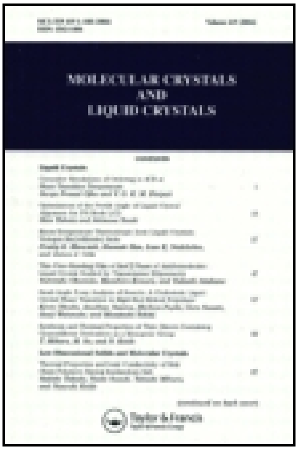

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Electro-Optical Characteristics Consideration for LC Material and Cell Optimization in SBE Liquid Crystal Display†

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We have introduced and defined such electro-optical characteristic parameters as are specifically essential to a SBE LCD and useful for realization of a highly multiplexed SBE LCD.

The characteristic parameters are the hysteresis H, the steepness γ^*, and the cell thickness dependences K and L for threshold voltage and hysteresis, respectively.

In order to increase the multiplexing capability in a SBE LCD, it is essentially needed to decrease the γ^* value as well as the H value and also to reduce both values of K and L.

On the basis of the LC material and cell optimization through these characteristic parameters, we have developed a 1/200 duty cycle multiplexed matrix SBE LCD with a high contrast ratio and a wide viewing angle.

I. INTRODUCTION

A considerable developmental emphasis is now laid on realization of highly multiplexed liquid crystal display (LCD), which has both a large information content and a high display quality comparable to a CRT display. The supertwisted birefringence effect (SBE) LCD has been recently developed by BBC members.[1] The SBE LCD may be one of the most feasible candidates for such a realization.

†Presented at The 11th International Liquid Crystal Conference, Berkeley, June 30–July 4, 1986.

In this paper, we will consider fundamental electro-optical characteristic parameters, which are specific and useful to LC material and cell optimization in a highly multiplexed SBE LCD, and also we will present a 1/200 duty cycle multiplexed matrix SBE LCD with a good legibility, developed based on such a consideration.

2. EXPERIMENTAL

Figure 1 shows a schematic view of a SBE LCD used in the experiments. The nematic LC layer was twisted by left-handed 270° and pretilted nominally by 25°. The LC layer thickness d was determined on the condition $\Delta n \cdot d \cdot \cos^2\theta = 0.8$, where Δn and θ are the birefringence and pretilt angle, respectively.

The polarizer configuration for the yellow mode[1] was mainly applied in the experiments; the front polarizer was aligned so that its axis made an angle of 35° clockwise with the projection of the nematic director onto the front substrate, and the angle between the polarizing axes of the front and rear polarizers was fixed at 70°. In the case of the blue mode,[1] only the front polarizer is rotated by 90° from the above-mentioned yellow-mode off-axis configuration.

The electro-optical characteristics in a SBE LCD were measured for the yellow mode at 25°C and at normal incidence, if not otherwise stated. Table I shows the four kinds of LC blends used in the measurements and their material parameters. The LC blends belonged to phenylcyclohexane/biphenyl (I), phenylcyclohexane/phenyldioxane (II), phenylcyclohexane (III), and phenylcyclohexane/phenylbenzoic acid ester (IV) classes, respectively.

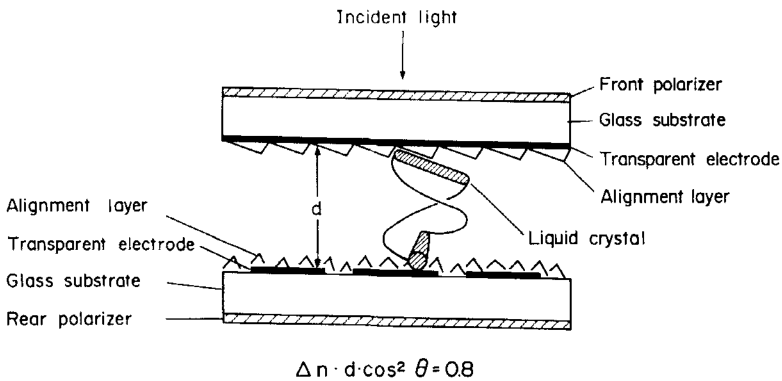

FIGURE 1 Schematic view of a SBE LCD.

TABLE I

Material parameters of the nematic LC blends used in the experiments.

