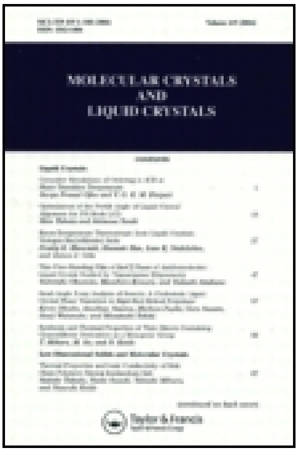


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl18

Highly Multiplexable Achromatic LCD Utilizing Double Layered Homogeneously Oriented Nematic Lc Cells without Twist

Susumu Saito [a] & Taiju Takahashi [a]
[a] Department of Electronic Engineering, Kogakuin University, 2665-1 Nakano-cho, Hachioji-shi, Tokyo, 192, Japan
Version of record first published: 24 Sep 2006.

To cite this article: Susumu Saito & Taiju Takahashi (1991): Highly Multiplexable Achromatic LCD Utilizing Double Layered Homogeneously Oriented Nematic Lc Cells without Twist, Molecular Crystals and Liquid Crystals, 207:1, 173-187

To link to this article: http://dx.doi.org/10.1080/10587259108032097

Mol. Cryst. Liq. Cryst., 1991, Vol. 207, pp. 173–187
Reprints available directly from the publisher
Photocopying permitted by license only

Printed in the United States of America

HIGHLY MULTIPLEXABLE ACHROMATIC LCD UTILIZING DOUBLE LAYERED HOMOGENEOUSLY ORIENTED NEMATIC LC CELLS WITHOUT TWIST

SUSUMU SAITO and TAIJU TAKAHASHI
Department of Electronic Engineering, Kogakuin University
2665-1 Nakano-cho, Hachioji-shi, Tokyo 192, Japan

Abstract This paper is concerned a highly multiplexable achromatic LCD utilizing the ECB effect is described which consists of two homogeneously oriented Np-LC cells with an equivalent retardation.

Both theoretical and experimental studies were made on the effects of material contants and cell parameters on the slope of V-T characteristics, which determine the cell's multiplexability. The transient response and viewing angle characteristics were also investigated. A good achromatic display image and a high multiplexability with a lower duty ratio than 1/200 have been actually obtained by using a cell of ZLI-2842(Merck Co. Ltd), where the field free retardation per layer $\langle\Delta n\rangle_0 d$ is 0.75 μm .

A new driving method to improve the multiplexability is proposed in which both layers are simultaneously driven in a same multiplexing level.

INTRODUCTION

The high information contents and high contrast ratio of direct matrix LCDs were achieved in the development of the SBE cell[1] and STN cell[2] . However, the background coloration of those LCDs has become a next problem to realize a full/multi-color display with micro color filters.

Several groups have proposed and studied the methods to reduce the background coloration. M.Schadt and F.Leenhouts[3] proposed an OMI cell with a colorless background in which the retardation $\langle\Delta n\rangle_0 d$ was decreased to 0.5 μm, where $\langle\Delta n\rangle_0$ means the mean birefringence for no applied voltage codition and d the thockness of LC layer. However, the OMI has a disadvantage in that the reduction of contrast ratio is accompanied by the decrease of

$\langle \Delta n \rangle_0 d$.

Hatoh et al.[4] proposed the B/W STN cell and showed that higher contrast ratio than that of OMI-cell could be obtained by increasing $\langle \Delta n \rangle_0 d$ to 0.6 μm. Okumura et al. and Katoh[5] proposed the double layer STN cell which consists of two STN cells with opposite twist to each other. This type of cell has excellent contrast because rotatary dispersion is completely compensated. However, it has disadvantages in its relatively heavy weight

I.Fukuda et al.[6] proposed an achromatic STN LCD with a birefringent film which is used to compensate the rotary dispersion of the STN-cell. This type of LCD has the advantage in light weight and high yield in comparison with a double layered STN-LCD.

Recently, H.Hirai et al.[7 9] proposed and developed a VAN (Vartically Aligned Nematic) LCD which is based upon an electrically controlled birefringence(ECB) effect of nematic liquid crystals with negative dielectric anisotropy[11 12]. By optimizing material parameters, cell parameters and pretilt angle, they achieved such excellent features as an achromatic display color, high contrant ratio and wide viewing angle.

J.F.Clerc et al.[8 10] proposed the CSH-LCD (Color Super-Homeotropic) LCD based upon the ECB effect of nematics with negative dieletric anisopropy. One or two biaxial films are adapted to the driving cell as an optical compensator differently from the VAN LCD.

