Invited Paper

Recent trends on wide-viewing angle color TFT-LCDs

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ABSTRACT

Many important innovations on LC display mode for wide-viewing angle color TFT-LCDs were reported within this several years, and recently the volume productions of LC monitors and LC TVs have been started using them. To realize good wide-viewing angle color TFT-LCDs, we have to design not only optical property of LC layer but also film polarizers and back lights. Typical wide-viewing angle LC display modes are classified into several categories and discuss their features.

Keywords: wide-viewing angle color TFT-LCD, film polarizers, back-light, TN, VA, OCB, IPS, AFLC, FLC

1. INTRODUCTION

With the progress of manufacturing technologies for TFT-LCDs, they can use rather large size mother-glass substrates and can product large size TFT-LCDs. Many users, therefore, will expect to have LC monitors and LC TVs with large size TFT-LCDs. For these applications, we have to solve the viewing angle problems that are not so serious items for smaller size TFT-LCDs used with notebook PCs. When the plural people are discussing using one LC monitor with conventional TFT-LCD designed for personal use, they may be watching different image, such as different color, different contrast ratio, on the LCD monitor. However, plural users are eager to discuss using a LC monitors in their office as shown in Fig. 1, and they are also eager to watch LC TVs with their family. An essential demand, therefore, on large size TFT-LCDs used for these applications should be a wide-viewing angle issue.

In order to solve the wide-viewing angle issue, many novel technologies are proposed within several years such as Wide View Film mode with conventional TN mode, In-Plane Switching mode, Vertical Alignment mode, and so on. Hitachi firstly proposed In-Plane Switching TFT-LCDs[1] using inter-digital electrodes scheme, and commercialized these LCDs and the desktop computers with wide-viewing angle TFT-LCDs.

Currently, many Asian LCD panel makers successfully product a lots of large size LCDs by using suitable type of wide-viewing angle LCD modes.

The purpose of this paper is to discuss the trends on these wide-viewing angle color TFT-LCDs. The other purpose is to discuss the optical characteristics of some components of the wide-viewing angle TFT-LCDs.

Fig. 1 Wide-Viewing Angle LCD

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2. NUMBER OF PAPERS ON WIDE-VIEWING ANGLE LCD MODES

Figure 2 shows the increase of the papers related to wide-viewing angle LCD modes. These data are corrected from major international display conferences which are SID, IDRC, IDW, and AM-LCD. The number of papers are rapidly increase from 1993, and still continue to increase.

In 1994 and 1995, the multi-domain mode seemed to be the major technology to realize wide-viewing angle TFT-LCDs. The manufacturing processes of the multi-domain mode, however, were rather difficult and their position was exchanged with the other modes after 1995. The In-Plane Switching mode (IPS) by using TFT with inter-digital electrodes was first reported in 1995. It had very good viewing angle characteristics, therefore, many people followed this mode after 1995. In 1998 Wide View Film mode (WVF) [2]and Vertical Alignment mode (VA)[3] increased rapidly. Then, IPS, WVF and VA are widely used in the wide-viewing angle LCDs.