LC blend	Class	N.R. (°C)	Δn	$\eta_{20°C}$(c.p)	Δε	Vth* (V)
I	PCH / BP	-21~90	0.154	24	+10.9	1.87
II	PCH /PDX	-30~75	0.130	22	+10.1	1.54
III	PCH	-40~89	0.129	21	+10.0	1.89
IV	PCH /PBE	-32~105	0.145	25	+ 8.8	1.85

* Vu (T=50 %) in a SBE LCD

3. ELECTRO-OPTICAL CHARACTERISTIC PARAMETERS

Figure 2 shows a typical hysteresis relation of transmission T vs. applied voltage Vrms in a yellow-mode SBE LCD. Considering this relation, we introduce and define the electro-optical characteristic parameters summarized in Table II. They are the hysteresis H, the steepness γ^*, and the cell thickness dependences K and L for the threshold voltage and hysteresis, respectively. These characteristic parameters are specific and essential to a SBE LCD and useful for realization of a highly multiplexed SBE LCD.

In Table II, Vu(T%) and Vd(T%) are the voltages at which the transmission reaches T%, obtained on increasing (up) and decreasing (down) an applied voltage, respectively. The threshold voltage Vth is defined as Vu (T = 50%) and d is the LC layer thickness.

4. HYSTERESIS H AND STEEPNESS γ^*

The hysteresis H is introduced to describe the degree of a hysteresis appeared in the transmission T vs. applied voltage Vrms characteristic curve. The steepness γ^* is introduced to describe the threshold steepness of the characteristic curve.

According to the experiments, as shown just later, the H value has been found to vary almost independently of the threshold steepness and the value γ^* has proved to have no definite relation to the H value itself. Therefore, in order to increase the multiplexing capability in a SBE LCD, it is essentially needed to decrease the γ^* value as well as the H value.

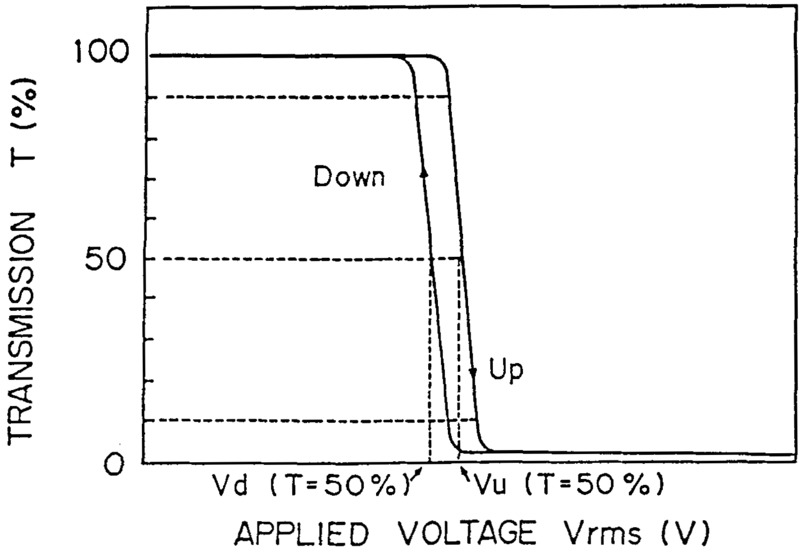

FIGURE 2 Typical hysteresis relation of the transmission T vs. applied voltage Vrms for a SBE LCD in the yellow mode.

Figure 3 presents the four representative kinds of a T vs. Vrms relation curve measured for SBE LCDs filled with the nematic LC blends I, II, III and IV. Both the relation curves I and II show no hysteresis, that is, their H values are zero. Nevertheless, their threshold behaviors quitely differ each other; the curve I has the steep

TABLE II

Electro-optical characteristic parameters specific to a SBE LCD.

