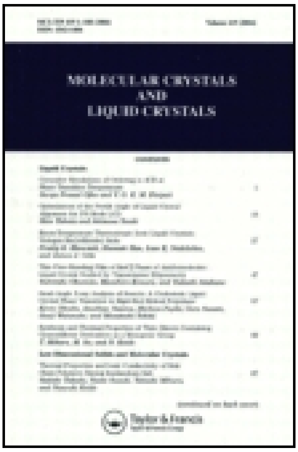

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Application of Antiferroelectric Liquid Crystals for Display and Photoaddressed Spatial Light Modulator

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APPLICATION OF ANTIFERROELECTRIC LIQUID CRYSTALS FOR DISPLAY AND PHOTOADDRESSED SPATIAL LIGHT MODULATOR

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Abstract After summarizing essential features of antiferroelectric liquid crystals (AFLCs), recent progress in the application of AFLC for displays and spatial light modulators is presented. These devices are based on the electric-field-induced antiferroelectric-ferroelectric phase transition characterized by sharp threshold and hysteresis.

INTRODUCTION

Nematic liquid crystals are nowadays widely used as flat panel displays, which have revolutionarily been changing the market of displays. Since the discovery of a ferroelectric liquid crystal (FLC)[1] and its fabrication in surface stabilized fashion,[2] many attempts for applying FLC to displays and spatial light modulators have been successfully made. They are about to be brought to market.

During the development of new FLC materials, we noticed a novel FLC-like compound which shows so-called the tristable switching.[3] Soon after this, we discovered the antiferroelectric liquid crystal (AFLC) phase and clarified that the tristable switching is the F-AF-F switching.[4] Since AFLC has some novel characteristics superiour to FLC, much attention has been paid. In this paper, we summarize orientational and switching characteristics of AFLC and represent the device applications for displays and spatial light modulators.

MOLECULAR ORIENTATIONAL STRUCTURE IN AFLC PHASE AND THE FIELD INDUCED SWITCHING

Figure 1(a) shows the local molecular orientation in the antiferroelectric phase:[4] molecules alternately tilt to the same direction and to the opposite sense in the succesive layers, so that the polarizations are cancelled out in adjacent layers. Because of the chirality of molecules, the local molecular orientation is twisted to make a double helical structure, in which two helices with a phase difference of about π gear into each other, as shown in Figure 1(b).[4] The index ellipsoid of this structure is biaxial and rotates along the helical axis with the period of half the helcal pitch, while the ferroelectric one has the period corresponding to a full pitch. This difference was optically confirmed by selective reflection of oblique incidence.[4]

In Figure 2 are shown the orientational change under an electric field and the

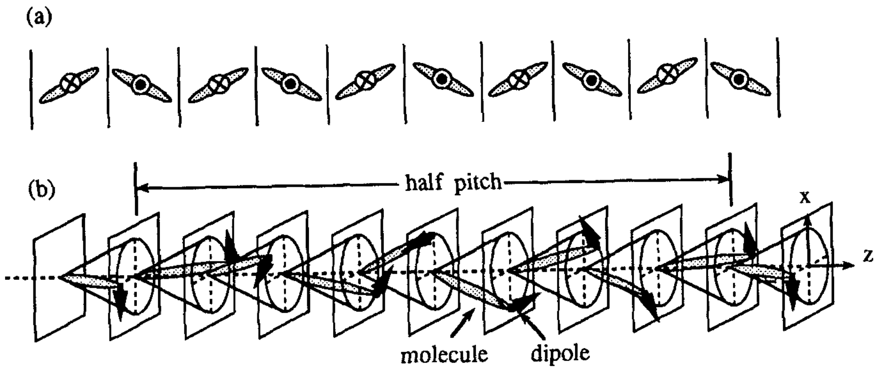

FIGURE 1 Molecular orientation in the antiferroelectric phase in (a) unwound state and (b) helical state.

