# 15.1: A Novel VA Architecture for Improved Response Time

***Jiwon Sohn, Nakcho Choi, Chul Huh, Dong-Ki Lee, Juae Yoon, Min-Sik Jung, Jaejin Lyu, Kyeong-Hyeon Kim and JunHyung Souk***

**LCD R&D Center, LCD Business, Samsung Electronics Corporation,**
**San 24 Nongseo-Dong, Giheung-Gu, Yongin-City, Gyeonggi-Do, 449-711 Korea**

## Abstract

*We designed a novel mountain-shaped cell architecture in order to obtain less than 15 ms of $t_r+t_f$ response time without an overdriving circuit in vertical alignment mode. This structure significantly reduces the $t_r+t_f$ time of PVA mode by eliminating abnormal motion in the turn-on process, which is detrimental to rapid switching.*

## 1. Introduction

Liquid crystal displays (LCD) occupy a prominent position in the flat panel display market, and these days the LCD market size is rapidly growing [1]. Samsung Electronics has developed its own PVA technology as a practical and wide viewing angle mode. PVA characteristics include a multi-domain structure formed by a fringe-field effect and optical compensation by retardation films [2-3]. Samsung's PVA mode has a worldwide reputation in the LCD TV and monitor markets as it has satisfied essential market requirements including high contrast ratio, high brightness, wide angle of view with no gray inversion, and fast response time. Among these properties, fast response time is mandatory for LCD-TV and monitors in order to faithfully reproduce dynamic moving images. Samsung has already achieved sub-8ms gray-to-gray response time using DCC2 (Dynamic Capacitance Compensation) [4, 5].

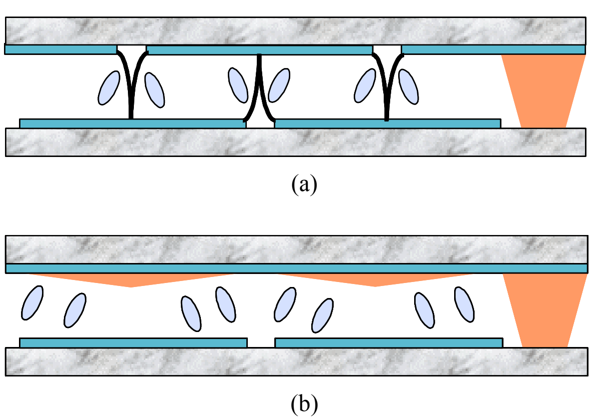

**Figure 1**. Schematic diagrams of (a) conventional PVA and (b) mountain-shaped structure.

Although DCC2 is a remarkably effective method for achieving fast turn-on time in PVA mode, due to the two frame storage requirement, DCC2 impacts cost competitiveness in the case of low cost products such as popular 17" and 19" monitors. Therefore, we have designed a novel mountain-shaped cell architecture in order to obtain less than 16ms of $t_r+t_f$ response time without requiring any overdriving or memory. Figure 1 (b) shows the schematic diagram of this architecture. It consists of a mountain-shaped structure built on the color filter ITO layer. The mountain-shaped structure is fabricated in the same process step as the column spacers. Through this new structure, we can achieve multi-domain pre-tilt in VA mode without requiring any rubbing. The structure significantly reduces $t_r+t_f$ response time of PVA below 15 ms in a 19" SXGA LCD monitor without any requirement to pre-tilt or overdrive the liquid crystal. This structure eliminates the abnormal (slow) motion of liquid crystals in the turn-on process, which is the source of delayed switching.

## 2. Results

### 2.1 Fast response time of mountain-shaped structure

Generally, the response time of an LCD panel can be improved by optimizing panel cell parameters such as cell gap, and by optimizing the physical properties of materials such as rotational viscosity and elastic constants of the liquid crystal. However, it is difficult to enhance the response time, especially rising time, of PVA mode without an overdriving circuit. In this research, we deeply studied the behavior of liquid crystal molecules in order to analyze and fully understand the mechanism of rising and falling response time in PVA mode.

As shown in Figure 2 (a), liquid crystal molecules at the edge of the pixel electrode (area A) move without delay by means of polar rotation according to the fringe field as soon as the electric field is applied. However, the liquid crystal molecules in the center area between the pixel electrode openings (area B) move to a more random polar orientation, only later becoming correctly aligned according to a slower azimuthal rotation. This azimuthal rotation is a much slower mechanism compared to the polar rotation. Therefore, the LC molecules in the zone of area B do eventually rotate into alignment with the molecules at the edge of the fringe field, but this takes a longer period of time, in turn causing a slow dark to light state transition.

