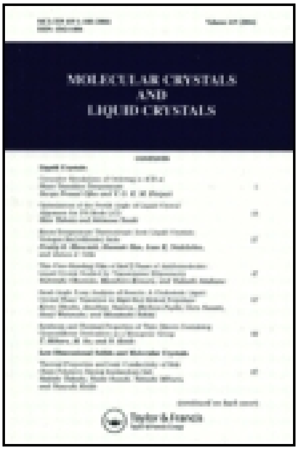

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Ferroelectric Liquid Crystal Materials with Wide Operating Range for τ-V Min Mode Devices

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Ferroelectric Liquid Crystal Materials with Wide Operating Range for τ-V Min Mode Devices

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We investigated τ-*V*min mode FLC materials with respect to the operating range in voltage and temperature. For wide operating voltage range, we developed smectic C host mixtures with low viscosity and high dielectric biaxiality, and added a small amount of chiral compound to them. On the other hand, for wide operating temperature range, we optimized the combination of host and chiral materials from the viewpoint of temperature dependences of dielectric anisotropy and spontaneous polarization. As a result, we developed the FLC material FDS71 showing fast response time, high contrast ratio and wide operating range in voltage and temperature. This FLC material is suitable for the multiplexed passive-matrix ferroelectric liquid crystal displays showing full color moving images due to the high bit temporal dither technique.

Keywords: ferroelectric liquid crystal display; τ-*V*min mode; operating voltage range; operating temperature range; chiral dopant method

INTRODUCTION

The discovery of ferroelectricity in a chiral smectic C (SmC*) phase[1] and the demonstration of a surface stabilized ferroelectric liquid crystal (SSFLC)[2] have attracted considerable attention to ferroelectric liquid crystal (FLC) materials. The SSFLC has shown a great potential for application in electro-optic devices due to such attractive properties as fast response time, bistability and in-plain switching. In particular, ferroelectric liquid crystal displays (FLCDs) are expected to offer good performance as a television hanging on the wall and replace the heavy, bulky cathode-ray-tube (CRT). Recently, some types of FLCDs with multiplexed passive-matrix drive and dense information content have been reported.[3-6]

We focus on the FLC materials useful for the τ-V_{min} mode displays,[7,8] which show a minimum in the response time (τ) -voltage (V) curve.[9] Combined with C2U molecular orientation,[3,10] this mode has several advantages such as fast line address time, high contrast ratio due to the AC stabilizing effect, high quality of alignment in wide temperature range, etc.[8,11] However, one of the problems for FLC devices is a restricted operating range in voltage and temperature. In this study, we have developed τ-V_{min} mode FLC materials with wide operating range in voltage and temperature adjusting the chiral dopant method.[12]

SWITCHING PROPERTY OF τ-Vmin MODE FLC MATERIALS

Figure 1 shows the typical τ-V_{min} property of the FLC mixture SCE8 in a C2 uniform orientation, filled into a 1.4 μm spacing cell. Here, the response time τ is defined as a shortest pulse width for the director to switch applying a pulse electric field of amplitude E to a cell.

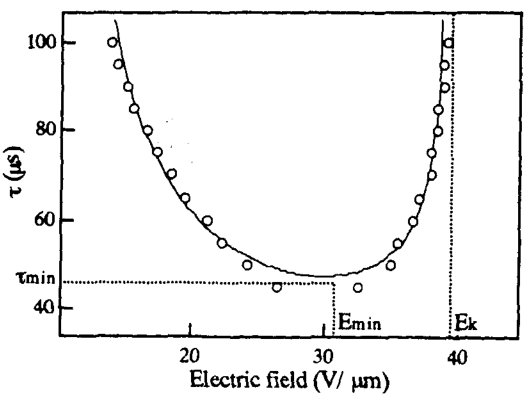

FIGURE 1 Typical τ-V_{min} property of the FLC mixture SCE8 at 25 °C.

