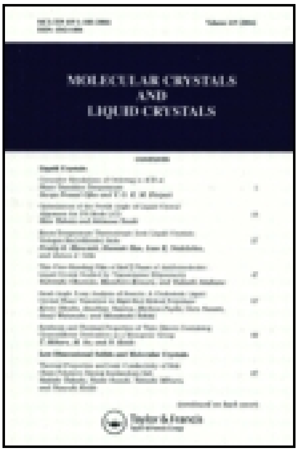

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Advanced in Development IR Modulators of Ferroelectric Liquid Crystals Utilizing Transient Light Scattering Effects

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ADVANCED IN DEVELOPMENT IR MODULATORS OF FERROELECTRIC LIQUID CRYSTAL UTILIZING TRANSIENT LIGHT SCATTERING EFFECT

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Abstract The highly efficient IR-modulation has been achieved using LC electro-optic elements. Experimental infrared modulator elements have been fabricated and demonstrated utilizing the transient light scattering effect of ferroelectric liquid crystal with asymmetric waveform voltage drive. The new elements performed 80%, 50%, 40% and 25% modulation degree in the 632.8nm, 2, 3-5 and 8-12 μm region. And we observed micro domain structure under the scattering state by a polarizing microscope to understand the mechanism of the domain switching. In addition, we evaluated properties of the scattering angular and temperature dependence quite important for the design of optics for the application in the infrared range.

1. INTRODUCTION

This research is based on the need to develop an liquid crystal (LC) electro-optic IR-modulators in order to interrupt periodically IR radiation and continuous output of IR detector such as pyroelectric sensors. They provide new functional application device, IR-imager or gas analyzers having no moving parts, fast response time and large optical aperture. The several LC elements was investigated but was not seriously considered from the point of view of the IR modulator design for the following reason (1)(2)(3). The twisted nematic effect makes low transmission due to requirement polarizers and long optical pass in the IR region. The dynamic scattering mode consumes large power to drive and is not expected long term reliability. The cholesteric-nematic phase change effect needs high voltage to respond fast.

The transient light scattering mode with ferroelectric liquid crystal (FLC) is also a viable modulator candidate(4). The TSM is the electro-optic effect using the transmission change at the instant of the domain switching by the polarity reversal of applied field. But the response time to rearrange from the scattering state is slow due to unwinding helical structure. Our key finding in carrying out the modulation is to use an asymmetric pulse drive in which the modulation degree was considerably greater than the normally square-wave drive. This effect is discussed in more detail below. This new type ferroelectric liquid crystal IR modulator offers an attractive solution.

2. EXPERIMENTAL

2.1 Preparation of the cell

Liquid crystals are essentially all organic molecules absorb infrared radiation. Certain work has been published on the infrared propertied of liquid crystals (3)(5). Our approach is to choose the FLC materials and measure the infrared transmission in the 2-12μm range. Response time depends on the spontaneous polarization. In the present experiments, the FLC Merck and Chisso which have 2-5 nC/cm^2 of the spontaneous polarization was employed .

And in the infrared region, liquid crystal having high temperature transition point have to be used to be stable under IR radiation. For that reason, we selected FLC materials having Curie point higher than 60℃. The liquid crystal cell with 100 μm thickness has been constructed by quartz crystal plates with ITO membrane which were separated by polyester film spacer for the measurement in the visible and near IR region. And also FLC was held between two optically flat silicon substrates with anti-reflecting coat which were sufficiently transmitting IR and conducting to serve as electrodes. By application of surface treatments of cotton rubbing, the molecules are aligned and the helical axis of smectic C* layer of FLC are oriented parallel to cell surface (homogeneous alignment).