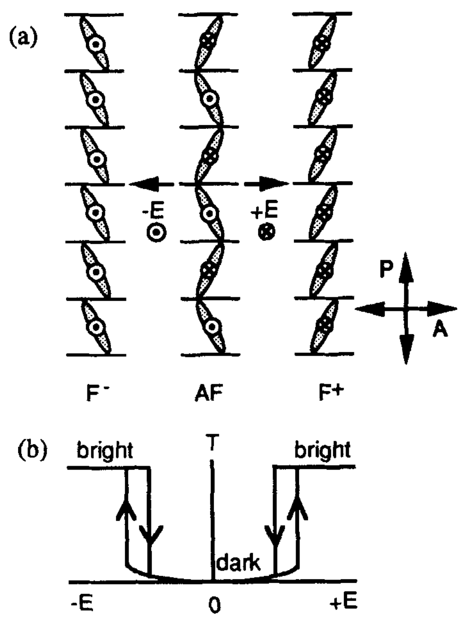

FIGURE 2 (a) Orientational change under an electric field and (b) the associated transmittance change.

associated transmittance change. By the application of an electric field parallel to the layer, the AF orientation changes to F orientations depending on its polarity, as shown in Figure 2(a). If a homogeneously aligned cell is fabricated between crossed polarizers, one of which is parallel to the smectic layer, high and low transmittance states can be obtained in F and AF states, respectively. Thus, the electric-field-induced AF-F phase transition is applicable to display devices. Two main characteristics are the sharp threshold behavior under a dc field between AF and F states and the hysteresis in the switching, bringing about a bistable device. The switching current peaks are observed at the voltages of the F-AF and AF-F switching and are equivalent to the double hysteresis in a D-E loop, which is characteristic to antiferroelectricity.

APPLICATION TO DISPLAY DEVICES

Using the above-mentioned characteristics, i. e., dc threshold and hysteresis, bistable switching is possible by applying positive and negative pulsed field. Figure 3 shows driving waveforms for multiplexing.[5] By applying an electric pulse of V_D in addition of a dc bias voltage of V_0, the transition to F^+ state is achieved, when $V_0 + V_D$ is larger than the threshold voltage V_{th}^H. For $-(V_0 + V_D) < -V_{th}^H$, F^- state is obtained. On the

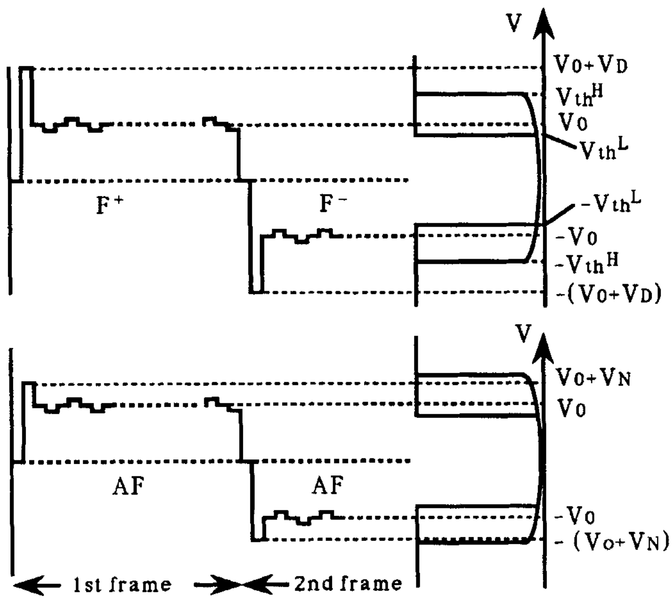

FIGURE 3 Driving waveforms for AFLCD.

contrary, AF state is stabilized for $V_0 + V_N < V_{th}^H$ and $-(V_0 + V_N) > -V_{th}^H$. You should note that the AFLC display (AFLCD) utilizes both F states, as clearly noticed by two driving frames. Two F states give the same transmittance, so that we can use them alternately. Thus, not only the AF state but also the F state are free from charge accumulation: the AFLCD is not suffered from ghost effect which is a serious problem in FLCD.

