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ELECTROOPTICAL DEVICES BASED ON THE STRUCTURE OF PLANAR WAVEGUIDE – SMECTIC C* - PLANAR WAVEGUIDE

Key words: ferroelecrtic smectic liquid crystal, selective reflection of light, planar waveguide

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Unique optical properties of chiral liquid crystals allow to use them in different electrooptical devices. It is possible to filtrate the light by length of a wave with the help of structures waveguide - liquid crystal - waveguide. Besides the electrical control of such structure enables to use the planar waveguide – smectic C* - planar waveguide structure as the switch without the complex constructive solutions.

1. INTRODUCTION

Chiral liquid crystal molecules connections form spatial spiral structure (helix). In a cell such as sandwich in case of planar orientation of a sample an optical axis chiral liquid crystals is perpendicular to a surface and selectively reflects light of the certain polarization and certain length of a wave.

Combining a layer of planar waveguide with a liquid crystal allow to create various components allowing to carry out a lot of operation above optical waves [1-3]. In thin-film waveguide structures it is possible to split, to modulate, to reject, to select, to radiate light in space or to generate by use of laser effect. The planar dielectric waveguide provide waveguide distribution of optical waves. Though exist various planar waveguide filters and monochromators on single layers of waveguide [4] in such structures not probably simultaneously to register some lengths of waves. By us and other authors are developed the planar waveguide - liquid crystal structure on a basis nematic and cholesteric types of liquid crystals. Offered by us the structure of waveguide - smectic C* - waveguide provides simultaneous registration of different lengths of waves in case integrated manufacture is suitable for the display appendix in multilayer of a design and electrical controlled filter of any length of a wave in a unary layer. Thus as result of dispersion of light, falling to the some angle, in waveguide will be distributed waves of different length. If to choose the pitch of each cell with a liquid crystal commensurable with length of a wave of the certain spectrum that a wave length, with which will be commensurable with a pitch of a liquid crystal as a result of selective reflection [5] to be reflected from spiral structure and other waves will be passes through a layer of a liquid crystal. Thus, we can to filtrate necessary length of a wave.

2. THE LIGHT PROPAGATION THROUGH THE LAYER OF CHIRAL SMECTICS

The theory of optical properties of cholesteric liquid crystals can be applied for chiral smectic liquid crystals, however there are qualitative differences caused by distinction of structures. Without fields smectic C* - the liquid crystal represents a composition of optical active monomolecular layers with smectical parameter θ_0 in a smectic phase [6]:

$$\theta_0 = \theta e^{i\varphi}. \qquad (1)$$

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In model of SmC* - phase it is supposed, that from a layer to a layer θ remains constant, while φ varies from 0 up to 2π and, where P_0- the pitch of a spiral. The location of dielectric property are characterized by three-dimensional ellipsoid, and tensor of dielectric permeability $\hat{\varepsilon}(z)$ through which the optical properties are determined is given in [7,8]. For smectic C* liquid crystal, as analogy cholesteric liquid crystals there is a spatially modulated structure with the pitch P_0 and on such structure is observed Bregg diffraction:

$$m\lambda_0 = 2R\bar{n}\cos\theta_i\,, \tag{2}$$

where m - number of the order, $\bar{n}$ - index of refraction of media, R - the pitch which for SmC*-phase is equal P_0. If in cholesteric phase with changing of z occurs orientations only two main axes of a tensor $\hat{\varepsilon}(z)$, in chiral smectic with changing of z changes orientations of all three axes of a tensor $\hat{\varepsilon}(z)$. According to helix structure of changing dielectrical properties along an axis z coincides with a pitch of a spiral P_0.

At tilt incident of light to the chiral smectic liquid crystal the second order of diffraction of smectics is similar to a first order of cholesterics and coupled with a second order of diffraction owing to polar structure there appear a first order of Bregg reflection, when length of a wave of a maximum of reflection in is equals $\lambda_0 = P_0\bar{n}$, where $\bar{n}$ - -is average parameter of refraction. [9,10]. In case of chiral smectic phase the first and second orders Bregg diffraction are equal in strength, while in cholesteric phase strong diffraction of scattering is observed only for the first order.

