26-4: Fast Response Time in IPS Mode Using LC mixtures with High Elastic Constant

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Abstract

For the fast growing Liquid Crystal Display (LCD) TV market, it is essential to make the LCD panels to show moving images without any visual difficulties such as blurring or tailing. Owing to reduction of the cell gap and the improved Liquid Crystal (LC) mixtures with low viscosity, it is possible that our S-IPS TFT-LCDs feature a response time (R/T) as fast as 1-frame time (16ms) for a white-black operation and less than a 16ms in all gray levels without Over Driving Circuit (ODC) technology. Currently, mass production of the large size IPS panels with high speed has been successfully achieved.
In order to achieve faster response time, new LC mixtures have been developed, optimizing the physical properties of rotational viscosity (γ1) and elastic constants (Kii). Also, the LC mixtures with high elastic constant allow us to increase the cell gap. In this paper, realization of fast switching time in IPS mode with optimized 'γ1/Kii' parameter in the LC mixtures forms the core of this paper.

1. *Response Time Introduction*

A milestone of the LCD TVs require technologies based on human perception and ergonomics because TV is a equipment for not only information but also entertainment. Achieved so far are the LCD panel specifications of the brightness from 400 to 500 nits and the response times from 25 to 16 ms etc. However, for the display as a premium TV, more sophisticated and upgraded properties are demanded for viewing angle, response times, brightness, contrast ratio and color gamut. Much efforts have been made to accomplish good image quality for TFT-LCD. Currently LCD engineers are trying to fill the gap between specification and moving image. Several new specification were proposed on response time. Two kinds of response time definition are used to describe the difference between static image and dynamic image. One is the conventional definition related to the nematic liquid crystals' slow response itself between black and white flush pattern to an external field, the other is new definition, so called moving picture response time (MPRT) related to the blurred image at the edge of a moving picture by the human eye perception sense. To overcome the limit of hold type displays compared to the peak display types such as PDP and CRT, the pulsed backlight technique and the black data insertion method have been under development [1,2]. However, the precondition for the optimization of those techniques is to obtain fast response time of the liquid crystal itself. In this paper, we focus on the way to improve liquid crystals' response time using LC mixtures with increased elastic constants in the IPS mode.

2. *Response Time in the IPS Mode*

Nowadays, we have been mass-producing the LCD-TVs in the size range of 15 to 55", which show 8ms gray to gray (G-G) response times. However, there are continuous demands for more beautiful moving images. Thus a 5ms G-G response time is targeted for reproducing moving images more precisely. In IPS mode, the response times of LCDs is a relatively complicated function of driving method, cell configuration, properties of liquid crystals etc. The rising time (τ_r) can be reduced by controlling the driving voltage. Generally, in most of the LCDs, the higher an applied voltage the faster rising time [3].

Improvement of a falling time (τ_f) can be made by reducing the viscosity of the LC mixtures. Considering the falling time, the viscous torque, which opposes the director rotation, should be included [4,5]. The Erickson-Leslie expression is known to describe the dynamics of the liquid crystal director rotation [6,7]. However the equation can be simplified by neglecting back-flow and inertial effects. Therefore the response times are derived from an equilibrium equation in which the elastic, and viscous torques are expressed as in Eq. (1);

$$\gamma_1 \frac{\partial \Phi}{\partial t} = K_{22} \frac{\partial^2 \Phi}{\partial z} + \varepsilon_0 |\Delta\varepsilon| E^2 \sin\Phi \cos\Phi \quad \text{---- Eq. (1)}$$

where γ1 is rotational viscosity, Φ is the twist angle, K_{22} is the elastic constant of twist deformation, Δε is the dielectric anisotropy, ε_0 is the vacuum dielectric constant , and E is the electric field strength. When the electric field is removed, the falling time τ_f for returning to the initial state of the liquid crystals can be expressed as

$$\tau_f = \frac{\gamma_1 d^2}{K_{22}\pi^2} = \frac{\gamma_1}{\varepsilon_0|\Delta\varepsilon|E_c^{\ 2}} \quad \text{---- Eq. (2)}$$

This analytical expression is indicative of the fact the falling time τ_f is governed by the rotational viscosity divided by the elastic property which is related to a restoring force [8].