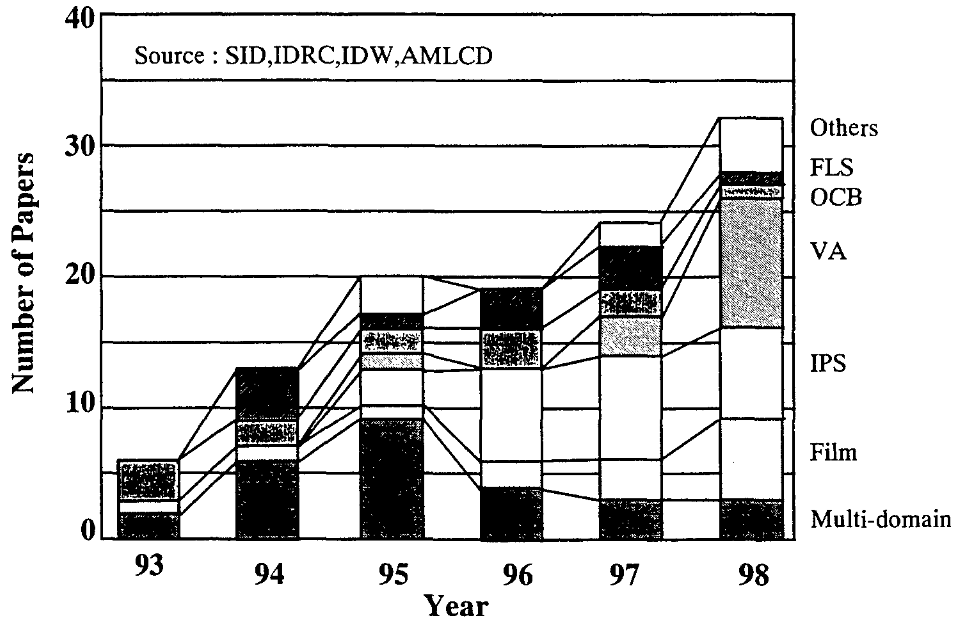

Fig. 2 Trend of papers for Wide-Viewing Angle LCDs

3. THREE MAJOR COMPONENTS IN WIDE-VIEWING ANGLE LCDS

When we discuss the optical properties of the wide-viewing angle LCDs , we have to consider following three components as shown in Fig.3.

(1) Film Polarizers
(2) LC Layer
(3) Back Light

Even though an LC layer has no angular dependence on brightness and contrast ratio, an LCD should have large angular dependence because of the angular characteristics of a couple of film polarizers which is, for example, cross-nicol state.

When the back lights are used with wide-viewing angle

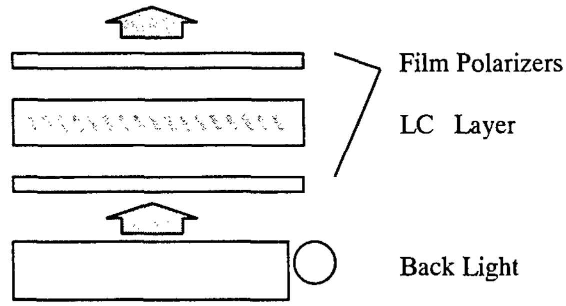

Fig. 3 Optical Components of LCDs

LCDs, the scattering angle of the back light should be wide as it can cover the viewing angle of the LCDs.

3.1. Angular dependence of film polarizers

Angular dependence is measured using the system shown in Fig. 4. A couple of film polarizers mounted on the case which can rotate in 3 directions as shown in this figure. The polarizing axes can change from cross-nicol state to parallel-nicol state.

The contrast ratio of the film polarizers, in this case, is defined as in the following formula at each angle.

$$CR = \frac{\text{Brightness of parallel-nicol state at right angle}}{\text{Brightness of cross-nicol state at each angle}}$$

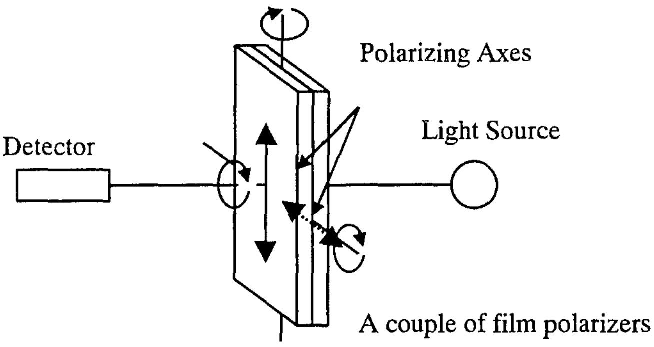

Fig.4 Measurement system on angular dependence for film polarizers

The measurement results are shown in Fig. 5. In the figure, maximum contrast ratio is 1150 at the center of the graph. This figure suggests that the film polarizers have serious angular dependence on their optical properties, so that, we must have much more interest in developing wide-viewing angle film polarizers.