Value of wave vectors $\vec{k}_0$ of waves appropriate own polarization are defined by the dispersion equation:

$$\det[(\omega/c)^2(\hat{\varepsilon}_0)_{ik} - k_0^2\delta_{ik} + k_{0i}k_{0k}] = 0\,, \tag{3}$$

where $(\hat{\varepsilon}_0)_{ik}$ - components of tensors of dielectrically permeability. The wave vector of refracted by smectic C* light has form $k_{sx} = k_{0x}$ and $k_{sy} = k_{0y}$ where χ_0 - wave vector of a falling wave outside of a sample, $k_{0x} = \chi_{0x}$ and $k_{0y} = \chi_{0y}$.

The second order of reflection in SmC* is qualitatively similar to the first order in CLC and the optical properties of SmC* are described to similar properties CLC and described by the same expressions for cholesteric with replacement:

$$\varepsilon \quad \text{on} \quad \varepsilon' = \frac{\varepsilon_1 + \varepsilon_2\cos^2\Theta + \varepsilon_3\sin\Theta}{2} - \frac{(\varepsilon_2-\varepsilon_3)^2 2\Theta}{8\varepsilon_3}$$

$$\delta \quad \text{on} \quad .\ \delta' = \left[\frac{\varepsilon_1 - \varepsilon_2\cos^2\Theta - \varepsilon_3\sin^2\Theta}{2} + \frac{(\varepsilon_2-\varepsilon_3)^2\sin^2 2\Theta}{8\varepsilon_3}\right]\cdot\frac{1}{\varepsilon'} \tag{4}$$

For the first order of the equation for waves E_0 and E_1 breaks up to two independent systems:

$$\left(\varepsilon_\sigma - \frac{k_0^2}{\chi_0^2}\right)E_0^\sigma + lE_1^\pi = 0\,, \qquad \left(\varepsilon_\pi - \frac{k_0^2}{\chi_0^2}\right)E_0^\pi + lE_1^\sigma = 0\,,$$

$$lE_0^\sigma + \left(\varepsilon_\pi - \frac{k_1^2}{\chi_0^2}\right)E_1^\pi 0\,, \quad lE_0^\pi + \left(\varepsilon_\sigma - \frac{k_1^2}{\chi_0^2}\right)E_1^\sigma = 0\,, \tag{5}$$

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where, $\chi_0^2 = \omega^2 / c^2$, $\varepsilon_\sigma = (\hat{\varepsilon}_0)_{11}$, $\varepsilon_\pi = (\hat{\varepsilon}_0)_{11} \sin^2\theta_i + (\hat{\varepsilon}_0)_{33}\cos^2\theta_i$, $l = (1/4)(\varepsilon_2 - \varepsilon_3)\sin 2\Theta \cos\theta_i$, $(\pi/2) - \theta$ - angle between an optical axis and direction of distribution of light. The wave with σ-by polarization becomes π- the polarized wave and on the contrary. The determination of the equation (2) and appropriate boundary equation is easier, than in a case CLC, and is completely similar to the determination in a case of diffraction x-ray beams.

For planar structure the angular (frequency) areas of reflection for σ- and π- of polarization determined by systems (2) coincide. Thus polarizing and frequency (angular) dependence of index of reflection are described:

$$R = \left| e_1^* \varepsilon_1 e_0 \right| \cdot \frac{\sin^2 \left[(\chi_0 L \sqrt{\Delta_B^2 - l^2/2} \cdot \sqrt{\varepsilon} \sin\theta_i \right]}{\Lambda_B^2 - l^2 \cos^2 (\chi_0 L \sqrt{\Delta_B^2 - l^2} / 2\sqrt{\varepsilon} \sin\theta_i}, \tag{6}$$

where e_0 and e_1- vectors of polarization of a incident and refracting waves, $\varepsilon = (\varepsilon_\sigma + \varepsilon_\pi)/2$, L-thickness of a crystal, Δ_B - a digression from a Bregg condition: $\Delta_B = (\tau / 2\chi_0^2)(2\chi_0 \sqrt{\varepsilon - \cos^2\Phi_i} - \tau$. The polarization of refracted wave depends only on polarization of a primary wave and not its intensity. The middle of area of reflection lays at $\Delta_B=0$, and the borders are defined by ratio: $\Delta_B = \pm l$.

