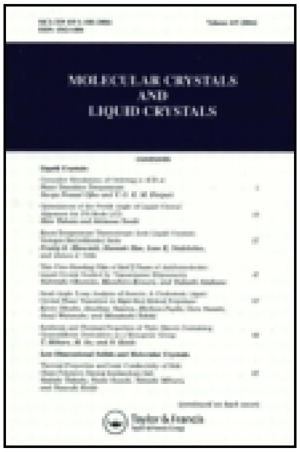

Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics

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Monitoring Electric Field Induced Refractive Index Changes in Liquid Crystals with Polymer Lightguides

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MONITORING ELECTRIC FIELD INDUCED REFRACTIVE INDEX CHANGES IN LIQUID CRYSTALS WITH POLYMER LIGHTGUIDES

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Abstract The evanescent field of guided modes is used to monitor electro-optic properties of polymer/liquid crystal interfaces. This investigation leads to electrooptic modulations up to 20 kHz.

INTRODUCTION

Liquid crystals have a large electrooptic anisotropy, which can be switched by electric fields. However in the interfacial region between the polymer and the liquid crystal there is a zone of preorientation[1], which can hardly be influenced by an external field[2-3]. In this study we investigate:

- the influence of different profiles in the liquid crystal cell on traveling modes in adjacent polymer lightguides
- the electrooptic behavior of the interfacial region
- the coupling between 2 polymer lightguides through a gap filled with liquid crystal.

EXPERIMENTAL

The experimental arrangement for the combination of polymer lightguides with liquid crystals is shown in Figure 1a for the modulator and in Figure 1b for the coupler.

The electrode material is indium-tin-oxyde (ITO) on glass[4]. As polymer lightguide materials we use poly-(α-methylstyrene) (PαMS) or a fluorinated polyimide. The buffer layer of poly(vinylalcohol) (PVA) is chosen thick enough to separate the lightwave from the lossy electrode (ITO) material. For a 2 μm thick PVA layer loss values of less than 0.1 dB/cm are obtained for the polymer lightguide PαMS/PVA/ITO/glass.

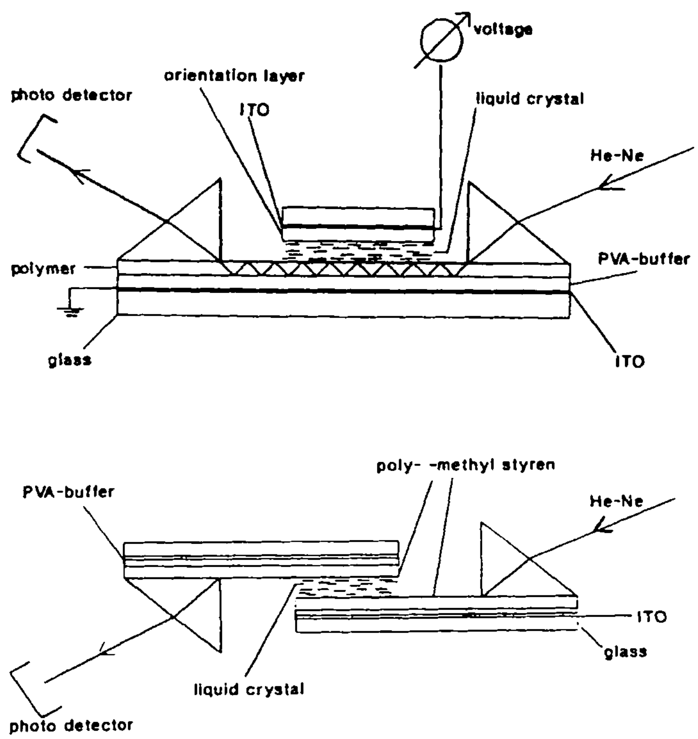

FIGURE 1 a) polymer lightguide/liquid crystal electrooptic modulator
b) polymer lightguide/liquid crystal electrooptic coupler

For the coupler we produced 2 planar polymer lightguides of the same structure.