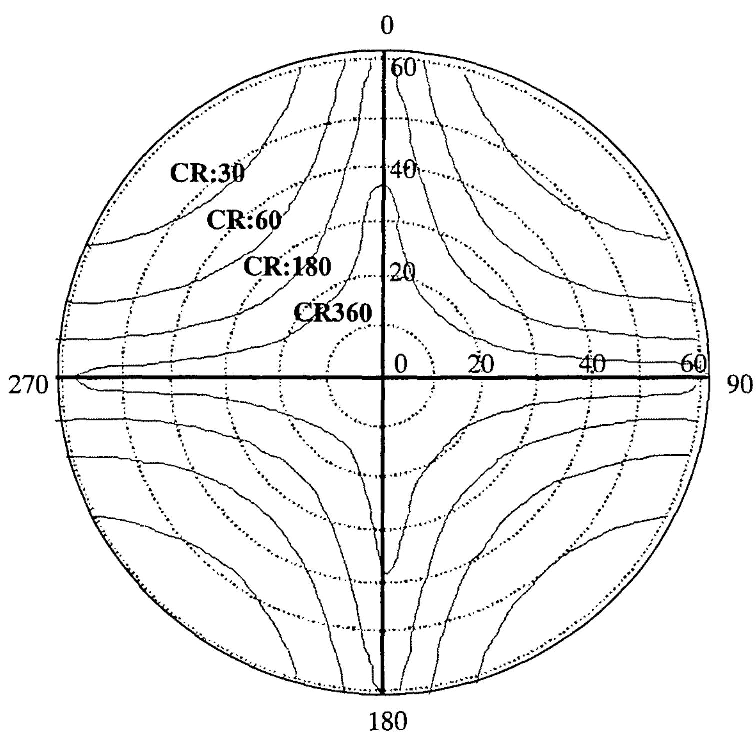

Fig. 5 Angular dependence on Contrast Ratio of film polarizers

3.2. Back light for wide-viewing angle LCDs

For the conventional LCDs used with notebook PCs, the major issue for the back lights is to get large brightness gain resulting narrow scattering angle property. However, recent demands for the back light are to achieve both large brightness gain and wide scattering property that can be work with wide-viewing angle LCDs.

The scattering properties of high gain and low gain back lights are shown in Fig.6. individually. As evident from Fig. 6, the brightness in the normal direction of high gain back light (a) is larger than that of low gain back light (b). But the uniformity of the brightness at different viewing angle of (a) is less than (b). It is evident that the low gain back light that has wide scattering angle is rather suitable for the wide-viewing angle LCDs.

In order to realize the suitable properties, many useful technologies are proposed and still use in the volume production.

For example, Fig. 7 shows the viewing angle dependence on brightness gain of the back light employed the 3M optical films.

Curve (1)	white PET film on the light guide
Curve (2)	(1)+DBEF
Curve (3)	(2)+BEF
Curve (4)	(3)+two BEFs (cross)

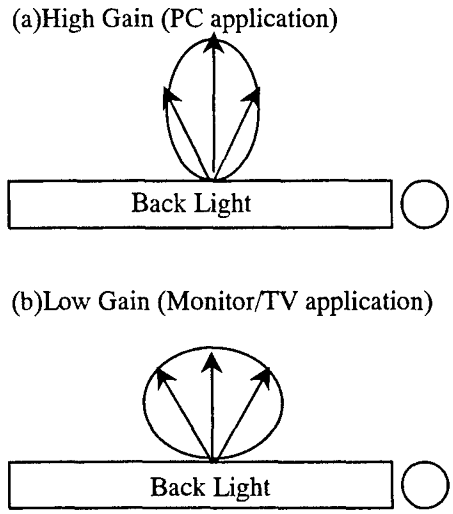

Fig. 6 Scattering properties of Back Lights

Among these curves, curve (2) or (3) are suitable for wide-viewing angle color LCDs, and curve (4) is suitable for personal use LCDs. Therefore the ratio of the brightness gain of curve (4) and (2) is approximately 1.7. When the wide-viewing angle LCD user wants to have same brightness as that of conventional LCDs, they need more electrical power 1.7 times as large as conventional LCDs. Thus, generally every wide-viewing angle LCD technologies have this essential trade-off relation between wide-viewing angle and power consumption.

