# 23.1: Advanced LC Development for LCD TV Application

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## Abstract

Flat Panel Display (FPD) application of Television (TV) application is booming. Liquid Crystal Display (LCD) is forecasted to play a dominant role for TV application in next years. We review in this presentation LC material development for LCD TV application.

## 1. Introduction

A new era of flat panel television is now dawning. LCD will play a dominant role in next years. Since the begging of 1990's of the introduction of Thin Film Transistor (TFT) LCD, LCD had been accepted and installed in several mobile applications (cellular phones, PDAs including Notebook application) due to its attractive features, less weight, thin and low power consumption. LCD has penetrated into these markets almost without competition.

LCD uses the so-called birefringence effect for its optical switching. Therefore, its viewing angle dependency had been thought to be an intrinsic problem. This problem had been improved in a striking manner by the introduction of new display switching modes, e.g. In-Plane Switching (IPS) [1] and Vertically Aligned (VA) [2]. After these findings, LCD began to compete with Cathode Ray Tube (CRT) in Monitor application. CRT has had a long development history and is a matured display technology. Thus, the market penetration of LCD into Monitor application encountered different situation from mobile application and was thought very difficult. However, after having improved the beginning big price difference between LCD Monitors and CRTs, LCD Monitors had been very fast accepted in the market. Market analysis says that LCD already overtakes (value-wise) CRT in 2003 due to the big growth of LCD Monitor market.

Next big challenge of LCD application is TV. However, the requirement of TV is far different from those of Monitors, for instance very high contrast, full moving picture capability and high colour quality. It means that only an installation of tuners into LCD Monitors is not good enough to replace CRT TVs in living rooms at home. Considerable efforts have been made in order to achieve these high requirements of TV not only from the side of LCD components (colour filter, polarizer, LC material) but also from the side of driving schemes. LCD TV seems to be now in the position to become a real competitor against CRT TVs.

We will review in this presentation LC material development in last years for IPS and VA modes together with an outlook into the future.

## 2. Requirement of TV application compared to other LCD products

The requirement of TV on LC materials is specific (Fig. 1). Cellular phones, PDAs require long battery life and broad temperature operation ranges as mobile tools, while these are not the case in TV. High resolution due to the relatively small displays in mobile tools is not necessary in TV application. Another striking difference is the display size. Although the display size of Monitors covers even 20 inch, the most attractive LCD TV size for living rooms is said to be 30-40 inch.

The most important challenging task is higher contrast and faster switching times for TV application. The contrast value of 400 is high enough for Note PC or Monitors, whilst the value of 800 is at least necessary for TV application in order to compete against the brilliant picture quality of CRT. Brightness can be enhanced by backlight and therefore has a direct relationship with the aperture ratio of displays. The aperture ratio is strongly dependent upon display design and cell configuration, which in turn requires a well-defined dn (birefringence constant) of LC material property.

Faster switching times have also been required for Note PC and Monitors since they have been utilized as the so-called multi-media, especially DVD. However, the requirement of faster switching times for TV is far higher because moving pictures are almost always shown on TV screens. Worse moving picture quality in the larger TV sizes is even more serious than the smaller screens.

Altogether, the most important requirement of TV on LC materials is the faster switching times by keeping a specified dn.

The switching on time $\tau on$ is given by,

$$\tau on \propto \frac{\gamma_{eff}}{K_{eff}} \frac{d^2}{\left[ V_{on}^2 / V_{off}^2 - 1 \right]} \qquad (1)$$

Where $\gamma_{eff}$ is effective viscosity, $K_{eff}$ is effective elastic constant, $V_{on}$ is switching on voltage and $V_{off}$ is switching off voltage.

The switching off time $\tau$ off is given by,

$$\tau off \propto \frac{\gamma_{eff}}{K_{eff}} d^2 \qquad (2)$$

These equations (1) and (2) [3] are valid in a strict sense only if the switching is made between black and white.

d is the cell gap where d*dn should be kept as a certain constant value dependent upon the switching mode. Thus, the cell gap reduction has a pronounce reduction effect on the switching times, but this is of course limited due to production feasibility.

$K_{eff}$ is related to threshold voltage and dielectric constant and therefore no free parameter. The main task of LC material development is to identify new materials for optimizing $\gamma_{eff}$ under the specified dn.