Parameter	Definition
Hysteresis : H	$\frac{Vu(T=50\%) - Vd(T=50\%)}{Vd(T=50\%)} \times 100$ [%]
Steepness : γ^*	$\frac{Vu(T=10\%) - Vd(T=90\%)}{Vd(T=90\%)} \times 100$ [%]
Cell thickness dependence of Vth : K	$\frac{\Delta Vth}{\Delta d}$ [V/μm] (Vth = Vu(T=50%) [V])
Cell thickness dependence of H : L	$\frac{\lvert \Delta H \rvert}{\Delta d}$ [%/μm]

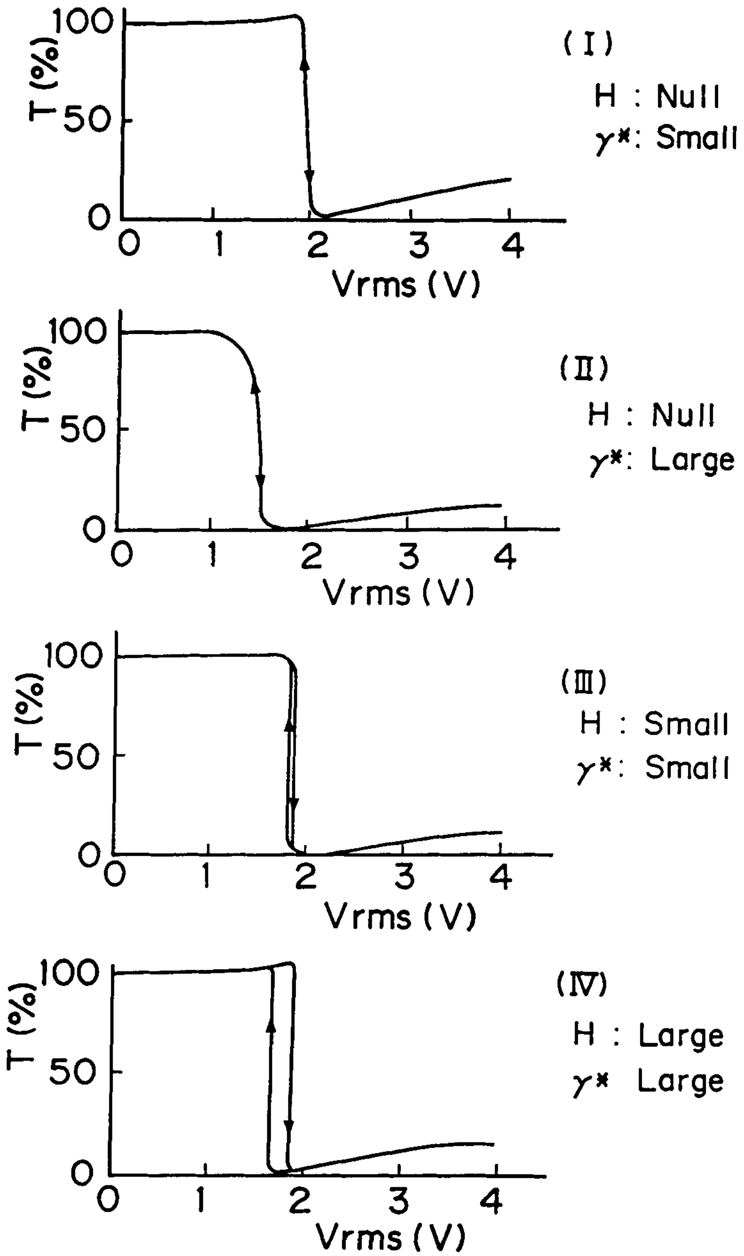

FIGURE 3 Representative kinds of the transmission T vs. applied voltage Vrms curves for SBE LCDs filled with the LC blends I, II, III, and IV.

threshold, *i.e.*, its γ^* value is small but the curve II exhibits the dull threshold, *i.e.*, its γ^* value is large.

On the other hand, as to the curves III and IV, both have the hysteresis but their electro-optical behaviors are not similar. While the curve III has the small H value as well as the small γ^* value, the curve IV has the large H value as well as the large γ^* value.

In Table III, the hysteresis H and steepness γ^* obtained from the T vs. Vrms curves are given for the four kinds of LC blends, together with the threshold voltage Vth and the maximum number of multiplexable lines Nmax calculated from the γ^* value. These results suggest that the LC blend I has the highest multiplexing capability except the blend III, since its H value is zero and its γ^* value is relatively small. The steepness $\gamma^* = 3.4\%$ in the case I corresponds to the maximum number of multiplexable lines Nmax = 890.