In recent year, we proposed a new highly multiplexabele achromatic LCD[17 18] utilizimg the ECB effect[11~15] which consists of two homogeneously oriented Np-LC cells with an equivalent retardation to each other.[17 18] One of them acts as the driving layer and the other as the retardation compensator. Hereafter, we abbreviate this double layered homogeneously oriented nematic LCD as "D-HON-LCD". At almost same time , H.Ikeno et al.[16] also reported independently the same type of LCD.

In this paper, both theoretical and experimental studies are made on the effects of material contants and cell parameters on the slope of V-T characteristics, which determine the cell's multiplexability. The transient response and viewing angle characteristics were also investigated. Furthermore, a new driving method to improve the multiplexability is proposed in which both layers are simultaneously driven in a same multiplexing level.

1. Structure and Principle of a D-HON-LCD

Figure 1 shows the structure of D-HON-LCD. Similarly to the D-STN-LCD, the D-HON-LCD employs the basic principle of

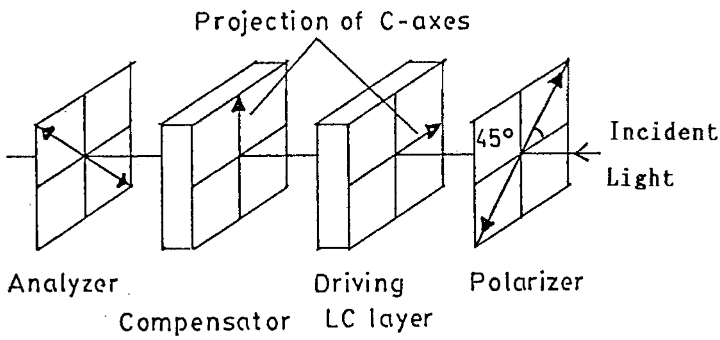


FIGURE 1 Structure of a D-HON-LC cell

retardation compensation in a well-known optical apparatus, the Babinet's Compensator. The D-HON-LCD , however, consists of two homogeneously aligned nematic layers. One of them acts as the driving layer and the other as the compensator. The molecular orientation in the driving layer has a low pretilt angle to suppress the appearance of reverse tilt disclination. As the compensation layer, not only an LC layer but also a birefringent film with equivalent retardation $\langle \Delta n \rangle_0 d$ to the driving layer is applicable, where $\langle \Delta n \rangle_0$ is the mean birefringence for no applied voltage condition and d is the layer thickness. Optical axes of the driving layer and the compensation layer are crossed perpendicular to each other. Crossed polarizers or paralleled polarizers are used according as the normally black (NB) mode or the normally white (NW) modes . The angle between the polarization axis of polarizer and the projection of optical axis to the rear substrate is set to be $\pi/4$. The transmittance T of the system with crossed and paralleled polarizers are given by eq.(1) and eq.(2), respectively.

$$T=T_p\sin^2\{\pi(\langle\Delta n\rangle_c d_c-\langle\Delta n\rangle_d d_d)/\lambda\} \quad (1)$$

$$T=T_p[1-\sin^2\{\pi(\langle\Delta n\rangle_c d_c-\langle\Delta n\rangle_d d_d)/\lambda\}] \quad (2)$$

Where T_p is the transmittance of polarizers, λ is wave length of incident light and the subscripts c and d denote the quantities with respect to the compensator and the driving layer, respectively . If $\langle\Delta n\rangle_c d_c=\langle\Delta n\rangle_d d_d$ and the dispersion of compensater is the same as the driving layer , the system has no overall birefringent effect for any wave length of incident light. The decrease of $\langle\Delta n\rangle_d d_d$ with the increase of applied voltage to the driving layer results in the monotonical increase of the overall birefringence of the system as shown in Fig.2(a). Thus, transmittance varies with the increase of applied voltage as shown in Fig.2(b). If the retardation of the driven layer and that of the compensator is equal at the no applied voltage condition , the variation of the overall birefringence and transmittance with an increase of applied voltage is completely equivalent to that of a VAN-LCD at least for a normal incident light.