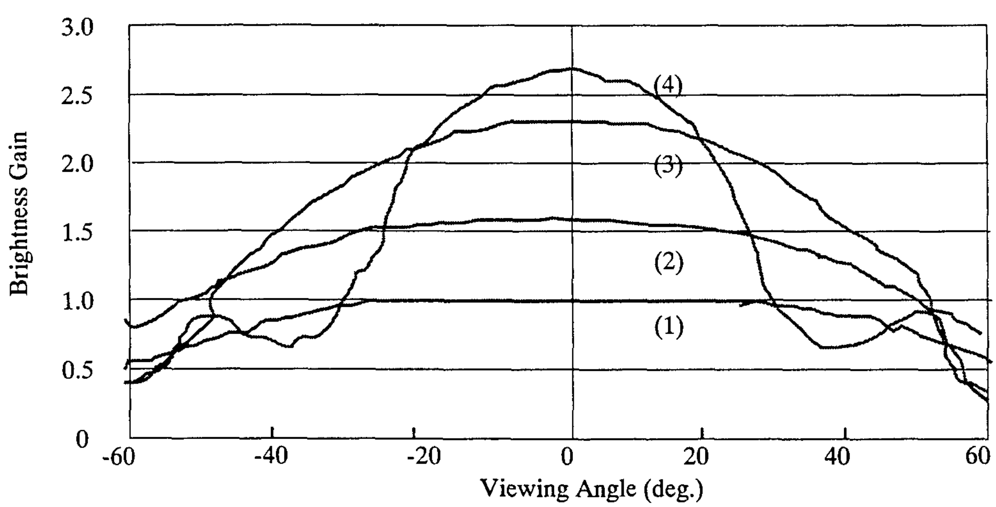

Fig. 7 Viewing Angle Dependence on Brightness Gain of Back Lights (Sumitomo 3M)

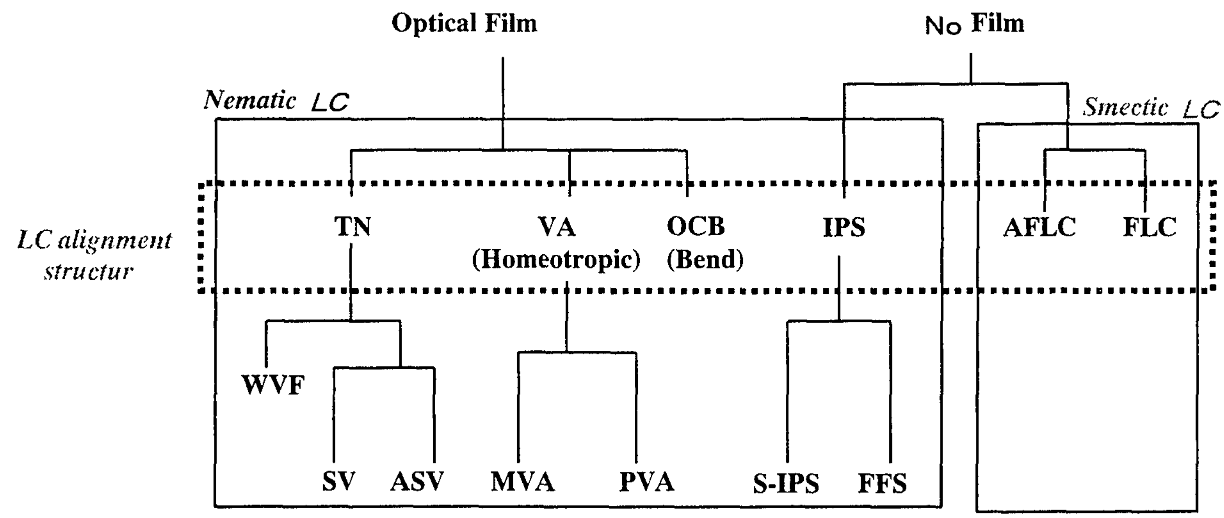

Fig. 8 Classification of Wide-Viewing Angle LCD Modes

3.3 LC layer for wide-viewing angle LCDs

Many wide-viewing angle LCD modes were proposed in this several years, and they are classified as in Fig. 8. The acronyms in Fig.8 are listed below.

TN	: Twisted Nematic mode
VA	: Vertical Alignment mode[3]
OCB	: Optically Compensated Bend mode[4]
IPS	: In-Plane Switching mode[1]
AFLC	: Anti-Ferroelectric Liquid Crystal mode[5]
FLC	: Ferroelectric Liquid Crystal mode[6]
WVF	: Wide Viewing Film mode[2]
SV	: Super V mode[7]
ASV	: Advanced Super V mode[8]
MVA	: Multi-domain Vertical Alignment mode[9]
PVA	: Patterned Vertical Alignment mode[10]
S-IPS	: Super In-Plane Switching mode[11]
FFS	: Fringe Field Switching mode[12]

Firstly they are divided into two groups. The feature of the first group is to use additional optical films except film polarizers, and that of the second groups is to use no additional optical films except film polarizers. Secondly, they can be classified by the LC materials such as nematic LCs and smectic LCs, then, each wide-viewing angle LCD modes can get their position by means of their LC alignment structures.