The mode spectra of both guides should be identical. Measurement of effective mode indices indicate a maximum deviation of $\Delta N_i = 5x10^{-4}$ for $i = 0 \ldots 5$. The optical coupling is achieved through an air gap first. As a function of the distance between the 2 guides 2 full cycles in the out-coupled intensity can be observed. Finally the air-gap in the coupling region is filled with the liquid crystal (LC). Commercially available nematic liquid crystals ZLI-3926 (Fa. E. Merck) with high positive anisotropy ($\Delta\varepsilon \approx 16$) are used for this investigation. The ordinary and extraordinary refractive indices of this material are 1.52 and 1.72 resp. Thus the refractive index of the polymer lightguide is intermediate: 1.6 (PαMS) and 1.54 (polyimide). The superstrate index (LC) of our lightguide can be altered from below (1.52) to above (1.72) the guide index.

RESULTS AND DISCUSSION

The orientation of the mesogenic units in an applied external electric field is mainly caused by induced dipole effects. In order to achieve electrically induced refractive index profiles an AC electric field is applied. This avoids hydrodynamic instabilities.

Modulating with the refractive index profile

Homogeneous refractive index profiles in a LC cell require a uniform pre-orientation. This is usually achieved by a propriate polishing treatment in a certain direction. In our waveguide/LC-cell the direction of microgrooves (polishing) determines the polarization to work with. In the following we restrict to a polishing direction parallel to the direction of the guided wave. In this case the modulator is only transparent for the TM polarization. The transparency of the modulator or the observed intensity at the out-coupling prism can be modulated by the applied voltage.

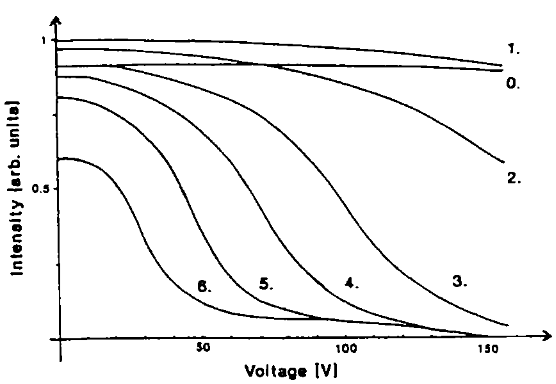

FIGURE 3 Light intensity for different TM modes, transmitted through an LC modulator

For an AC voltage (100 Hz) the transmission of different TM modes is measured and the results are plotted in Fig. 3. For the modes m = 0 and m = 1 there is only a small influence of the applied voltage. Higher order modes (m = 3 ... 6) can be influenced strongly. With U = 30 V the mode m = 6 has decreased to less than one half of the value for U = 0. If we increase the resolution in Fig. 3 there appears a certain level in the voltage. Below this level of U ≈ 3 V there is no change in the transmitted intensity detectable, but as soon as this voltage level is crossed the drop in the observed out coupled light intensity appears. We think, this is an indication of a refractive index profile building up above this voltage level. The different modulation effect on the different modes is related to the increasing evanescent field with the mode number. The decreasing intensity at the output prism with increasing voltage is due to a continuous rise of the refractive index profile in the LC cell area. The refractive index in the LC cell is switched to 1.72 for the TM modes, which is higher than the polymer film index. Thus we introduce a "leaky superstrate" with higher voltages, separated from the polymer film by a thin interfacial region.

The frequency of 100 Hz, used to measure the characteristic curve light intensity versus applied voltage of Fig. 3 was high enough to avoid any hydrodynamic instabilities. There is over all no change detectable using higher frequencies. With the knowledge of Fig. 3 we can switch a guided optical TM mode. This is shown in Fig. 4.

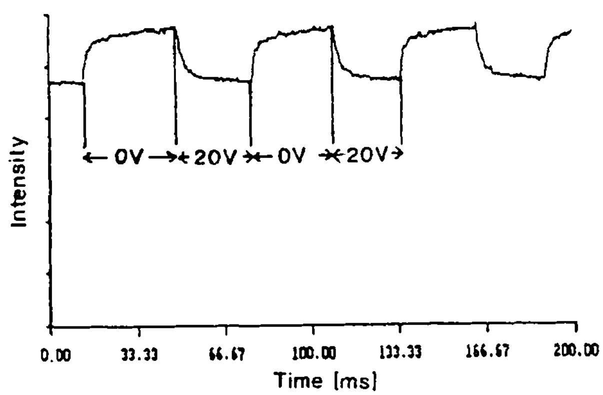

FIGURE 4 Switching a TM mode with a 20 V AC voltage (300 kHz)

Modulation with the interfacial region

In the previous chapter we got the best modulation with the higher order modes (m = 3 to m = 6). With an increased resolution of the output signal a superposed modulation is detectable. Especially for the low order modes m = 0 or m = 1 we find a modulation up to 20 kHz.