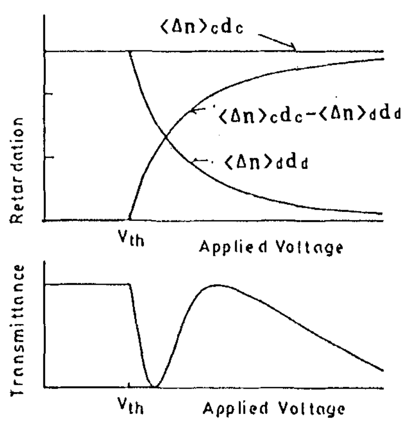


FIGURE 2 Schematic explanation of electro-optical properties of a D-HON-LC cell

2. Multiplexability

Multiplexability depends strongly on the zero field retardation $\langle \Delta n \rangle_{d0} d_d$, the pretilt angle θ_0, the dielectric constant ratio $\varepsilon_p/\varepsilon_n$ and the elastic constant ratio K_{33}/K_{11} . Hereafer, we assume that $\langle \Delta n \rangle_{d0} d_d = \langle \Delta n \rangle_c d_c$, and denote it as $\langle \Delta n \rangle_0 d$. In Figs.3(a)-(b) , calculated relationships between $\varepsilon_p/\varepsilon_n$ and k_{33}/k_{11} as a parameter of sharpness Γ are shown for two cases of $\langle \Delta n \rangle_0 d$. The sharpness Γ is defined as $\Gamma = (V_{50} - V_5)/V_5 \cdot 100$ [%], where V_{50} and V_5 are defined as the voltages at which the value of Y in the CIE(1931) standard colorimetric system (x,y)/Y is decreased by 50% and 5% from the maximum of Y, respectively. The relation of V vs. Y was calculated under the assumption of the standard C light source after the numerical calculation of the relationship between the applied voltage and the transmittance on the basis of F.C.Framk's continuum theory and eq.(2) .

As is well known for the ECB effect, the larger $\langle \Delta n \rangle_0 d$ results in the better sharpness. From Figs.3(a)-(b), we know that a good sharpness is obtained as $\varepsilon_p/\varepsilon_n$ approaches to unity and K_{33}/K_{11} to 0.5 [13]. In Fig.3(d), circles represent those values for some Np-LC materials which are currently commercialized by Merk Co. Ltd. Taking into account that the larger $\langle \Delta n \rangle_0 d$ results in the

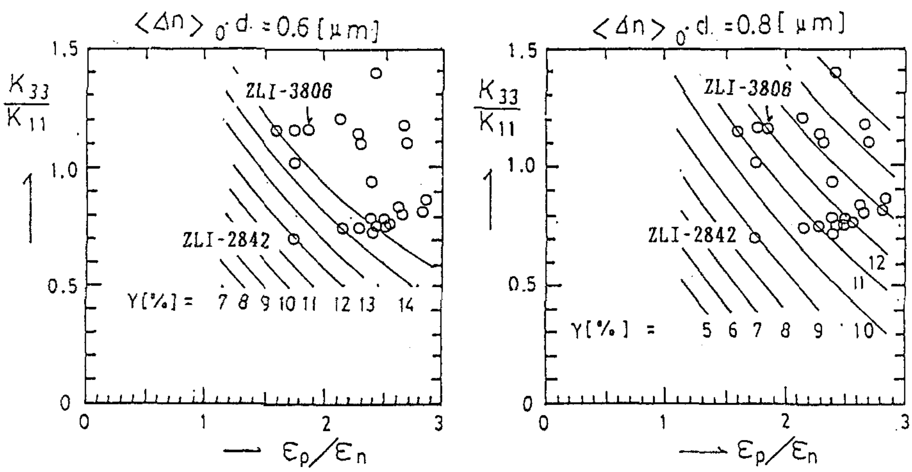


FIGURE 3 Influences of K_{33}/K_{11} and $\varepsilon_p/\varepsilon_n$ on the sharpness Γ in D-HON-LCDs with $\langle \Delta n \rangle_0 d$=0.6[μm] and $\langle \Delta n \rangle_0 d$=0.8[μm].
Solid lines represent calculated values and circles are plots of nematic materials commercialized from Merck Co.Ltd..

narrower viewing angle and the slower response, the value of $\langle\Delta n\rangle_0 d$ should be made as small as possible. It is found that the sharpness of 7.5% which is reqired to realize the high multiplex operation of 1/200 duty ratio is obtained by the use of ZLI-2842 cell with $\langle\Delta n\rangle_0 d$ =7.5μm. The material parameters of ZLI-2842 are K_{33}/K_{11}=0.7, $\varepsilon_p/\varepsilon_n$=1.75 and Δn=0.162 . Experimental results of the relationship between the retardation $\langle\Delta n\rangle_{d0}d_d$ and the sharpness γ are shown in Fig.4 for three Np materials including ZLI-2842. The Np material ZLI-2842 gave the best sharpness among those three materials agreeing well with the theoretical prediction above mentioned.