The LC blend III dose not seem less favorable for a high multiplexing, compared to the LC blend I, from only a viewpoint of the H and γ^* values themselves. Nevertheless, the blend is not so practical, because the cell thickness dependence of its hysteresis is very large, as shown later.

5. CELL THICKNESS DEPENDENCES K AND L FOR THRESHOLD VOLTAGE AND HYSTERESIS

In the case of a SBE LCD, the electro-optical characteristics themselves have been found to be sensitively affected by the variation of cell thickness, besides its unfavorable effect on the birefringence color

TABLE III

Measured electro-optical characteristic parameters in a SBE LCD for the four kinds of LC blends.

LC blend	Cell thickness d (μm)	Threshold voltage Vth (V)	Hysteresis H (%)	Steepness γ^* (%)	Maximum multiplex-ability N max	Cell thickness dependence of Vth K (V/μm)	H L (%/μm)	Response times τ_{on}/τ_{off} (m sec) 1/100 duty	1/200 duty
I	6.7	1.87	0	3.4	890	0.18	0	140/140	210/210
II	6.5	1.54	0	11.4	86	0.16	0	200/200	240/240
III	7.3	1.89	1.6	2.2	2120	0.19	9.1	240/240	300/300
IV	6.3	1.85	10.0	11.8	82	0.16	3.5	—	—

shift. Accordingly, both the cell thickness dependence parameters K for the threshold voltage Vth and L for the hysteresis H are essentially important for a SBE LCD.

With decreasing the K and L values, the operating voltage margin available for multiplexing and the fabrication allowance for the cell thickness variation effectively increase.

Figure 4 presents the representative cell thickness dependence of a T vs. Vrms curve for a SBE LCD. The dependence I, III and IV are for the LC blends I, III and IV, respectively. The threshold voltage Vth increases with increasing the cell thickness, similarly in all cases, but the cell thickness dependence of the hysteresis considerably differs in each case.

While no hysteresis is found at every cell thickness in the case I, the degree of hysteresis is definitely influenced by the cell thickness in the cases III and IV. Especially in the case III, the hysteresis becomes remarkably large with a deviation of the cell thickness from an optimized one. Such an increase in the hysteresis inevitably results in a deterioration of the threshold steepness γ^*.

In Table III the cell thickness dependence parameters K and L for the hysteresis and threshold voltage, obtained from such relation curves in Figure 4, are summarized for the four LC blends. These reuslts indicate that the LC blends I and II are practically much more favorable from a viewpoint of both the operating voltage margin for multiplexing and the cell fabrication allowance for a SBE LCD, since their L values are zero and their K values of 0.18 and 0.16 V/μm are not so large.

The detailed correlation between the above-mentioned electro-optical characteristic parameters of H, γ^*, K and L and the various LC material parameters are now under investigation.

6. TEMPERATURE EFFECT ON ELECTRO-OPTICAL CHARACTERISTICS

Figure 5 shows the temperature effect on a T vs. Vrms curve for SBE LCDs filled with the LC blends I, III and IV. The threshold voltage Vth decreases with increasing the temperature similarly in all cases, but the temperature dependence behavior of the hysteresis is not similar in them. Namely, in the case I no hysteresis appears regardless of the temperature, but in both the cases III and IV the hysteresis distinctly increases with decreasing the temperature. Such an increase in the hysteresis inevitably results in a deterioration of the threshold steepness γ^*.

