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Material Considerations in Liquid Crystal Television Display

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The liquid crystal (LC) class, material parameter and LC molecular alignment influence on display performance for an LC TV panel, using an MOS active matrix and dc dynamic scattering mode, has been investigated, including the conductivity dopant effect. The material considerations have indicated the following:

(1) An LC material with birefringence larger than 0.14 and with viscosity lower than 30 cp is required to be synthesized by an optimized blending of different class LCs, in order to achieve both high contrast and fast response acceptable for TV display.

(2) Parallel LC molecular alignment is preferable to perpendicular alignment because, in the latter alignment, response time is considerably increased, although display contrast is rather improved.

(3) Simultaneous doping of electron donor and acceptor dopants to LCs is needed to assure an effective improvement in display contrast and dc operating lifetime.

Bearing in mind these results, an LC material for use in the LC TV panel has been successfully designed and optimized.

1. INTRODUCTION

The authors have developed a prototype pocketable TV set employing an LC matrix display panel (see Figure 1), whose specifications are summarized in Table I.[1] The display panel uses an MOS active matrix, consisting of an array of field-effect switching transistors and signal storage capacitors integrated on a silicon wafer, and dc dynamic scattering (DS) LC in a reflective mode.[2,3]

As is well known, an LC display has a limited multiplexing capability, because LCs respond to the rms value of applied voltage and does

FIGURE 1 LC TV set showing on-the-air TV image.

not have a sufficiently nonlinear response. So, in conventional multiplexed matrix addressing, an LC display suffers from low response time and low contrast, which are caused by a short duty cycle and half-select problems.

On the other hand, in active matrix addressing which uses an MOS active matrix, each display picture element can operate, theoretically, on a 100% duty cycle with no half-select problem, regardless of the number of address lines N in a line-at-a-time addressing scheme with a $1/N$ duty cycle. The reason is that the necessary nonlinear response and signal energy storage are provided by a transistor and capacitor extrinsically added at each picture element. Therefore, the MOS active

TABLE I
Main LC TV set and display panel specifications

Item	Specification
TV set	
External dimensions	170(H) × 80(W) × 16(D) mm
Weight	300 grams, including dry batteries
Antenna	Telescopic rod antenna
Frequency range	VHF/UHF all channels
Audio output	150 mW
Power consumption	2.2 W
Power source	DC 3V UM-3×2 / jack for AC 100V
Zoom-up feature	2 times
Display panel	
Effective picture size	30.8(H)×40.8(W)mm, diagonally 2 inches
Number of picture elements	220×240 = 52800pels
Addressing scheme	Line-at-a-time, 60 frames per second
Contrast ratio	More than 20:1
Response times	Less than 30 msec, both rise and decay times
Halftone capability	More than 8 gray shades
Power supplies	$-10\,V_{dc}$ and $-23\,V_{dc}$
Power dissipation	280 mW

matrix addressing makes it considerably easy to build a relatively high contrast and fast response LC display with a reasonable gray scale.

However, note that only the active matrix adoption by itself cannot lead to the realization of display performance required for a LC TV panel. For the desired realization, an LC material for use in the TV panel needs to be effectively optimized.

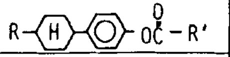
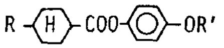
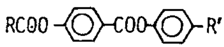
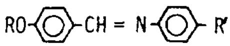
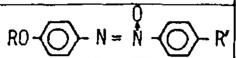
In this paper, the influence of chemically different nematic LC classes and material parameters on the above-mentioned LC TV panel display performance is described, together with the LC molecular alignment influence. Also, electron donor and acceptor conductivity dopant effects on dc dynamic scattering improvement are presented.

2. EXPERIMENTAL

The nematic LCs used were multicomponent blends with negative dielectric anisotropy, representatively summarized in Table II. They belonged to phenylcyclohexane, phenyl cyclohexanoate, phenyl benzoate, Schiff base and azoxybenzene classes, respectively, and their mixed-class classes. The abbreviations for the LC blends shown in the first column of the Table are used in the following.