2.2 FLC modulation experiments

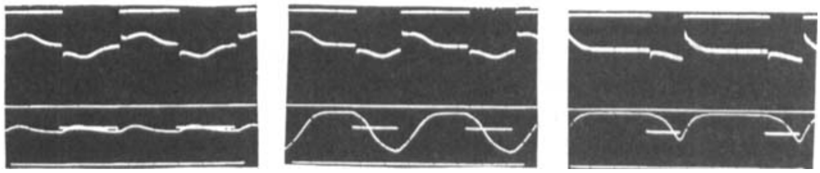
A NF 4310 high voltage amp was used with HP8225 signal generator to provide the waveform. Tektronix 7834 storage oscilloscope was used to monitor the waveforms. The modulation degree defined with the difference between the transmitted and scattered light intensity of a He-Ne laser light (632.8nm) through a cell was monitored with PIN photo diode. And the IR experimental setup included a black body radiation source used with separate band-pass filters covering the 2, 5 and 10 μm and Belov Technology HgCdTe sensor to detect the 2-10 μm IR. And the evaluation of the scattering angular dependence was employed the ceramic heater as the light source and Shimadzu PLT LiTaO3 pyroelectric sensor.

3. RESULT AND DISCUSSION

3.1 Asymmetric pulse-wave drive

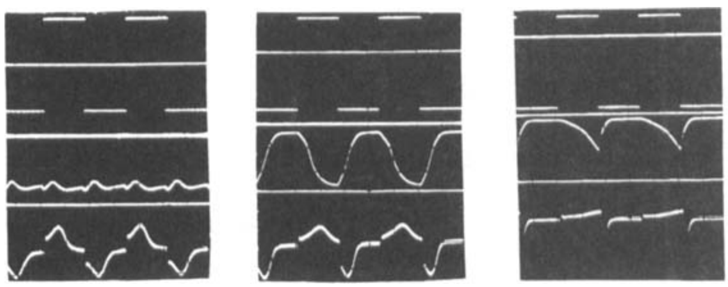
According to TSM, by the application of dc bias voltage, the helical structure of FLC is unwound and appear the transparent state. When the polarity of the applied field is reversed, the direction of spontaneous polarization is reversed and the high transmission state through the cell become opaque state quickly derived from the turbulence which is considerably associated with the helical structure of FLC. Therefore the applied square drive allow continuously switching between the transparent and opaque state. So that, two sorts of the transparent states exist on both of the polarity sides. But this drive method can not follow the fast switching because of slow response to unwound the helical structure.

Figure 1 provides a summary of the results obtained from the FLC cells measured in the visible region, using the normally square-wave drive (a) and rectangular-wave drive with the 60% duty ratio (b) and 70% duty ratio (c). Figure 2 shows the same modulation results as fig.1 obtained from the FLC cells driven at square wave with bias voltage , using the normally square-wave drive (a) , with 10V bias (b) and with 20V bias (c).This asymmetric operation introduced remarkably higher modulation degree and faster response of light switching than that by means of 50% duty ratio without dc bias voltage of square wave drive. The modulation degree is found to be obtained maximum 80% under these asymmetrical method.



(a) (b) (c)

Fig.1 Oscillograms demonstrating modulation of He-Ne laser radiation at controlled rectangular wave voltage. Upper trace corresponds to polarization reversal current, 80V peak-peak, 70Hz :, (a) duty ratio 50% (b)duty ratio 60% (c) duty ratio 70%). Modulation output provides lower trace between two lines. (Top line is transparent without LC cell, lower line is completely blocked light beam).



(a) (b) (c)

Fig.2 Oscillograms demonstrating modulation of He-Ne laser radiation lower trace corresponding to polarization reversal current wave at electrically controlled rectangular wave voltage (80V peak-peak 70Hz : (a) bias 0V (b)bias 10V (c) bias 20V). Center trace is modulation output between two lines. Top line is transparent without LC cell, lower line is completely blocked light beam.

But the excessive duty ratio or bias voltage reduced the modulation degree.

