INTEGRAL-OPTIC WAVEGUIDE STRUCTURES WITH NANOSIZED ACTIVE LAYER ON THE BASE OF CHALCOGENIDE GLASSY SEMICONDUCTORS (CGS)

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Abstract. The investigations of the two-layer waveguide integral-optic structures are carried out: diffuse waveguide — active nanosized gradient layer CGS with exponential and parabolic distribution of the refractive index profile. Waveguide parameters of the received structures and their change at the photoinduced change of the refractive index of the active layer CGS were determined.

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Introduction

Integral-optic waveguide structures are widely used as light-controlled optic switches and other elements of integral optic [1-4], and lately, due to the mass-dimentional characteristics [5-7], maintainaility, simplicity and reliability of construction, as far as the total optic tract is realized as the integral-optic scheme on the single substrate [2, 7, 8], they found a wide application as of optical, chemical and biochemical sensors [7-10].

The most investigated class of materials, characteristic of the photoinduced change of the optical parameters (refractive index and the position of the absorption edge), is chalcogenide glassy semiconductors (CGS) [11-13]. In such materials depending on the composition, illumination can cause the shift of the transmission edge either into the long-wave spectrum region (photodarkening), or in the direction of the short waves (photoenlightening) [14-16]. Simultaneously the essential change of the refractive index value is observed in the range of percent units. Nowadays, there rich experimental material is accumulated which shows that in the course of lightening of the CGS layers by light in the spectral region of the edge of their own absorption a number of CGS shows the effect of the reversible or non-reversible change of their optical parameters [14-17].

The main disadvantage of the usage of CGS or other materials which possess the photostimulated change of the optical parameters (refractive index and the position of the absorption edge), is chalcogenide glassy semiconductors (CGS) [11-13]. In such materials depending on the composition, illumination can cause the shift of the transmission edge either into the long-wave spectrum region (photodarkening), or in the direction of the short waves (photoenlightening) [14-16]. Simultaneously the essential change of the refractive index value is observed in the range of percent units. Nowadays, there rich experimental material is accumulated which shows that in the course of lightening of the CGS layers by light in the spectral region of the edge of their own absorption a number of CGS shows the effect of the reversible or non-reversible change of their optical parameters [14-17].

The main disadvantage of the usage of CGS or other materials which possess the photostimulated change of the optical parameters during the creation of elements of the integral-optic waveguide systems, is that they should have simultaneously good waveguide and light-sensitive properties [6, 8, 19-22]. But these characteristics are opposite to each other and cannot have high values for the separate wave-length because light-sensitivity is proportional, and waveguide characteristics are inversely proportional to the light absorption in the medium [6-8]. That’s why to solve this problem, we proposed to use multilayer planar waveguide structures, in particular the glass diffusion waveguide, which has insignificant loss in the visible spectrum region and gradient nanosized film on the basis of CGS, which possesses the significant changes of the refractive index \( n \) and the absorption coefficient \( \alpha \) at the relatively insignificant optical excitation.

Methods of the exsperiment

For the purpose of the complex investigation of devices on the base of the thin-film waveguides the setup was developed which permits to investigate the excitation processes of the waveguide regime, the mode composition, to determine the optical losses and on the base of the determined angles of the input of radiation into the waveguide layer, to calculate the refractive index of the waveguide being investigated. The received information about the waveguide is sufficient for the calculation of such parameters: disperse characteristics, the effective width of the waveguide layer and the coefficient of the localization in it.

The measurement of the waveguide characteristics was carried out at the selective excitement of the defined waveguide modes. As the input-output elements, microprisms from GaP were used, and the angles of the radiation input into the waveguide, at which optical modes are exited, are measured with the help of the geniometer G-5. The received information was used for calculation of the main waveguide structures parameters.

It is known [23], that in the thin-film dielectric waveguides the losses, connected with the absorption of the optical energy by the material of the waveguide layer are dominant, and the losses, the mechanism of which is caused by the dispersion of the radiation on the optical inhomogeneities and on waveguide-substrate and waveguide-air interfaces. The experimental device permits to measure the total optical losses (1.1) and losses on dispersion (1.2) for each excited mode. Total optical losses are calculated according to the equation:

\[
\alpha_n = \frac{10}{x_1} \log \left( \frac{U_1 - U_2}{U_1 - U_b} \right) \text{dB/cm},
\]

(1.1)

where \( x_1 \) — the distance between two positions of the output prism, where the output signal is measured (Fig. 1.1); \( U_1 \) — the value of the output signal at the point A; \( U_2 \) — the value of the output signal at the point B; \( U_b \) — voltage of the background.

The losses, connected due to the dispersion of energy, are determined with the help of equation:

\[
\alpha_n = \frac{10}{x_2} \log \left( \frac{U_3 - U_4}{U_3 - U_b} \right) \text{dB/cm},
\]

(1.2)

where \( x_2 \) — the distance between the two positions of the fiber-optic probe (fig. 1); \( U_3 \) and \( U_4 \) — the values of the output signal, determined at the points C and D, respectively. The relative error of the measurement of the optical losses is 5%.
The result and discussion

The investigation of the structure of the diffusion waveguide with exponential distribution of the profile of the refractive index was carried out (diffusion of Ag into the glass with refractive index 1.516) — active nanosized gradient layer CGS (GeS$_2$ — As$_2$S$_3$) with exponential and parabolic distribution of the refractive index profile (Fig. 2).

