered as a result:

i) With the optical compensating layers of the optically-positive anisotropy, the gray scale inversion at upper and lower directions can be retarded, while the transmittance becomes non-symmetrical at right and left directions, thus not applicable for display use.

ii) With the optical compensating layers of the optically-negative anisotropy, the gray

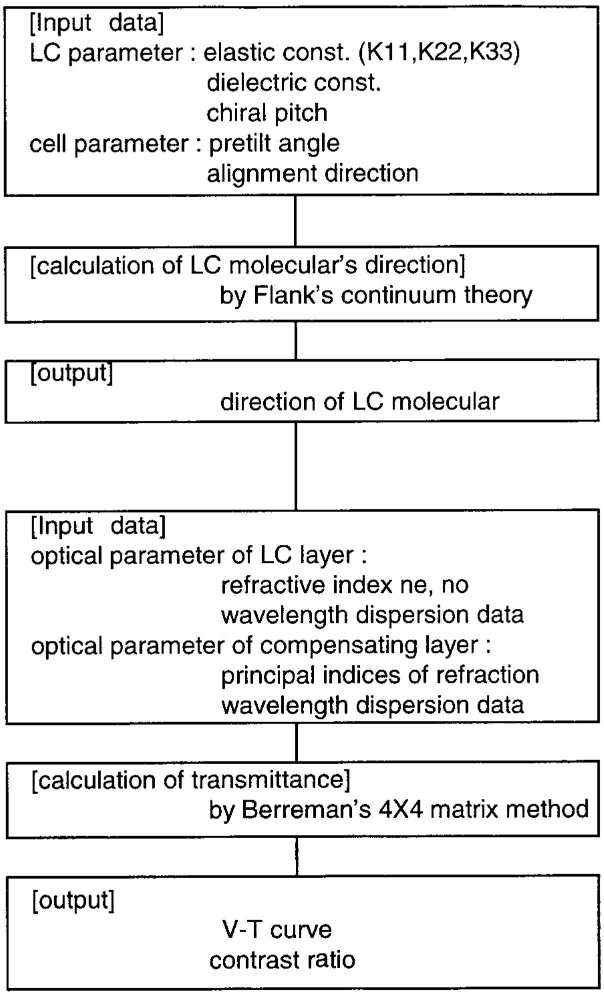

Fig. 1 Simulation flow.

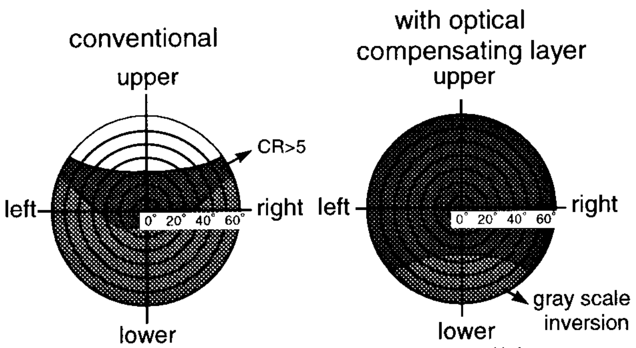

Fig. 3 The effect of optical compensating layer to the viewing angle.

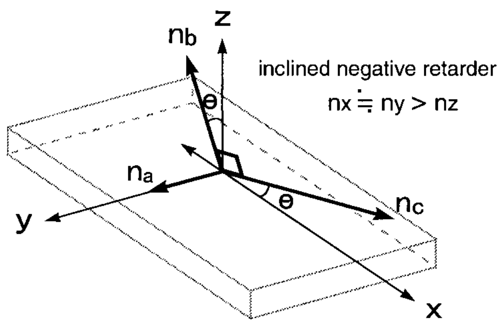

Fig. 2 The image of the refractive index ellipsoid of optical compensating layer.