Because of this two-step (polar, then azimuthal) motion of liquid crystals in the center area (area B), it is hard to obtain less than 16 ms of $t_r+t_f$ response time without overdriving in PVA mode. The random motion of liquid crystals and slow azimuthal rotation to

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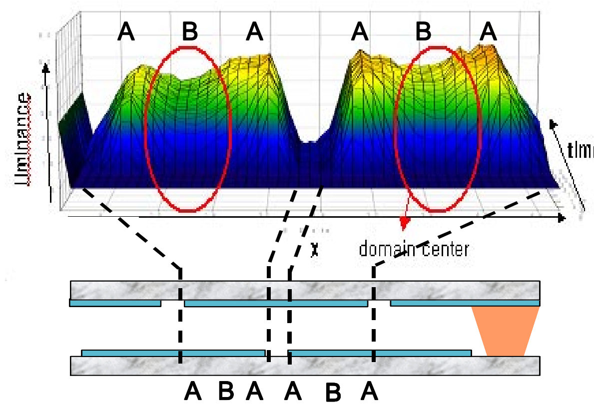
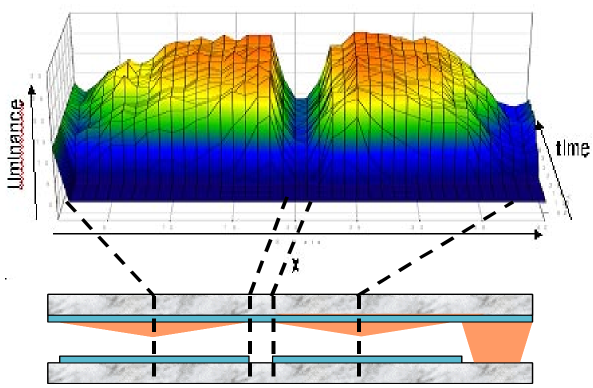



(a)




(b)

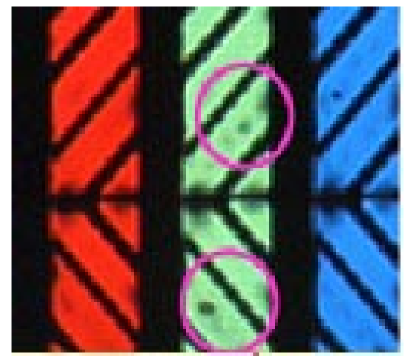
**Figure 2.** Increase of transmittance at the time of switching from gray level 1 (black) to gray level 64 (full white) in (a) normal PVA and (b) mountain-shaped structure.

the correct orientation causes the abnormal texture in domain center (area B) as shown in Figure 3(a).

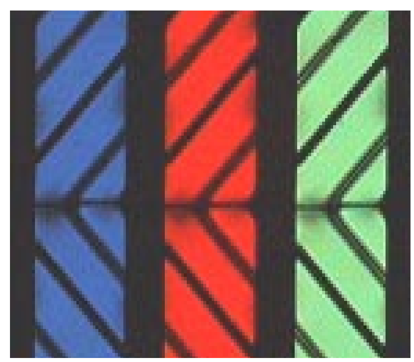
In order to control the random motion in center domain area, we tried several methods. The first of these was to reduce the area that gives rise to the random motion. By decreasing the distance between the pixel electrode open areas, faster response time could be obtained. However, this approach could only reduce the response time by 2 ms. Additionally, reduction of the distance between active electrodes comes at the expense of low aperture ratio and therefore reduced transmittance.

Our second approach was to apply a pre-tilt in the VA cell in order to control the direction of liquid crystal motion. Simply, we tested a rubbed mono-domain VA panel, which shortened the response time by 4 ms compared to multi-domain PVA. However, it is difficult to obtain a wide viewing angle, multi-domain VA panel with such kind of rubbing process, which would actually be a four-stage rubbing process.

Our final approach was to form a mountain-shaped structure on the pixel electrode using an organic layer as shown in Figure 1 (b). This structure was formed with photolithography using a slit mask. The tilted organic layer reduces the $t_r$+$t_f$ response time to below 16 ms. Using this structure, we observed that the random motion in the domain center area disappears as shown in Figure 3 (b). Figure 2 (b) shows that the structure greatly reduces response delay in the domain center, also Figure 3 (b) shows there is no abnormal texture such as in Figure 3 (a). In addition, this approach simplifies preparation of the color filter sheet, because the color filter ITO does not need to be patterned, and the column spacer and mountain-shaped structure are formed simultaneously, *i.e.*, through only one photolithography process.



(a)



(b)

**Figure 3.** Comparison of random texture of domain center area 7 ms after application of fringe field (a) in PVA mode and (b) using mountain-shaped structure

## 2.2 Design of mountain-shaped structure

When the tilted organic layer of the mountain-shaped structure is formed, the slit mask covers the entire active area of the pixel. To form the mountain peak area in the tilted structure, openings in the slit mask are closely spaced. To form the gradual decrease in the tilted structure height, openings in the slit mask are spaced further apart proportionally with the decrease in mountain height. In order to find the optimum angle of the tilted structure and the height and width of the organic layer, we evaluated optical properties at the various ratios of open area to closed area. Figure 4 shows a SEM image of the organic tilted layer. This mountain-shaped structure