Another problem in FLCD is the weakness against mechanical shock because of the smectic layer structure. We found that AFLC cells have a remarkable feature of self-alignment recovery during an operation from damage caused by mechanical and thermal shocks.[6] This property originates from reversible layer switching between the quasi-bookshelf and the bookshelf structures associated with the AF-F switching. Hence the alignment recovers spontaneously while addressing each pixel. The non-chevron, i.e., the bookshelf or the quasi-bookshelf, structures give rise to additional advantage; relatively high contrast ratio of 20~30 is easily obtained.

What prevents AFLCD from achieving further higher contrast ratio is the pretransitional effect for the electric-field-induced AF-F phase transition, which appears as a slight increase of transmittance below the threshold voltage, as shown in Figure 2(b). The increase largely depends on materials. Therefore, the extensive search of materials including mixtures is necessary.

We can easily notice by observing the optical response upon stepwise field application that there exist two components, fast and slow, as shown in Figure 4.[7] The fast one is due to the pretransitional effect and is observed as a uniform color change under a polarizing optical microscope. The movement of the F-domain boundary is responsible for the slow one. The movement speed, namely the response time, τ, is

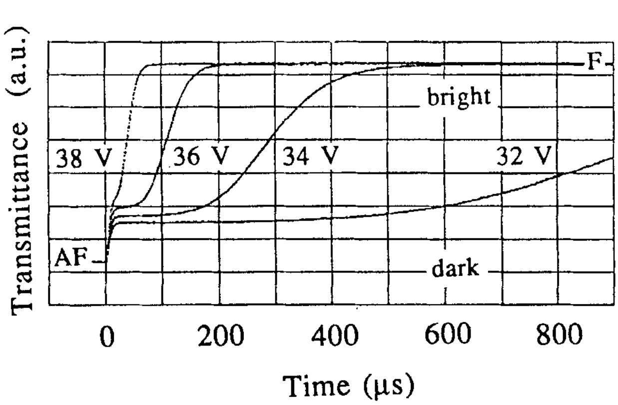

FIGURE 4 Optical response upon stepwise field application in an AFLC cell.

governed by the difference between the final and threshold voltages, $\Delta V = V_0 + V_D - V_{th}^H$.[7] Empirically τ is proportional to ΔV^{-n}, where n depends on material and is typically 4 (see Figure 6).[7] Thus, the field dependence of τ is very large.

In the 4th international ferroelectric liquid crystal conference (Tokyo, 1993), Nippondenso Co. Ltd. and Citizen Watch Co. Ltd. display prototype AFLCD's. According to the former presentation, full-colored TV image with a video-rate can be displayed with the contrast ratio of 20:1. Wide viewing angle of more than 60° from any directions is one of the attractive features.

APPLICATION TO SPATIAL LIGHT MODULATORS

Photoaddressed spatial light modulators (SLM's) are important devices for various optical data processings such as real-time holography and optical computing. Recently FLC is paid attension as one of the most promising materials for SLM which shows high-speed switching and the memory effect. AFLC must also be a promising material for SLM as well as display devices. Here we introduce our recent proposal for a novel photoaddressed SLM using AFLC.[8]

Figure 5 shows the principle of the AFLC-SLM. This SLM is fabricated using homogeneously aligned AFLC doped with photochromic dye molecules between ITO coated glass plates. On light irradiation the photochromic molecules are excited from trans to cis. This photoisomerization slightly distorts the orientation around dye

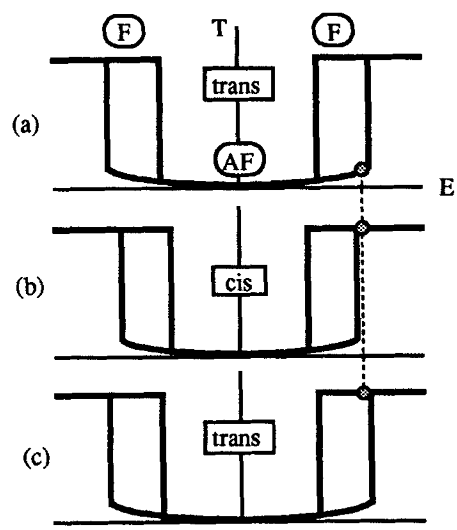

FIGURE 5 Principle of AFLC-SLM.

