

## High-Resolution LTPS TFT-LCDs for mobile phone applications

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### Abstract

In order to implement high pixel density in AMLCDs, high aperture ratio is a very important design factor. We have implemented VGA panels with IPS and TN modes. IPS mode is a very attractive solution to meet the requirement for mobile phone displays. It provides much higher aperture ratio as well as wider viewing angle at extremely high pixel density over 400 ppi.

### 1. Introduction

As various new services for mobile phones develop from simple voice and character based ones into multimedia ones, the demands for high performance displays are rapidly increasing. High-resolution camera function, game, movie, and digital multimedia broadcasting (DMB) are the key features of recent mobile phones. In addition, wireless-internet service might accelerate the use of high performance displays. Among various requirements for mobile phone displays, high resolution seems to be the most important factor since most of newly developed services are based on higher resolution video contents. Pixel densities of the screens for mobile phone were between 100 and 150 pixels per inch (ppi) like other large area displays for monitors of computers and TVs. Recently, the QVGA resolution of 240X320 pixels has been widely adopted and even higher resolution displays have been developed [1].

As shown in Fig. 1, the resolution of mobile phone displays will evolve from QCIF to VGA while the screen size stays around 2 inches, so that the pixel density will increase dramatically.

Along with high resolution, high color reproducibility and high brightness are additionally required like other LCD screens for TVs and computers. Wide viewing angle mode is also preferable to provide better image quality for both landscape and portrait images. However, high color reproducibility is hardly achievable at very high pixel density maintaining high brightness, without increasing the brightness of back light unit. The transmittance of LCD cells decreases further more by adopting wide viewing liquid crystal modes such IPS as MVA. Even though the increase of power consumption is unavoidable in LCDs with high resolution, high brightness and high color

reproducibility, it is very important to optimize LCD panel design.

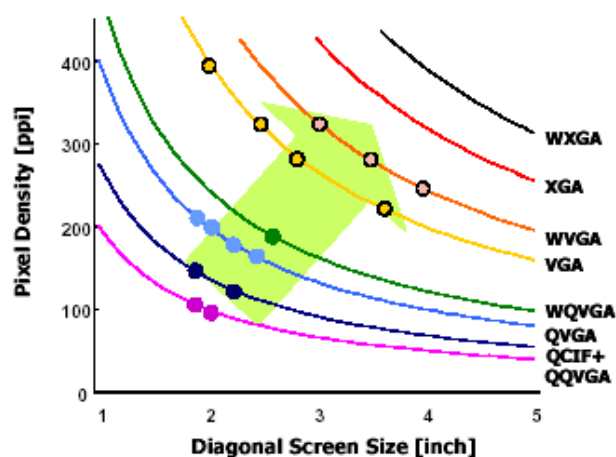


Fig.1 The resolution trends of AMLCD panels.

In this paper, we focus on extremely high pixel density over 300ppi. Low-temperature poly-Si thinfilm transistor technology is employed to implement high aperture ratio in pixel arrays. The fine patterning process of LTPS and the circuit integration on the peripheral area make it easier to obtain high aperture ratio and compact module. It is also shown that IPS mode provides better performance than TN mode at the high pixel density region over 340 ppi.

### 2. Panel Design Issues for High Pixel Density

It is necessary to reduce the pattern size of panels in order to make high pixel density without the severe sacrifice of the pixel aperture ratio. As the pixel density increases, the occupation portion of the dead area increases. The bus lines for data, scan, and storage voltage are generally dead zone in the normally white TN mode pixels as shown in figure 2. Even though the transparent pixel electrodes are overlapped with the dark data and gate bus lines to maximize aperture ratio, the dark area by the bus lines occupies quite wide portion in a pixel. We have calculated the aperture ratio according to the design rule for the pixel array. Figure 3 and figure 4 shows the degradations of the aperture ratio according to the space between two ITO electrodes and the storage capacitance, respectively. The aperture ratios degrade

rapidly in the high pixel densities over 300 ppi as the pixel electrode space and the storage capacitance increase. In order to maximize the aperture ratio, it is simple approach to reduce the patterning size and the storage capacitance. However, it is not adequate to simply reduce pattern size by adopting high-resolution photo-lithography and dry etching, since it degrades the productivity of large glass substrates. If we reduce the storage capacitance in proportion to the pixel area, the data voltage variation in the pixel electrode would increase by the capacitive coupling and the leakage current of TFT. While the capacitance coupling decreases in proportion to the pixel pitch, the storage capacitance should be decreased in proportion to the square of the pixel pitch in order to maintain the similar aperture ratio at highly dense pixels. The leakage current of pixel TFT is dependent on the channel width. However, there is little room to reduce the TFT size because the size is already minimized to the limit of patterning. Therefore, the degradation of aperture ratio at high pixel density is not avoidable considering the productivity and the picture quality.

