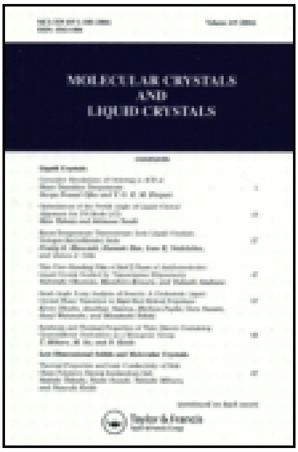

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LIQUID CRYSTAL LIGHT ATTENUATOR FOR FIBER OPTIC NETWORK

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Abstract An ellectrically controlable optical light attenuator operating on the light scattering effect in a liquid crystalline cell was arranged for optoelectronic applications and examined. Its optical properties and performance are presented and discussed.

INTRODUCTION

Many of the current optoelectronic systems have to be feed by stable light sources. However, a semiconductor lasers used now in major part of optic applications show significant fluctuations of light power. One of the simplest method of light level stabilisation is the use of an electrically controlled optical power attenuators. The addressable light attenuators are also useful in automatic control, measurement and sensing optics. As most devices working in optoelectronic systems the attenuator should satisfy some general requirements, as miniaturisation ability, low driving signals, low cost. Actually, the electrooptic devices based on liquid crystalline (lc) light modulators usually comply with this conditions. However, all the interference devices utilising controlled birefringence of liquid crystals as applied to light power modulation have to be provided with external polarizers situated outside in the modulator structure. Such a structure needs two separate electrodes and two polarizers in addition to the birefringent layer. This complexity of the interference devices impedes their integration with waveguide network. Therefore, much more convenient for this purposes are the lc modulators which work on light scattering effects, as for example PDLC devices.

Recently, we have demonstrated [1] lc light modulator also based on the light scattering principle, which we have named the scattering liquid crystal cell (SLC). The device in its basic version has a typical sandwich geometry, however, in the SLC, the cell-forming glass plates strongly scatter the incident light. I our case, the scatter texture was produced on the internal surfaces of the both cell electrodes as parallel scratches of irregular dimensions and surface density. Refraction index of the substrate glasses was matched to either ordinary (n_o) or extraordinary (n_e) index of the lc material. Obviously, the propagating light is scattered if a pronounced optical interface exists in a transparent medium. This situation correspond to the case in which the index of refraction of the glass plates carrying the scattering texture differs from the effective n value of liquid crystal layer. However, if they are close to each other, the scattering of the light does not occur because optically neither the interface between the lc layer and the glass substrate nor the scattering texture exist. Since the voltage applied across the cell reorients lc layer and changes its effective refraction index between n_o and n_e , thus it switches the SLC states from scattering to transparent one or vice-versa.

In the present work we have combined the SLC modulator with fiber optic waveguides, taking care to integrate all elements as large as possible. Therefore the problems, which we have had to solve before we could apply our SLC modulator to fiber optic network , were:

1. simplifying the structure as far as possible,
2. miniaturising the modulator,
3. obtaining acceptable device performance by maintenance of the above two conditions.

THEORETICAL APPROACH

The interface between two transparent media will scatter the incident light under the two conditions:

1. if $h \sin\alpha > \lambda/8$, where α is the angle of incidence, λ the wavelength, and h is the height of surface irregularities,
2. if the adjoining media are optically different, what differentiates theirs indices of refraction, $n_1 \neq n_2$.

The first condition is known as the "Rayleigh criterion" of surface roughness and is rather qualitative. It expresses the fact that the effect of scattering depends not only on surface properties , but on light and way of its incidence, as well. The second condition should be quantitative in describing how depends the intensity of scattered light on optical parameters of a scaterer.

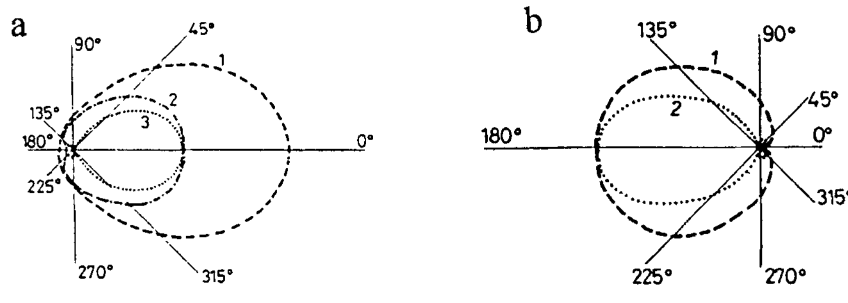

FIGURE 1 The polar diagrams for Mie (a) and Rayleigh-Gans (b) scattering; the curves 1,2,3 are for various incident light polarisations.