For fast switching time until recently, the LC development work has been mainly focused on identifying LC materials which can significantly improve both the rotational viscosity of LC mixtures and the cell gap of panel. Even the IPS mode has good point in response time characteristics as compared with the VA mode, the falling time of the IPS mode is in a disadvantage position. Considering the fact that the IPS mode has to compete with the VA mode, we are paying attention to increase the twist elastic constant (K_{22}) of LC material.

3. Development of Liquid Crystal (LC) Materials for Fast Switching Times

In IPS mode, achieved was a 16ms (on-off) switching time by utilizing the polar LC materials, which consist of a CF2O- group between two fluorinated phenyl rings [9]. It has been already reported that this class of LC materials possesses a very good combination of rotational viscosity (γ_1) and dielectric anisotropy (Δε), which made it possible to develop LC mixtures with lower γ_1.

Furthermore, a switching time of Gray to Gray (G to G) level less than 5ms has been newly targeted for the better moving picture image quality in IPS TV and monitor application. In order to achieve a G to G switching time target, several approaches have been applied such as lowering cell gap and reduction of γ_1 of the LC mixture since these are directly linked with improvement of switching times. However, lowering cell gap could be taken to limit with respect to productivity. LC mixtures are required to have a certain level of stability under vacuum process condition when one can consider to reduce the γ_1 value of the LC material to its largest extent.

Another LC property, elastic constants (Kii) are also related to the switching times of the displays. In IPS-case, the twist elastic constant K_{22} plays the dominant role. The elastic constant values of the LC mixtures are inversely proportional to switching times. However, the threshold voltage of the LC mixtures becomes higher by increasing the elastic constant values, which should be compensated by higher Δε. Consequently, both properties should be taken into account and optimization of the 'γ_1/K_{22}' parameter can make a further contribution to improve switching times.

Newly identified LC material consists of biphenyl core structure with alkenyl terminal chain as illustrated in Fig. 1. This LC single material is dielectrically neutral with the high Δn value of around 0.21.

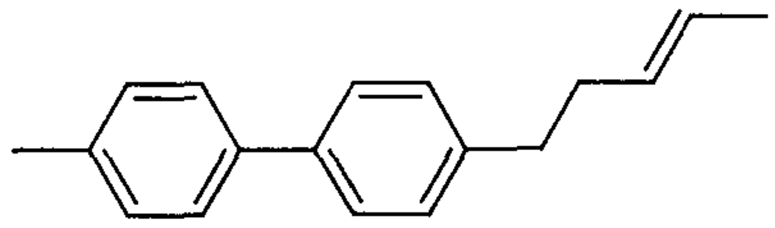


Figure 1: New LC material structure

This new LC material has relatively high elastic constant values among LC materials. Therefore, it can effectively act for an optimization of the 'γ_1/K_{22}' parameter of the LC mixtures.

Several mixtures have been developed utilizing the new LC material and the physical properties are summarized in Table 1.
In comparison to the reference mixture, γ_1 values of LC_A, B and C were kept in the range of 70 ~ 80 mPas with higher K_{22} values, which resulted in the smaller 'γ_1/K_{22}' parameter.

	Tni [℃]	γ1 [mPa.s]	γ1/K22 [mPa.s/pN]
Ref.	75	73	12.6
LC_A	78	80	11.3
LC_B	81	72	Est. 10.9
LC_C	79	68	Est. 10.5