The wide-viewing angle property of WWF is not so excellent compare with the other modes. WVF, however, seems to get major market share about 80% because the production process is simple and completely same as the conventional TN LCDs. IPS (S-IPS) and MVA have the best properties in wide-viewing angle, e.g. color shift, contrast inversion. Therefore both modes should have big market share in the near future.

AFLC and FLC are still in development stage. Because of their high seed response and wide-viewing angle properties, users are eager to apply them especially in TV applications.

4. Properties of major wide-viewing angle LCDs

The features and R&D items for major wide-viewing angle LCD modes are listed in Table 1. The notable feature of WVF is that its cell structure is the same as that of conventional TN mode. Therefore, they can easily take WVF into volume production resulting low cost. And WVF has approximately 80% market share, even though, its wide viewing angle properties is inferior to other modes.

Concerning the response time, AFLC, OCB and ASV are superior to the others. Especially AFLCD has ultra fast response time less than microseconds.

It is evident that MVA and IPS have the best properties in the viewing angle characteristics such as color shift and contrast ratio. Both MVA and IPS, however, have some weak point. Small aperture ratio is the biggest weak point of IPS. In order to overcome this weak point, FFS is newly developed by using transparent inter-digital electrodes instead of metal inter-digital electrodes. S-IPS can improve, furthermore, wide viewing angle property of IPS by adopting multi-domain configuration.

Table 1 Features and R&D Items for each Wide-Viewing Angle LCD Modes

Mode		Features	Color stability	CR	R&D Items
Film	WVF	·The same cell structure as TN (mass productivity)	○	○	·Color shift less ·Film cost
Film	ASV	·Total balance ·Fast response	○	○	·Film cost
Film	MVA	·The best WVA ·Fast on-off response (25ms)	◎	◎	·Nn LC material
Film	OCB	·Fast response (<several ms)	○	○	·Bend alignment stability
No Film	IPS	·The best WVA ·Gray level response	◎	◎	·Transmittance (Aperture ratio)
No Film	AFLC	·Ultra fast response (<<ms)	○	△	·Alignment ·Polarization

◎:Excellent、○:Good、△:must be improved

5. IPS and S-IPS mode

In IPS mode, we use inter-digital electrodes on the TFT substrate to apply electric field parallel to the substrate. By this electric field, LC molecule can be switched their direction within the plane parallel to the substrate resulting extremely wide-viewing angle properties.

The schematic structures of the pixel are shown in Fig.9. The pixel of the conventional TFT-LCD is shown on the left hand side, and that of IPS TFT-LCD is shown on the right hand side. As you can find in the figure, the common electrode , that is inter-digital electrode, is engaged on the TFT substrate of IPS mode. By using the common electrode and pixel electrode, the electric field can switch LC molecular direction in the plane parallel to the substrate (in-plane switching). And there is no electrode on the upper substrate.

Because of the in-plane switching, there are no LC molecule that have opaque direction which induce angular dependence of the optical properties such as color shift, contrast degradation, contrast inversion.