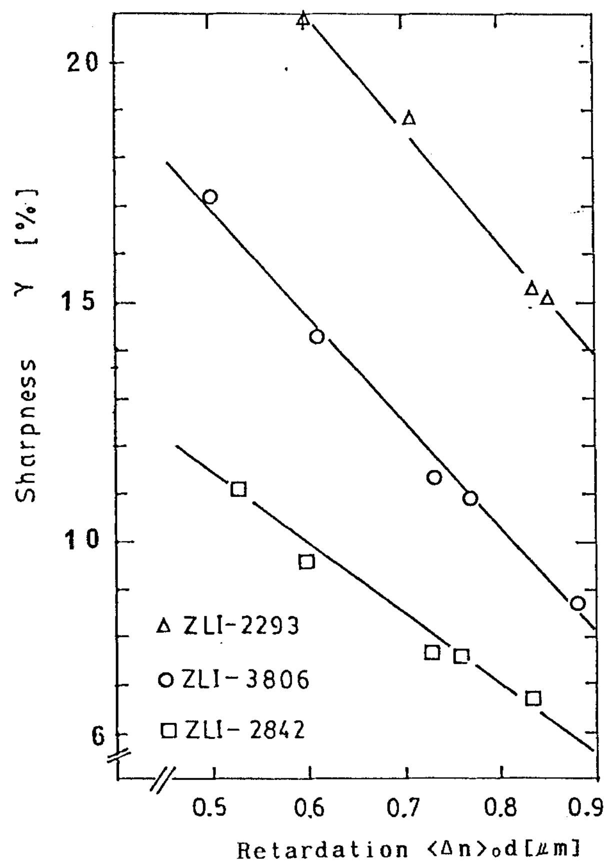


FIGURE 4 Experimental results of $\langle\Delta n\rangle_0 d$ dependence of sharpness γ for three kinds of Np material.

3. Transient behavior

Figures 5(a) and 5(b) show the $\varepsilon_p/\varepsilon_n$ and K_{33}/K_{11} dependence, respectively, of reduced transient response times calculated under the assumptions of the non-select voltage of $V_{ns}=1.05 \cdot V_{th}$ and the scanning line number of N=100, where $V_{th}=\pi(K_{11}/\varepsilon_0\Delta\varepsilon)^{1/2}$. The reduced rise and decay times τ_{rn} and τ_{dn} are defined as $\tau_{rn}=\tau_r/\tau_0$ and $\tau_{dn}=\tau_d/\tau_0$, where $\tau_0=\eta d^2/\pi^2 K_{11}$, η is the viscosity coefficient. These results were obtained by solving numerically the torque equation for the director which is obtained using the continuum theory.

Both τ_{rn} and τ_{dn} decrease with the decrease of K_{33}/K_{11} and are almost independent of $\varepsilon_p/\varepsilon_n$. To make the value of K_{33}/K_{11} small for the improvement of response characteristics results in the reduction of multiplexability . Thus, it may be concluded that to make the viscosity coefficient η lower and to make the cell thickness thinner is most effective to realize a first transient response .

Figures 6(a) and 6(b) show the experimental results of V_{ns} dependence of rise and decay times (τ_r,τ_d) for two different

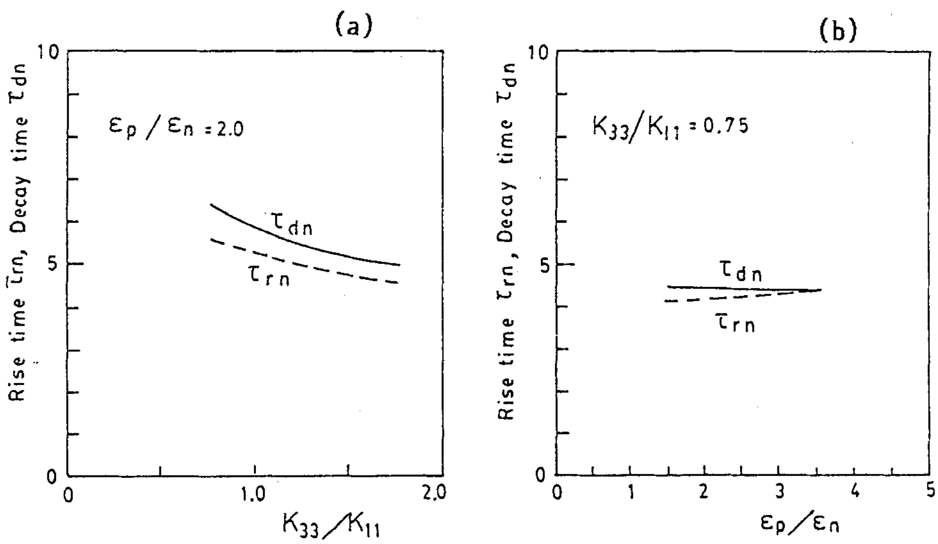


FIGURE 5 Calculated results of the dependences of the reduced rise and decay times on K_{33}/K_{11} (a) and $\varepsilon_p/\varepsilon_n$ (b). Subscript n means the reduced times by $\tau_0=\eta d^2/\pi^2 K_{11}$. Calculations were made on the assumptions of $V_{ns}=1.05V_{th}$, N=100 and $\langle\Delta n\rangle_0 d=0.5[\mu m]$.

