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A Study of New Operation Mode for High Contrast Ratio and Fast Switching Time in Antiferroelectric Liquid Crystal(AFLC)

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A new method of switching mode in AFLC cell is proposed for faster switching time and higher contrast ratio. In this mode the "dark" state is obtained by applying negative full voltage while the "bright" state is achieved by applying positive full voltage to the cell. The switching time is reduced to 100 μs for the cell whose switching time is 22 ms when operated in conventional mode. The contrast ratio is also improved vastly with this method. The possibility of achieving gray scale was shown in this mode of operation.

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I. INTRODUCTION

In nematic liquid crystal display technology, there have been vast improvements in viewing angle and contrast ratio. However, the response speed is too slow to be used in video image display. On the other hand, ferroelectric liquid crystal(FLC) materials first discovered by Meyer in 1975 have very fast response time to external electric fields [1]. After Clark and Lagerwall first succeeded in fabricating a surface stabilized FLC mode in 1980 [2], numerous efforts have been devoted to this mode of FLC display [3]- [9].

With very narrow cell gap (~2 μm) between the two surface aligning substrates, the ferroelectric and antiferroelectric liquid crystal molecules form a bookshelf geometry in which the LC molecules are parallel to each other in smectic layers because the otherwise natural helical structure is being suppressed by the strong interaction with the surface. This FLC mode has the advantage of fast response time and wide viewing angle. However, it also has the disadvantage of low contrast ratio due to such problems as zigzag defects originating from chevron structure or non optimized cone angle at chiral smactic C phase(SmC*) of FLC [10]- [12]. Also, it is hard to obtain gray scale mode from this since the FLC is only bistable in this configuration. Therefore in this work we have studied a new display mode using antiferroelectric liquid crystal(AFLC) materials to improve the switching speed and contrast ratio as well as to achieve better gray scale mode.

II. THEORY

Fig. 1 show the rod-like (A)FLC molecules at chiral smactic C phase. The equation of motion of this state is described by

$$\gamma\frac{\partial\varphi}{\partial t} = -PE\sin\varphi + \frac{1}{2}\Delta\epsilon\epsilon_0 E^2\sin^2\theta\sin 2\varphi + K\nabla^2\varphi, \quad (1)$$

where φ is the azimuthal angle of cone motion, γ is the viscosity of the materials, P is spontaneous polar-

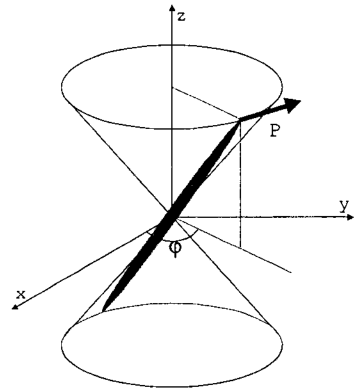


FIG. 1. The cone motion of rod-like AFLC at SmC* phase.

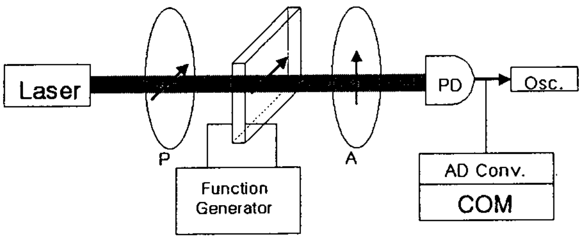


FIG. 2. The schematic diagram of experimental setup for measuring the AFLC's response time (P : polarizer; A : Analyzer; PD : Photodiode).

ization and K is the Oseen-Frank elastic constant [13]. and K is the Oseen-Frank elastic constant [13]. The first term of the right side is the torque due to the applied external field, the second term is the dielectric term for quadratic torque and the third term is the elastic term.

When an electric field of square wave shape is applied, the rise time of electro-optic response is given by $\tau \sim \gamma/\mathbf{P}\cdot\mathbf{E}$ [13]. So it can be made shorter by applying a higher electric field. However, the decay time to zero transmittance can not be shorter in the conventional AFLC cells because the zero transmittance state is achieved without external field in the conventional mode of operation. Since the decay time is the order of ms compared to 100 μs for the rise time, conventional AFLC cell cannot be used in the application where one needs fast response.