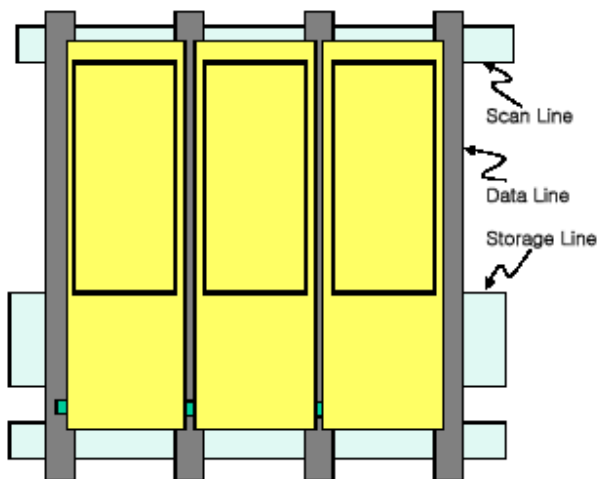


Fig. 2 Pixel structure of normally white TN mode.

### 3. IPS Panel Design

It is generally understood that the aperture ratio of IPS mode is lower than other modes while it provides the best viewing angle performance among various wide viewing techniques. Since the common and the data electrodes are located in the TFT layer and the light is not transmitted through these electrodes, the aperture ratio sacrifice is larger than in other modes. Figure 5 shows the schematic layout of IPS mode pixels. The transmitting area is proportional to the gap(d) between common electrode and pixel electrode. However, the

difference of aperture ratio between IPS and TN modes becomes small as the pixel density increases since the portion of the pixel electrode located in the middle of pixel becomes smaller than that of the storage capacitor of TN modes.

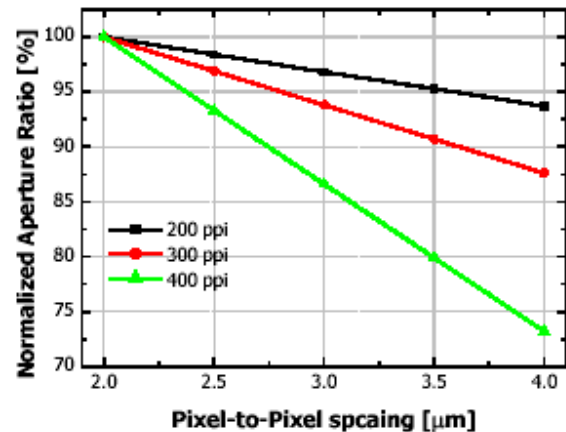


Fig. 3 The variation of aperture ratio vs. the space of pixel electrodes.

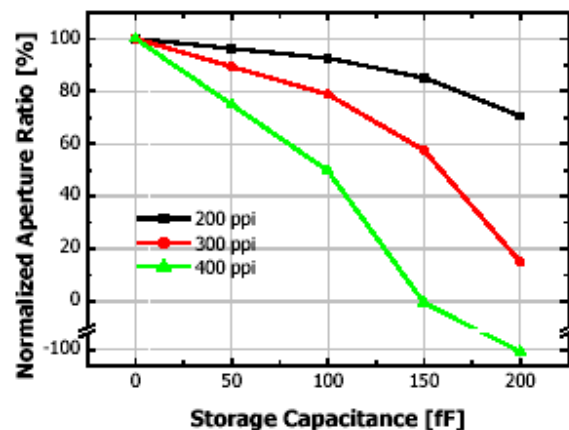


Fig. 4 The variation of aperture ratio vs. the storage capacitance.

Optimizing the electrode gap (d) is a key design factor in IPS mode. As the electrode gap(d) increases, the aperture ratio increases but the driving voltage accordingly increases. Figure 6 shows the variation of the liquid crystal driving voltage and the aperture ratio according to the electrode gap in a 400ppi pixel array. The power consumption in the driving circuitry increases proportional to the square of LC driving voltage, but the power consumption in the back light unit decrease due to the increase of aperture ratio. Therefore, the optimal electrode gap in terms of power consumption depends on the target brightness,

the efficiency of backlight unit, and the power consumption in the circuitry, which is strongly dependent on the resolution.

