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# VERTICALLY ALIGNED TFT-LCDs

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*Fujitsu has developed several types of vertically aligned TFT-LCD: with protrusion; with photo-alignment; and with comb-shaped electrodes. The protrusion-type TFT-LCD has the best balance of specifications and is in mass-production. It has a transmittance of 5% for a 15-inch XGA LCD, a response of 25 ms ($\tau_{on} + \tau_{off}$), and a contrast ratio of over 400. The photo-aligned type gives highest transmittance (7.5%) with dual domains. The lamp for UV irradiation can be a tube type and non-polarized UV is possible. We think it is a good candidate for notebook-type applications. The comb-shaped electrode type has the fastest response of better than 17 ms for any gray-scale switching. We think it is a good candidate for video applications.*

## 1. INTRODUCTION

Liquid crystal displays (LCDs) are now finding a wider range of applications. In addition to devices such as cellular phones, personal computers, and PDAs, they are being applied to audiovisual equipment including wide-screen television sets. The primary advantages prompting the expanded application of LCDs have been their space- and power-saving features. Further expansion of these devices will depend on the progress made in solving problems in their display characteristics. The performance of a display device is usually evaluated in terms of its contrast, brightness, viewing angle, color reproduction, resolution, and response speed. Among these parameters, the conventional LCD has a very tough time at achieving a superior viewing angle, brightness, and response speed [1–31]. We have developed three types of VA LCDs; VA TFT-LCD with protrusions offers a well-balanced specification [21,26,29,30], VA TFT-LCD with photo-alignment offers a high transmittance [19,20,23,30], VA TFT-LCD with comb-shape electrodes and oblique electric field offers a fast response [27,28].

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## 2. VA TFT-LCD WITH PROTRUSIONS

A new alignment control technology with protrusions has been developed. The principle is illustrated in Figure 2-1. Instead of processing the surface of alignment layer, as done in the conventional approach, this technology adopts the new concept of processing the underlying structure beneath the alignment layer. Structures installed partly beneath the alignment layer form protrusions. When the voltage supply is turned OFF, most of the liquid crystal molecules align themselves vertically to the substrate, but those positioned above the protrusions incline slightly towards the substrate due to the slope of the protrusions beneath them. When the voltage is turned ON, the molecules on the sloped protrusions initially start tilting in the direction shown by the arrow in Figure 2-2, and then the molecules in the regions without protrusions are affected by the tilting molecules and align themselves in the same direction. In this way, stabilized alignment is attained in the entire pixel. In other words, controlled alignment is achieved over the entire display area starting from the protrusions.

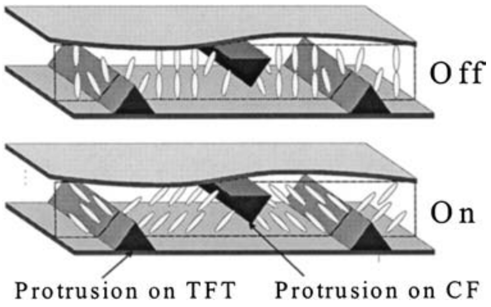


**FIGURE 2-1** Principal structure of new LCDs.

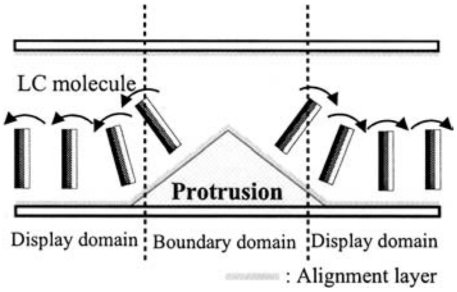


**FIGURE 2-2** Tilting of LC molecules.

Figure 2-3 illustrates alignment control by a combination of electrode slits and protrusions on color filter (CF) substrate. As can be seen from the figure, the TFT substrate has no protrusion formed on the surface, and parts of the ITO pixel electrode are etched off (electrode slits). When voltage is supplied, a deformed electric field (diagonal electric field) is generated in the vicinity of the individual slits, providing field distribution and alignment control of the liquid crystal molecules similar to those attained when protrusions are installed. The simultaneous formation of slits with ITO pixel electrodes can eliminate the need for additional processes.

Figure 2-4 shows the micro-photograph of the real TFT pixels with protrusions and slits of ITO. Slits are fabrication in ITO electrode in stead of protrusions on ITOs. The liquid crystal molecular alignment is divided into four domains, North-East, North-West, South-East, South-West.

Actual photograph of the pixel when the voltage is applied (white state) is shown in Figure 2-5. The big disclination lines are seen at specific position near the pixel edge. This results in the reduced transmittance of the multi-domain vertically aligned (MVA) panels. The tilted directions of the