TABLE II

Multicomponent nematic blends of different LC classes used in the experiments

Blend	Chemical class	General structure	T_{NI}(°C)	η_{RT}(cp)	Δn_{RT}	$\Delta\varepsilon$
PCH	Phenylcyclohexane		60	14	0.09	-0.6
ECH	Phenyl cyclohexanoate		55	18	0.10	-1.2
PB	Phenyl benzoate		55	40	0.14	-0.5
SB	Schiff base		63	39	0.26	-0.5
AZ	Azoxybenzene		75	31	0.29	-0.2
PCH/SB	Phenylcyclohexane + Schiff base		62	20	0.15	-0.6
ECH/SB	Phenyl cyclohexanoate + Schiff base		58	26	0.16	-0.8
PCH/ECH	Phenylcyclohexane + Phenyl cyclohexanoate		52	23	0.08	-0.7
PCH/PB	Phenylcyclohexane + Phenyl benzoate		74	33	0.14	-0.4
ECH/PB	Phenyl cyclohexanoate + Phenyl benzoate		60	37	0.12	-0.7

The conductivity dopants added to the LC blends included typical electron donors such as dibutylferrocene (DBF) and tetrathiafulvalene (TTF), and strong electron acceptors such as tetranitrofluorenon (TENF) and tetracyanobenzoquinodimethane (TCNQ). The total doping concentration was typically 1.0% wt. in an electron donor-acceptor pair doping.

The experimental results, unless otherwise stated, refer to a parallel aligned LC cell, consisting of two transparent In_2O_3-coated glass electrodes separated by an 8 μm gap, under dc electric field. In ac case, a 32 Hz sq. wave voltage was applied.

Electro-optical measurements were carried out by using a microscope of 100 magnifications, equipped with a photodetector. The on and off response times were defined as the times needed for a 90% decrease and 90% recovery of the initial transmittance in a LC cell.

3. LC CLASS AND MATERIAL PARAMETER INFLUENCE

The influence of nematic LC classes with a negative dielectric anisotropy and their material parameters, such as optical birefringence Δn, viscosity η and dielectric anisotropy $\Delta\epsilon$, on DS display characteristics and an optimized blending of different class LCs for use in the LC TV panel are described.

3.1 Birefringence Δn influence on display contrast

DS display is based on a light scattering phenomenon, so it is expected that the display contrast will depend intensively on the Δn value. In Figure 2, transmittance T^s at applied voltage V_s, threshold voltage V_{th} plus 15 V, is plotted as a function of Δn for DS cells filled with various class multicomponent LC blends, doped with electron donor-acceptor pairs. The voltage V_s is employed for the highest gray shade display in the LC TV panel.

The separate experiment showed that display contrast increases definitely with decreasing transmittance and that an LC material with T^s smaller than 55% is needed to achieve a contrast ratio higher than 20:1 in the LC TV panel. Therefore, it is obvious from Figure 2 that an LC material with Δn larger than 0.14 is required for realizing a contrast acceptable for TV display.

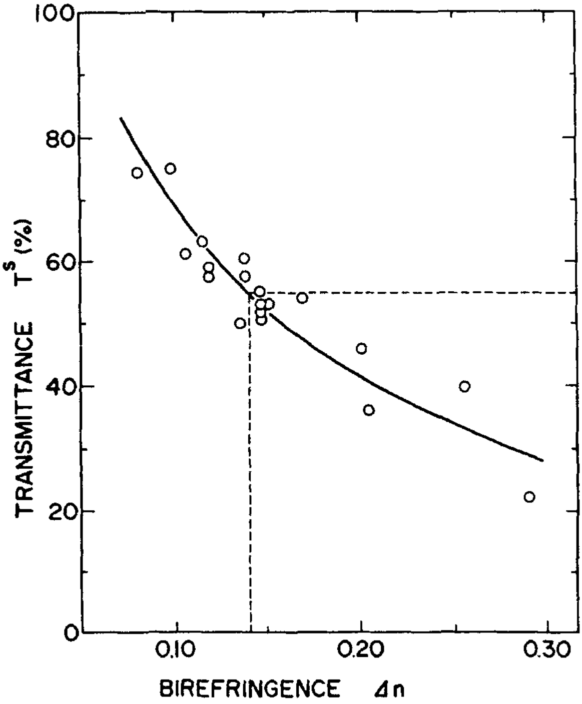


FIGURE 2 Transmittance under applied voltage vs Δn for different LC class DS cells.