In the first order of reflection from SmC* right hand polarized wave passes in left hand polarized and on the contrary. At dispersion of linearly polarized light the scattering wave is polarized linearly, and the angles φ_0 and φ_1, formed by a plane of polarization with a plane of dispersion in a incident and retracted wave accordingly, are connected by a ratio: $\varphi_1 = (\pi/2) - \varphi_0$.

The diffraction occurs not at a natural direction of a falling wave, and in the whole interval of a direction and width of this interval of the order $(\chi L)^{-1}$. The intensity of a retracted wave is maximal at exact performance of a Bregg condition:

$$\left(\frac{I_s}{I_0} \right)_{\max} \approx \left| \vec{e}_s^{\,*} \hat{e}_s \vec{e}_0 \right| \frac{\omega^2}{c^2} L^2. \tag{7}$$

The restriction of allowable thickness of a crystal is determined from a condition $I_s / I_0 << 1$:

$$\left| \vec{e}_s^{\,*} \hat{e}_s \vec{e}_0 \right|^2 \frac{\omega^2 L^2}{c^2} << 1. \tag{8}$$

In a case, when the axis of a spiral is parallel to surface of a sample the area of reflections for σ- and π- of polarization do not coincide, though can be cover partially. At that, considering (i.e. is realized a Bregg diffraction, and not a Raman diffraction), it is possible to receive a polarization coefficient of reflection of a incident wave and its frequency (angular) dependence for σ - and π- of polarization in the following form:

$$R = \frac{l^2}{(\Delta_L \pm m)^2} \sin^2 \left(\frac{\chi_0 L \sqrt{(\Delta_L \pm m)^2 + l^2}}{2\sqrt{\varepsilon}\cos\theta_i} \right), \tag{9}$$

where:

$$m = \frac{\varepsilon_\sigma - \varepsilon_\pi}{2} = \frac{\cos^2\theta_i}{4} \left[\varepsilon_1 + \varepsilon_2 (1 - 3\sin^2\Theta) + \varepsilon_3 (1 - 3\cos^2\Theta) \right],$$

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$$\Delta_L = \frac{\tau}{2\chi_0^2}(\tau - 2\chi_0 \sin\theta_i)\,.$$

Sign plus gives index of reflection σ- of polarized light, and sign a minus - π- polarized. At m=0 of a zone of reflection the polarizing properties in this case same, as in a case Bregg coincide also.

3. DISTRIBUTION OF LIGHT WITH PLANAR WAVEGUIDE

For complete total reflection incoming to the planar waveguide light by angle ψ should be within the limits of determined in [11]. For the propagation waves in waveguide is satisfied a condition: $n_0 \sin\psi = n_1 \sin(90 - \theta_i)$, where n_0- a refractive indices outside of the selector.

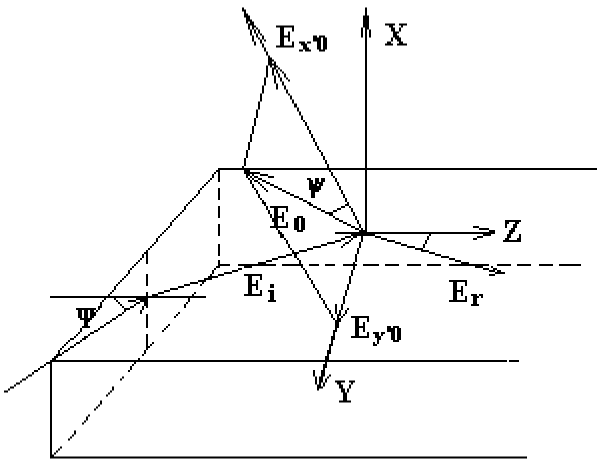

Fig. 1. The circuit of passage of a beam through planar waveguide

If all components of a field of a wave incoming waveguide changes under the law:

$$\exp\left[j\omega\left(t - n_0 \frac{x\sin\psi + z\cos\psi}{c} \right)\right] \tag{10}$$

than in waveguide will be distributed a wave which interference picture is result of addition i- incident on the first border and r- reflected from the first border of waves (fig. 1):

$$E_T = E_i + E_r = E_0 \exp[-j(\omega \cdot t + k_1 n_1 z \sin\theta_i - \delta_s/2) \times 2\cos(k_1 n_1 x \cos\theta_i + \delta_s/2)]\,. \tag{11}$$