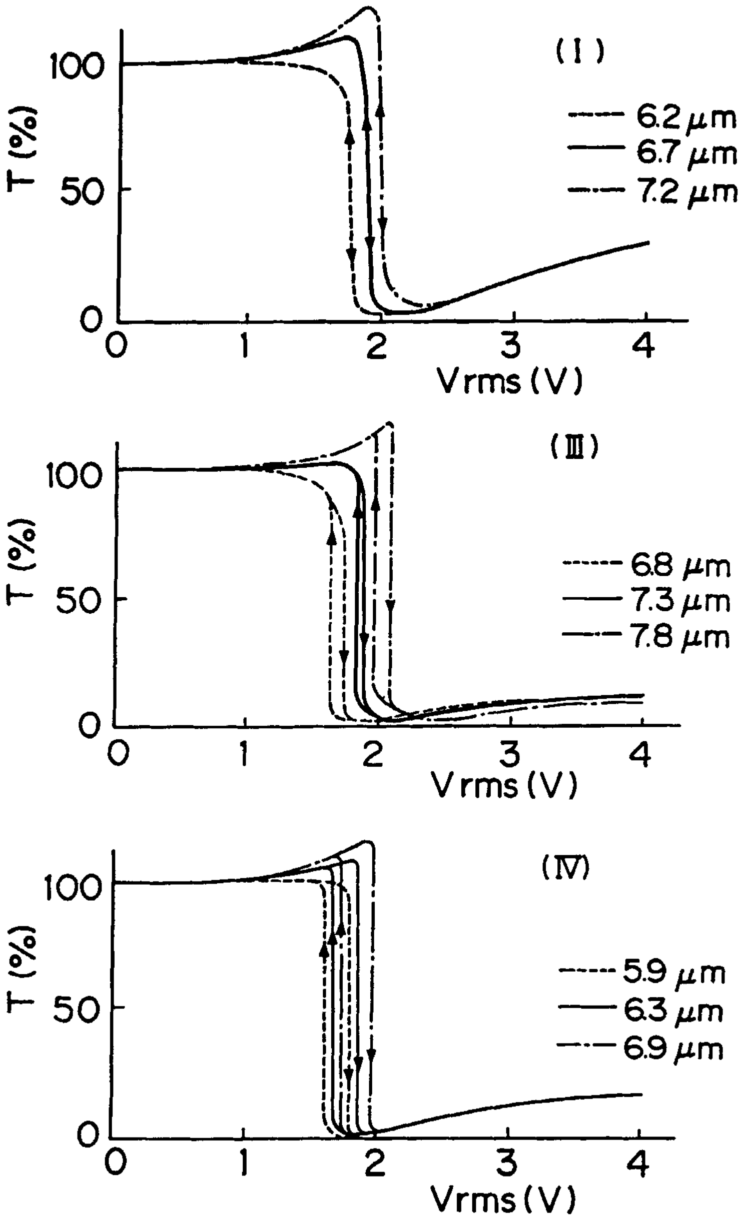

FIGURE 4 Cell thickness dependence of the transmission T vs. applied voltage Vrms curves for SBE LCDs filled with the LC blends I, III and IV.