Table 1: The physical properties of the LC mixtures

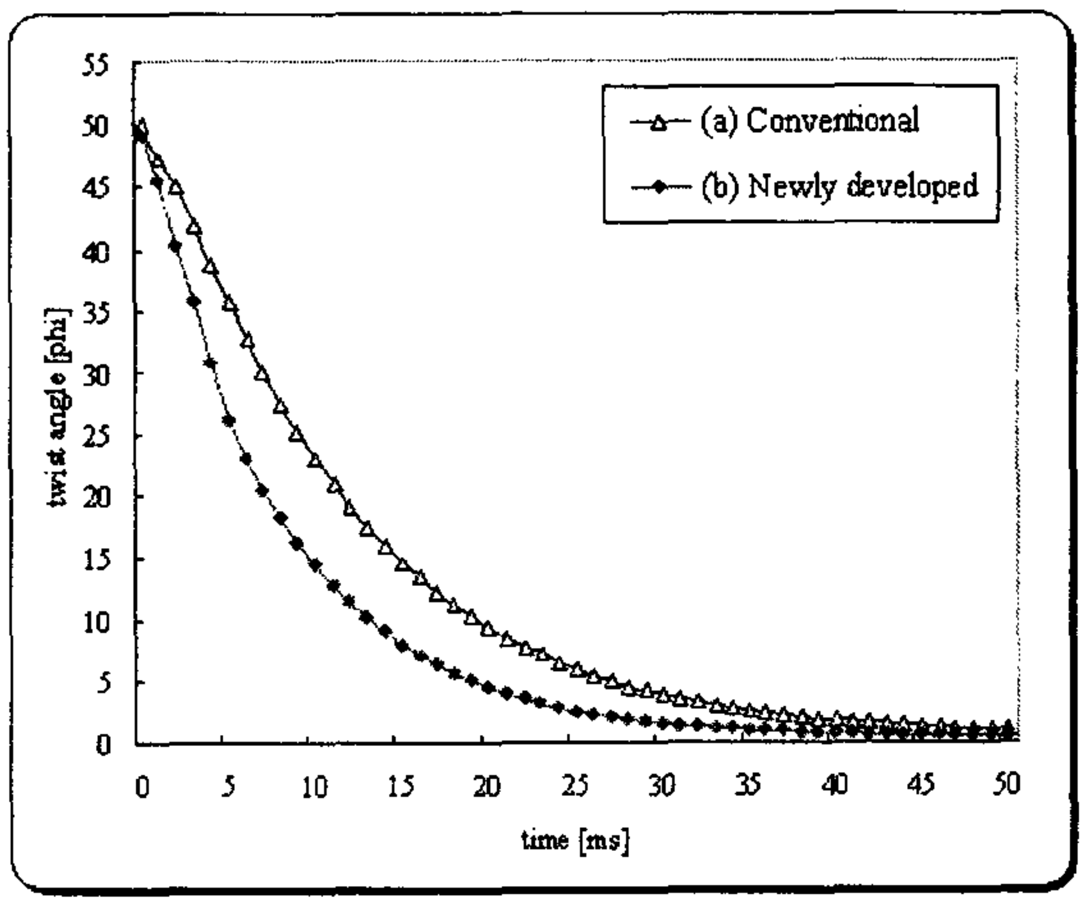


Figure 2: Simulation result of the restoration process in IPS mode.