3.2 Viscosity η influence on response time

In Figure 3, on and off response times τ^H at applied voltage V_H, at which the exactly midpoint gray shade display is obtained, is plotted as a function of η for the same DS cells as in Figure 2. The results indicate that τ^H values decrease effectively with decreasing η and that an LC material with η smaller than 30 cp is required to realize τ^H faster than 40 msec.

3.3 Dielectric anisotropy Δε influence on display characteristics

Figure 4 gives the $\Delta\epsilon$ dependence of threshold V_{th}, transmittance T^s and response τ^s at voltage V_s for DS cells with PCH LC blends, in which Δn and η values were kept nearly constant. The results suggest that the $\Delta\epsilon$ influence on DS display characteristics is not marked, compared to Δn and η influence, although a decrease in $\Delta\epsilon$ results in a slight increase in V_{th} and τ^s_{on} and also a slight decrease in T^s and τ^s_{off}.

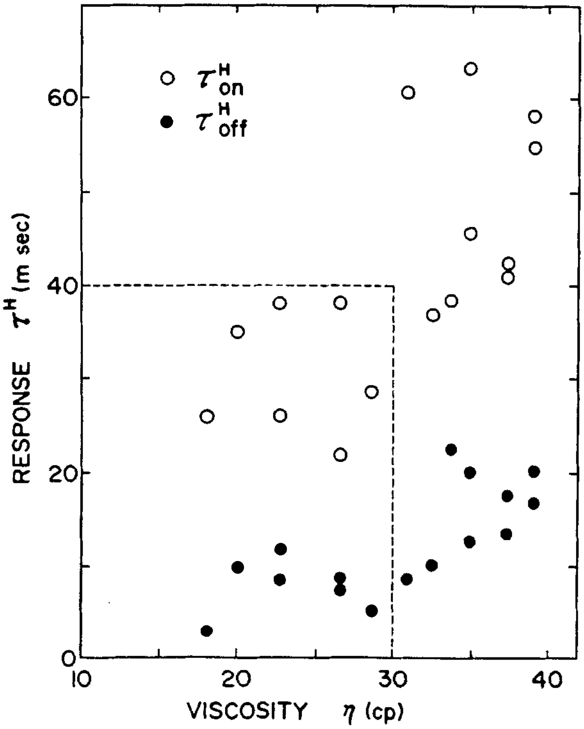


FIGURE 3 Response time vs η for different LC class DS cells.

3.4 Mixed-class LC blending

The previous results have indicated that an LC material having sufficiently large birefringence ($\Delta n > 0.14$) and, at the same time, sufficiently low viscosity ($\eta < 30$ cp) is required in order to achieve both high contrast and fast response acceptable for TV display.

However, as shown in Figure 5, presenting the η vs Δn correlation for various LC classes, there is no such favorable single LC class (see 1-9 in Figure 5). LC classes with low η, such as ECH and PCH, exhibit very small Δn, while LC classes with large Δn, such as SB and AZ, have relatively high η.

Thus, the resultant display contrast/response trade-off problem needs to be solved by an optimized blending of different class LCs (see 14-18 in Figure 5). Here, note that such a mixed-class LC blend does not always solve the trade-off problem, as shown in 10-13 in Figure 5.

