Blue-Phase Liquid Crystal Display with Contrast Ratio over 1000:1

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With the purpose of enhancement in the contrast ratio of a cholesteric-blue-phase liquid crystal display by reducing driving voltage and light leakage, we made a prototype of a 3.4-inch polymer-stabilized blue-phase (PS-BP) liquid crystal display including highly reliable crystalline oxide semiconductor. As a result, the contrast ratio over 1000:1 was achieved in a dark place.

1. Introduction

In 1985, a crystalline structure of $InGaZnO_4$ was reported by Kimizuka et al[1-4]. In addition to application of oxide semiconductor (OS) to organic EL[5] panels or LCD[6-8] panels in which In-Ga-Zn-oxide (IGZO) is used for driving transistors, our development includes application to a variety of products that can make use of characteristics of OS FET[9, 10] as shown in Figure 1[5-8, 11-16]. In particular, development of c-axis aligned crystal (CAAC) (Figure 2)[1-4, 9, 10, 17, 18], which will enable high performance and high reliability, opens up the possibility of application.

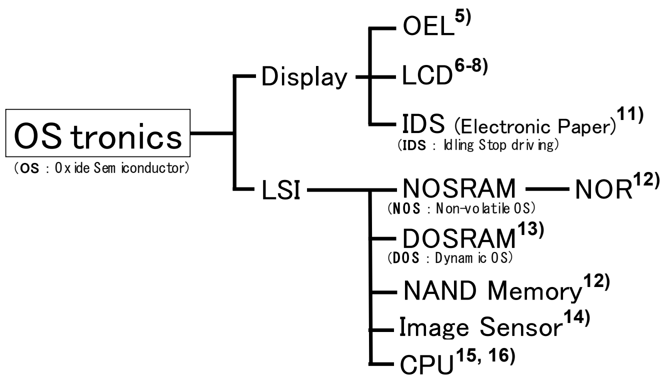

Fig. 1. Product development in OS tronics.

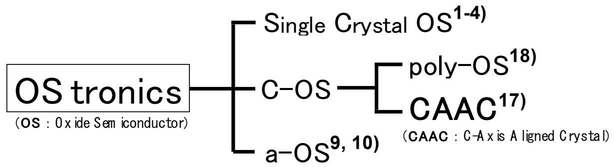

Fig. 2. Classification by crystallinity in OS tronics.

The PS-BP liquid crystal[19, 20] is generally driven by a lateral electric field as in an in-plane-switching (IPS) mode. For its electrode structure, various types of structures which enable high electric-field intensity and low driving voltage have been proposed [7), 21-25] because driving voltage of blue-phase liquid crystal is high and a high white luminance is not easily obtained, and thus to obtain high contrast ratio is difficult. In addition, light leakage occurs due to Bragg diffraction in the blue-phase liquid crystal. It is necessary to solve these problems in order to improve the contrast ratio.

Thus, a blue-phase material was optimized to lower the driving voltage and to make diffraction wavelength have a peak in the ultraviolet region, and light leakage from a pixel electrode was suppressed. As a result, the contrast ratio over 1000:1 of a liquid crystal display was achieved without using a black matrix (BM) for the first time in the world.

2. Optimization of Blue-Phase Material

Selection of Chiral Material

For low-voltage driving of PS-BP liquid crystal, it is important to employ a chiral material with high helical twisting power (HTP) and reduce the amount of added chiral material. The HTPs of Chiral Material A and Chiral Material B were measured using a wedge-shaped cell. Table I shows the measurement results.

From Table I, Chiral Material B has higher HTP than Chiral Material A, so Chiral Material B is suitable for a blue-phase material.

Table I. HTP of Chiral Material.

	Chiral Material A	Chiral Material B
HTP(1/μm)	60	107

Characteristics of PS-BP Liquid Crystal

Chiral Material B, a monomer, and polymerization initiator were added into liquid crystal, the mixture was injected into cells to which lateral electric field is applied, and polymer-stabilization treatment was performed, so that PS-BP liquid crystal was obtained.

Figure 3 shows the results of V-T characteristics of the obtained PS-BP liquid crystal. The cell used here was an IPS cell with a protrusion electrode having a rib. The rib is made of a photosensitive resin and covered with a transparent electrode. The width of the rib was 2 μm and the interval of ribs was 3 μm. The width of the transparent electrode was 3 μm and the interval of transparent electrodes was 2 μm. PS-BP with this structure containing Chiral Material B enabled low voltage driving. The voltage V_{100} at which the normalized transmittance is 100 % was as low as 31 V, and the voltage V_{90} at which the normalized transmittance is 90 % was as low as 22 V.

In addition, the peak of the diffraction wavelength of the PS-BP is 367 nm when no voltage is applied, which means that the amount of light leakage due to Bragg diffraction is small.