The general and exact solution of this problem is not yet found [2]. However, simplifying the reality, the scattering phenomena can be categorised in several specific types, described by different approaches. If the both conditions are obeyed, scattering will appear and optical energy will be dispersed in all directions over the sphere although certain directions may be privileged receiving more energy than others. The angular distribution of scattering light depends on the type of scattering. We assume, the scattering in the SLC modulator can be described in terms of Mie approximation, as Rayleigh-Gans scattering or as a transient type, depending on how the scatter texture of the cell was prepared. Fig.1 presents, after [3], polar diagrams for Mie (a) and for Rayleigh-Gans (b) scattering. The transient type would show a symmetric loop over the axis of incidence composed partially from plots a and b.

In determining of the intensity of scattering field the profile of a scatter texture is of prime concern. If an approximate assumption of random, zero-mean-value normal distribution of the height h of texture irregularities over the contributing area is in our case sufficiently justified, the total scattering intensity in the central field can be written[2,4] as:

$$I = I_0/N + [I_0 - I_0/N] \exp\{k^2 s_h^2 (n_1 - n_2)^2\} \qquad (1)$$

where: N- number of scratches in a contributing texture, $k=2\pi/\lambda$ - wave number, s_h^2 - standard deviation of surface irregularity, and I_0 - light intensity in the cell transparent state.

For a different profile distributions the expression may change, but in all cases the intensity of scattering substantially depends on the relative index of refraction n_1/n_2 at the scatter interface. If N is large, eq.1 transforms to :

$$I = I_0 \exp[k^2 s_h^2 (n_1 - n_2)^2] \qquad (2)$$

For low N values the assumption of gaussian texture statistics loses the validity.

EXPERIMENT

In order to miniaturise and simplify the attenuator we have reduced the number of its elements by joining in one element the beam forming function (i.e. focusing, indispensable for fiber optic connections) with light modulation. Namely, a scatter texture was made directly on a front plane of the gradient-index lenses (selfocs), used in our devices. The selfoc planes were polished unidirectonally until they became mat. However under microscopic examination they showed parallel grooves and scratches of various size and density. Thereafter the selfocs were cleaned and coated with ITO electrodes in a standard sputtering process. Next we have imposed the desired surface orientation by typical surfactants and rubbing. Estimate thickness of the all auxiliary interlayers was much less than λ. Finally we could set our attenuator together , which then consisted of only two selfoc rods, simply on an optic table, fixing theirs position by precise Sensomed manipulators. The distance between the selfos electrodes was set to about 30 μm and the gap was filled with the liquid crystalline 6CHBT, commercially available positive nematic having n_o=1,52 and n_e=1,67. Here is reasonable to mention, that we have experienced a few technological problems with preparation of the above version of the SLC modulator. They arose owing to the selfocs small size and fragility. Several of them , damaged during treatment we have lost, although it was taken great care by all operations and they were pasted for protection in a special glass holder. Thus, in order to prevent damages, one version of the modulator was made with the selfos rods mounted in a permanent support.

RESULTS AND DISCUSSION

The above described symmetrical version of the attenuator pertain best for a fiberoptic applications. Unfortunately, under examination it showed a minor performance; it worked not as good, as we expected, on account of its low contrast particularly. The reasons of unacceptably high light losses in the device presumably were:

- microdamages of the selfoc front planes, which we did not avoid during polishing, and resulted disordering of the lc layer,
- certain dismatch between refracting indices of the given selfocs and liquid crystal in the transparent state, since we did not dispose at the time of the specially composed lc material.

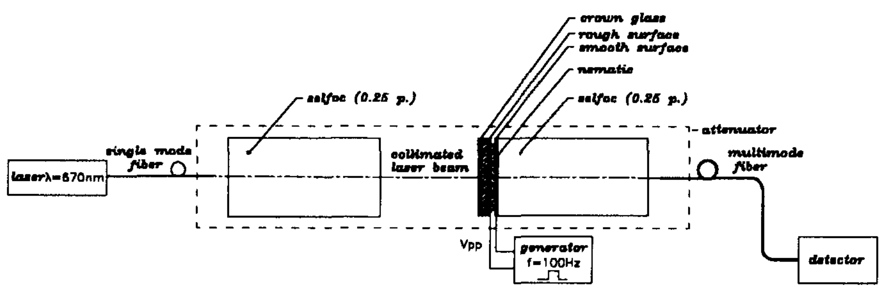

FIGURE 2 Experimental setup consisted of the attenuator with fiber optic connections, laser and detector.