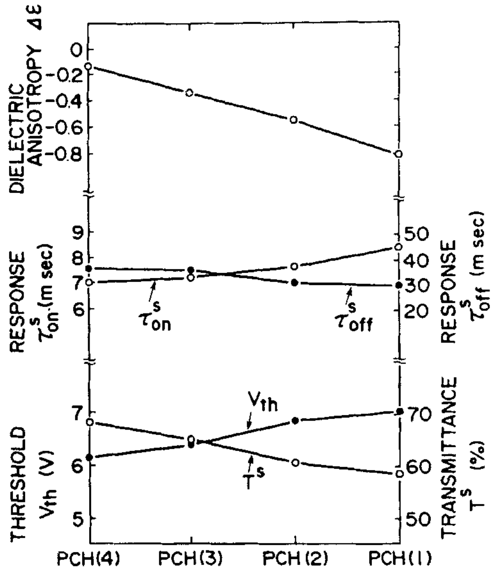


FIGURE 4 Dielectric anisotropy dependence of DS display characteristics.

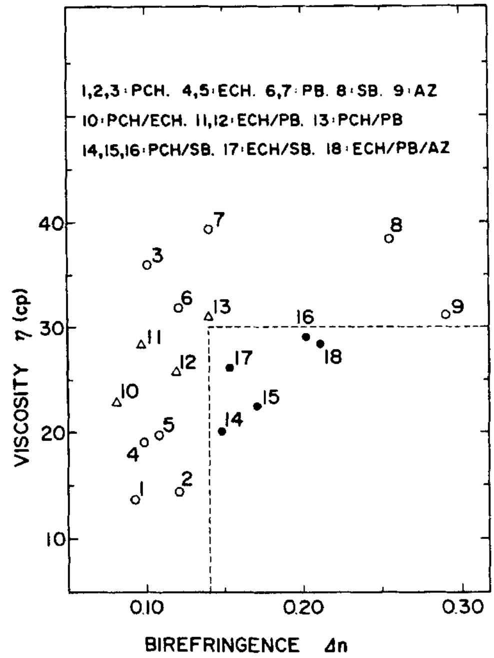


FIGURE 5 Correlation between Δn and η for various LC classes.

3.5 Mixed-class LC blend optimization

In Figure 6, parameters η and Δn and DS display characteristics, such as V_{th}, T^s and τ^s, are plotted as a function of mixed-class LC blend composition. The LC blends were composed of PCH with small Δn and low η and SB with large Δn and high η, doped with a donor-acceptor pair DBF · TENF. The results indicate that the DS characteristics can be effectively optimized by employing the LC blend with a wt. % composition ranging from PCH/SB = 60/40 to 25/75.

The above-mentioned different-class LC blending also makes a favorable contribution to a moderate gray scale achievement, as represented in Figure 7 concerning an ECH—PB/AZ mixed class LC blend.

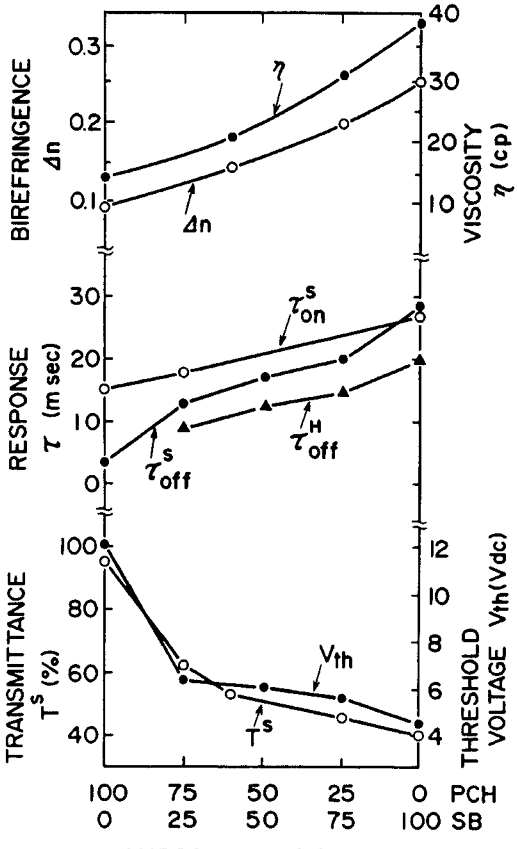


FIGURE 6 Mixed-class LC composition dependence of material parameters and DS display characteristics.

