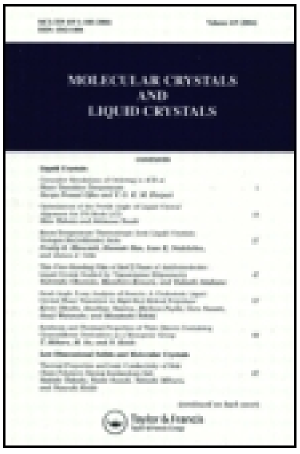

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LIQUID CRYSTAL MODULATOR FOR FIBER COMMUTATION CHANNELS

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Abstract. The results of the development and investigation of the modulation characteristics of a coaxial liquid crystal modulator are presented. The active part of the modulator under investigation is implemented on the basis of a "cylindrical geometry". Specific design solutions of such a coaxial modulator are considered. It is shown that in the case under study, the modulation depth increases 2 or 3-fold as compared with conventional LC modulators and exeeds 50%, noise level becoming lower.

INTRODUCTION

In order to modulate optical radiation propagating through an optical fiber use is made of modulators which are inserted in its optical tract. Various electrooptic and acoustooptic media, including liquid crystals, are used as a working medium of such modulators. Problems arising in matching aperture characteristics of the modulator and optical fiber result in additional losses of optical radiation in input/output sections, and fairly intricate technical solutions have to be found to properly connect optical fiber with modulator. As alternative to such modulators it is suggested to employ devices designed to modulate optical radiation without breaking the optical fiber. For this purpose, use is made of either directed local (in the modulation zone) mechanical influence on the fiber or controlled changing of the refractive index of external medium with which the fiber core is in contact over selected modulation part. In the latter case, liquid crystals are the most promising external media because of their extremely high sensitivity to controlled influences. There has been a number of works devoted to such LC-modulators implementing thermooptical[1] and electrooptical[2,3] modulation modes in optical fibers. Modulators in question represent ordinary plane LC cells wherein an optical fiber is inserted with its cladding-free core being in contact with oriented LC layer. Under the action of control signal, e.g. electric field, there occurs reorientation of LC molecules around the core and the refractive index n_{LC} changes accordingly. However, such modulators are characterized by ninuniform boundary conditions of the core-LC layer contact. This fact has a considerable effect on modulation efficiency by worsening its transfer characteristic. This paper presents the results of investigation of a coaxial LC modulator whose design ensures a uniform surface contact between the fiber core and LC layer.

EXPERIMENTAL CASES

The electrooptical modulator under consideration consists of a cylindrical cell with oriented LC layer. Fig.1 shows the scheme of the LC modulator. In our studies we used a step-index multimode fiber ($\varnothing_{core}$ ~20 μm, $\varnothing_{clad}$ ~100 μm). In its working section, 10 mm in length, cladding was removed and the core was exposed. Special fixture were used to prevent breaking of the exposed core in subsequent assembly process and study. The exposed core section was sequentially coated with semi-transparent conductive and orienting (lycitin) layers by using chemical methods. According to our estimates, the conductive layer thickness was about 0.1-0.05 μm and surface resistance of $R_{\square} \sim 10^4\ \Omega$. Evaluation of these parameters was based on the results of analysis of analogous layer on test substrate which was obtained by fiber processing. Thus, the fiber core acts as an LC-cell's substrate. The second electrode and orienting layers were formed on flexible or rigid substrate in a similar manner. Then, these substrates are joined as illustrated in Fig.1, forming a cylindrical LC cell. In such a cell, LC layer thickness is determined by geometric parameters of the fiber and is $(\varnothing_{clad} - \varnothing_{core})/2 = 40$ μm. To connect the assembled modulator to control unit, use was made of contacts based on conductive "zebra-type" rubber. He-Ne laser was employed as a radiation source.