Since the AFLC cell has its unique advantage over FLC cell even though it has the above mentioned disadvantages, in this work we propose a new way of operating an AFLC cell where the above mentioned disadvantage can be eliminated. This has been done by achieving the dark state by applying negative full voltage while the bright state is achieved by applying positive full voltage. In this way the switching time for dark to bright state as well as bright to dark state can be made faster with higher electric field, since the times are inversely proportional to the applied field. The contrast ratio in this mode of operation can also be improved vastly since the molecular ordering in the dark state is much higher than that of conventional mode of operation where no field is applied in that state.

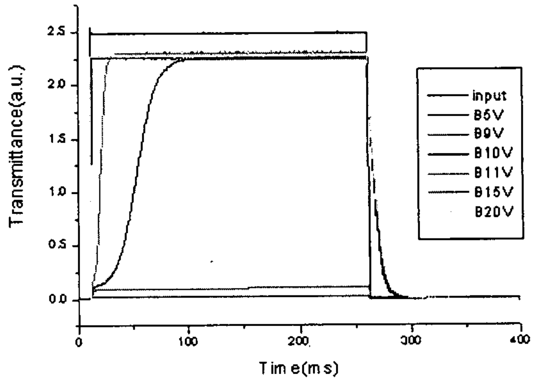


FIG. 3. The response characteristics of the mode operating in zero to positive full voltage.

III. EXPERIMENT AND RESULT

Fig. 2 shows the schematic diagram of our experimental setup for the study of switching characteristic of the cell response time. We use 632.8 nm, 7 mW He-Ne Laser for light source, and the polarizer and the analyzer are aligned perpendicular to each other. The AFLC material used for this experiment is CS4001 supplied by Chisso Co. The phase transition temperature of this material is Cr-(below-70°C)→$SmC_A{}^*$-(66°C)→SmC*-(69°C)→SmA-(88°C)→ Iso. The spontaneous polarization P_s is -79.7nC/cm^2, and tilt angle is 24.9°C. The cell is driven by a square wave from a function generator and the transmitted light is detected by a photodiode.

As shown in Fig. 1, it has been known that FL C molecules at SmC* phase rotate on a cone and the layer normal of the smectic layer direction is nearly parallel to the rubbing direction. So the FLC molecules are tilted at the cone angle from the rubbing direction.

Before setting up the cell in our mode we measured the response characteristics of the cell in the conventional AFLC mode where one uses the field off state as the dark state and the field on state as the bright state. Fig. 3 shows the electro-optic response of this

TABLE 1. The response time of the cell for each mode of operation.

Voltage/μm	for convention mode 0 ↔ + (dark state) (bright state)		new mode − ↔ + (dark state) (bright state)	
	rising time	decay time	rising time	decay time
5 V	1.5 ms	60 μs	40 μs	40 μs
10 V	70 ms	22 ms	140 μs	160 μs
15 V	740 μs	23 ms	110 μs	120 μs
20 V	140 μs	27 ms	100 μs	100 μs

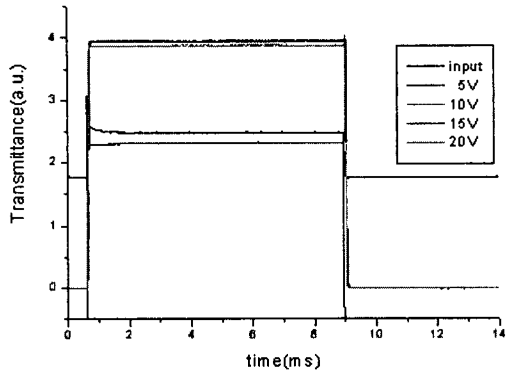


FIG. 4. The response characteristics of the mode operating in negative to positive full voltage.

conventional cell when we applied voltages of various strength at modulation frequency 2Hz. The rise time gets shorter as the voltages increase. However, the decay time remains about 20 ms except for the low applied voltage case(+5V). So this mode of operation is too slow to be used for applications such as electro-optic shutters.

To operate the cell in our mode we have rotated the AFLC cell so that we get a minimum transmittance state when negative full voltage is applied. The maximum transmittance state is achieved by applying positive full voltage. Since the maximum transmittance is proportional to $\sin 2\varphi$ where φ is the angle between the maximum state and the minimum transmittance state orientations of LC molecules, we have achieved a higher transmittance state in our mode compared to the conventional mode of operation. The electro-optic response curve measured in this mode is shown in Fig. 4. It is clear that we have much faster response in both rise and decay process.