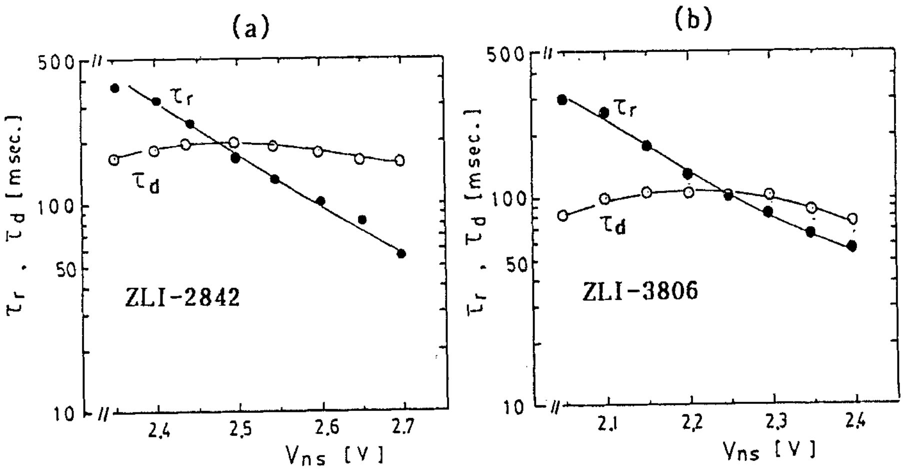


FIGURE 6 Experimental results of the rise and decay times τ_r and τ_d as functions of applied non-select voltage V_{ns}.

materials, ZLI-2842 and ZLI-3806, respectively. Those measurments were made under the condition of 1/100 duty ratio multiplex driving. The transient response time, which is defined as the value of τ_r or τ_d at which $\tau_r = \tau_d$ is satisfied, are 200msec. and 100msec. for the cells of ZLI-2842 and ZLI-3806 respectively. This defference is mainly atributed to the difference of viscosity coefficient between them, since the viscocity coefficient-s of ZLI-2842 and ZLI-3806 are 32cP and 13cP, respectively.

4. Achromaticity of displayed color

Figure 7 shows the experimental results of chromaticity

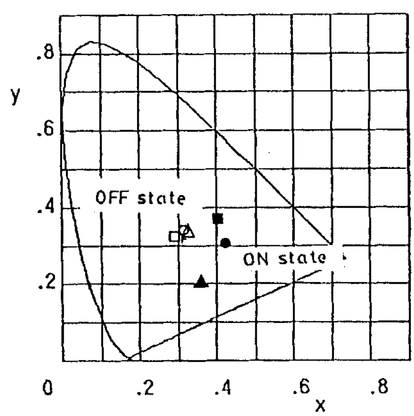
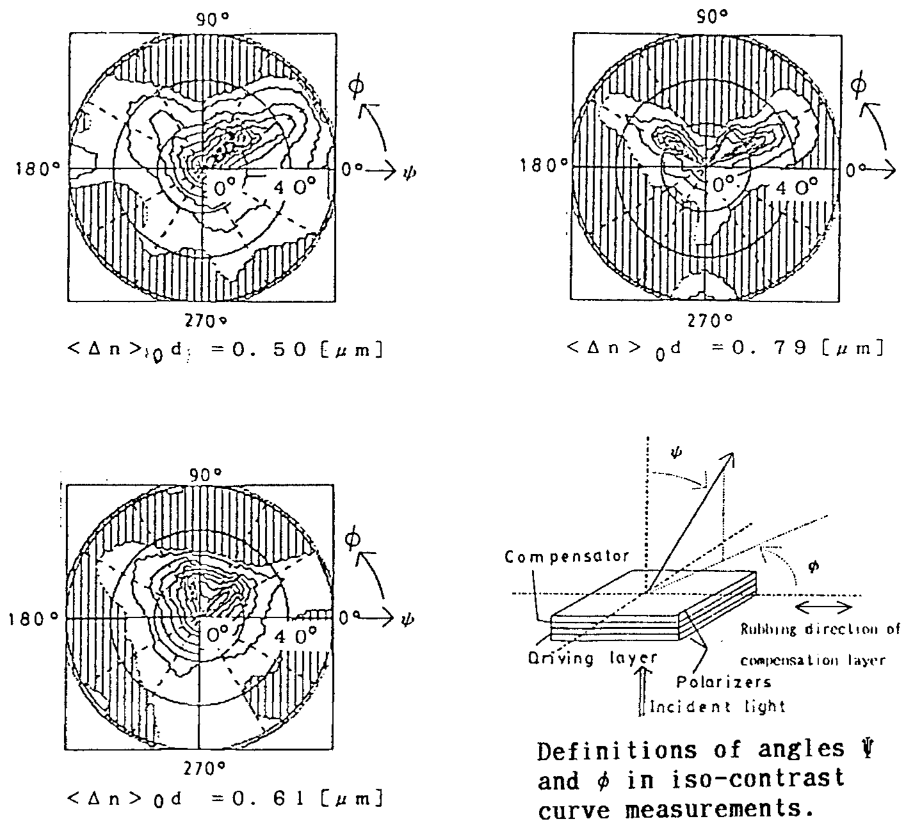