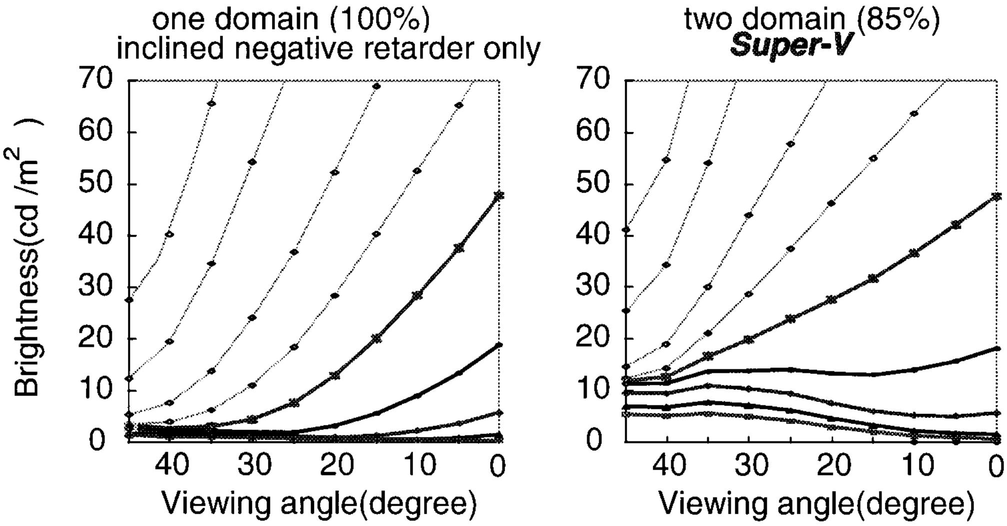

Fig. 4 Viewing angle properties at lower direction.

scale inversion at right and left directions can be retarded, but not at upper and lower directions, thus not yield sufficient viewing angle.

While the conventional refractive-index ellipsoid of optical compensating layer runs parallel to the panel plane, we came up with a different structure of optical compensating layer, allowing a certain amount of angle (θ) between the panel plane and the refractive-index ellipsoid. We simulated the transmittance using three parameters of the three main refractive indexes of the refractive-index ellipsoid, a degree value (θ) between the refractive-index ellipsoid and the normal line of the layer plane, and the thickness of the layer. **Figure 2** shows the image of the refractive-index ellipsoid of optical compensating layer. One result of this simulation proved that there was no gray scale inversion at right and left directions and also that the contrast largely improved at right/left and upper directions. Another result was that the gray scale inversion at lower direction is retarded.

2. Optimization of LC Cells [2)]

We tried to make further improvement in display quality. The display that we discussed in the above had the gray scale batter in the dark side gray scale at the lower direction **(Figure 4)**. To

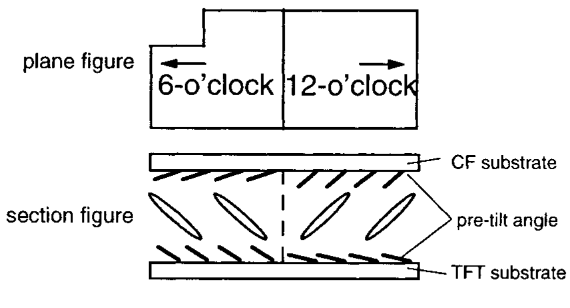

Fig. 5 Two-domain LCD structure.

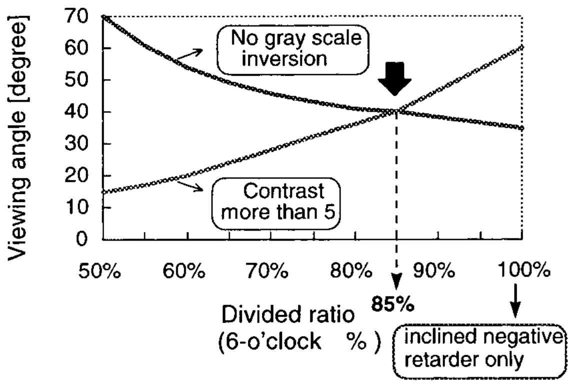

Fig. 6 The simulation result at lower direction.

Table 1 Properties of the Super-V TFT-LCDS.

Contrast	300
Brightness	200cd/m^2
Response Time	32msec
Power Consumption	12W
Viewing Angle right, left, upper lower	 70degrees 40degrees *no gray scale inversion*

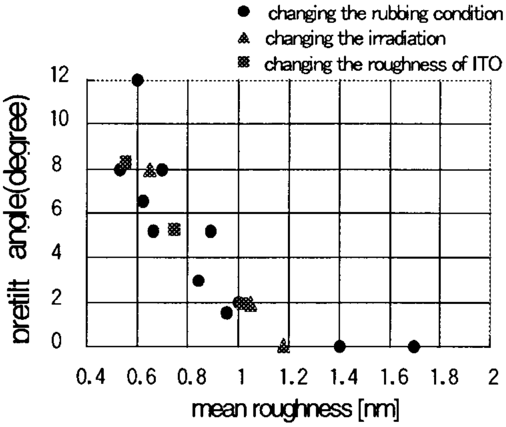

Fig. 7 Relation between mean roughness and pretilt angle.

improve the gray scale properties at lower direction,
we focused on the two-domain cell, which has two different structure domains in one picture-pixel. Furthermore, we focused on the structure of LC molecule alignment. We simulated the transmittance using the twist-angle, pre-tilt angle, alignment direction, refractive index and cell-gap as parameters. The simulation result proved that the two-domain cell with two different alignment directions much improved the gray scale properties at lower direction.