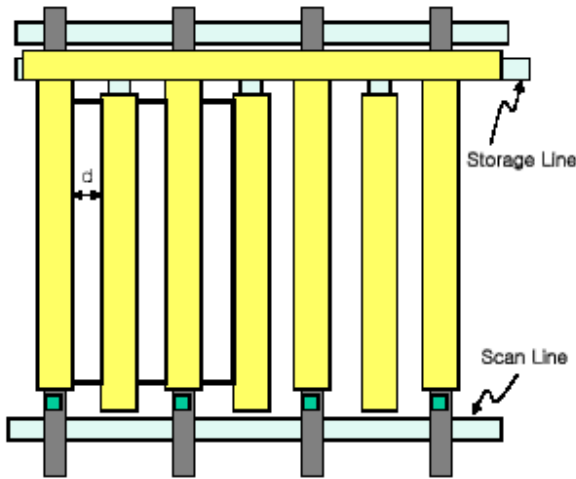


Fig. 5 A schematic pixel structure of IPS mode

A new liquid crystal material and the process are developed to reduce the driving voltage. Since conventional liquid crystal materials have been developed for TV or monitor panels, the driving voltages are above 5V. However, the driving voltage must be lower than 5V to use commercially available driving ICs developed for mobile phone display. The driving voltage is lowered less than 5V even at the electrode gap of 7  $\mu\text{m}$  as shown in figure 6. Figure 7 compares the normalized transmittance of newly developed LC with a conventional LC according to the driving voltage. The driving voltage is reduced by at least 2V.

We have calculated the transmittance of IPS and TN mode after optimizing the electrode gap distance and the results are shown in figure 8. The transmission ratio of the IPS mode is larger than that of TN mode above 320ppi. While the aperture ratio of TN degrades rapidly by the increase of pixel density, the aperture ratio of IPS mode increases. Since the electrode gap is fixed, the ratio of dead zone decreases at high pixel density.

#### 4. Panel Implementation

We have implemented VGA resolution panels both with IPS and with TN mode to compare the picture quality. Gate driving circuits, de-multiplexing switches are integrated to implement narrow bezel and high pixel density [2].

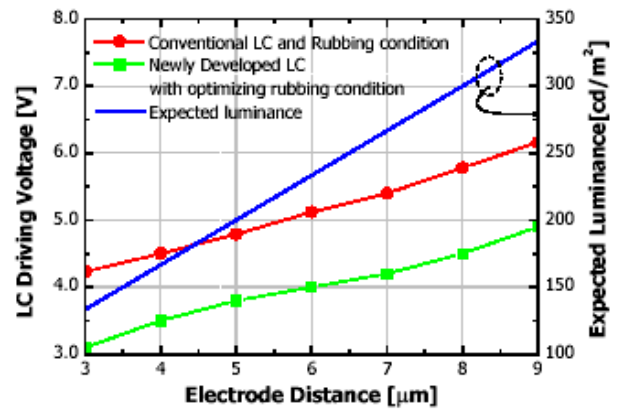


Fig. 6 The variation of driving voltage and aperture ratio according to the electrode gap distance.

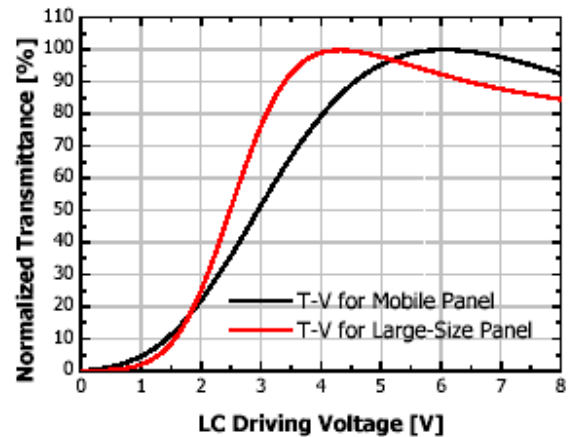


Fig. 7 Transmittance-Voltage characteristics of IPS mode liquid crystals.