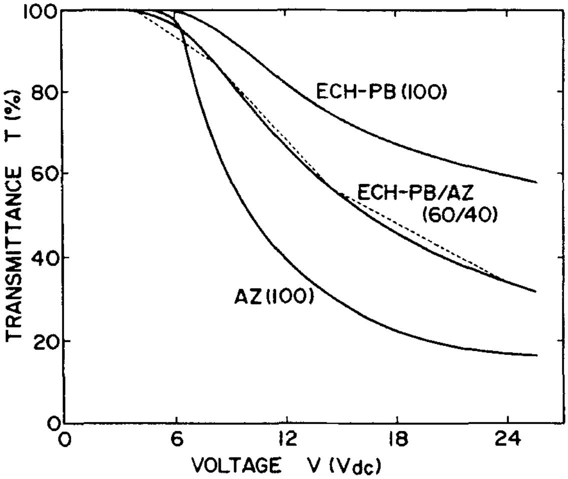


FIGURE 7 Transmittance vs applied voltage for single and mixed class LC DS cells.

4. LC MOLECULAR ALIGNMENT INFLUENCE

The particular LC molecular alignment is not essentially prerequisite for a DS LC display device, but DS characteristics depend largely on the alignment employed.[4] The following describes perpendicular and parallel LC alignments influence on DS display performance.

4.1 LC alignment influence on display contrast

Figure 8 presents transmittance vs applied voltage for perpendicular and parallel aligned DS cells, under dc and ac electric fields. An ECH/PB LC blend, doped with a donor-acceptor pair DBF · TCNQ, was used. The results indicate that dc operation is definitely preferable to ac operation in order to realize low operating voltage and high contrast. In addition, the preference is conspicuous in perpendicular alignment, compared to parallel alignment.

4.2 LC alignment influence on response time

Figure 9 gives LC alignment and bias voltage V_b influence on response τ^s. The LC used was a PCH/SB LC blend doped with a donor-acceptor pair DBF · TCNQ. It is obvious that both on and off τ^s in perpendicular alignment are large, compared to those in parallel alignment, re-

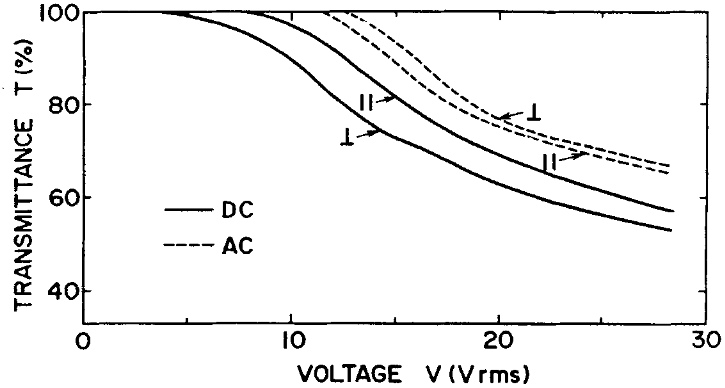


FIGURE 8 LC alignment influence on transmittance vs dc and ac applied voltages for a DS cell.

gardless of the V_b value and that perpendicular off τ^s is conspicuously increased by application of $V_b = V_{th}$, although the bias decreases perpendicular on τ^s to a point near parallel on τ^s.

These results are mostly true for response times for lower gray shade display. Therefore, perpendicular alignment is not applicable to the LC TV panel, which requires a bias voltage application.

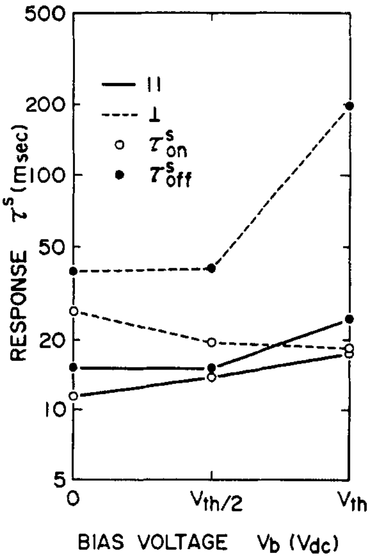


FIGURE 9 LC alignment influence on response time for a DS cell, with and without V_b.