Where δ_s - a changing of a phase at complete total reflection for considered polarization, i.e. the completely reflected wave suffers changing of a phase, which depends both on an incident angle and from polarization. The phase displacement for two condition of polarization is written [12]:

$$tg\varphi_{TE} = tg\left(\frac{\delta_s}{2}\right) = \frac{\sqrt{n_1^2 \sin^2\theta_i - n_2^2}}{(n_1 \cos\theta_i)} \tag{12}$$

$$tg\varphi_{TM} = tg\left(\frac{\delta_p}{2}\right) = \frac{n_1}{n_2^2}\frac{\sqrt{n_1^2 \sin^2\theta_i - n_2^2}}{(n_1 \cos\theta_i)}\,, \tag{13}$$

at that:

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$$tg\left(\frac{\delta_p}{2}\right)=n_1^2 tg\left(\frac{\delta_s}{2}\right). \tag{14}$$

This wave is distributed in a direction 0z with wave number $kn_1\sin\theta_i$, and its amplitude varies in a direction 0x under the law:

$$\cos(k_1 n_1 x\cos\theta_i+\delta_s/2)\,. \tag{15}$$

The intensity of a wave on each of two borders is identical, cause a waveguide is symmetric, i.e. [12]:

$$\cos^2(\delta_s/2)=\cos^2(k_1 n_1 d_c\cos\theta_i+\delta_s/2)\,, \tag{16}$$

or:

$$d_c k_1 n_1\cos\theta_i+\delta_s=m\pi\,, \tag{17}$$

where d_c- thickness of waveguide, m- whole number.

In case of ideal orientation of a liquid crystal the reflected wave will have a same angle of distribution with incident wave to a liquid crystal and in a case of not of ideal orientation the angle of propagation reflected waves from a liquid crystal will have some digression from a angle of distribution before interaction with a liquid crystal.

For the account of passing coefficient and intensity of a target signal in a case of multiplayer structure the devices will be interpret some aggregate of layers with various optical thickness and different refractive indices or as multilayer interference film. If to number layers that Frenel coefficient for layer «k» when light goes from a layer «k-1» to «k+1» will be determined as follows [13]:

$$\begin{gathered}
(r_s)_{k-1,k}=\frac{c_{k-1}n_{k-1}-c_k n_k}{c_{k-1}n_{k-1}+c_k n_k}=\frac{\sin(\theta_{k-1}-\theta_k)}{\sin(\theta_{k-1}+\theta_k)};\\
(r_s)_{k,k+1}=\frac{c_k n_k-c_{k+1}n_{k+1}}{c_k n_k+c_{k+1}n_{k+1}}=\frac{\sin(\theta_k-\theta_{k+1})}{\sin(\theta_k+\theta_{k+1})};\\
(r_p)_{k-1,k}=\frac{c_k n_{k-1}-c_{k-1}n_k}{c_k n_{k-1}+c_{k-1}n_k}=\frac{tg(\theta_{k-1}-\theta_k)}{tg(\theta_{k-1}+\theta_k)};\\
(r_p)_{k,k+1}=\frac{c_{k+1}n_k-c_k n_{k+1}}{c_{k+1}n_k+c_k n_{k+1}}=\frac{tg(\theta_k-\theta_{k+1})}{tg(\theta_k+\theta_{k+1})},
\end{gathered} \tag{18}$$

where c_{k-1}, c_k and c_{k+1}- cosine of incidence angles (θ_{k-1}) and refraction angles (θ_k and θ_{k+1}) media with refractive indices n_{k-1}, n_k and n_{k+1}. At that:

$$\begin{gathered}
c_{k-1}=\cos\theta_{k-1};\\
c_k=\frac{1}{n_k}\sqrt{n_k^2-n_{k-1}^2\sin^2\theta_{k-1}};\\
c_{k+1}=\frac{1}{n_{k+1}}\sqrt{n_{k+1}^2-n_{k-1}^2\sin^2\theta_{k-1}}\,.
\end{gathered} \tag{19}$$