FIGURE 7 Chromaticities in the ON and OFF states.

coordinates for the OFF state and the ON state of the cells with $\langle\Delta n\rangle_0 d$=0.50μm, 0.61μm and 0.79μm. The measurements were done for the NW mode. This result represents that the D-HON-LCD exhibits virtually no inherent coloration.

5. Viewing angle characteristics

Figure 8 show the iso-contrast polar plots of D-HON-LCDs with $\langle\Delta n\rangle_0 d$=0.50μm,0.61μm and 0.79μm, respectively. The definitions of Ψ and φ are illustrated in the figure. It is found that the viewing cone become narrow with the increase of $\langle\Delta n\rangle_{d0}d_d$ as is well known for the ECB cell. Comparing these with those of



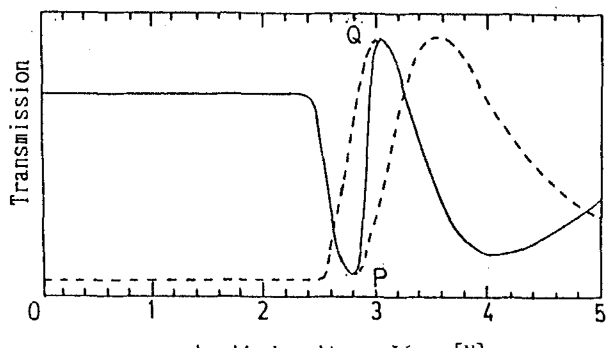
Definitions of angles Ψ and φ in iso-contrast curve measurements.

FIGURE 8 Experimental results of iso-contrast curves.

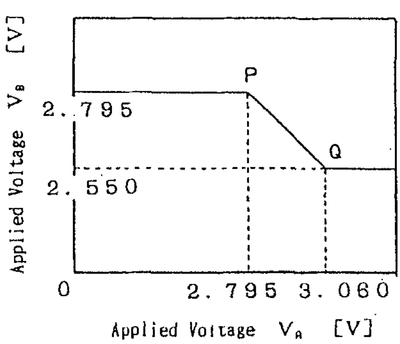
remarkablly narrower, particularly in a direction of $\Psi=0°$ and $90°$. However, the viewing cone in a direction of $\Psi=30°$ and $150°$ is relatively wider than those in other directions. Thus, carefule arrangement of the D-HON-LCD pannel will be necessary for practical applications.

6. Improvement of multiplexability by the simultateous driving method

In a previous section, we have discussed the case in which only one layer of double layered cells is driven. In this section, we will propose a new driving method called the simultaneous driving method in which both layers are simultateously driven in a same multiplex level, and show that the multiplexability can be improved by the method.



(a)



(b)

FIGURE 9 Schematic illustration for the improvement of the sharpness of V-T curve by the simultaneous driving method in which voltages V_A and V_B shown in (b) are applied.

the original curve(dotted curve). This suggests us the possibility to improve the multiplexability by operating the system in a range between P and Q.