The efficiency of a modulator is usually characterized by a modulation depth $\Delta I/I_0$ with ΔI = modulated intensity and Io = transmitted average intensity. In Fig. 5 the modulation depth for the modulator according to Fig. 1 is given as a function of modulation frequency. Above 100 Hz the transmitted intensity is almost independent of the frequency and the magnitude is few percent of the incoupled light.

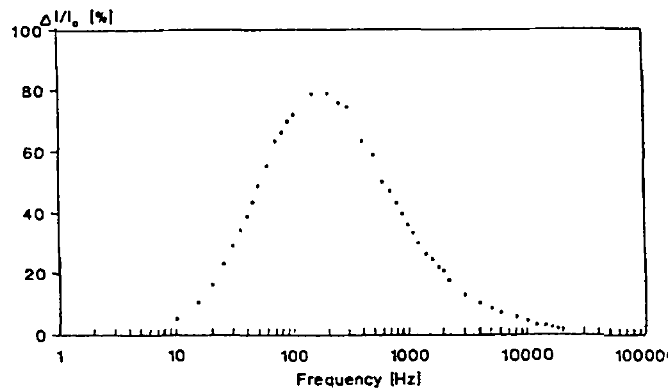

FIGURE 5 The obtained modulation depth for a polymer lightguide/LC modulator, m = 0.TM

The modulation depth reaches a maximum at about 200 Hz. I_0 decreases with increasing frequency reaching a saturation value at 200 Hz. An interesting result is the observation of a reasonable modulation effect up to 20 kHz. Although the amplitude of these modulations is small compared to the 200 Hz region the obtained signals are well resolved and reproducable. This result is quite interesting because from bulk experiments with nematic liquid crystals modulations above 1 kHz are not reported.

A typical modulation is shown in Fig. 6 for v = 1 kHz. The modulated signal appears at the double frequency due to the induced dipole moments. An anisotrpy appears for the positive and the negative half waves of the generating AC signal. Switching a square voltage this anisotropy can be detected as well.

For a DC voltage of ± 130 V two different levels of out coupled intensity and different relaxation times can be seen from the results shown in Fig. 7.

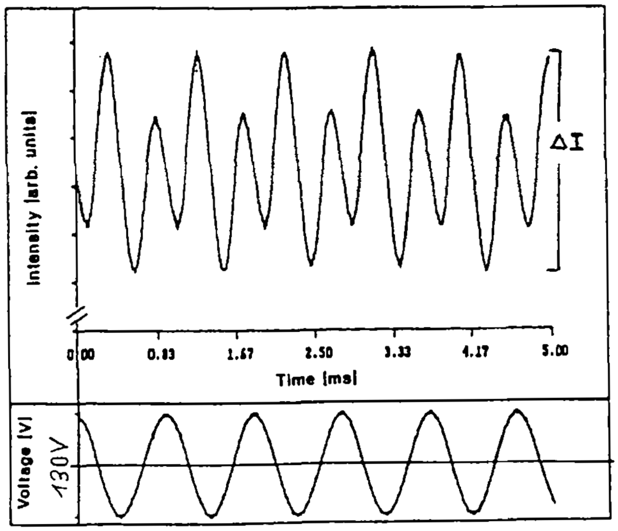

FIGURE 6 Modulated output signal (above) for the m = 0 TM mode and the corresponding voltage signal (U = 140 V, 1 kHz), taken from a digital oscilloscope