## 3. IPS mode

IPS technology possesses very good viewing angle property even without compensation films. This is an important advantage of IPS mode since LCD TV in living rooms requires very good viewing property. $\gamma_{eff}$ in equation 1 and 2 is the rotational viscosity $\gamma_1$ in IPS case. The threshold voltage Vth (IPS) is given by

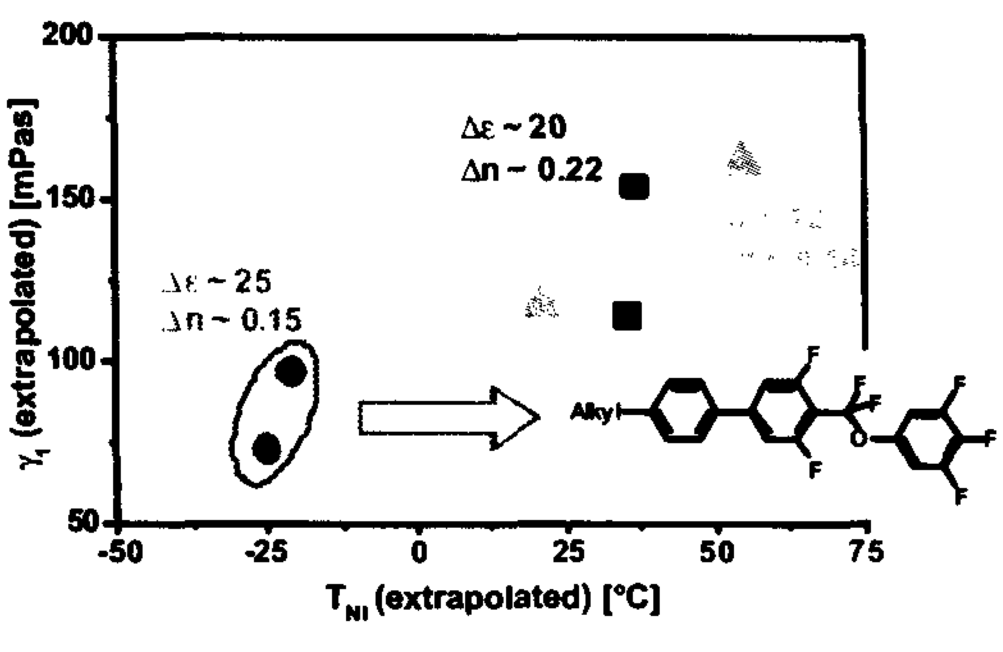
$$V_{th} = \frac{d_{inter}}{d}\pi\sqrt{\frac{K_{eff}}{\varepsilon_0 \Delta\varepsilon}} \qquad (3)$$

$d_{inter}$ is the inter-digital electrode distance and d is the cell gap. $K_{eff}$ is $K_2$.

Due to this inter-digital electrode, it is not easy to achieve high aperture ratio compared with VA mode. One feasible possibility is to make $d_{inter}$ larger, which requires, however higher de value in order to compensate the corresponding increase of Vth (equation 3).

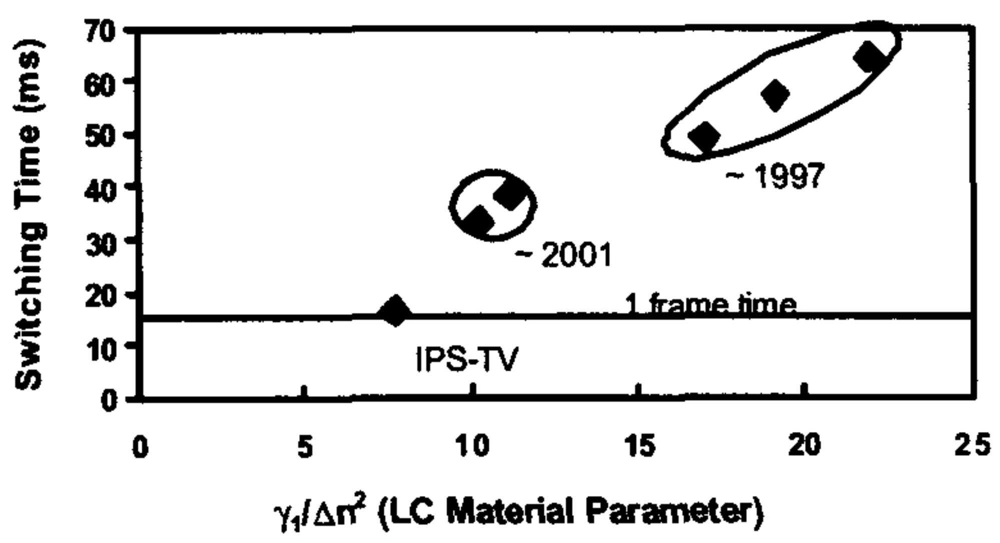
It means that the lower rotational viscosity, $\gamma_1$ with the higher de materials is of essential importance for IPS TV.