Figure 3 indicates, for example, the dependence on the duty ratio. By the way, compared with (a) method,the asymmetric drive provide the transparent state at an alternative side of the voltage polarity , while the other side is still opaque state. This result suggests that higher contrast arose from unsuccessful domain switching due to interruption of the growth of reversed scattering domain(6). The polarization reversal current also depends on this drive waveform, showing even (c) state which was observed little polarization reversal current peak occurring on the transient light scattering phenomenon, which means that only certain parts of

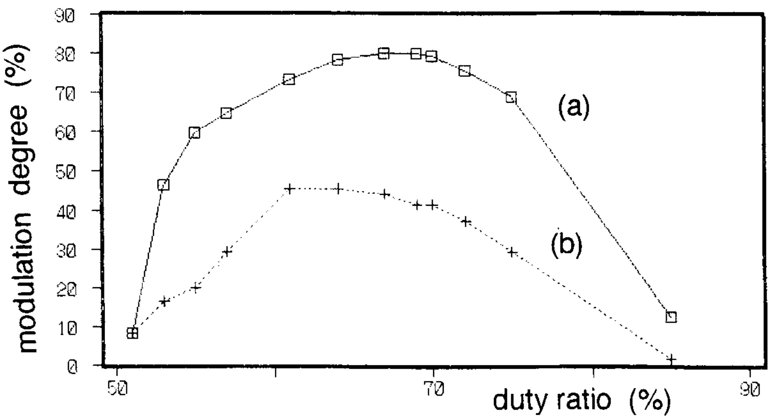
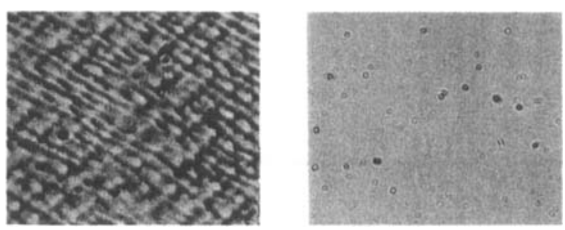


Fig. 3 Dependence of modulation degree on the duty ratio of rectangular pulse with two kinds of FLCs, (a) MERCK ZLI4237 (b) ISC-103 Chisso

bulk of FLC would contribute to the high and fast scattering domain switching(7).

And we observed micro domain structure under the scattering state by polarizing microscope to understand the mechanism of domain switching,as shown fig.4. Fig.(a) corresponds to the opaque state with transient light scattering structure and fig.(b) corresponds to the transparent state with dc voltage drive.



(a) (b)

Fig. 4 Polarizing microscope photographs of FLC showing (a): opaque state transient light scattering structure (b): transparent state with DC voltage drive.

As shown (a), many micro domains having dimensions of about 5μm appear at the scattering state. This domain would derive light scattering as turbulence grains. The light scattering in liquid crystal has been interpreted as a 'Tyndall' (3) effect with three parts of areas. Firstly, when the scattering regions are large compared with the wavelength, the amount of scattering is independent of wavelength. Secondly, when the scattering regions are of the same order as the wavelength the scattering intensity is a maximum (Mie scattering). thirdly, when the scattering regions are smaller than the wavelength the total amount of scattering decreases as λ^{-4}. The result as shown fig.1, 2. suggests that the scattering grains size may be different among the drive condition , duty ratio or bias voltage because of the different scattering intensity. That means TSM have the potential use at longer wavelength, if the scattering region size is optimized to obtain the maximum scatter at the desired wavelength under controlled drive condition.

3.2 IR-modulation

Figure 5 show the result of the measurement of the modulation degree with various applied rectangular wave voltage at 63% duty ratio and 90 Hz drive frequency,employing the three different kinds of FLCs.

