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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.

Keywords: waveguides, gradient layer, chalcogenide glassy semiconductors, refractive index profile

ІНТЕГРАЛЬНО-ОПТИЧНІ ХВИЛЕВОДНІ СТРУКТУРИ З НАНОРОЗМІРНИМ АКТИВНИМ ШАРОМ НА ОСНОВІ ХАЛЬКОГЕНІДНИХ СКЛОПОДІБНИХ НАПІВПРОВІДНИКІВ (ХСН)

Г. Т. Горват, І. І. Сакалош, Й. П. Шаркань, І. І. Попович

Анотація. Проведено дослідження двошарових хвилеводних інтегрально-оптичних структур: дифузійний хвилевод — активний нанорозмірний градієнтний шар ХСН із експоненціальним та параболічним розподілом профілю показника заломлення. Визначено хвилеводні параметри отриманих структур та їх зміни при фотоіндукованій зміні показника заломлення активного шару ХСН.

Ключові слова: хвилеводи, градієнтний шар, халькогенідні склоподібні напівпровідники, профіль показника заломлення

ИНТЕГРАЛЬНО-ОПТИЧЕСКИЕ ВОЛНОВОДНЫЕ СТРУКТУРЫ С НАНОРАЗМЕРНЫМ АКТИВНЫМ СЛОЕМ НА БАЗЕ ХАЛЬКОГЕНИДНЫХ СТЕКЛООБРАЗНЫХ ПОЛУПРОВОДНИКОВ (ХСП)

Г. Т. Горват, И. И. Сакалош, Й. П. Шаркань, И. И. Попович

Аннотация. Проведены исследования двухслойных волноводных интегрально-оптических структур: диффузный волновод — активный наноразмерный градиентный слой ХСП с экспоненциальным и параболическим распределением профиля показателя преломления. Определены волноводные параметры полученных структур и их изменения при фотоиндуцированном изменении показателя преломления активного слоя ХСП.

Ключевые слова: волноводы, градиентный слой, халькогенидные стеклообразные полупроводники, профиль показателя преломления

Introduction

Integral-optic waveguide structures are widely used as light-controled optic switches and other elements of integral optic [1-4], and lately, due to the mass-dimentional characteristics [5-7], maintainalility, 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 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 wavelength because light-sensitivity is proportional, and waveguide characteristics are inversely proportional to the light absorbtion 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 absorbtion coeficient α at the relatively insignificant optical excitement.

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 excitement 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 calcution of the main waveguide structures parameters.

It is known [23], that in the thin-film dielectric waveguides the losses, connected with the absorbtion 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:

$$\alpha_n = \frac{10}{x_1} \lg\left(\frac{U_1 - U_b}{U_2 - U_b}\right)\left[\text{dB/cm}\right], \qquad (1.1)$$

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:

$$\alpha_u = \frac{10}{x_2}\left(\frac{U_3 - U_b}{U_4 - U_b}\right)\left[\text{dB/cm}\right], \qquad (1.2)$$

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%.

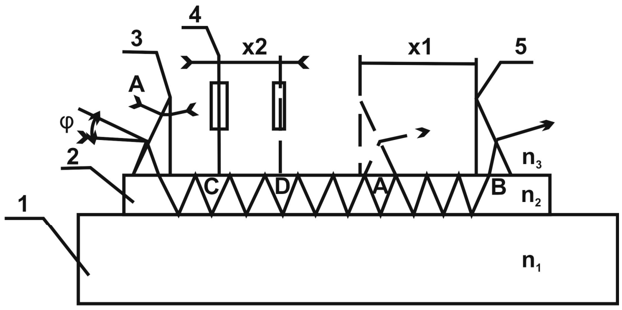


Fig. 1. The measurement scheme of the optical losses in the waveguide structure: 1 — substrate; 2 — waveguide layer; 3 — input prism; 4 — fiber-optic probe; 5 — output prism

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_2S_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 liesin 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 a such 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 bye indepedent 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.