Now, we investigate the way to determine the voltages to be applied to both layers in the simultaneous driving method. Present description is restricted to the case of NB mode. Similar method, however, is applicable to the case of NW mode after a slight modification.We now denote values of V_A and V_B at the select state as V_{AS} and V_{BS}, and at the non select state as V_{ANS} and V_{BNS}, respectively. Figure 10 shows schematically the relationships between V_A and V_B at which the transmittance takes the first maximal(dotted line) and the first mimimal(solid line). In the case of the NB mode, the retardations are perfectly compensated each other at voltges on the solid line satisfying $V_A=V_B$. At the non-select state, V_{ANS} and V_{BNS} should be taken a certain value V_{AB} on this solid line to make contrast ratio as high as possible. If $V_{ANS}=V_{BNS}=V_{AB}$ and the system is driven by the optimum bias condition of multiplex driving, V_{AS} and V_{BS} must satisfy following relations at the select state

$$V_{AS}=V_{AB}\cdot K(N) \qquad (3)$$

and

$$V_{BS}=V_{AB}/K(N), \qquad (4)$$

where $K(N)=\{(\sqrt{N}+1)/(\sqrt{N}-1)\}^{1/2}$ for the multiplex diriving of 1/ N duty ratio. To determine the value of V_{AB}, we now assume that when $V_B=V_{th}$ the transmittance takes the first maximum at $V_A=V_{Tmax}$ which corresponds to the point Q in FIG.10 . Then there exist certain values of N denoted as N' and V_{AB} which satisfy that $V_{th}=V_{AB}/K(N')$ and $V_{Tmax}=V_{AB}\cdot K(N')$. From these relations, we can easily obtain

$$V_{AB}=(V_{th}\cdot V_{Tmax})^{1/2}. \qquad (5)$$

Since the distinction between the driving layer and the compensation layer is inappropriate in this driving method, well known for the ECB cell. Comparing these with those of Figure 9 shows experimental results of the relationship between the voltage V_A applying to the cell-A and the transmittance NB mode. When no voltage was applied to both cells , the retardations of those cells, denoted as $\langle\Delta n\rangle_{A0}d_A$ and $\langle\Delta n\rangle_{B0}d_B$, were the same with each other . If a certain voltage V_B higher than V_{th} is applied to the cell-B, the retardation of the cell-B, $\langle\Delta n\rangle_B d_B$, becomes lower than $\langle\Delta n\rangle_{B0}d_B$. Thus, to achieve zero over all retardation of the system , that is, to obain a perfect cmpensation effect, the same voltage V_A with the voltage V_B has to be applied to the cell-A. Such point is designated as P in Fig.9. When a voltage V_B lower than V_{th} was applied to the cell-B, the first maximal of the transmittance appeared at the voltage V_A designated as Q in Fig.9. The slope of the V_A vs. T curve in the range between P and Q became sharper than that of

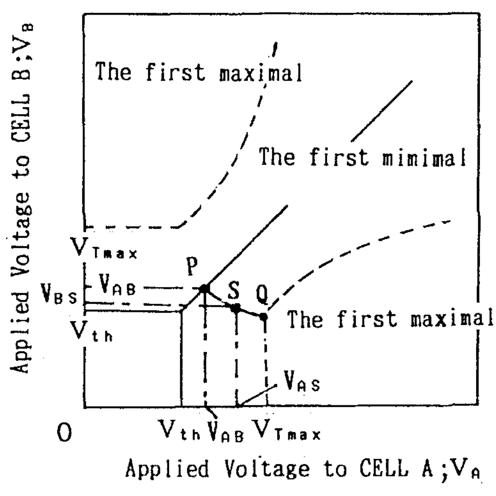


FIGURE 10 Schematic illustration for a method determining voltages to be applied to both cells in a multiplexing operation.
Solid and dotted curves represent combinations of applied voltages V_A and V_B at which transmittance takes the first minimal and the first maximal,respectively.

The points P and S in FIG.10 indicate the non select state satisfing $V_{ANS}=V_{BNS}=V_{AB}$ and the select state satisfing $V_{AS}=V_{AB}\cdot K(N)$ and $V_{BS}=V_{AB}/K(N)$, respectively.

To comfirm the availability of the simultaneous driving method for the improvement of multiplexability, the relationships between the contrast ratio and the scanning line number were measured for the existing single layer driving method and the simultaneous driving method. Those results are shown in Fig.11. It is found that in a region of N>50, the contrast ratio was remarkablly improved by the simultaneous driving method. For instance, when N=500, the contrast rato obtained by the single layer drive method was merely unity, but it was improved to 7.5 by the simultaneous driving method.