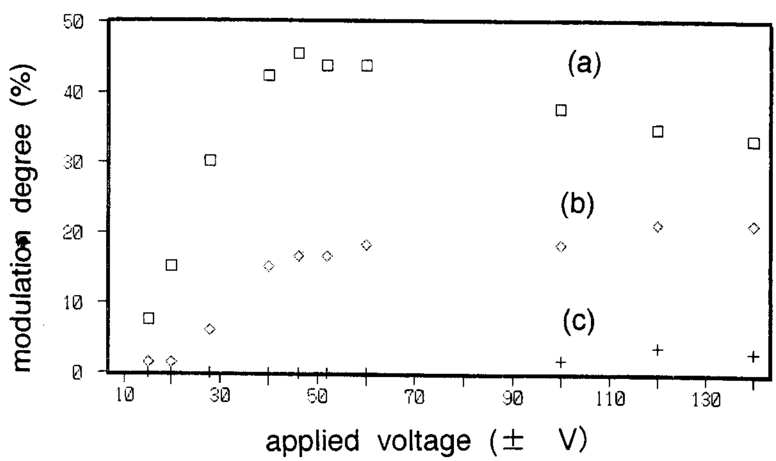


Fig. 5 Voltage dependence of modulation degree at 2 μm wavelength with various FLCs. FLC: (a) Merck ZLI 4237 (b) Chisso cs1014 (c) Chisso cs1017

The property of them gave different transition temperature, spontaneous polarization and helical structure etc. Indicating as the behavior of the material (a) and (b), extremely turn out lower in the modulation degree as decrease in the applied field above threshold (about ±5V at 100μm thickness), while almost independence of the voltage under higher voltage drive. From these result, the size of the scattering regions would considerably change at low applied field . There may be scattering grain to apply to the λ^{-4} law. Figure 6 is the polarizing microscope photograph of ZLI 4237 as fig.5 (a) material showing the dependence on the applied voltage with 600Hz square wave . But unfortunately in the present study, we could not observe the instantly appearing micro domain under the asymmetric drive method.

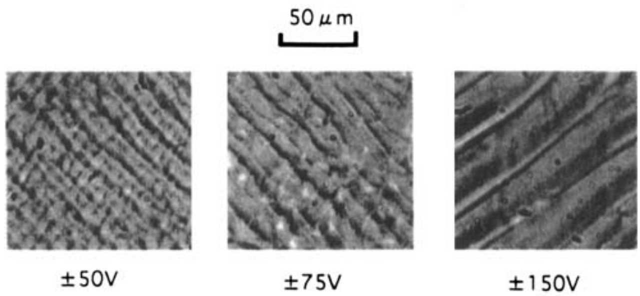


Fig. 6 Polarizing microscope photographs of scattering structure of FLC Merck ZLI 4237 at different square wave drive voltages, (a) ±50V (b)± 75V (c) ±150V, frequency 600Hz.

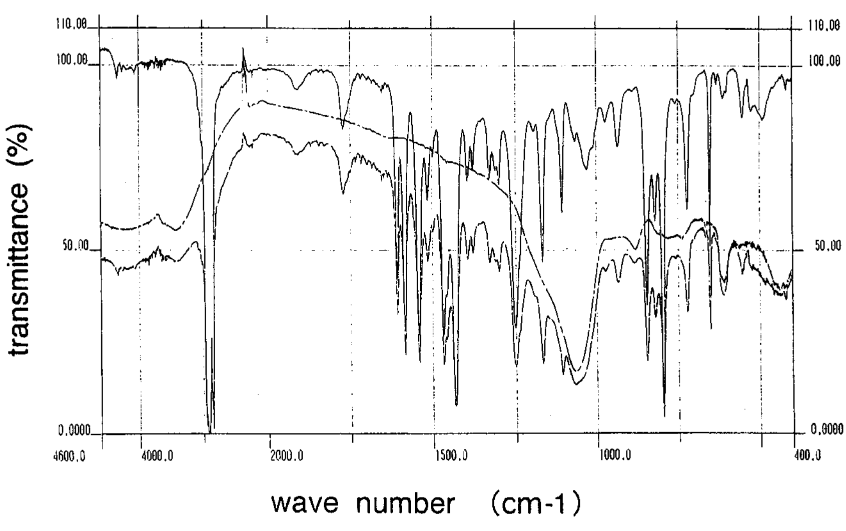


Fig. 7 Curve a : infrared transmission spectrum of FLC with BaF2 windows, curve b : transmission of the empty cell, curve c : transmission of FLC held in a 100 μm cell for 3-5 μm modulation.