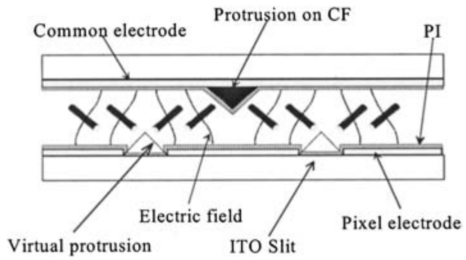


**FIGURE 2-3** Alignment control by electrode slits and protrusions.

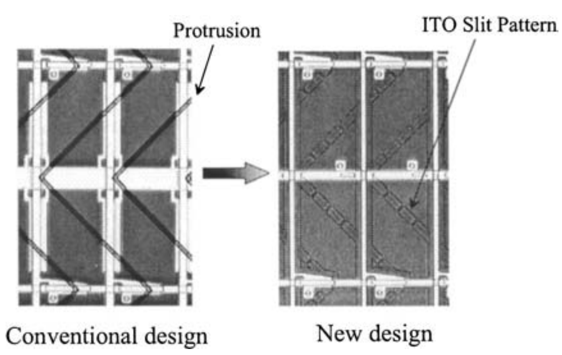


**FIGURE 2-4** Real pixel design with protrusions or slits.

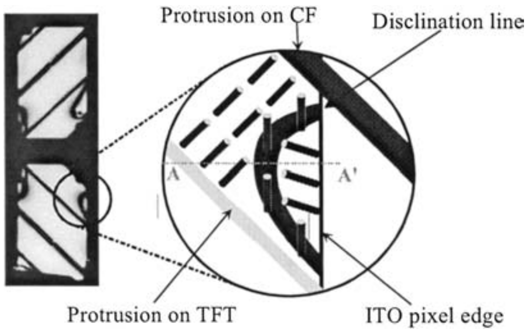


**FIGURE 2-5** Actual micro-photograph of pixel and alignment.

LC molecules are also illustrated in Figure 2-5. The tilted directions are opposite way for domains divided by the disclination line and the cause can be estimated by the edge field effect of the pixel ITO.

To remove this disclination line, we put additional protrusion on the counter electrode which is placed just in front of the pixel edge (Figs. 2-6, 7).

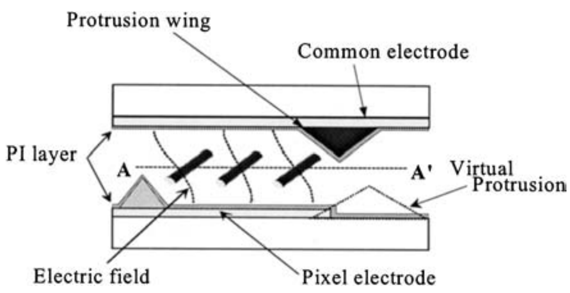


**FIGURE 2-6** Cross sectional view of protrusion wing.

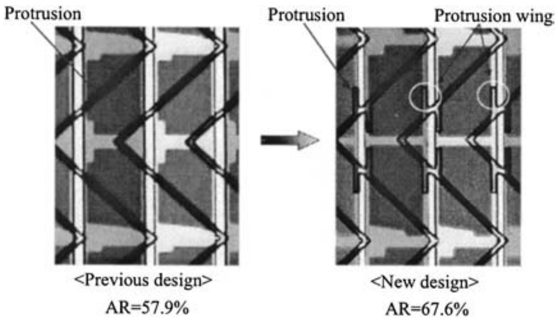


**FIGURE 2-7** Previous and new design with protrusion wing.

The newly adopted protrusion is called protrusion wing and the ability to control the tilted direction is much bigger than that of the edge field effect due to distorted electrical field.

Figure 2-8 shows the newly designed columnar spacer panel. The layers of Red, Green, and Blue resin filters are stacked only on the pixel borders to minimize the leakage of light rays from the borders (stacked RGB color filters prevent the transmission of light rays). This eliminates the need for black matrix required in the existing manufacturing processes. In addition, a protrusion is formed on the color filter-stacked point to provide a cell spacer and create a cell gap. This protrusion acts as a spacer and an alignment controller. This approach eliminates the black matrix forming process and spacer distributing process, simplifying the process on the whole. Figure 2-9 shows SEM photograph of spacer. The protrusion layer stacked on ITO enables to avoid an electrical short between CF and TFT substrates and to keep an appropriate cell-gap.

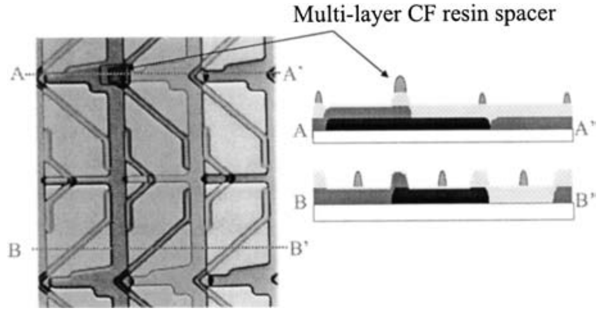


**FIGURE 2-8** Multi-layer color filter resin spacer.

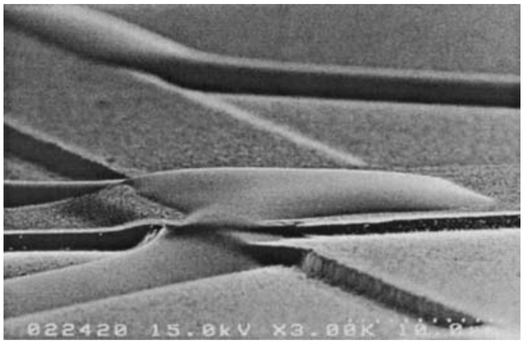


**FIGURE 2-9** SEM photograph of spacer.

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