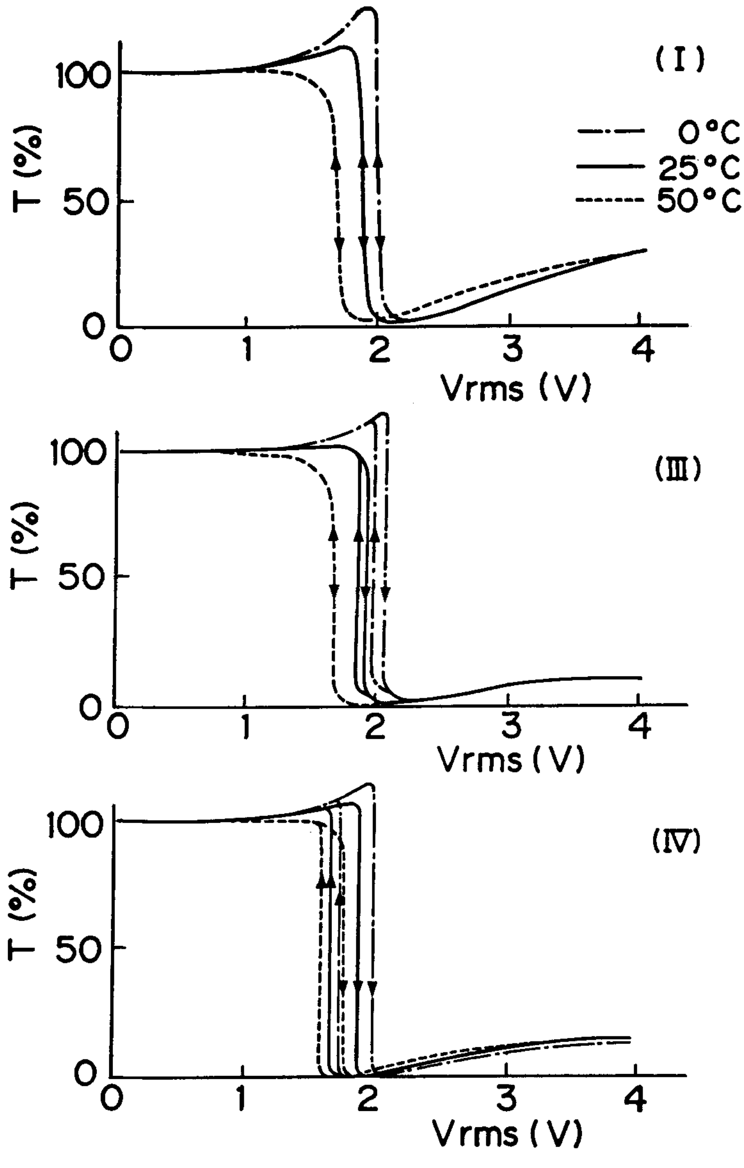

FIGURE 5 Temperature effect on the transmission T vs. applied voltage Vrms curves for SBE LCDs filled with the LC blends I, III and IV.

The temperature dependence of the threshold voltage has been estimated at a value from −5 to −7 mV/°C from Figure 5, which nearly corresponds to the typical temperature dependence in a conventional TN LCD. This temperature dependence of the threshold voltage can be, if necessary, easily reduced by using a temperature compensated LC mixture added with right- and left-handed chiral agents.

However, according to our experimental results, such a temperature compensation technique seems to increase the hysteresis rather than reduce it.

7. MULTIPLEXING CHARACTERISTICS AND RESPONSE TIMES

Figure 6 presents the relation of transmission T vs. operating voltage Vop for SBE LCDs with different hystereses, multiplexed at a duty cycle of 1/200. In the Figure, the operating voltage Vop means the drive voltage in Alt and Pleshko multiplexed addressing.[2] The Vop margin available for the addressing is indicated by the width of a shaded area. The area exists between the select and nonselect T vs. Vop curves in the case of no hysteresis (the LC blend I) or between the outer (up) select and inner (down) nonselect T vs. Vop curves in the presence of a hysteresis (the LC blends III and IV).

The results show explicitly that the presence of a hysteresis definitely reduces the operating voltage Vop margin as well as the multiplexing capability. In the case of the LC blend I V, such an adverse situation occurs so seriously that there is no available Vop margin for a 1/200 duty cycle multiplexing.

Figure 7 explains the operating voltage Vop dependence of turn-on and turn-off times τon and τoff and the hysteresis effect on the response times, for SBE LCDs multiplexed at a duty cycle of 1/200. In the measurements two kinds of SBE LCDs with different hystereses were used, which have different cell thicknesses but were filled with the same LC blend III. Both the turn-on and turn-off times critically depend on the operating voltage; τon increases steeply when Vop approaches the lower limit of Vop and τoff increases sharply as Vop approaches the higher limit of Vop.

These results mean that the minimum response times τon and τoff are achieved at the intersecting point of the turn-on and turn-off response curves and that the response times increase with an increase