The figure 7 shows infrared transmission spectrums of FLC employing ZLI 4237 with BaF2 window, the empty cell and FLC held in a 100μm cell for the 3-5μm modulation. As shown spectrum (c), there was enough high transmission to introduce the high modulation degree.

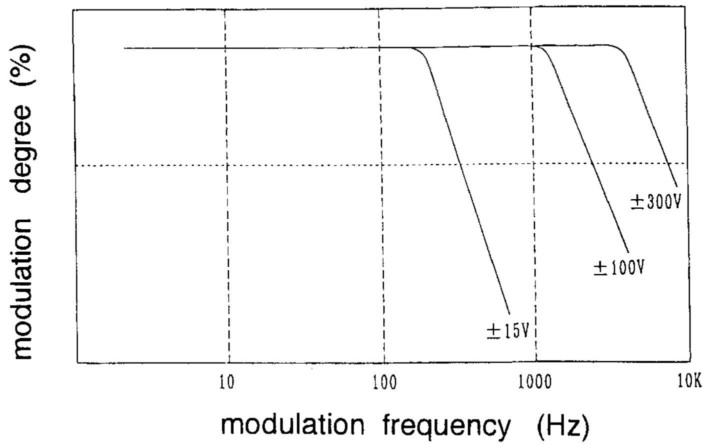


Fig.8 Dependence of modulation degree on drive frequency as a function of drive voltage with IR modulation

The performance of this elements was exhibited as fig.8. Dependence of modulation degree on drive frequency indicates the achievement of the 40% and 5kHz modulation at ±300V , 60% duty ratio drive.

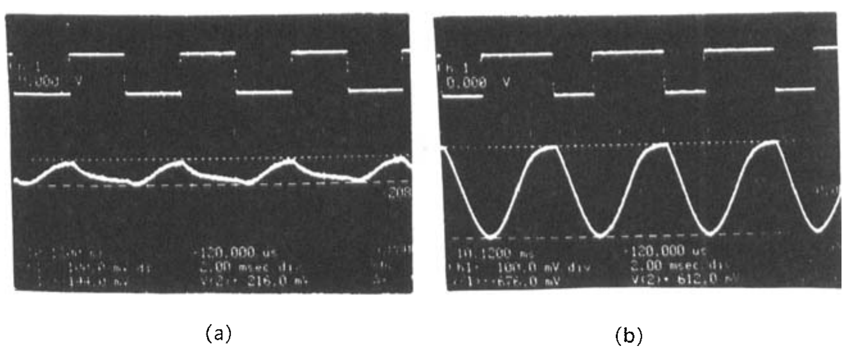


Fig.9 Oscillogram demonstrates IR-modulation output at 5μm wavelength of silicon cell with 100μm thickness under rectangular wave voltage, (a) duty ratio 50% (b) duty ratio 60%. (Top trace and bottom trace corresponds to drive waveform and modulation waveform respectively.

Normally TSM was supposed to need high electric field to drive but even lower applied voltage (±20 ,200Hz,60% duty ratio) which is quite important for the application has also found to provide sufficient modulation as shown fig.9. Those results suggest that the highly scattering grain derived from the low voltage drive on the present method induced the efficient modulation. The detail about the relation between the applied voltage and the size of the scattering domain is not clarified yet.

The modulation in the 10μm region was also evaluated and resulted in 25% modulation degree caused probably by the strong IR absorption due to the intra-molecule vibrational modes of FLC occurring in the 7-14μm.

3.3 Angular dependence

Figure 10 shows the result of the measurement of the angular dependence of the modulation degree in the 3-5μm region employing the ZLI4237 FLC under ±20 ,200Hz,60% duty ratio pulse drive method. There was a broad peak after decrease in the modulation degree as increase in the set up angle.