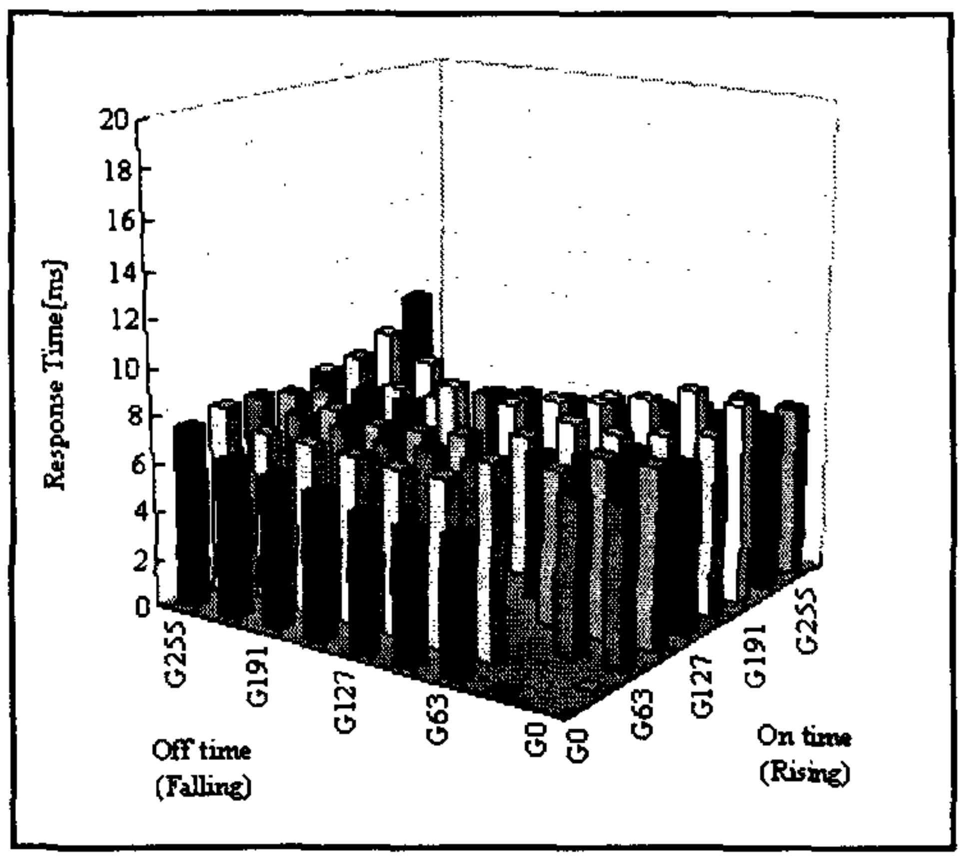
Using the properties of LC mixture shown in Table 1, a simulated twist angle (Φ) against switching times is plotted in Fig. 2. The newly developed IPS (b) shows the steeper slope compared with the conventional IPS (a). The low viscous and large elastic properties accelerate the steep slope in twist angle (Φ), which is the intrinsic parameter in order to express gray scale in IPS mode.

Ref.	K11 K22 K33	Δε	γ1/K22	Vmax	GTG R/T (Ave.) [ms]
Ref.	12.9 5.8 12.6	8.4	12.6	7.1	7.5
LC_A	17.1 7.1 16.3	9.4	11.3	7.4	6.0
LC_B	14.5 Est. 6.6 14.5	7.0	Est. 10.9	8.1	5.5
LC_C	13.9 Est. 6.5 14.6	7.0	Est. 10.5	8.1	5.3

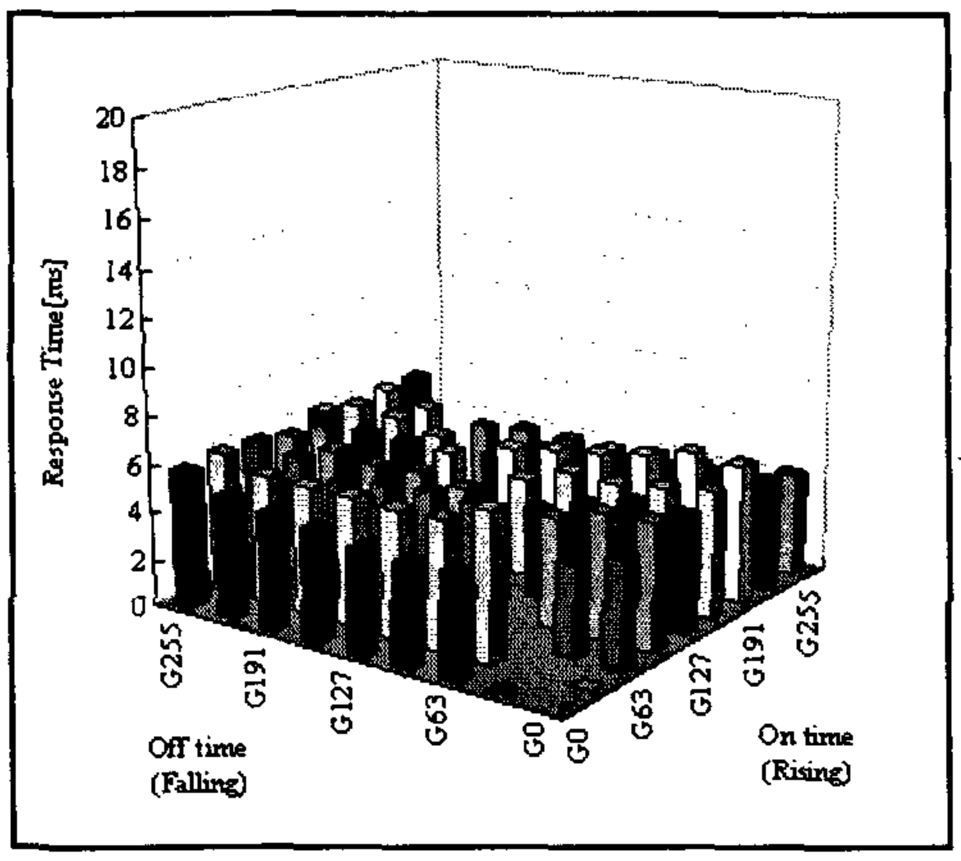
Table 2: Vmax and Response times of LC mixtures for IPS