molecules and effectively decreases the order parameter, resulting in the decrease in the transition temperature. This transition temperature decrease brings about the descent of the threshold voltage for the field-induced AF-F transition, as shown in Figure 5(b). If the cell is under dc bias voltage just below the threshold voltage for AF-F transition, the transition occurs from AF to F by light irradiation. This F state is memorized after the Ar^+ laser irradiation is turned off because of bistability based on the hysteresis, as shown in Figure 5(c). Thus this AFLC-SLM is based on the photo-induced AF-F phase transition, and utilizes the same characteristics as the electric-field-induced one such as sharp dc threshold and hysteresis. Switching from F to AF can be achieved by turning off the dc bias voltage instantaneously. In this way, we can use this SLM repeatedly.

We have already shown in the binary system of TFMHPDOPB ((R)-4-(1-trifluoromethylheptyloxycarbonyl)phenyl 4-(5-dodecyl-oxypyrimidin-2-yl)benzoate)[9] with methyl red (4'-N, N dimethylaminoazobenzene-1-carboxylic acid) of approximately 2.5 mol% that the response time of 30 ms is achieved by irradiation of a 10 mW Ar^+ laser without focusing. The response time τ is governed by the photoinduced threshold voltage shift $\Delta V'$. As clearly shown in Figure 6, τ vs $\Delta V'$ obeys the same relation as τ vs ΔV for the electric response mentioned above.[10]

We have also demonstrated the recording ability of continuous gray levels by changing either light intensity or pulse duration.[8,10] Figure 7 shows the transmittance change by irradiation of Ar^+ laser beam of 90 ms duration with various powers, clearly

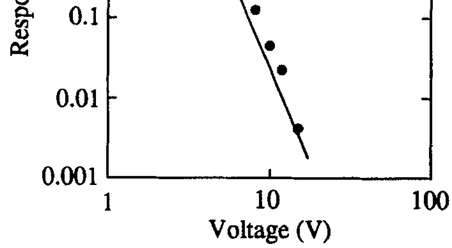

FIGURE 6 Response time of electric field induced AF-F phase transition (closed circles) and photo-induced AF-F phase transition (open circles) as a function of ΔV and $\Delta V'$, respectively.

substanciating the gray level recording ability. This AFLC-OASLM may not be suited for image storage devices, since a constant voltage has to be applied to the cell in order to memorize addressed images. Instead this may be applicable for real time holography. The performance such as the response time will be improved by choosing liquid crystals and photochromic compounds.

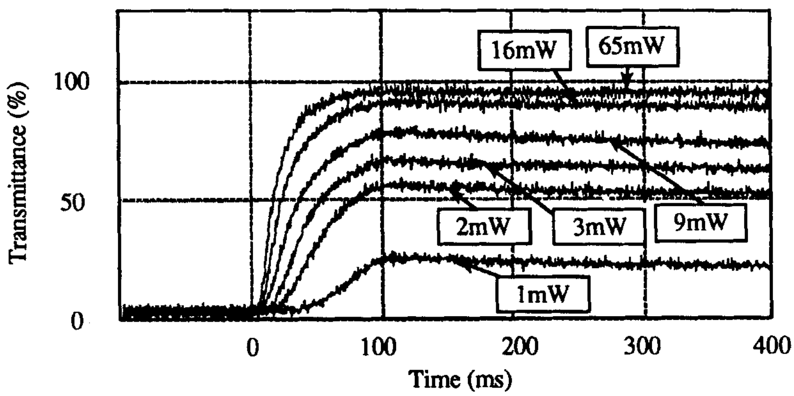

FIGURE 7 Dynamic response of AFLC-SLM upon irradiation of various powers of light.

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