The obstacles could have been temporary overcome by changing the symmetric geometry of the modulator onto asymmetric one. Namely, we have replaced the both mated selfocs - one by immune, transparent one and the other by mated piece of optical glass (Crown BK7, n_g=1.52) selected according to the desired refracting index in regard of the lc material, as it is shown in fig.2. The asymmetric version of the attenuator showed acceptable light losses of the order of 2 dB in relation to the direct-beam measurements. Thus the modulator was connected with a piece of the 200 μm core receiving multimode optical fiber clad-polymer (fig.2) and was put into examination on the whole as attenuator, although measurements were also carried for the separate modulator.

The voltage-transmission characteristics for two orthogonally polarised beams are presented in fig. 3. As we have already discussed [1], the modulator is polarisation-sensitive in the sense, that it modulates only that component of the incoming light which is polarised in the plane determined by optical axis rotation of lc layer ("in axis" curve in fig. 3) while the orthogonal component propagates throughout the device unaffected (remaining curve in the fig.3).

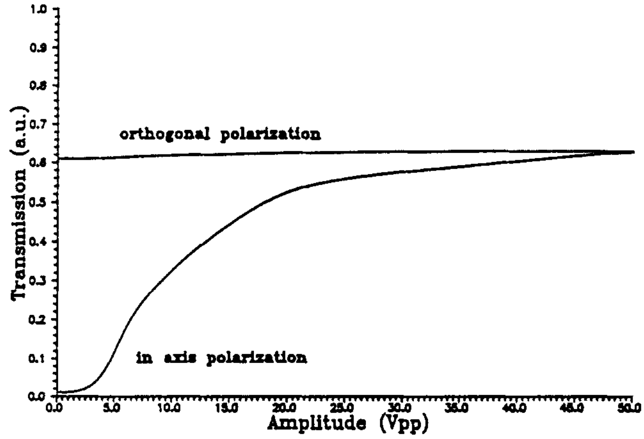

FIGURE 3 Voltage-transmission dependence for the attenuator for the both orthogonal polarisations.

The modulating selectivity with respect to the light polarisation can be inferred also from figs 4a, 4b, which demonstrate the angular intensity dependence of the beam passed through the device by two driving voltages for the both selected polarizations. From this (and the succeeding) measurements it can be presumed that in the effect of scattering the light energy is rejected out of the front field of the modulator (total integrals of the curves seem to be not equal) . It must be then directed to some other angles of the sphere. In the measurements we could see the symmetrical fan of back scattering, resembling the polar diagrams from fig. 1.

The average contrast value of the attenuator calculated from the above measurements by comparing the extreme points of the voltage-transmission curve is 60. Obviously, contrast of the SLC modulator will depend essentially on the intensity of optical power dispersion under scattering , and therefore on the relative index of refraction at the scatter interface (according to eq.1). In order to improve the contrast and to optimise the operating conditions of the attenuator we have examined the scatter function of the SLC modulator for different values of relative refracting index of the scattering interface. After removing the lc layer , the modulator cell was filled with 11 various isotropic liquids with refracting indices n_l ranging from 1.33 to 1.72. The example results of the measurements are shown in fig .5.

Then the values of the scattering intensity in the central point of the light field (i.e. in the axis of the incident beam) were extracted and drown versus the indices difference $\Delta n = n_g - n_l$. This plot is presented in fig. 6. It is now easy to infer, that by the given birefringence Δn_{lc} =0.15 of the lc layer (for 6CHBT it corresponds to horizontal segment 0.15 in fig .6) the contrast in our measurements, as represented by vertical bold line, depends significantly on the working point of the modulator.