As shown in Table 1 and 2, mixture development for LC_A was aimed at having very high Kii values. Especially, K_{22} of LC_A was 7.1 pN whereas that of the reference mixture was only 5.8 pN. Consequently, T_{ni} and γ_1 of LC_A were also increased and the higher V_{th} of LC_A was compensated by increasing $\Delta\varepsilon$. Thus, the V_{max} for both mixtures could have a similar level. When an identical voltage was driven, the R/T of LC_A with the higher γ_1 was about 1.5ms faster than the reference mixture. This indicates that a R/T can be improved by the enhanced elasticity as well as low viscosity of the LC mixtures.

In mixture developments for LC_B and LC_C, for the higher driving condition, $\Delta\varepsilon$ value was reduced and the Kii values were increased. Since the same level of Vmax was obtained in both mixtures, the K_{22} values were also expected to be similar. In the R/T measurement, further improvement was made compared to the reference mixture.



(a)



(b)

Figure 3: Response time characteristics between gray levels. (a) conventional IPS-LCD (b) newly developed IPS-LCD

4. Response Time Characteristics of a S-IPS Panel Using LC Mixtures with High Elastic Constants

Fig. 3 shows the experimentally switching behavior of LC_A in the IPS-LCD. In case of the low visco-elastic coefficient (γ_1/K_{22}) which came from high twist elastic energy, the response time is shorten in comparison with the conventional condition. This enables faster S-IPS mode response time without degrading other panel quality aspect. It is expected that high elastic concept will be applied to TFT-LCD TVs to achieve blur-free moving images. Fig. 4 shows that our newly developed high elastic constant concept can achieve much better response performance (under 40% among 256×256 grayscale transition ≤ 5ms in the conventional IPS-LCD *vs.* approximately 100% in the new one). The response time characteristics less than 5ms meets the requirement for adopting black data insertion technology with minimizing brightness loss [10,11]. Consequently, it is confirmed that the low γ_1/K_{22}' concept is one of the main factor to reduce response time of IPS-LCD.