5. CONDUCTIVITY DOPANT FOR DC OPERATION

DC operation is inescapable for driving a DS LC display device employing an MOS active matrix, from a viewpoint of simplifying the drive electronics. Pure LCs with high electrical resistivities do not show a DS phenomenon. Therefore, a conductivity dopant is essentially prerequisite,[5,6] and various organic electrolytes have been effectively used as such a dopant in conventional ac dynamic scattering.

The organic electrolytes, however, are not applicable to dc dynamic scattering, because of drastic electrochemical degradation in LCs; note that the dc operating lifetime for DS display devices using the electrolytes is, at most, only a few tens of hours. Hence, usage of several electron donors and acceptors as conductivity dopants was tried in the following.[8–11]

5.1 Dopant effect on display contrast

Figure 10 represents transmittance vs applied voltage for DS cells employing a PCH/SB LC blend, doped separately and simultaneously with DBF as a donor and TENF as an acceptor. The results indicate that the simultaneous but not separate doping of a donor and an acceptor, by more than a certain minimum quantity, is definitely required to achieve an effective improvement in display contrast.

The simultaneous doping also makes a favorable contribution to the reduction of operating voltage (see Figure 10) and to the exclusion of

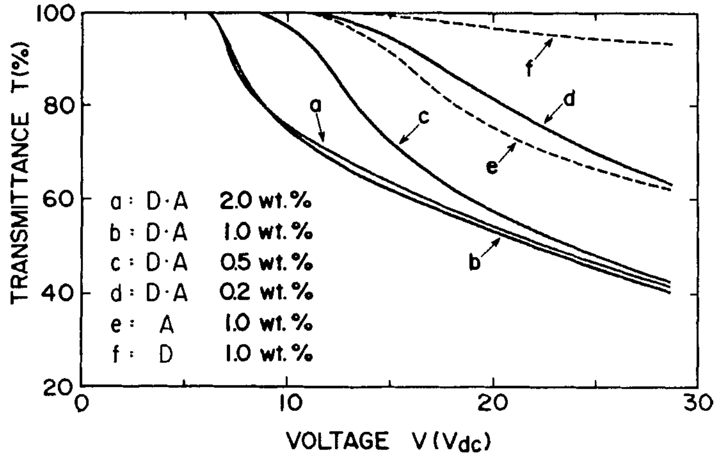


FIGURE 10 Transmittance vs applied voltage for DS cells employing LCs doped with electron donor and/or acceptor.

display contrast temperature dependence in dc operation, as shown in Figure 11.

Practically, of course, it is necessary to select a specific donor-acceptor pair suitable for the given class LC blend, because such DS display characteristics improvement effect by the simultaneous doping depends strongly on LC classes, as well as dopants themselves.[11]

5.2 Dopant effect on dc operating lifetime

In Figure 12, current density is plotted as a function of time, together with typical deterioration appearance, for DS cells filled with simultaneously and separately doped PCH/SB LC blends under continuous dc 20 V application. The results indicate that the dc operating lifetime for a DS LC display panel can be considerably improved by a donor-acceptor simultaneous doping. In the doping, of course, note that the donor-acceptor pair must be selected according to the LC class used and a minimum doping quantity is needed.

Figure 13 gives the electrochemical behavior schemes for electron donor and/or acceptor in LCs under dc electric fields, recently proposed by the present authors.[11] In LCs with a donor-acceptor pair, as represented in Figure 13(a), the electrochemical behavior should be dominated by the reversible redox reaction of donor and acceptor dopants, preventing LCs themselves from electrochemical reaction, since the redox potential of the dopants are quite low, compared to those of LCs. This may explain the long dc operating lifetime for simultaneously doped LCs.