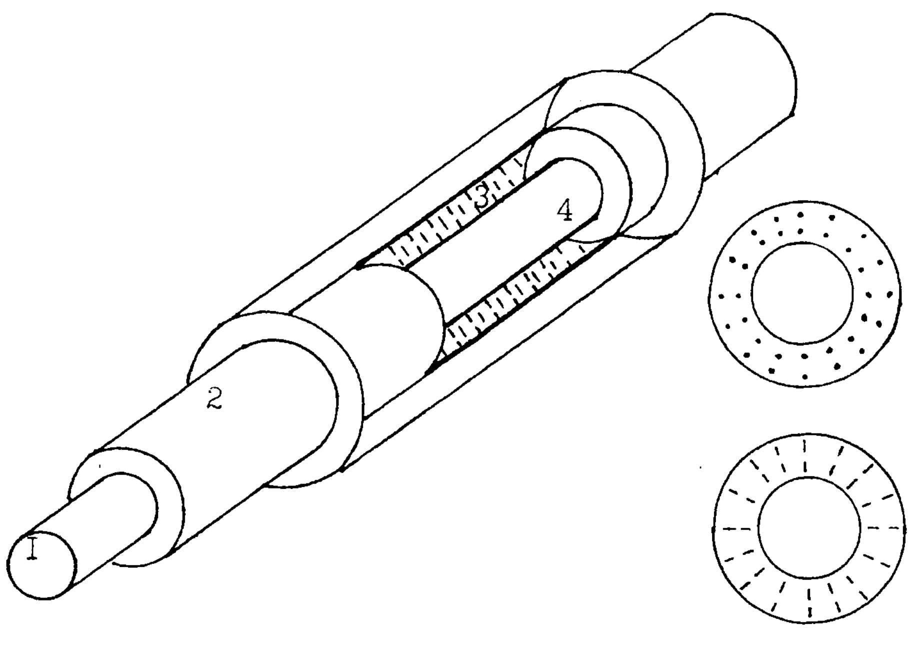

Fig.1. Schematic of coaxsial LC-modulator: core (1), cladding (2), liquid cristal (3), electrode (4).

The main problem faced in making a coaxial modulator is optical matching of LC material and fiber material. The choice of working LC material is dictated by the condition $n^0_{LC} < n_{clad}$ and $n^e_{LC} > n_{core}$ ($n_{clad} < n_{core}$). In the general case, it is possible to introduce the concept of effective refractive index of LC layer which depends on the LC-director orientation angle Θ and is a function of applied electric field (E):

$$n^*_{LC} = n^0_{LC}\, n^e_{LC}\ \{[\, n^e_{LC}\ \sin\ \Theta\,(E)]^2 + [n^0_{LC}\ \cos\Theta\,(E)]^2\,\}^{-1/2}, \qquad (1)$$

In the $n^*_{LC} < n_{core}$ range, changes in the LC layer refractive index cause changes in the aperture characteristics of the modulation section of the fiber.The modulation coefficient is described as follows:

$$m = \frac{J_{in}\ -\ J_{out}}{J_{in}}, \qquad (2)$$

where J is determined by the numerical aperture of the fiber before and in the modulation section ($J \sim (NA)^2$).
Numerical aperture of the fiber is found from:

$$NA \sim (n^2_{core}\ - n^2_{clad}\,)^{1/2}\ \sim 2\ n_{core}\,(\Delta)^{1/2},\ \text{where}\ \Delta = (n_{core}\ - n_{clad}\,)\,/\,n_{core}, \qquad (3)$$

Hence, in the n^*_{LC} variation range under consideration, we can write:

$$m\,(E) \sim \frac{n^*_{LC}\ - n_{clad}}{n_{core}\ -\ n_{clad}}, \qquad (4)$$

Thus, the function m (E) can be defined as:

$$m\,(E)\ \ \sim\ A\, n^*_{LC}\ (E) - B\,, \qquad (5)$$

where the constants A and B are determined by the fiber parameters. The expression (5) is meaningful in the range of n^*_{LC} variation up to n_{core}.

In the geometry under consideration, LC molecules can orient either along cylindrical surface or at right angles to it (Fig.1). In the former case, $n^0_{LC} < n_{core}$, and conditions of total internal reflection (TIR) are fulfilled for radiation in this part of the fiber; in the latter case, $n^0_{LC} > n_{core}$, the TIR conditions are disturbed, and almost all propagating radiation leaks out of the core (both symmetrical and nonsymmetrical modes). With intermediate values of $n^*_{LC}(E)$, mode selection is observed.

In order to increase the modulator response speed, we have used an LC with low-frequency inversion of (f= 10 kHz). At frequencies $f > f_{inv}$, $\Delta\varepsilon < 0$, and at $f < f_{inv}$, $\Delta\varepsilon > 0$. The LC modulator was controlled by using pulses of special form and various frequency values. Control pulse amplitude was varied in the 45-60 V range. Fig. 2 shows typical oscillograms of modulation pulses. Experimentally, the modulation depth was 0.6. Using LC of this type makes it possible to reduce the effect of nonuniformities in LC molecular orientation which arise in the process of making the modulator.

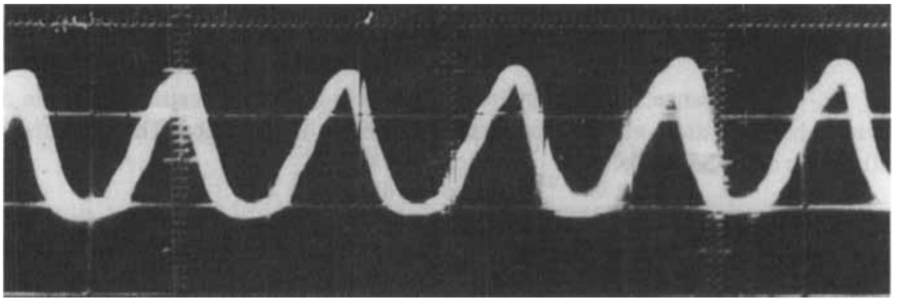

Fig.2. Oscillogram of modulation pulses for control pulse amplitude 50 V (1 ms/div)

The coaxial modulator described has small dimensions, and the simplicity of its fabrication allows its installation on any section of a finished fiber-optical line. However, in respect of coaxial LC modulators further efforts are required to optimize the control regimes and refine fabrication technology.

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