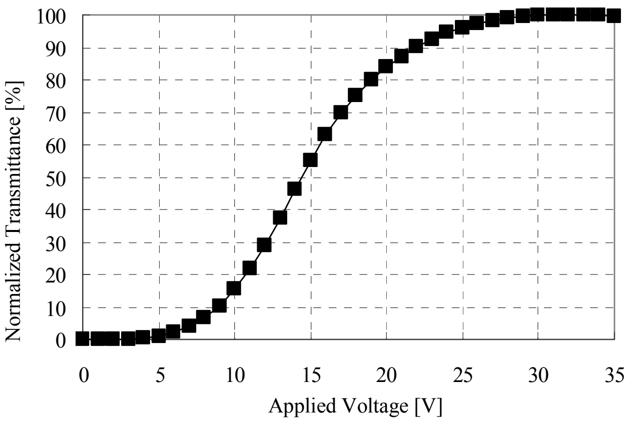

Fig.3. Measurement results of V-T characteristics.

3. Panel Structure

A lateral electric field driving mode such as an IPS mode is used for driving a blue-phase liquid crystal. The angle formed by the absorption axis direction of the polarizers and the pixel electrode direction needs to be 45°. However, with this arrangement structure, light leakage occurred (Fig. 4-(1)). Such light leakage was markedly observed in the vicinity of a source wiring and a gate wiring, and at a pixel electrode having a rib which is made for decreasing the driving voltage of a blue phase liquid crystal.

Further, the state of light leakage changed as the polarizers rotated, i.e., anisotropy was confirmed. Light leakage, particularly light leakage due to the electrode having a rib is probably caused by not only a difference between refractive indices but also another factor, and this factor might be derived from form birefringence.

Thus, the factors of anisotropic light leakage were divided into a factor due to a pixel electrode and a factor due to a source wiring and a gate wiring, and the panel layout and the pixel electrode structure were reconsidered, so that a reduction in light leakage was verified(Fig. 4-(2)).

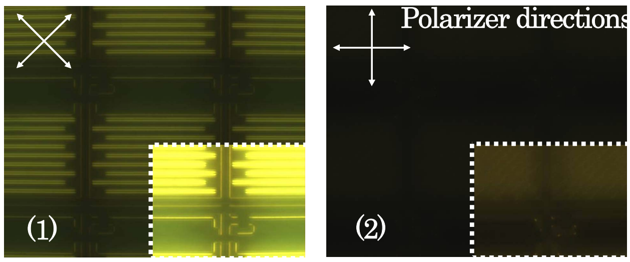

Fig. 4. Micrograph of electrode having a rib.

(1) Structure on which countermeasure against light leakage is not performed (2) Structure on which countermeasure against light leakage is performed (micrographs surrounded by dashed lines are contrast enhancement images)

Panel Layout

In a general liquid crystal display, light leakage is reduced by blocking light with BM. In the case of PS-BP, uniform light irradiation on the entire surface of a panel is needed for polymer stabilization treatment, which makes it difficult to provide BM on a counter substrate.

As a countermeasure to this problem, wirings such as a source wiring and a gate wiring are arranged to be parallel or vertical to the absorption axis direction of polarizers, and only pixel electrodes are arranged at an angle of 45° to the absorption axis direction of polarizers. Thus, light leakage caused by the source wiring and the drain wiring can be reduced without using BM.

Pixel Electrode Structure

Form birefringence is caused by phase difference generated between a direction where the periodic structure exists and a direction perpendicular to the direction. The electrode structure with a linear rib has a periodic structure formed by liquid crystal, a transparent electrode, and a rib. In such a structure, the phase difference is probably generated to break the polarization state and thus light leakage occurs.

In order to reduce light leakage due to form birefringence, we focused on the thickness of the transparent electrode and made the experimental cells of PS-BP in which the thicknesses of the transparent electrodes with a linear rib are 20 nm, 40 nm, 60 nm, 80 nm, and 100 nm.

Figure 5 shows the relation between the black luminance when no voltage is applied and the thickness of the transparent electrode. In Fig. 5, *ref.* represents a state where polarizers are arranged in crossed Nicols without an experimental cell. The black luminance was measured using polarizers arranged in crossed Nicols with incidence of diffusion light. The absorption axis direction of polarizers was arranged at an angle of 45° to the pixel electrode direction.

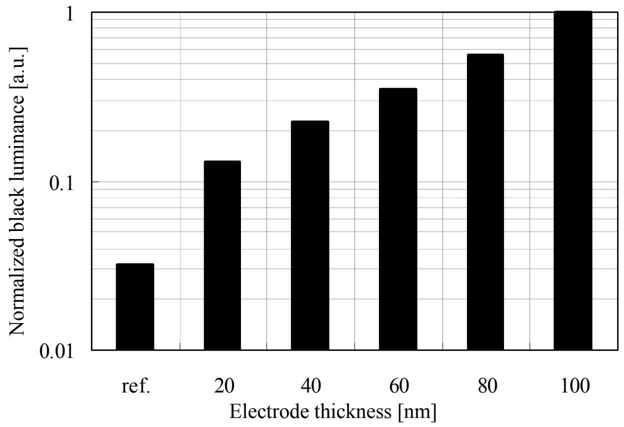

Fig. 5. Relation between black luminance and electrode thickness.

The data of the black luminance indicates that light leakage increases as the electrode becomes thicker.