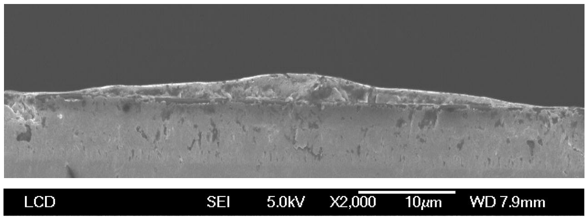
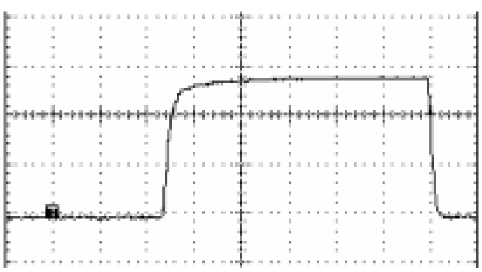



**Figure 4.** SEM image of mountain-shaped layer. (vertical view).

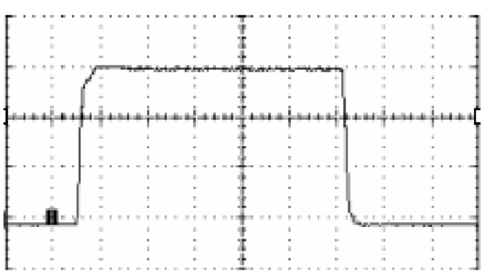
is different from the protrusions of MVA mode, because it not only divides the domains to achieve wide viewing angle, but it also prevents the liquid crystal director from random motion which causes response time delay.

## 2.3 Characteristics of mountain-shaped structure

As shown in Figure 5, the curve profile of on/off switching is very sharp compared with conventional PVA mode. Also, the undesired texture in the center domain area does not appear with the mountain-shaped structure as shown in Figure 3. The $t_r$+$t_f$ response time of the structure is about 15 ms in our prototype 19" SXGA monitor, a remarkable result considering that $t_r$+$t_f$ response of a normal 19"SXGA PVA monitor is ~21 ms. In addition, the structure shows symmetrical switching behavior, that is, rising and falling time are similar at ~7.5 ms each. This response time



(a)



(b)

**Figure 5.** On/off switching profiles of (a) PVA and (b) mountain-shaped structure.

symmetry also eliminates wire-frame flicker and line dimming seen in conventional PVA [6].

Because the organic layer on the pixel electrode results in a voltage drop due to capacitance of the organic material, the electric field applied to the liquid crystal molecules in this structure is lower than the externally applied electric field. Therefore, mountain-shaped structure requires higher voltage compared to conventional PVA, but it does not require a special driver IC. Moreover, important characteristics of this structure are the faster response time as well as higher transmittance with the higher external field. On the other hand, in a conventional PVA panel, random motion in the domain center area gets worse with increased voltage, therefore higher voltage cannot be applied to a conventional PVA panel due to response time issues. As shown in Figure 6, at the white state, the pixel of the new mountain-shaped structure is as clear as that of conventional PVA.

Black luminance of this structure is a little higher compared to conventional PVA because the liquid crystal is slightly tilted at the black state. However, compared to MVA mode, the black state LC tilt angle is much lower in this structure due to residual retardation from the MVA protrusions. Therefore, the mountain-shaped structure delivers superior contrast compared to MVA. The organic material does not affect the color properties, so that the white point color coordinates remain unchanged at x, y = (0.315, 0.338). Other properties including viewing angle and the off-axis image quality are comparable to PVA mode. The same polarizer and compensation films are used with this structure.

With this technology, there is a risk of image sticking due to the organic material layer on the pixel electrode over a very large area. In our studies, image sticking clearly depended on the properties of the organic material selected for the mountain-shaped structure and the column spacer. Optimization of the organic material by way of intensive material research provided the solution for this issue.

(a) (b)

**Figure 6.** Pictures of pixel at 64 gray (full white) (a) PVA and (b) mountain-shaped structure.

**Table 1.** Characteristics of a novel VA alignment mode (19" SXGA)

| | |
|---|---|
| Ton+off (Ton / Toff) | 15ms (7.5ms / 7.5ms) |
| Contrast ratio | 900:1 |
| Luminance | 260 nit |
| Color gamut | 72.3% |
| White color coordinates | (0.315, 0.338) |
| Transmittance | 3.8% |
| Viewing angle | All >80$^o$ |

## 3. Impact and conclusion

Intense study into the motion of vertically aligned liquid crystal molecule switching has led to our design of the mountain-shaped cell structure, a novel VA architecture which provides fast response time using a tilted organic layer. This innovation has improved $t_r$+$t_f$ response time to ~15 ms without overdriving, which is a significant improvement compared to 21 ms for normal PVA. Additionally, 5-mask color filter preparation significantly reduces cost, as it is not necessary to pattern the color filter ITO and the mountain-shaped structure and column spacer are formed using one photolithography process step. This work is the first example sub-16 ms $t_r$+$t_f$ without overdriving in VA mode. Furthermore, it is expected that even faster gray-to-gray response time in VA mode can be achieved by applying overdriving (such as DCC) to this structure.

## 4. References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