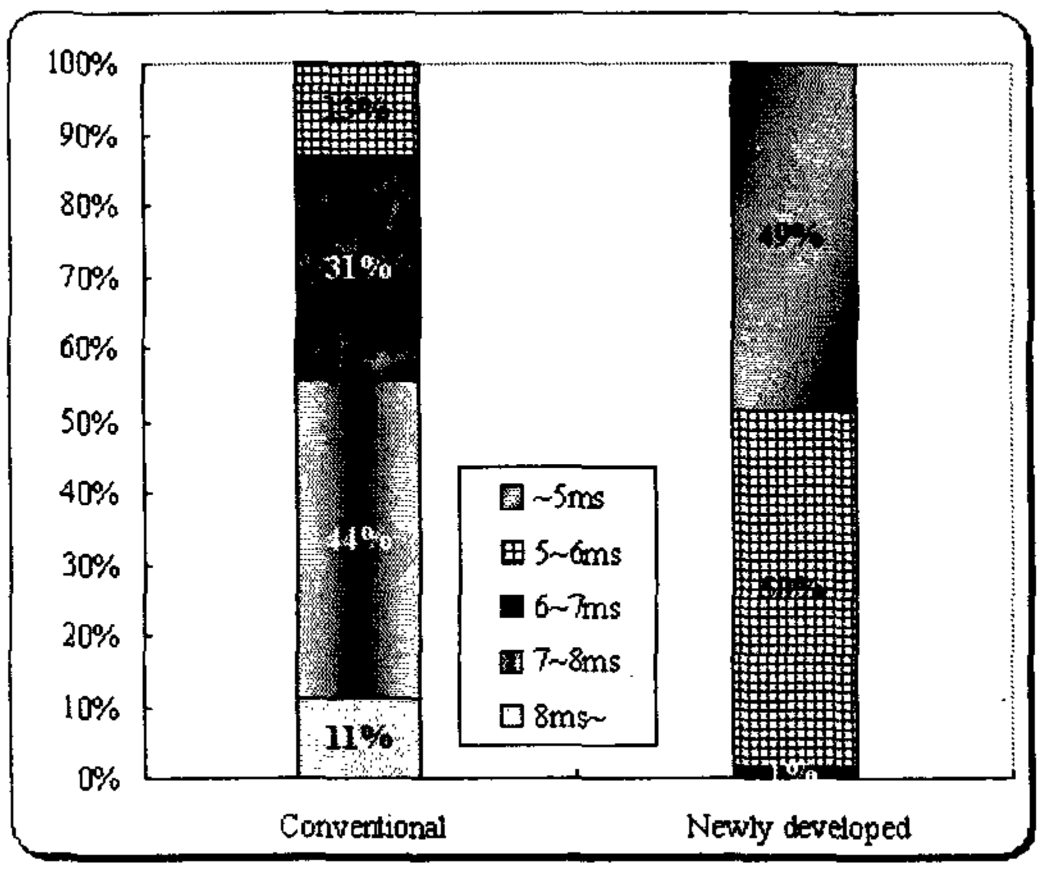


Figure 4: Response time range comparison between the conventional IPS-LCD and newly developed IPS-LCD

5. Conclusion

For fast switching times, the LC development work has been so far mainly focused on identifying LC materials which can significantly improve the rotational viscosity of LC mixtures. But, we are turning on our interest to another property of the LC mixtures, elastic constant (K). The newly developed LC mixtures with optimized '$\gamma 1$/Kii' parameter lead to fulfill response time less than 5ms. In the end, we are willing to apply this technology to LCD TV products in order to satisfy the human vision property.

6. References

[1] Sueoka, K., Nakamura., and Taira Y., SID '97, 203 (1997)

[2] Kurita T., SID '01,, 986 (2001)

[3] J. K. Song, K. E. Lee, H. S. Chang, SID '04 48.2 (2004)

[4] M. Oh-e and K. Kondo, Appl. Phys. Lett. 67, 3895 (1995)

[5] E. Jakeman and E. P. Raynes, Phys. Lett. 39a, 69 (1972)

[6] J. L. Erickson, Trans/ Soc. Rheol. 5, 23 (1961)

[7] F. M. Leslie, Arch. Ration. Mech. Anal. 28, 265 (1968)

[8] M. Oh-e and K. Kondo, Appl. Phys. Lett. 69, 623 (1996)

[9] C. S. Lim, J. H. Lee, C. H. Oh, H.C. Choi, S.E. Lee, M.O. Jins, M. Klasen-Memmer, K. Tarumi : IMID '03 Digest, 4.3 (2003)

[10] K. Kumagawa, et al, SID '02 48.4 (2002)

[11] Y. Shimodaira, SID '03 31.1 (2003)