Index of reflection R of multiplayer system is defined by the following expression:

$$R_x=\frac{(r_x^2)_{k-1,k}+(r_x^2)_{k,k+1}+2(r_x)_{k-1,k}(r)_{k,k+1}\cos\alpha}{1+(r_x)_{k-1,k}(r_x)_{k+1,k}^2+2(r_x)_{k-1,k}(r_x)_{k,k+1}\cos\beta}, \tag{20}$$

where:

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$$\alpha = -\Delta_{k-1,k} + \Delta_{k,k+1} - \frac{4\pi c_k n_k h_k}{\lambda};$$

$$\beta = \Delta_{k-1,k} + \Delta_{k,k+1} - \frac{4\pi c_k n_k h_k}{\lambda}.$$

The index «x» concerns to the s- or p- a component. For s- component $\Delta_{k-1,k}$ and $\Delta_{k,k+1}$ also do not depend on a incidence angle, i.e. leap of a phase at s- by a component does not occur on one of borders. And for p- component change of a sign at $(r_p)_{k-1,k}$ and the leap of a phase on previous border is observed at a Brouster angle, valid for media of «k»:

$$\sin^2 \varphi_{B_k} = \frac{n_k^2 n_{k+1} 2}{n_{k-1}^2 (n_k^2 + n_{k+1}^2)}. \qquad (21)$$

4. CONCLUSION

From all above setted out in writing optical properties of chiral liquid crystal structures the application of ferroelectric smectic liquid crystals in quality filtrating element more preferably than cholesteric is without any visible cause. If shortly to analyse:

The force diffraction of reflection quickly falls down with increasing index of reflection for cholesteric liquid crystals, in that time for smectic phase the first and second orders of reflection are equal in strength. From here follows, that in a case chiral smectic liquid crystal of leaving intensity of waves from the selector will be more than at CLC.

-In cholesteric liquid crystal at falling of light to some angle there appears an area of light reflection with any polarization and complicates polarizing characteristics. And in case chiral smectic in the first order of refraction the linearly polarized light dissipates with linear polarization.

- In low value of thickness in cholesterics the maximum of selective reflection narrowing also becomes weakly expressed and consequently for supervision of s- order of reflection the rather large thickness of a layer is necessary. The increase of thickness results in multipleted dispersion and weakening of intensity of a leaving wave. Chiral smectics have the large pitch than cholesteric therefore on the same thickness on which the second order of selective reflection is observed at falling of light to some angle it is possible to observe and first order of selective reflection.

-In smectic phase angular (frequency) areas of reflection σ- and π- of polarization coincide when in cholesteric area of reflection π- of polarization narrow than area of reflection σ- of polarization.

-In a case of orientation by an electrical field or in a case, when there will be a necessity electrically control the selector time of operation chiral smectic faster on some orders than in cholesteric.

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MODULE FOR FUEL CONSUMPTION MEASUREMENT

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Today is important for transport companies to monitorize fuel consumption. To perform this task is necessary to have on the car a black box inaccessible to driver. This can be done using a flow transducer coupled to a smart electronic module. The authors designed a volumetric rotational transducer that contains a Hall sensor. The pulses generated by this sensor as well as driving wheels rotation information are used by an electronic module to calculate total fuel consumption.

1. INTRODUCTION

Fuel consumption is a very important problem for a company activating in the field of constructions or transporting. Small decreases of this parameter can lead to higher profits and better economic efficiency. The first step in order to reduce fuel consumption is to measure properly this quantity; the level of remaining fuel in fuel tank is not a good estimation of consumption because nobody can be sure that the missing fuel in the tank was consumed by the engine or it was a leakage in the fuel circuit or, even worse, the fuel was stolen form the tank. To avoid this incertitude the best way to evaluate fuel consumption is to measure the fuel flow from the injection pump to the engine and compute fuel consumption using this parameter. This paper describes the fuel consumption measurement system and shows some experimental results performed on a hydraulic stand involving flow measurement with this system; the system will be tested on a car as soon as possible.

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