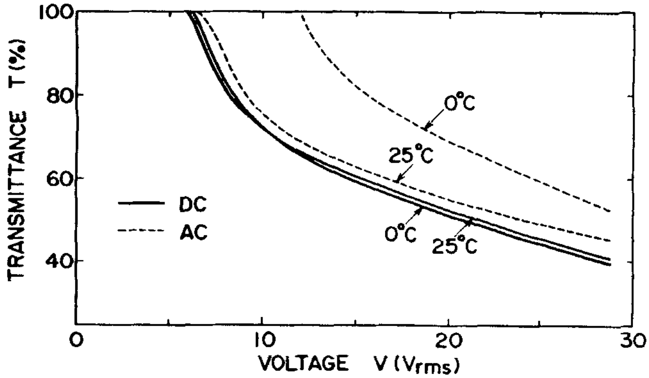


FIGURE 11 Temperature influence on transmittance vs dc and ac applied voltage for DS cell (a) in Figure 10.

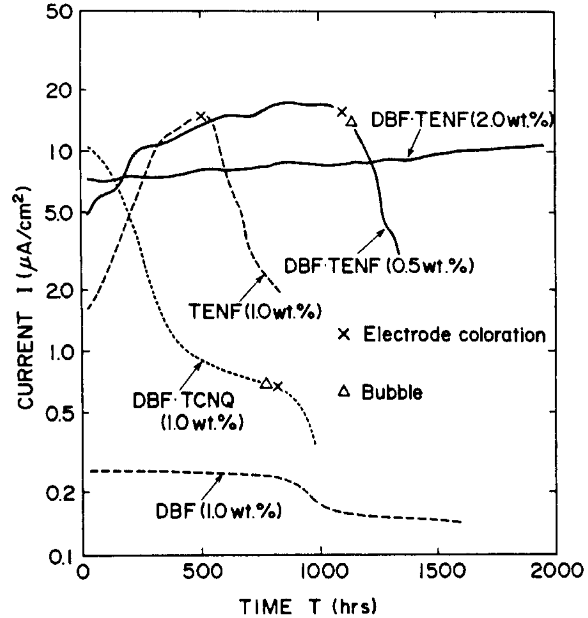


FIGURE 12 Current density change with time for DS cells employing LCs doped with electron donor and/or acceptor.

In case of LCs with a single dopant, on the other hand, LCs themselves are forced to participate in electrode reaction, as shown in Fig. 13(b) and (c). This may cause a drastic degradation in LCs and remarkably shorten the dc operating lifetime, because the redox potentials for LCs are extremely high and their electrochemical redox reaction is not reversible.

Practically, besides the above-mentioned conductivity dopant optimization, the suitable selection of electrode material is required for dc operating lifetime improvement. Platinum and tin oxide electrodes have been found the most preferable, respectively as specular metal and transparent conducting electrodes, for a long dc operating lifetime.

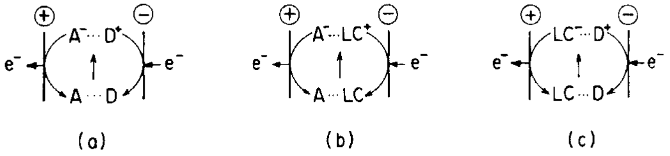


FIGURE 13 Electrochemical behavior schemes for donor and acceptor dopants in LCs.

6. CONCLUSIONS

The influence of chemically different nematic LC classes and material parameters on display performance for a dc dynamic scattering and MOS active matrix LC TV panel has been investigated, together with the LC molecular alignment influence. Also, the electron donor and acceptor conductivity dopant effect has been studied.

The results indicate the following:

(1) An LC material with birefringence larger than 0.14 and with viscosity lower than 30 cp is required to be synthesized by an optimized blending of different class LCs, in order to achieve both high contrast and fast response acceptable for TV display.

(2) Parallel LC molecular alignment is preferable to perpendicular alignment because, in the latter alignment, response time is considerably increased, although display contrast is rather improved.

(3) Simultaneous doping of donor and acceptor dopants to LCs is needed to assure an effective improvement in display contrast and dc operating lifetime.

Bearing in mind these results, an LC material for use in the LC TV panel has been successfully optimized. This optimization has realized a performance practically acceptable for TV display, such as higher than 20:1 contrast ratio, faster than 30 msec response time and more than eight shades of gray, together with a pronounced improvement in dc operating lifetime.

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