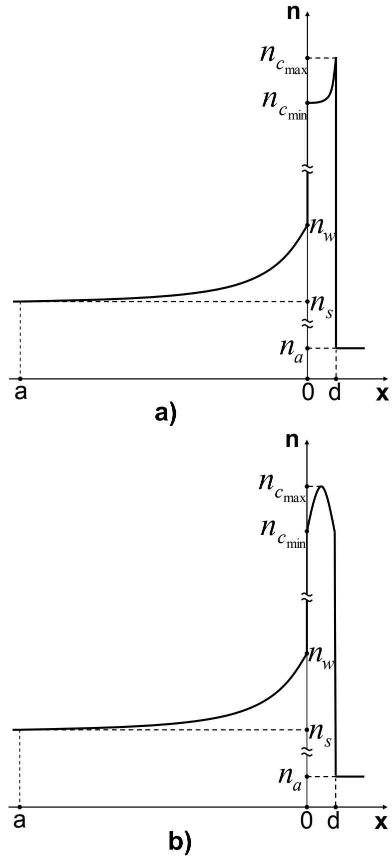


Fig. 2. Waveguide optical structures of the *diffusion waveguide with exsponential distribution of the refractive index profile — active nanosized gradient layer CGS with exponential a) and parabolic b) distribution of the refractive index profile: the diffusion waveguide thickness CGS* : a = 1 μm; the gradient layer thickness CGS: d = 100 nm; the substrate rafractive index — n_s = 1.45; the waveguide refractive index– n_w = 1.516; refractive index of the gradient layer CGS — $n_{c_{min}}$ = 2.05, $n_{c_{max}}$ = 2.4; air refractive index — n_a = 1; λ = 0.63 μm

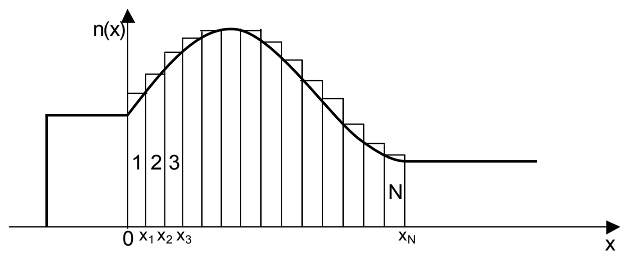


Fig. 3. The schematic representation of the stratification method

As a radiation sourse, He-Ne laser was used (power — 8 mW and the wavelength λ=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.

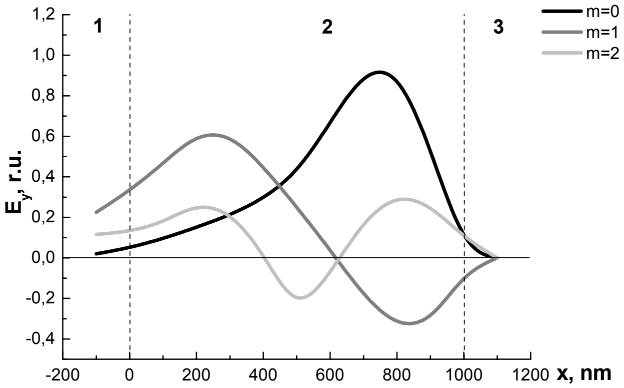
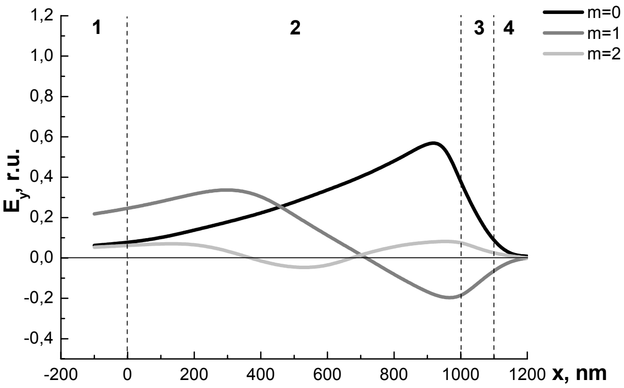
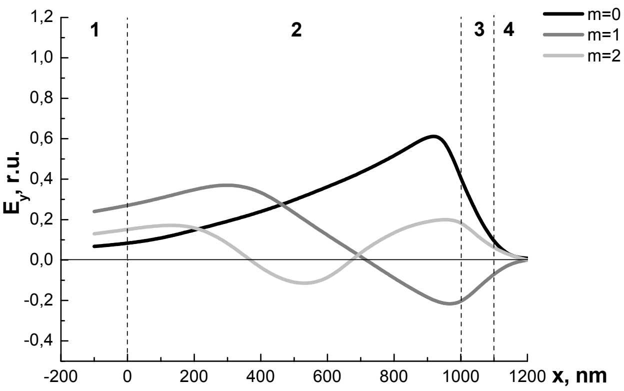