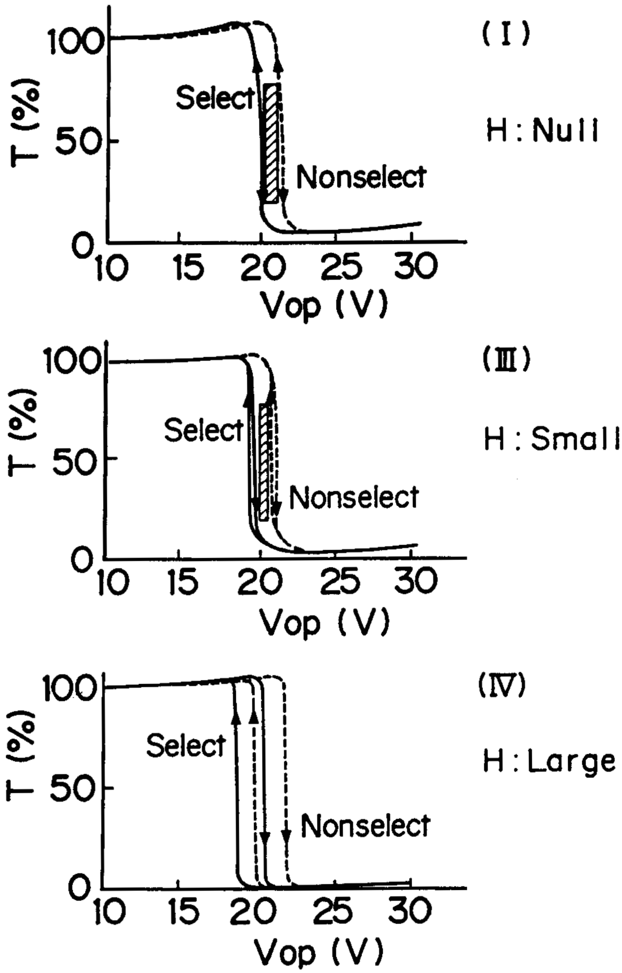

FIGURE 6 Select and nonselect curves of the transmission T vs. operating voltage Vop for SBE LCDs with different hystereses, multiplexed at a 1/200 duty cycle.

of the hysteresis. The latter situation is easily understood by comparing the results for the SBE LCDs with small and large hystereses in Figure 7.

In Table III, the minimum response times τon and τoff obtained from the above-mentioned intersecting point are shown for both the cases of multiplexed duty cycles of 1/100 and 1/200.

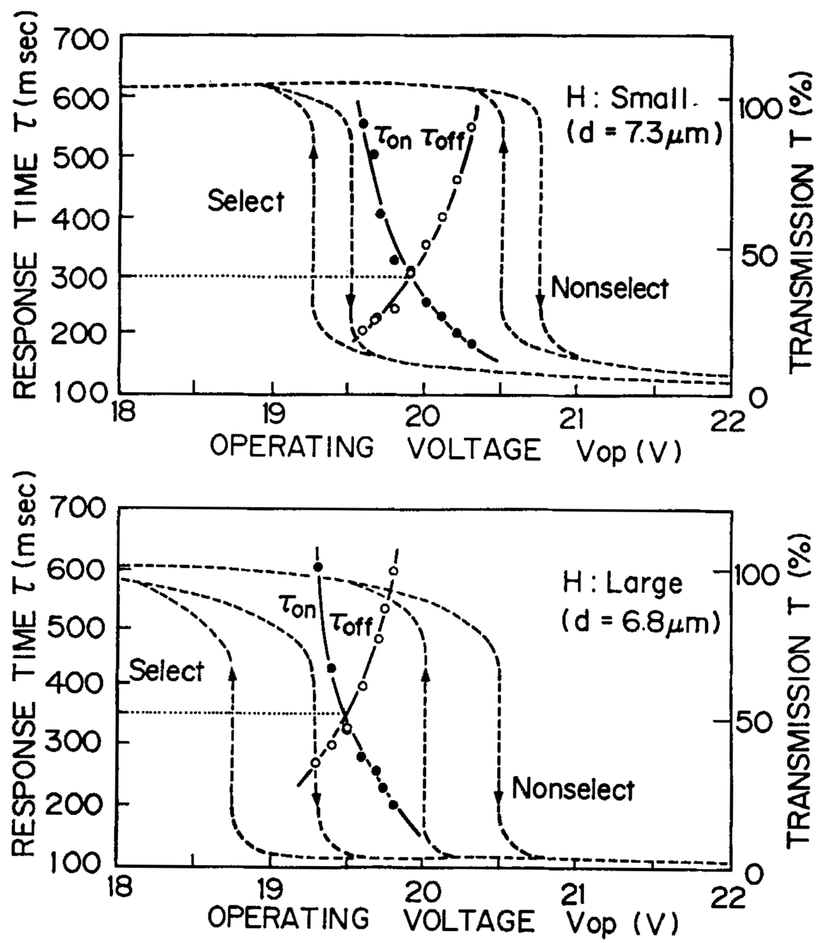

FIGURE 7 Operating voltage Vop dependence of the response times τon and τoff for SBE LCDs with different hystereses, multiplexed at a 1/200 duty cycle.