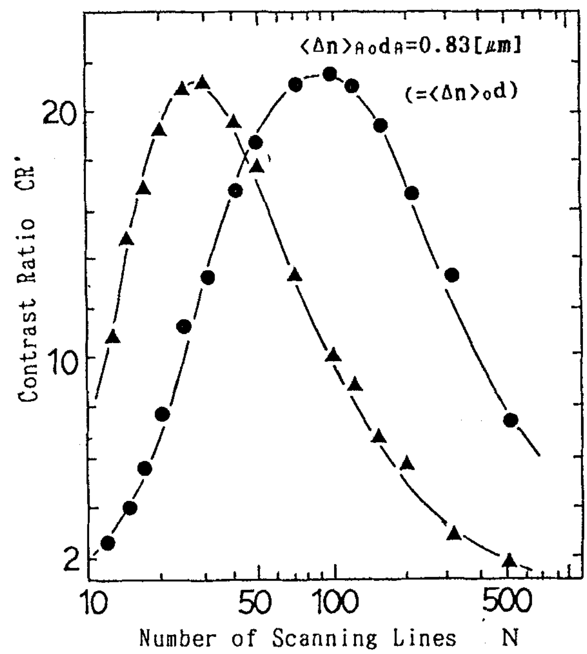


FIGURE 11 Comparison of contrast ratio CR' between the existing single side driving method "▲" and the simultaneous driving method "●".

SUMMARY

Relationships between electro-optical properties of the D-HON-LCD and such conditions as material constants and cell parameters have been investigated. The sharpness of V-T characteristics can

be easily improved by making $\langle \Delta n \rangle_{do} d_{d}$ larger. However, it is desireable to make $\langle \Delta n \rangle_{o} d$ as small as possible by another means because making $\langle \Delta n \rangle_{o} d$ larger results in a narrow viewing angle characteristics and slow response times. One of the means is to optimize material parameters. In this paper, requirements on LC material parameters to achieve a good sharpness were clarified, and high multiplexability with a lower duty ratio than 1/200 was actually confirmed by using a cell of ZLI-2842 with $\langle \Delta n \rangle_{o} d=$ 0.75μm. As another mean to achieve high multiplexability, a new driving method was proposed in which both layers are simultaneously driven at a same multiplex level. The availability of this method was experimentaly confirmed.

At the present stage, viewing angle of the D-HON-LCD is remarkably narrower than the VAN-LCD and the STN-LCD.

However, the D-HON-LCD is thought to be applicable to a projection type LCD in which narrow viewing angle has rather less problem.

ACKNOWLEDGMENTS

The authers would like to express their appreciation to Prof. M. Kamihara of Kogakuin University for his helpful suggestions.

REFERENCES

1. T.J.Scheffer and J.Nehring, Appl.Phys.Lett.45(1984), p.1021.
2. N.Kinugawa, Y.Kando, N.Kanasaki, M.Kawakami and E.Kaneko, SID'68 Digest, (1986), p.122.
3. M.Schadt and F.Leenhouts, Appl.Phy.Lett.50(1987), p.236.
4. H.Hatoh, M.Shoji, T.Yamoto and S.Yamamoto, ITEJ Technical Report,11 (1987), p.79(in Japanese).
5. K.Katoh, Y.Endo, M.Akatsuka, M.Ohgawara and K.Sawada, Jpn.J.Appl.Phys. 24,11(1987), p.L1784.
6. I.Fukuda,Y.Kotani and T.Uchida, Proceeding of the SID,30/3 (1989),p.263.
7. Y.Kinoshita, K.Shohara, H.Hirai, H.Hatoh and S.Matsumoto, Abstract of The 14th Japan Liquid Crystal Conference, 2B107(1988),p.72.
8. S.Yamauchi, M.Aizawa, J.F.Clerc and T.Uchida, SID '89 Digest of Technical Papers,(1989),p.378.
9. H.Hirai, Y.Kinoshita, K.Shohara, A.Murayama, H.Hatoh and S.Matsumoto, Japan Display '89 Digest of Technical Papers, (1989),p.184.

10. J.F.Clerc, M.Aizawa, S.Yamauchi, J.Duchene, Japan Display '89 Digest of Technical Papers,(1989),p.188.
11. M.F.Schiekel and K.Fahrenschen.Appl.Phys.Letters,Vol.19,(1971),p.391.
12. R.A.Soref and M.J.Rafuse, J.Appl.Phys.,Vol.45,No.5,May(1972),p.2029.
13. H.Gruler,T.J.Scheffer and G.Meier,Z.Naturforsch,Vol.27a,(1972),p.966.
14. S.Matsumoto,M.Kawamoto and K.Mizunoya, J.Appl.Phys.,Vol.47,No.9,September(1976),p.3842.
15. S.Saito, Mol.Cryst.Liq.Cryst.,Vol.139,(1986),p.187.
16. H.Ikeno,T.Nakamura,H.Ichinose,Y.Hirai,S.Kaneko and C.Tani, Eurodisplay'90 Proceedings,(1990),p.228.
17. T.Takahashi and S.Saito, Trans.IEICE(in Japanese),C-II, Vol.J73-C-II,No.11,(1990),p.681.
18. T.Takahashi and S.Saito, Trans.IEICE(in Japanese),C-II, Vol.J74-C-II,No.2,(1991),p.681.