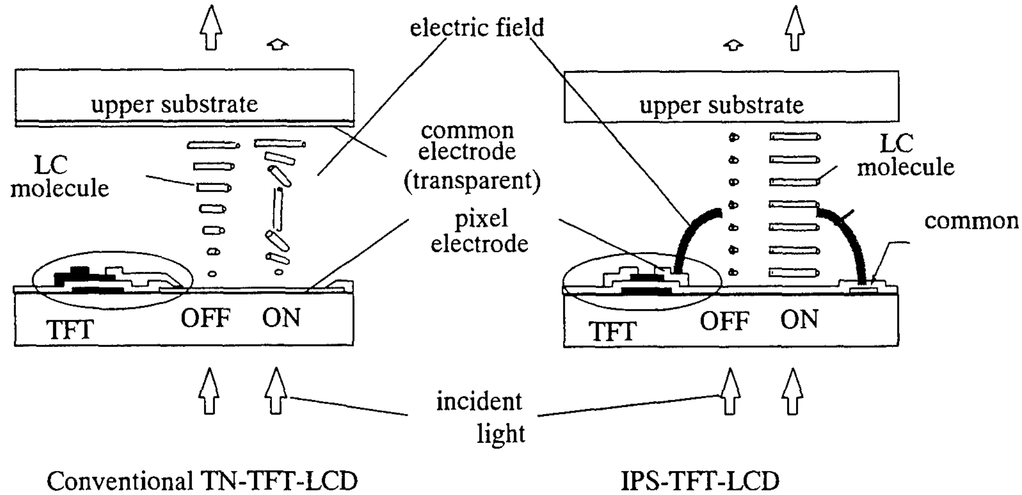

Fig 9. Schematic Structures of Pixel for Conventional TN-TFT-LCD and IPS-TFT-LCD

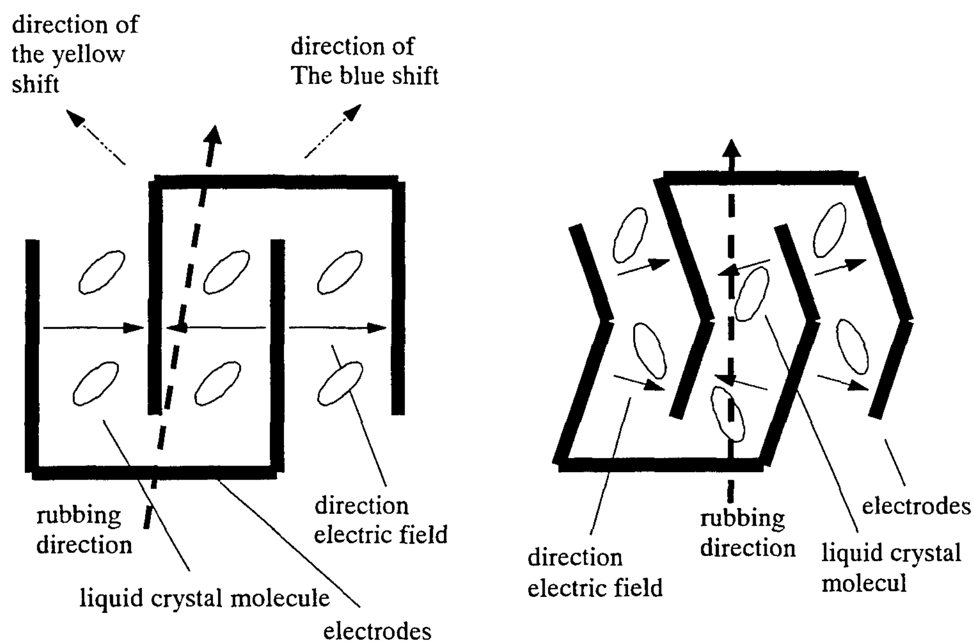

Fig. 10 Inter Digital Electrode Structures for IPS and S-IPS

Even though IPS has extremely good wide-viewing angle, there remains the small angular dependence. For example, there are small color change in white color, e.g. white changes to yellowish white or bluish white. In order to improve this white color shift, we introduced “Zigzag Electrode Pattern” as shown in Fig. 10. By this “Zigzag Electrode Pattern” direction of electric fields are different in the upper part of the pixel and in the lower part , therefore, multi-domain structure is builded up automatically. Thus we can easily achieve multi-domain structure with only one direction rubbing process.

Because of this multi-domain structure, the small white color shift remained in IPS are almost vanished. Then we named this mode as “Super IPS”.

In 1999, we have succeeded to develop a 18.1-inch diagonal Super IPS SXGA Module introducing above technologies and more newly developed technologies such as new LC material, improved optical and electrical design. Table 2 shows the specifications of the Super IPS Module. This module has also better features such as 20ms response time with high brightness and mechanical small foot print of thinner thickness with narrower display frame.

Table 2 Specifications of Super IPS Module

Item		Specifications
Resolution		SXGA
Number of pixel		H1280xV1024
Pixel Pitch (mm)		H0.2805xV0.2805
Number of Colors (Million)		16.7
Contrast Ratio		350
Brightness (cd/m^2)		350
Viewing Angle Range	Horizontal/Vertical Directions CR$\geq$10	170 deg.
	Δ u'v < 0.0	160 deg.
Response Time between White & Black Level	Rise Time (ms)	12
	Fall Time (ms)	8
	Total Time (ms)	20
Color Position on CIE 1931	R(x,Y)	(0.62,0.32)
	G(x,y)	(0.28,0.60)
	B(x,y)	(0.14,0.09)
	W(x,y)	(0.29,0.30)
Color gamut (%)		65
Dimensions of Outline (mm)		H396xV31xt24
Weight(g)		2000
Power Consumption (W)		50

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