In the region of a low electric field, the director switches due to the ferroelectric torque and τ decreases with increasing a field as[13,14]

$$\tau = \frac{\eta}{P_s E \cos\delta}\left(\frac{\pi}{2} - \phi_0\right), \tag{1}$$

where η is the rotational viscosity, P_s the spontaneous polarization, δ the layer tilt angle, ϕ_0 the azimuthal angle at the initial state without an electric field. As increasing a field further, the dielectric torque becomes dominant with respect to the ferroelectric one and τ shows a minimum at E_{min} and then rises to infinity approaching to E_k. The threshold electric field E_k is calculated as[13,14]

$$E_k = -\frac{P_s \cos\delta}{A\left(\frac{\pi}{2} - \phi_0\right)}. \tag{2}$$

The dielectric coefficient A is defined by

$$A = \varepsilon_0\left[\left(\Delta\varepsilon \sin^2\theta - \partial\varepsilon\right)\cos^2\delta - \frac{\Delta\varepsilon}{4}\sin 2\theta \sin 2\delta\right], \tag{3}$$

where $\Delta\varepsilon$ and $\partial\varepsilon$ are two kinds of dielectric anisotropies[15] and the latter is called dielectric biaxiality. In τ-V_{min} mode FLC materials, the sign of A is negative.

OPERATING VOLTAGE RANGE

First of all, FLC materials are required to show the fast response time for multiplexed passive-matrix FLCDs with dense information content and large number of colors due to the high bit temporal dither.[16] Equation (1) indicates that the fast response time can be obtained by high spontaneous polarization P_s or low rotational viscosity η. However, the high P_s shifts the operating range into a high voltage region and makes it narrow because of the occurrence of the reverse electric field. Figure 2-(b) shows the incomplete electro-optic response at switching due to the reverse electric field in a high P_s material. This distorted electro-optic response is improved to some extent using a thinner insulator film or adjusting an applied voltage waveform, but FLC materials with low values of P_s

and η are essentially required for fast response time together with clean switching performance.

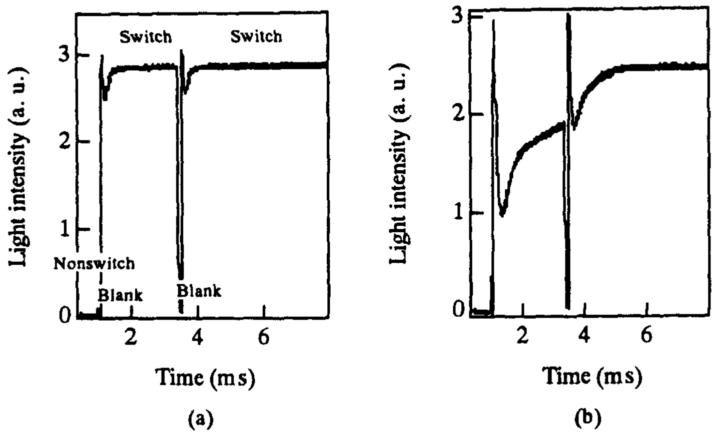

FIGURE 2 P_s dependence of the electro-optic response. Two FLC samples are composed of the same SmC host mixture and the different amount of chiral dopant with (a) 3 wt.% and (b) 4 wt.%. The drive scheme used in this study is DRAMA-3[16,17] with the line address time of 12 μs/line. The signal pattern of an applied field is " nonswitch-blank-switch-blank-switch".

A host material is required to have other properties in addition to a low viscosity.[11,18,19] An Isotoropic–Nematic–SmA–SmC (INAC) phase sequence and wide temperature range of the SmC phase around room temperature are necessary for a high quality of alignment. Moreover, for wide operating voltage range, it should possess high negative dielectric coefficient A shown in Eq. (3), or high positive dielectric biaxiality. We add the biaxial material LC-A, which possesses the high dielectric biaxiality, to the low viscous SmC base material and use this mixture as a developed host material. Figure 3 shows the effect of LC-A addition, which reduces the value of E_k and makes the operating range wide in a low data (V_d) - strobe (V_s) voltage region. Low voltage drive is necessary for low power consumption, alleviation of the panel heating and alignment uniformity without line defects .