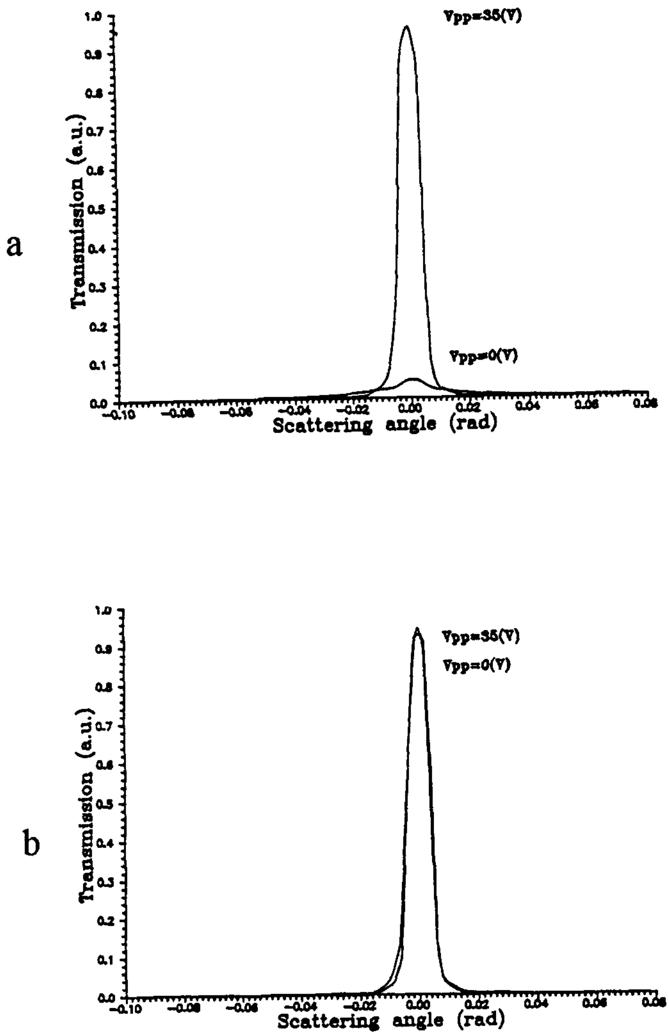

FIGURE 4 The angular dependence of scattering of the SLC modulator on driving voltage by parallel (a) and perpendicular (b) incident polarisation with respect to its optical axis.

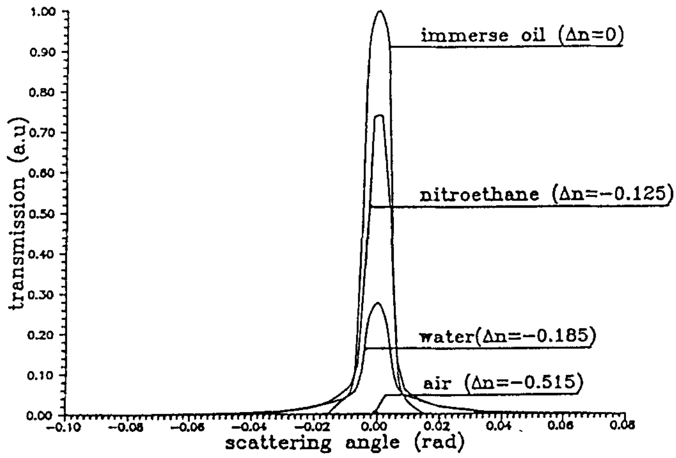

FIGURE 5 The angular dependence of the SLC cell on the refracting index difference at the scatter interface.

By introducing an initial detuning of glass electrodes and lc layer Δn_0=0.12 the operating range of the modulator will be shifted to the left (toward the slope of the curve) and contrast will increase (double vertical line on the plot of fig.6). It can be easy done by choosing the appopriate scatter glass in the modulator , e.g. the phosphofluoride light glass[3] having n_g=1.36 .

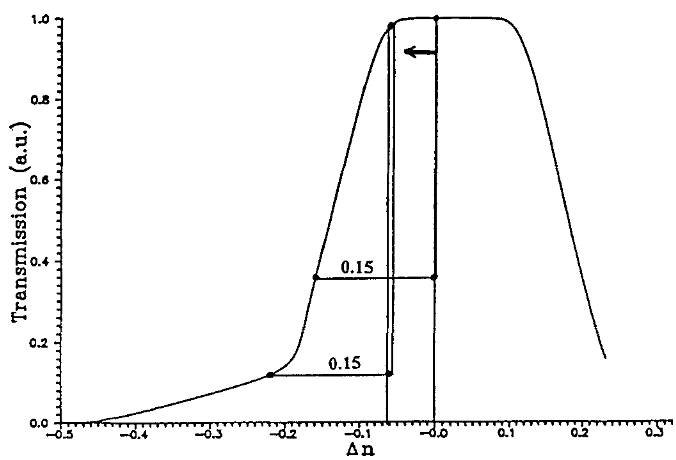

FIGURE 6 The scattered light intensity in the center of the modulator as a function of the refraction index difference.

CONCLUSIONS

We have arranged and examined the electrically controllable optical attenuator, which is projected for fiber optic applications. It consists of only two selfocs, one scattered, and connecting optical fibers. The basis of the device is the lc modulator, operating on the light scattering effect. The main properties of the attenuator are:

-selectivity with respect to the incident light polarisation,

-preservation of the initial polarisation of modulated beam,

-ability to easy integration with fiber optic network.

We also have investigated the optical performance of the attenuator .It showed contrast value of the order of 60 and light losses of 2dB. The possibility of improvements of the device operation was also discussed.

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