Fig. 2 shows one of our recent new LC materials for IPS TV and possesses exactly this required property.




[Fig. 2] New LC Materials for IPS Mixtures

By applying these advanced LC materials, we have succeeded in improving the switching times since the first IPS LCD introduction of 1997. The most recent IPS-TV achieved the so-called 1 frame time.




[Fig. 3] Development History of IPS-LCD

## 4. VA mode

VA mode needs LC materials with negative de. One of the advantages of VA mode is the pure black state in the switching off states (LC molecules are oriented homeotropically), which enables high contrast values. In order to avoid undefined fall directions of VA molecules for the switching on states, several ideas had been proposed (e.g. MVA [4], PVA [5], ASV [6]).

The effective elastic constant $K_{eff}$ is $K_3$, which is the largest elastic constant (cf. $K_2$ and $K_1$) in commercial nematic mixtures. It should be noted $\gamma_{eff}$ in equation (1) in the switching on time is

$$\gamma_{eff} = \gamma_1 - \gamma_{flow} \qquad (4)$$

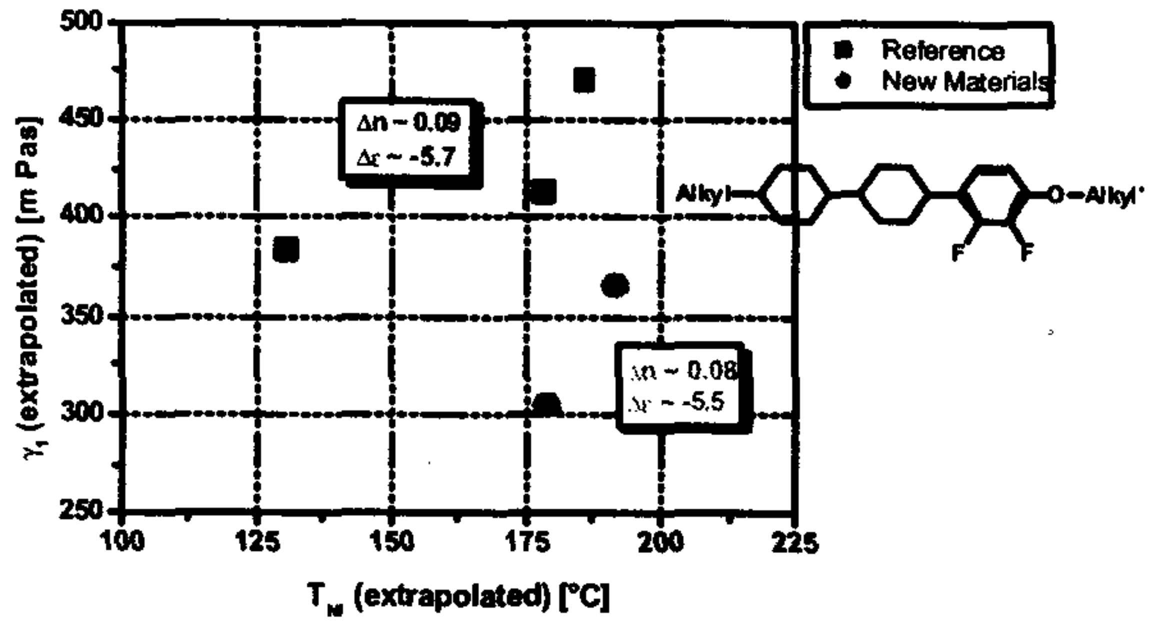
$\gamma_{flow}$ is flow term.

The first consideration about this flow term was already made [7] in the begging of 1970's. More precise and rigorous simulation result was very recently reported [8].