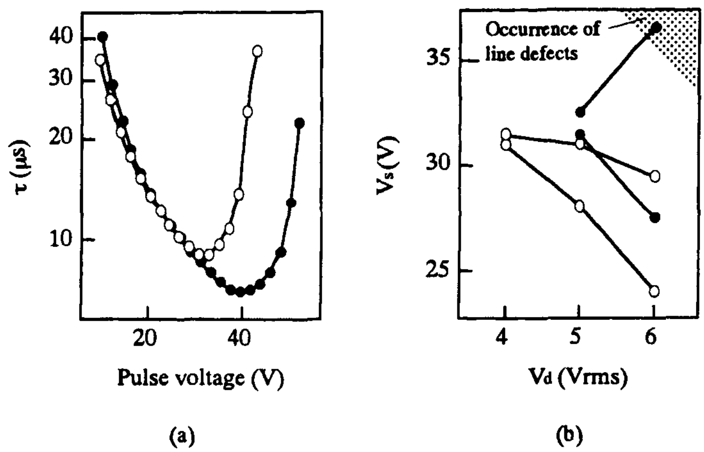

FIGURE 3 (a) τ-V_{min} property at 25 °C and (b) operating voltage range at 35 °C in two FLC samples with LC-A (open circle) and without LC-A (filled circle). The operating voltage range was measured by DRAMA-3 drive scheme with the line address time 12 μs/line. A data V_d and a strobe V_s are designed waveforms applied to the column and row electrodes in an FLC display.

OPERATING TEMPERATURE RANGE

The large temperature dependence of the switching property in FLC devices makes the operating temperature range restricted.[14,20-22] This temperature sensitivity in FLC materials is strongly related to the temperature dependences of physical parameters such as rotational viscosity, dielectric anisotropy and spontaneous polarization.

From Eq. (2), it is known that the value of the threshold electric field E_k can be controlled by matching of dielectric coefficient and spontaneous polarization, each of which primarily originates from achiral host material or the chiral dopant one, respectively. In Eq. (2), the values of A and $P_s\cos\delta$ are dependent on temperature and that of ϕ_0 is almost independent.[13,14] Therefore, the same temperature dependent form of A and $P_s\cos\delta$ leads to a constant value of E_k. Actually, the value of A decreases almost linearly with decreasing temperature in some FLC host mixtures having high dielectric biaxiality,[14] and it is effective to dope to them such chiral material as induces linearly or more steeply changing spontaneous polarization.[16,23,24]

In both practical FLC samples of FDS2[5] and FDS71[16], the value of A increases almost linearly with decreasing temperature due to the property of their host mixtures. On the other hand, the value of $Ps\cos\delta$ for FDS2 shows the normal temperature dependence obeying the mean-field model, and that for FDS71 decreases almost linearly with increasing temperature as shown in Fig. 4. Based on this difference, τ-V curves of FDS2 and FDS71 shift differently with changing temperature as shown in Fig. 5.

The FLC materials with constant E_k, such as FDS71, show the wide operating temperature range, because there exists the common operating voltage region at various temperatures. They are effective for the global temperature change and the local temperature non-uniformity over the panel area.

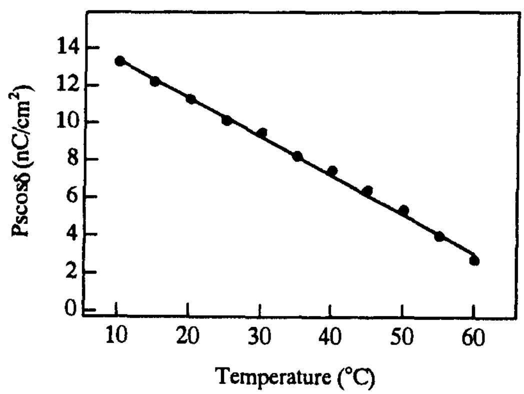

FIGURE 4 Temperature dependence of $Ps\cos\delta$ for FDS71. This measurement was carried out by the triangular wave method[25] in a 1.4 μm spacing cell.