8. 1/200 DUTY CYCLE MULTIPLEXED MATRIX SBE LCD

On the basis of the above-mentioned consideration on various electro-optical characteristic parameters and LC material and cell optimization through the parameters, we have developed the highly multiplexed matrix SBE LCDs. They have 640 × 200 pixels in an A4 half-page size, operating in the yellow and blue modes. Figure 8 shows photographs of the developed SBE matrix LCDs, which display black colored characters in the yellow background and blue colored char-

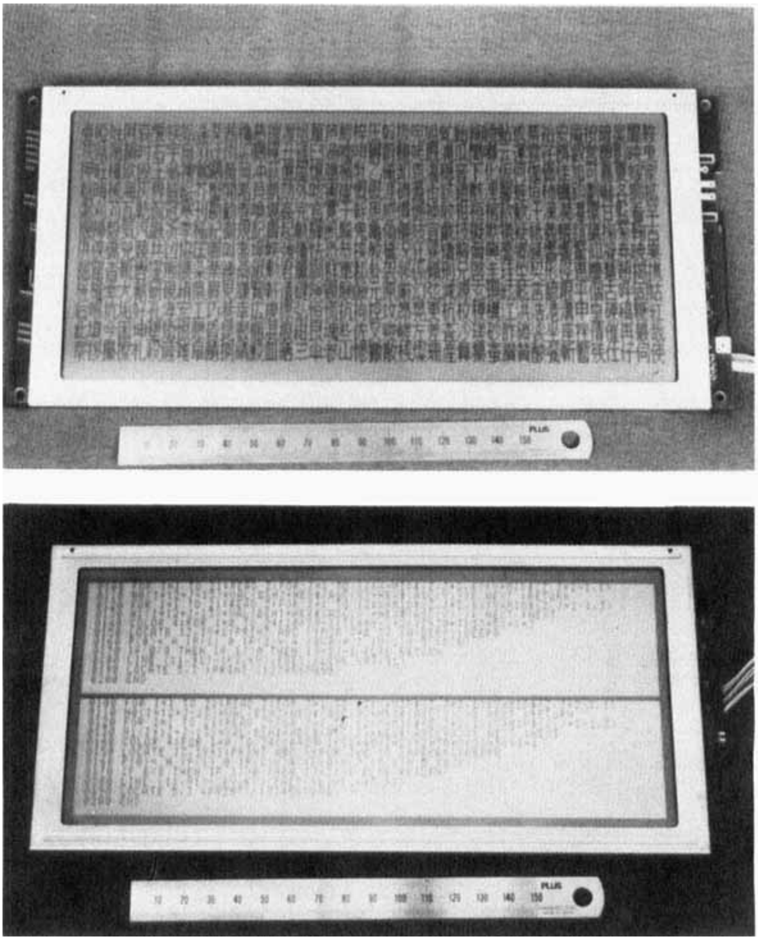

FIGURE 8 1/200 duty cycle multiplexed matrix SBE LCDs with 640 × 200 pixels in the yellow (upper) and blue (lower) modes. **SEE COLOR PLATES I AND II.**

acters in the colorless background, respectively.

The matrix SBE LCDs are driven at a multiplexed duty cycle of 1/200 and display sophisticated graphic patterns as well as 25 lines by 80 characters in an 8 × 8 font. According to a simulated multiplexing operation, these developed SBE LCDs have practically a multiplexing capability higher than a duty cycle of 1/400.

As summarized in Table IV, together with their mechanical characteristics, their display performances are sufficiently practical for

TABLE IV

Display performances and mechanical characteristics of the 1/200 duty cycle multiplexed matrix SBE LCDs in the yellow and blue modes.

Items		Yellow mode	Blue mode
Performance	Contrast ratio (CR)	18 : 1 (Max.)	10 : 1 (Max.)
	Viewing angle	45°cone (CR >9 : 1)	45°cone (CR >5 : 1)
	Response times (τ)	210msec ($\tau_{on} = \tau_{off}$)	210msec ($\tau_{on} = \tau_{off}$)
Mechanical	Number of pixels	640 (Horizontal) x 200 (Vertical)	
	Number of characters	2000 (25 lines by 80 characters)	
	Display area	224 (W) x 98 (H) mm^2 (A4 half-size)	
	Pixel size	0.32 (W) x 0.46 (H) mm^2	
	Outline dimension	275 (W) x 126 (H) x 14 (D) mm^3	

most uses. The contrast ratio is 18:1 for the yellow mode and 10:1 for the blue mode. The viewing angle is over a 45° cone for both the modes. The turn-on and turn-off response times are 210 m sec.

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