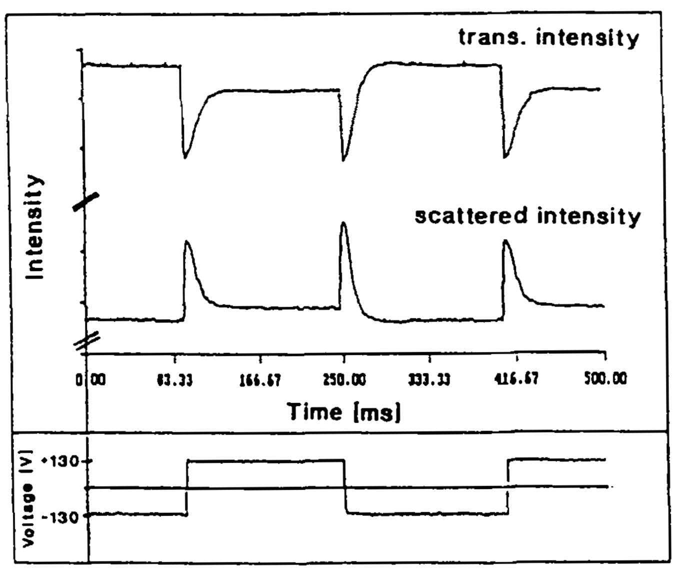

FIGURE 7 Modulating with a DC voltage
top: out coupled intensity
middle: scattered intensity
bottom: external voltage (ν = 3 Hz, DC, U = ± 130 V)

The complementary behavior of scattered light and transmitted light is obvious in this Figure. The relaxation times τ depend upon the mode index. With higher mode indices these relaxations become slower. After switching the voltage on there is a relative fast response in the range of 10^{-4} s. This is the magnitude of the capacitive time constant of the LC cell $\tau = R \cdot C$.

The fast modulation we observed is probably limited by this response time. The mode dependence indicates the origin of the process to be localized in the interfacial region between the polymer film and the LC cell, which is the region of preorientation. In this space charge zone electric double layers are reported to form when there are different amounts of mobile positive and negative charge carriers[5,6]. This interfacial region produces high local electric fields, which act on the mesogenic units of the LC molecules. Switching the voltage on such a double layer produces currents which finally lead to another equilibrium state. Thus the electrooptic response is limited by space charge currents.

<u>Electrooptic modulated coupling</u>

With the arrangement of Fig. 2 we achieve optical coupling between the 2 polymer lightguides through an air gap. Then this gap is filled with liquid crystals forming a thin (< 1 µm) LC cell in the gap region. In this cell the electrooptic properties are dominated by the interfacial regions.

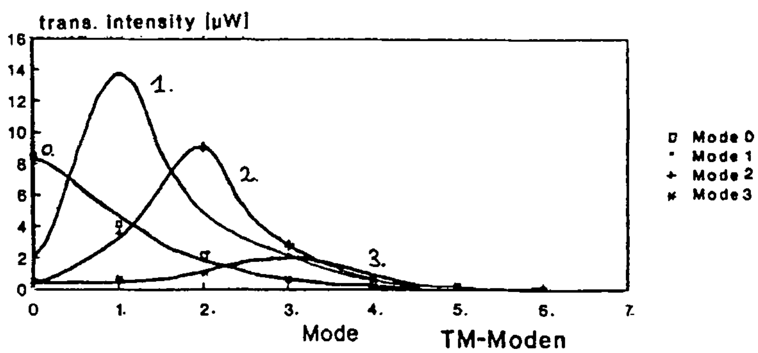

FIGURE 8 Mode conservation in the polymer/LC coupler

With the LC filled cell in the coupling area the conservation of modes is still found, as can be seen in Fig. 8. The modulation characteristics of the coupler arrangement is quite similar to that described in the chapters 3.1 and 3.2 for the modulator. the fast modulation, caused by the interface regions is more dominant in the coupler.

CONCLUSIONS

A multilayer structure using polymer lightguides/buffer layer/ITO/glass is characterized to give low loss optical lightguides in the vicinity of planar electrodes.

With the 2 arrangements modulator and coupler combinations of polymer lightguides with liquid crystal cells are presented which lead to mainly 2 results:

- Slow electrooptic switching is demonstrated for a modulator and a coupler setup using refractive index profile modulation.
- In the interfacial region local charge fluctuations allow faster modulations up to 20 kHz. On the other side a traveling lightwave can be used for monitoring electrooptic fluctuations in the interface zone.

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