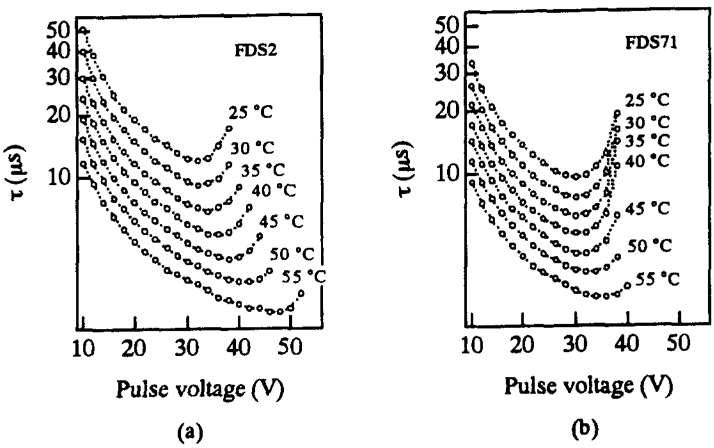

FIGURE 5 Temperature dependence of τ-V_{min} property for (a) FDS2 and (b) FDS71.

CONCLUSIONS

For wide operating voltage range, we developed smectic C host mixtures with low viscosity and high dielectric biaxiality, and added a small amount of chiral compound to them inducing low spontaneous polarization. On the other hand, for wide operating temperature range, we optimized the combination of host and chiral materials from the viewpoint of temperature dependences of dielectric anisotropy and spontaneous polarization. We used a chiral compound which induces a linearly decreasing spontaneous polarization with increasing temperature. As a result, we developed the FLC material FDS71 showing wide operating range in voltage and temperature.

This material is suitable for τ-V_{min} mode FLCDs showing full color moving images due to the high bit temporal dither. It performs fast line address time of 12 μs/line and higher contrast ratio than 100:1. Compared with other FLC materials, FDS71 has advantages in many respects, as shown in Table I and Fig. 6.

Table I Physical properties of some FLC materials in 1.4 μm-gap cells. The values of memory angle $2\theta_m$, optical anisotropy Δn (550 nm), τ_{min}, V_{min} and $P_s\cos\delta$ were measured at 25 °C. The value of $2\theta_m$ with field was measured under a square wave voltage of ±5 V and 100 kHz.

	SCE8	FDS2	FDS71
Phase transition temp. (°C)	C 58 A 78 N 98 I	C 69 A 89 N 101 I	C 69 A 92 N 100 I
$2\theta_m$ without / with field (deg)	14 / 18	15 / 21	16 / 28
τ_{min} (μs) / V_{min} (V)	43 / 41	12 / 33	9.5 / 30
Δn	0.15	0.177	0.182
$P_s\cos\delta$ (nC/cm^2)	3.7	9.6	10.1

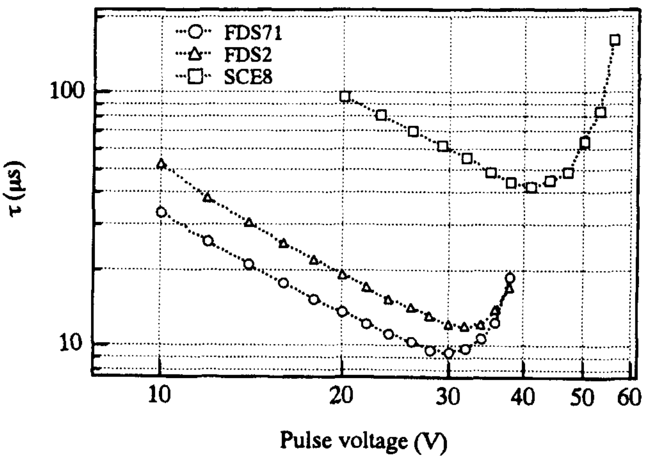

FIGURE 6 τ-V_{min} properties of SCE8, FDS2 and FDS71. FLC materials are required to show both lower values of τ_{min} and V_{min}, which is closely related to the fast line address time, low voltage drive and wide operating range. The position of the minimum point is based on a balance of spontaneous polarization, dielectric anisotropy and rotational viscosity.[26]

Acknowledgments

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