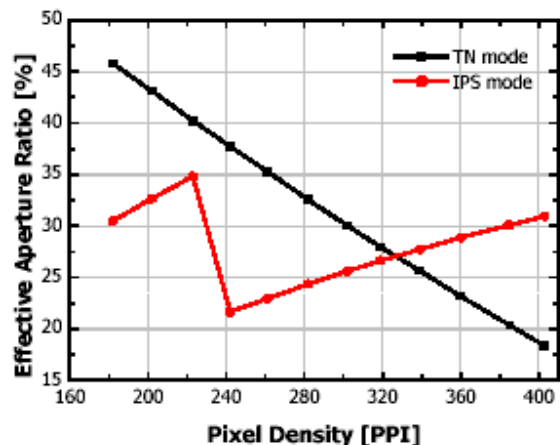
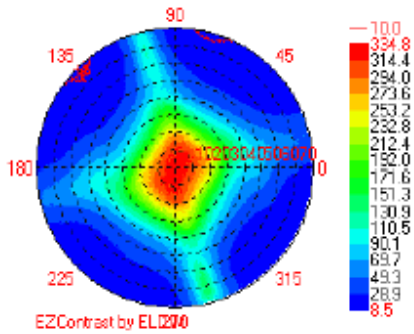
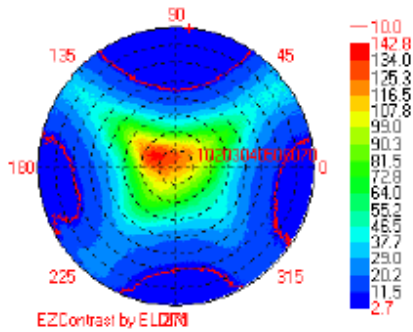


Fig. 8 Effective aperture ratio of IPS and TN modes vs. pixel density.

Figure 9 shows the comparison of polar chart of the contrast ratio between IPS and TN mode. IPS mode shows good contrast ratio all over viewing angle while low contrast ratio less than 10:1 is observed in TN mode at high viewing angles as expected. Figure 10 shows the display images taken from various viewing angle with IPS mode and TN mode. Even though a viewing angle compensation film is used for TN mode panel, gray inversion and low contrast ratio can be observed from top and bottom viewing direction.



(a) Polar chart of contrast ratio for IPS mode



(b) Polar chart of contrast ratio for TN mode

**Fig.9 Comparison of the polar chart of contrast ratio characteristics between IPS and TN mode(WV-film).**

Color reproducibility is another key issue. Figure 11 shows the color reproducibility variation according to the viewing angle. The color reproducibility of the TN mode is lower than NTSC 20% beyond the viewing angle of 40 degree. However, the IPS mode keeps good color characteristics all over viewing angle. In general, the transmittance degrades dramatically as the color purity increases, since the thickness of color resin is adjusted to enhance the color gamut. In order to obtain good color performance over wide viewing angle with TN mode, the thickness of color filter

should be increased. Since IPS mode provides better color perception than TN mode at oblique viewing angle, the thinner color resin can be used to achieve the same color perception compared with TN mode.

Figure 12 shows the display image of a 2.0-in. VGA panel implemented with IPS mode. The display provides very good picture quality both for picture image and for character image.



(a) IPS mode

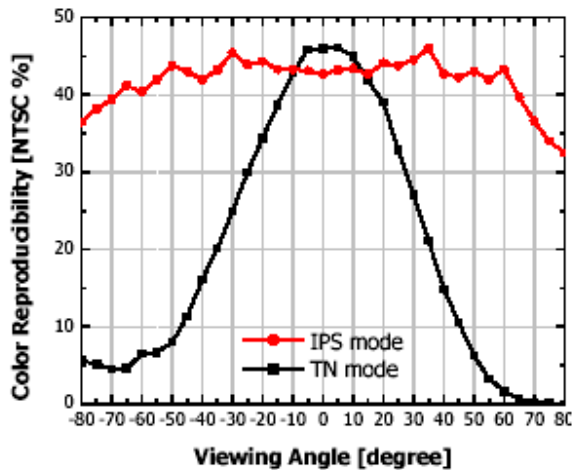


**Fig.10 Comparison of display image between IPS and TN mode(WV-film).**

### 5. Summary

We have discussed the issues for implementing high pixel density above 200ppi. The fine patterning is very important to achieve high aperture ratio in pixel arrays. Considering the productivity and picture

quality, it is not easy to scale down the storage capacitance. Therefore, the aperture ratio degrades drastically by the increase of the pixel density in conventional TN mode. On the while, the aperture ratio of IPS mode increases as the pixel density increases in the range of 240ppi or more. It is considered that IPS mode is one of the best solutions for high pixel density since it provides wide viewing angle and high brightness.



**Fig.11** Color reproducibility variation according to the viewing angle in IPS and TN modes.



**Fig.12** Photograph of 2.0-in VGA panel.

## 6. References

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