Table 1 shows the summary of these response times of the cell operating in our mode as well as that in the conventional mode. In the case of ±5 V of applied voltage, the rise time of the conventional cell is too long (~1.5 ms) although the decay times is only 60 μs. However, both the rise and decay time are reduced to 40 μs in our mode of operation. In the conventional mode of operation with high operational voltage (±10 V ~ ±20 V), the decay time becomes much slower (over 20 ms) whereas the rise times are of the order of 700 μs. Both decay and rise times are reduced to 160 ~ 100 μs in our mode even in this range of operational voltage.

To investigate the influence of frequency of the applied field to the response time of the cell, we measured the response of the cell for various frequencies and found no difference in the response time in the range of 1Hz to 1kHz. Also the long term stability of the cell operating in our mode was measured by applying ±30 Volt with duration ratio 1 : 15 for +V to -V. No change in operating characteristics was found, which means the system is very stable without any charge accumulation during the operation. For the purpose of application to a large size optical shutter, we tested the cell with an expanded beam with the size of 10 mm in diameter from the initial 1 mm diameter size and we could not find any change in the response times of the cell.

The contrast ratio achieved in our mode is much larger than that achieved in the conventional mode as is shown in Table 2. This is due to the fact that not only the bright state transmittance in the +V to -V mode of operation is higher than that of +V to 0 V conventional mode of operation, but also the dark state transmittance of our mode is much lower compared to that of the conventional mode because the LC molecules are ordered more highly by the applied field.

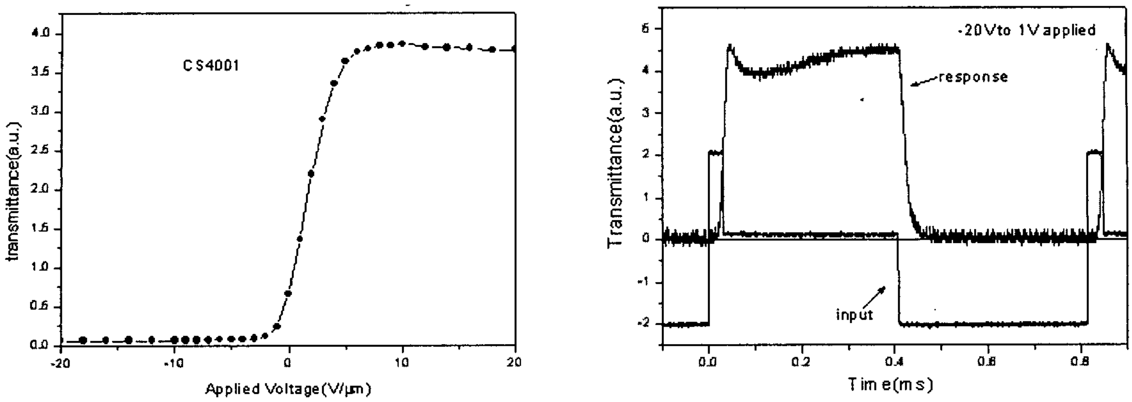
Fig. 5 shows the electro-optic response of the bistable system. Instead of holding the threshold voltage at a high level throughout the bright state (or the dark state), we applied the switching voltage for a short period of time and then decreased it to low level of holding voltage. The characteristics of transmittance are very similar to those in the mode of operation where the high voltage is applied during the whole period. However, the transmittance versus the applied voltage curve shows some thresholdless behavior in the range of 0 to 6V. This may be used as a gray scale mode of operation. We need some more research to fully take advantage of this and are currently investigating.

IV. CONCLUSION

A new fast switching mode of operation with response time of 100 μs is realized in the AFLC cellwith 22 ms response time when operated in the conventio-

TABLE 2. The contrast ratio of bright to dark state transmittance for each mode of operation.

Condition	T_{max}	T_{min}	Contrast Ratio	ref.
TN cell(2V/10 μm)	6783.6 mV	1.3 mV	5217	100 %
FLC -±20V	7179.0 mV	0.5 mV	14358	275 %
FLC - 0 ↔+20V	4581.6 mV	2.2 mV	2087	40 %



(a) (b)

FIG. 5. The transmittance curve as function of the applied voltage (a), and as function of time (b).

nal mode of operation. This is achieved by setting the dark state with negative full voltage while the bright state is set with positive full voltage. In this mode the contrast ratio is increased by a factor of 7 from that of AFLC cell operated in the conventional cell. The possibility of gray scale mode of operation is also shown in this new mode of operation.

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