The calculation of the field distribution in two-layered waveguide optical structures was carried out using the proposed and developed software, the algorithm of which is based on the method of stratification [24].

The stratification method lies in the replacement of the known gradient distribution of the refractive index by a multilayer structure in which the number of layers and refractive index of each layer are selected in such a way to better approximate the initial profile (Fig. 3). In this method, first they find the solution of the scalar wave equation in the middle of each layer, and then these solutions are joined together on the interfaces.

The result of the calculation of the electric field component are given in the fig. 4–6. The calculated values of the energy localization coefficient in the waveguide are given in the Table 1.

The gradient film CGS was deposited using the method of discrete thermal evaporation by independent input of the initial components from the separate bunkers into the common evaporator [25]. Moreover, the feed rate of the supply of each substance changed in the course of the growth of the film, and the law of the rate changes for supplying of the substances was determined by the refractive index profile of the received inhomogeneous structures [26], and the thickness of the film $d = 100$ nm was chosen so that in waveguide regime was not exited in it.

As a radiation source, He-Ne laser was used (power — 8 mW and the wavelength $\lambda = 0.63$ μm), the radiation of which was input into the investigated system and was output from it by prism elements. Radiation losses, propagating through a waveguide structure, were measured by the light dispersion with the help of the quartz fiber probe.
The optical losses in the given system increase because the exponential profile of the refractive index increases the difference $\Delta n$ on the waveguide — air interface. In the case of the parabolic refractive index profile of the gradient film (GeS$_x$)$_y$(As$_2$S$_3$)$_z$ three modes (TE$_0$, TE$_1$, and TE$_2$) also appear (Fig. 6), but in this case, unlike the previous one, a decrease of optic losses concerning the diffusion waveguide was determined experimentally what is obviously caused by the increase of energy localization.

Consecutive excitement of the three modes of the diffusion waveguide (Table 2) was experimentally determined on the working wavelength ($\lambda = 0.63 \mu m$).

Three modes were observed at exponential profile of the refractive index of the gradient film CGS (Ge-As-S composition) (Fig. 5) (TE$_0$, TE$_1$, and TE$_2$).

Analyzing the received results of calculations (Table 1, Fig. 4–6) and experimental investigations (Table 2), we can make the conclusion that the usage of the active nanosized layer CGS with gradient distribution of the refractive index as a cover layer provides the possibility to significantly influence the waveguide parameters. Thus, the construction (Fig 2, a) with the regulated sensitivity at the expense of the photoinduced changes in the active nanosized layer CGS, may be successfully used in the integral-optic sensor systems which are used for
The values of the localization energy coefficient in the waveguide.

| Waveguide optic structure | m=0 | m=1 | m=2 |
|---------------------------|-----|-----|-----|
| Diffusion waveguide       | 0.73 | 0.54 | 0.36 |
| Diffusion waveguide — gradient layer CGS with exponential distribution of the refractive index profile | 0.35 | 0.24 | 0.07 |
| Diffusion waveguide — photoinduced gradient layer CGS with exponential distribution of the refractive index profile | 0.39 | 0.28 | 0.17 |
| Diffusion waveguide — gradient layer CGS with parabolic distribution of the refractive index profile | 0.83 | 0.69 | 0.23 |
| Diffusion waveguide — photoinduced gradient layer CGS with parabolic distribution of the refractive index profile | 0.89 | 0.78 | 0.56 |

Table 2

The main, experimentally established (ascertained), parameters of the system diffusion waveguide — gradient ayer CGS.

| The profile of the CGS film refraction coefficient | The mode composition | $N_{ef}$ | $K_1$, dB/cm | $K_2$/$K_1$ |
|---------------------------------------------------|---------------------|---------|-------------|-------------|
| Exponential                                       | $TE_{m}$            | 1.529   | 7.33        | 1.047       |
|                                                   | $TE_{m}$            | 1.526   | 9.17        | 1.301       |
|                                                   | $TE_{m}$            | 1.5253  | 12.87       | 1.609       |
| Parabolic                                          | $TE_{m}$            | 1.5255  | 2.99        | 0.427       |
|                                                   | $TE_{m}$            | 1.5231  | 3.04        | 0.431       |
|                                                   | $TE_{m}$            | 1.5217  | 3.79        | 0.474       |

Where: $N_{ef}$ — the effective refraction coefficient of the waveguide system; $K_1$ — the optic losses in the system diffusion waveguide — CGS layer; $K_2$ — optic losses in the diffusion waveguide.

investigation of the bio-objects with high refractive index and absorption bands in the near IR spectrum region. Another construction (Fig. 2, b), due to small losses and high values of the localization coefficient, may be used in the integral-optic schemes as the fully optic switches and directed branchers of the optical signals.

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