The black luminance of the electrode having a rib is higher than that of the polarizers arranged in crossed Nicols without an experimental cell, so that light leakage cannot be satisfactorily suppressed by only a reduction in thickness of the electrode. Therefore, as an additional countermeasure against light leakage, a rib electrode in which square pyramids are arranged as illustrated in Fig. 6 was made.

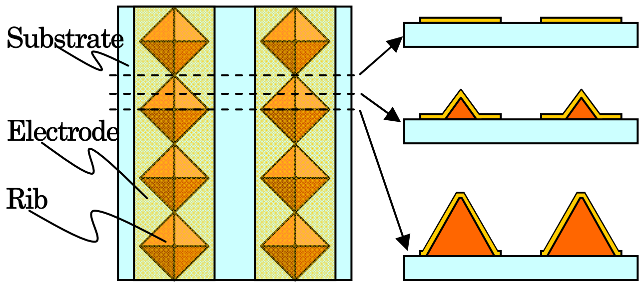

Fig. 6. Schematic view of rib electrode structure.

The experimental cells of PS-BP were manufactured with the use of a substrate with this electrode structure.

Figure 7 shows relation between the black luminance when no voltage is applied and the electrode structure (the rib shape-thickness of the electrode). Two types of rib shapes, a square-pyramid rib and a linear rib were used. In Fig. 7, *ref.* represents a state where polarizers are arranged in crossed Nicols without an experimental cell. The black luminance was measured using polarizers arranged in crossed Nicols with incidence of diffusion light. The absorption axis direction of polarizers was arranged at an angle of 45° to the pixel electrode direction.

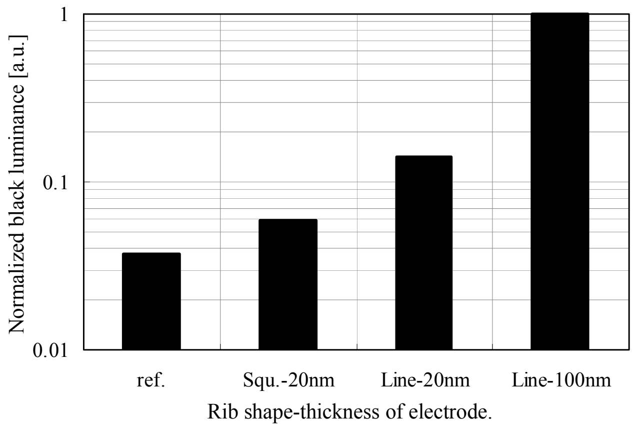

Fig. 7. Relation between black luminance and rib electrode structure.

The data of the black luminance indicates that light leakage is reduced due to the square-pyramid rib.

The probable reason of this is that the rib region which is at an angle of 45° to the absorption axis direction of polarizer is reduced by employing a rib electrode in which square pyramids are arranged and thus light leakage caused by form birefringence is also reduced.

4. Display Characteristics

We made a prototype of a 3.4-inch blue-phase liquid crystal display (Table II). The FETs used here include crystalline IGZO with a CAAC structure. Figure 8 shows TEM images of an

IGZO thin film we fabricated. In this film, c-axes are aligned in a direction perpendicular to a substrate, and the a-b planes of IGZO crystals are formed in mosaic arrangements. The crystal grain boundaries are unclear. The pixels and driver circuits are formed in an integrated manner with FETs including crystalline IGZO.

Table II. Specifications of the LCD.

Display Type	Transmissive
Screen Diagonal	3.4 inch
Resolution	540 (H) × 960 (V)
Pixel Pitch	78 μm (H) × 78 μm (V)
Pixel Density	326 ppi
Color System	Field sequential
Data Driver	Integrated
Scan Driver	Integrated
Liquid Crystal Mode	Blue phase mode
Cell Gap	4 μm
Aperture Ratio	50%
Contrast Ratio	＞1000:1

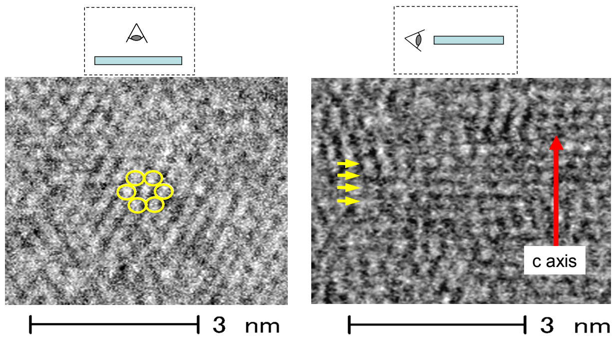

Fig. 8. Planar TEM image (left) and cross-sectional TEM image (right) of In-Ga-Zn-oxide film showing c-axis alignment.

Fig. 9 is a photograph of an image displayed on the panel. The contrast ratio 1100:1 of the liquid crystal display without using BM can be achieved in a dark place.

Fig. 9. Image displayed on the panel.

5. Conclusion

With the use of the optimized blue-phase material and electrode structure, a prototype of a 3.4-inch blue-phase liquid crystal display including a highly reliable crystalline oxide semiconductor was manufactured, so that the contrast ratio 1100:1 was achieved in a dark place.

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