The two-domain LCD structure is shown in the **Figure 5**. Two kinds of viewing angle are formed in each picture pixel: 6-o'clock viewing domain and 12-o'clock viewing domain (See the Plane Figure in the **Figure 5**). We simulated transmittance using the divided ratio of these two domains as a parameter, and earned the viewing angle properties. **Figure 6** shows how the viewing angle at lower direction changes as the divided ratio of the 6-o'clock viewing domain shifts from 100% to 50%. The gray scale inversion is retarded in accordance with increase in the 12-o'clock viewing domain, while the contrast goes down. We consequently discovered the optimal point of the divided ratio: 85% for the 6-o'clock viewing domain and 15% of the 12-o'clock viewing domain.

According to the result, we fabricated a two-domain LCD panel. In the two-domain LCD structure, as Figure 5 illustrates, one picture-pixel has two different domains. In each domain, each substrates of CF (on the top of **Figure 5**) and TFT (at the bottom) has different pre-tilt angle. One substrate, for example TFT substrate in **Figure 5**, is aligned to provide the 6-o'clock viewing angle and the other, for example CF substrate in **Figure 5**, the 12-o'clock viewing angle. It is possible to fabricate an LCD panel with two domains within one picture-pixel because the alignment direction of LC depends on the substrate with higher pre-tilt angle. We applied the pre-tilt angle control technology (reviewed hereafter) to produce the two-domain LCD panel. We formed the boundary line between the two domains on the gate busline and the Cs-busline, thus preventing light from coming through the boundary line.

Figure 4 (the right) shows the brightness change at lower direction in the case of 8-gray-scale display of this two-domain LCD. Not only is retarded the gray scale inversion, but also the gray scale is well maintained without the gray scale batter. **Table 1** indicates the properties of the Super-V TFT-LCD of 15-inch XGA type: a wide-viewing angle has been achieved to maintain high brightness, high contrast, high-speed response time, low-power consumption performances.

3. Pre-Tilt Angle Control Technology [3)]

We had studied on the mechanism of the pre-tilt angle generation. We focused on the factors that reduce the pre-tile angle, and discovered the inter-relation between pre-tilt angle and mean roughness of the alignment layer surface.

Figure 7 shows this inter-relation. The mean roughness of the alignment layer surface is varied by the rubbing condition, the amount of light irradiation, and the roughness of the ITO surface. As the mean roughness becomes rougher, the pre-tilt angle becomes lower. Applying this result, we have developed a method to get any pre-tilt angle that we needed to produce a two-domain structure. Controlling the mean roughness of the alignment layer surfaces of CF and TFT substrates, we can make a domain that has two kinds of pre-tilt angles - one on CF and the other on TFT. Followings are the processes to change the surface roughness. Resist was patterned on the ITO surface with photolithography and soaked into 37%-concentration hydrochloric acid for ten minutes to enlarge the roughness on the ITO (Soaking Process).
By the effect of the roughness of ITO surface, the roughness of the alignment layer surface was shifted from 0.4nm to 1.9nm. The pre-tilt angle showed 0 degrees in the soaked region, while it did 8 degrees in the resisted region. The same effect was obtained by light irradiating. In this case, only the light irradiating process is added to the conventional processes. The increase of the number of processes remains at minimum.

Conclusion

We have developed the Super-VA technology, optimizing the optical compensation layer and the optical parameters of the liquid crystal cell. Applied with this technology, the Super-V TFT-LCD has made possible the wide-viewing angle of over 70 degrees in right/left and diagonal directions, 70 degrees in upper direction and 40 degrees in lower direction. This does not cause any trade-off in LCD performance. Other excellent features are also maintained, such as brightness of 200cd/m^2, contrast of 300, consumption power of 12W (15-inch XGA) and response time of 32msec.

Furthermore, the Super-V TFT-LCD has no trade-off in the operating temperature range and the response time, because it is not restricted in selecting LC materials. Therefore, it can be applied in a wide range of display fields, from desk-top PC monitors, notebook-type PCs, TVs, in-car TVs/navigations, to movie cameras, offering high-quality display performance.

References

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