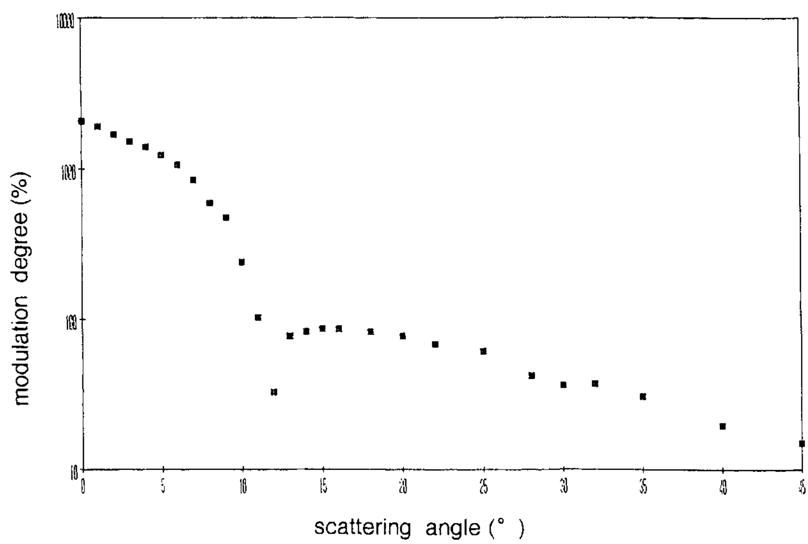


Fig. 10 Scattering angle dependence of modulation signal output with pyroelectric sensor in the 3-5μm region.

This suggests that the mainly scattering angle was included in the 10-15° low angle which would be related with a part of the fast response domain switching(6)(7). Firstly, the director in bulk rotates allows the fast response of scattering and secondly, the nucleation and the growth of the reversed domain occurs on the cell surface slowly to complete the reversal of the spontaneous polarization. In our present method to modulate IR, the corresponding fast stage may contribute to the domain switching.

3.4 Temperature dependence

Modulation degree was found to be flat under 25-42℃, decreases on lower temperature due to slower response to applied field because of increase in the rotating viscosity and slightly decreases on higher temperature also due to slower response because of decrees in spontaneous polarization approaching the Curie point. In addition,the scattering intensity was influenced by the nature of FLC, dependence of helical structures.

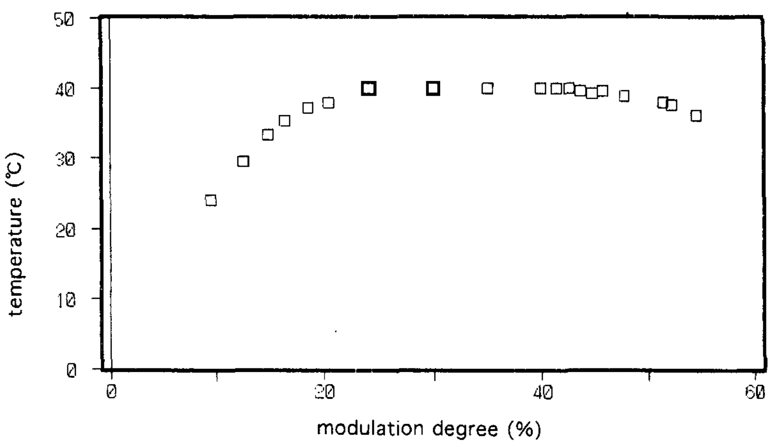


Fig. 11 Temperature dependence of IR-modulation degree.

This FLC have 60℃ of Curie point which has to be set point by selecting material especially for IR application to require wide temperature margin .

4.CONCLUSION

The highly efficient IR-modulation has been achieved using the asymmetric waveform voltage drive. The new elements performed 80%, 50%, 40% and 25% modulation degree in the 632.8nm, 2, 3-5 and 8-12 μm region. And we observed micro domain structure under the scattering state to understand the mechanism of domain switching. In the preset study, we could not observe the strong scattering grain on the new method. The detail about the relation between the applied voltage and the size of the scattering domain would like to be clarified next. In addition, we evaluated the dependece of the scattering angle and found to be the origin of the fast switching. We also measured the temperature dependence.

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