Fig. 4. Distribution of the electrical component of the field in the diffusion waveguide



a)

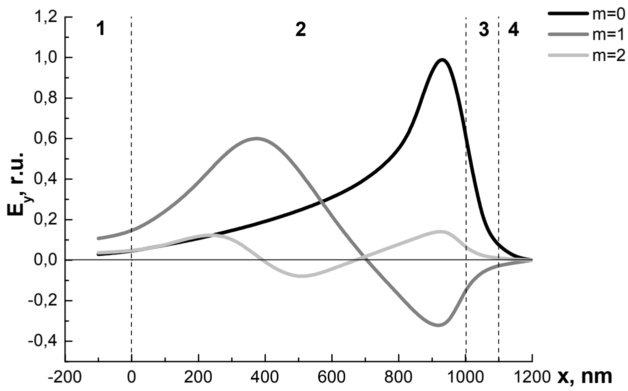


b)

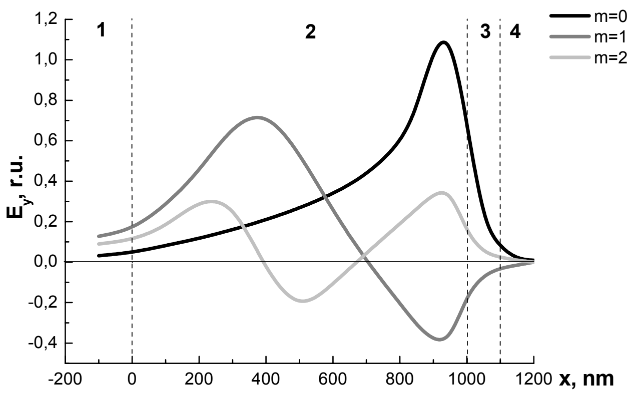
Fig. 5. Distribution of the electrical component of the field in the *diffusion waveguide — gradient layer CGS with exponential distribution of the refractive index profile (a)* and *the diffusion waveguide — photoinduced gradient layer CGS with exponential distrbution of the refractive index profile (b)*

Consecutive excitement of the three modes of the diffusion waveguide (Table 2) was experimentally determined on the working wavelength (λ=0.63 μm).

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). The optical losses in the given system increase because the exponential profile of the refractive index increases the difference Δn on the waveguide — air interface. In the case of the parabolic refractive index profile of the gradient film $(GeS_2)_x(As_2S_3)_y$ 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 lokalization.



a)



b)

Fig. 6. Distribution of the electrical component of the field in the *diffusion waveguide — gradient layer CGS with parabolic distribution of the refractive index profile (a)* and *the diffusion waveguide — photoinduced gradient layer CGS with parabolic distrbution of the refractive index profile (b)*

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

Table 1
The values of the localization energy coefficient in the waveguide.

Waveguide optic strcture	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 inex profile	0,35	0,24	0,07
Diffusion waveguide — photoinduced gradient layer CGS with exponential distribution of the refractive inex profile	0,39	0,28	0,17
Diffusion waveguide — gradient layer CGS with parabolic distribution of the refractive inex profile	0,83	0,69	0,23
Diffusion waveguide — photoinduced gradient layer CGS with parabolic distribution of the refractive inex 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_1/K_2
Exponetial	TE_0	1.529	7.33	1.047
	TE_1	1.526	9.17	1.301
	TE_2	1.5253	12.87	1.609
Parabolic	TE_0	1.5255	2.99	0.427
	TE_1	1.5231	3.04	0.431
	TE_2	1.5217	3.79	0.474

Where: N_{eff}. — the effective refraction coeficient 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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