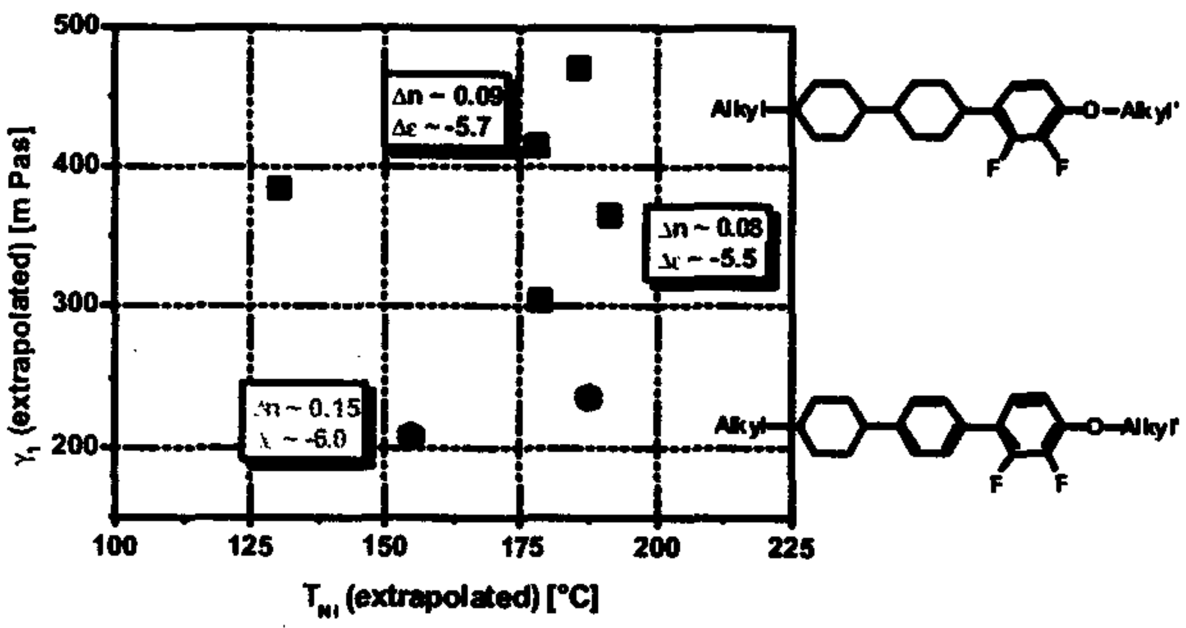
This largest elastic constant $K_3$ and the positive contribution of the flow term is the reason for the fast switching on time of VA.

$\gamma_{eff}$ of equation 2 is $\gamma_1$.

Fig. 4 and Fig. 5 show the advanced LC materials for VA application with the lower rotational viscosities.

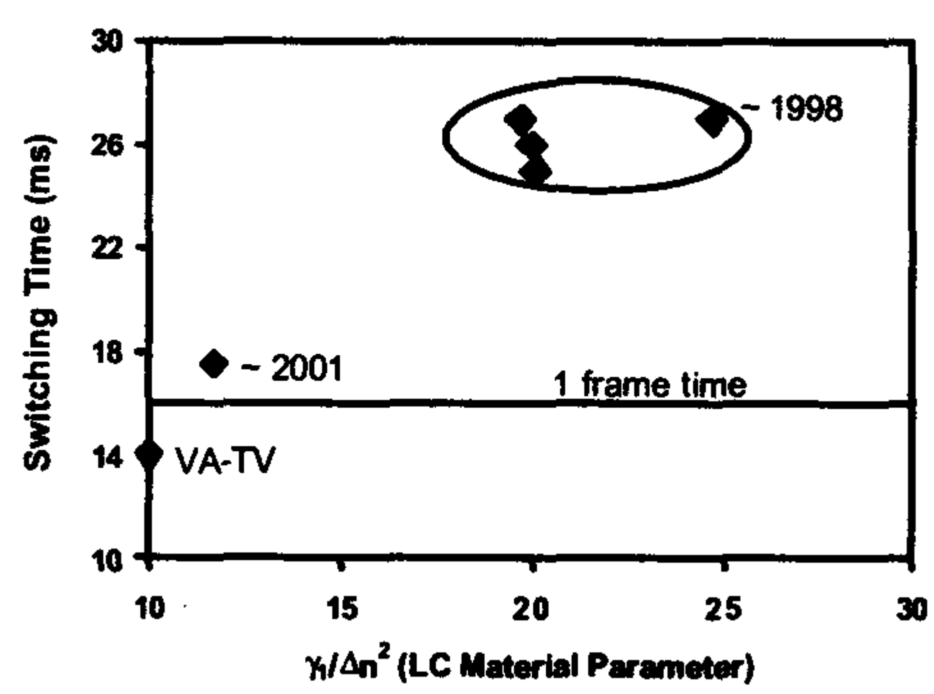



[Fig. 4] New LC Materials for VA Mixtures




[Fig. 5] LC Materials for VA Mixtures

By applying these advanced LC materials, we have successfully improved the switching times (Fig. 6).




[Fig. 6] Development History of VA -LCD

## 5. Comparison between IPS and VA

There are several reports that have compared the performance between IPS-TVs and VA -TVs [9]. It is not easy to discuss the picture quality of TV only from the standpoint of IPS and VA, since even within VA-TVs there exists also picture quality difference.

In general advantages and challenging points of each display mode may be summarized as follows. IPS has an intrinsic advantage of good viewing angle property that is of essential importance for TV application. Less colour shift or less independent gamma correction curve is reported in IPS-TV against VA-TV [9]. VA-TV has improved this challenging point by introducing a new retardation film [10]. On the other hand VA -TV has an intrinsic advantage of good contrast values. In order to improve this challenging point, IPS-TV might simply be able to introduce a stronger backlight to enhance the brightness. However, this in turn could give rise to the deterioration of the black state due to light scattering that comes from an inhomogeneous molecular alignment at surfaces (e.g. corners of inter-digital electrodes). This challenging point has recently been improved by optimizing colour filters and cell configurations [11].

One difficult challenging point of VA is a slow gray scale switching near black states that comes from the steep V-T curves. After the introduction of the so-called overdriving schemes, this point has significantly been improved and is no longer intrinsic problem.

At this moment one cannot say which LCD TV mode has a promising future. Each mode has characteristic advantages. One of the decisive points seems how better picture qualities can be achieved by taking good use of the advantages of each display mode.

## 6. Outlook and Summary

LCD TV seems to be accepted in the market and an optimistic market forecast say s that LCD will occupy a considerable market share (even 15-20% in 2007) against CRT. LCD TV picture quality has been improved and is now in the position to be able to begin a serious competition against CRT. However, there exist still several challenging points in order to replace CRT not only because of the attractive features of LCD like flat screens, less weight and less power consumption.

The switching times have been reduced under one frame time and even slower gray scale switching times are also now under one frame time by applying overdriving schemes. However, LCDs have holding pictures that remain still problematic even if the switching times could be zero [12]. One of the solutions is to insert the black stripes, which requires faster switching times far less than one frame time. It is, therefore important for us to further improve the corresponding viscous properties of LC. This trial also enables to make easier the overdriving schemes.

## 7. References

[1] Oh-e, M., Asia Display, 1995 (577)
[2] Ohmuro, K., SID Digest, 1997 (845)
[3] Tarumi, K., J. J. Appl. Phys., 1992, 31 (2829)
[4] Takeda, A., SID Digest, 1998 (1070)
[5] Kim, K.H., IDRC 1998 (383)
[6] Ishii, Y., SID Digest, 2001 (1090)
[7] De Genne, P. G., Mol., Cryst., Liq., Cryst., 193 (1971)
[8] Iwata, Y., ILCC 2004
[9] Nakamura, J. Microdevices, 2004
[10] Kim, K. H., SID Digest 2004 (106)
[11] Yeo, S. D., SID Digest 2004 (758)
[12] Kurita, T., SID Digest 2001 (986)

| | Most important requirements | | LCD-TVs |
|---|---|---|---|
| **Cellular phones** | Longer battery life | → | Not necessary; power supply available |
| | Broad operating temperature range | → | Not necessary; room temperature |
| | Small displays with lots of information | → | Much lower resolution |
| **Note PCs** | Longer battery life | | |
| | Display size 12 inch – 15 inch | → | Totally different size; 20-40 inch |
| **Monitors** | Utilization as multi media display with high information content | → | Much lower resolution |
| | | | However, absolutely necessary<br>• Faster switching<br>• High contrast ratio |

[Fig. 1] Requirements for LCD-TVS and other LCDs