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Geodetic and two-layer lenses realized basing on dielectric diffusion lightguide

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Production methods of two type of lenses employed in the integrated optics, i.e., of geodetic and hybride two-layer lenses are described. Also, the parameters of the produced elements are given.

1. Introduction

The structure of a thin-layer lens, called also a lightguide structure, creates a modified region in a planar lightguide. This region is suitably localized and has precisely defined shape and dimensions. The modification concerns the change (usually the increase) of the optical path within the structure. Denoting the optical path by Nz (where N is effective refractive index of the lightguide layer, and z is geometric path) the three ways of its changing may be marked with the symbols: $N^{*}z$, Nz^{*}, $N^{*}z^{*}$. Here, the factor subject to modification is denoted by an asterisk. The change of N may be realized by two methods: the first one involves the doping which leads to creation of single-layer structures, the other one consists in creation of an additional thin-film element on/or under the lightguide leading to a hybride two-layer structure. The change in geometrical path is obtained by making a depression of definite profile in the substrate, on the surface of which the lightguide is next produced [1].

In the lens structures, similarly as it is the case for the other thin film optical elements, the wedge-geometric or concentration transitions on the input and output edges are necessary [2].

2. Geodetic lens

The structure of a geodetic lens of Nz* type is shown schematically in Fig. 1. This structure has been realized on a glass substrate depression by applying a diffusion lightguide. An increase of the geometrical path has been achieved by performing a spherical depression in the substrate. This is the basic type of the geodetic lens produced most frequently. So far, the elements of this type have been examined many times. The most complete analysis of the dependence of the optical lens properties on the geometric parameters of the depression as well as on the ratio of the refractive indices in the substrate and the layer, respectively, may be found in the work [3].

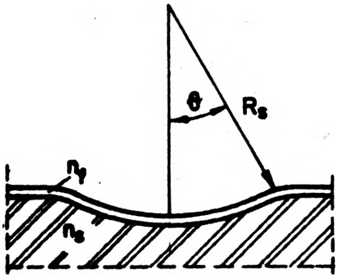

Fig. 1. Scheme of the geodetic lens structure with a spherical depression, n_f, n_s - refractive indices of the lightguide layer and the substrate, R_s, θ - geometric parameters of the depression

The production of a geodetic lens involves two processes. The first of them consists in making a depression in the substrate. This is made by grinding and next polishing the region of the structure by a tool of a spherical shape of its processing surface and using suitable grinding and polishing powders. It is well known that beside the basic depression parameters R_s and θ the lens properties depend significantly on the character of transition from the depression to the substrate plane. The best effects, so far as the elimination of the scattering at the structure boundary is concerned, are achieved by employing a mild transition of toroidal shape. Then, however, the mechanical processing of the lens becomes much complicated. In our experiments a sharp edge between the spherical surface and the plane was removed by additional grinding with a sphere of diameter greater than the diameter of the sphere used to make the depression and next by fine polishing with a tool of toroidal profile. The second process is the production of the planar lightguide. To this end the ion exchange method was applied, in which - by exploiting the glass substrate - the modifier Na^+ ions were exchanged with Ag^+ ions in the near-surface layer [4].

To examine the optical properties of the lenses 10 tentative elements have been made, of which one half possessed sharp edges, the others being chamfered. In all the cases a diffusion six-mode lightguide was applied. The examinations were carried out mainly to find the way of determining the focal length, the aberration and the influence of the structure edge shape on these quantities. The value of focal length has been determined in two ways: by calculations based on the lens cross-section profile and by direct measurement of the focal length of the lens "in action". The real parameters, R_s and θ, of the depression have been determined with the help of a profile microscope and verified additionally on the base of the photomicrographs of the structures. The results obtained were used to calculate the focal length according to the relation: $f = R_s/2(1 - \cos\theta)$. The results of both the calculations and the direct measurements are given in Table. From the comparison of the results obtained from observations and the measurements of two series of lenses mentioned above the following statements may be formulated:

Table. Relations $f(R_s, \theta)$: calculated - f_1, measured - f_2

R_s, [mm]	θ, [deg]	f_1, [mm]	f_2, [mm]
10.855	20.69	84.12	90.00
10.511	22.82	67.15	71.00
10.314	22.86	65.67	68.00
10.457	22.33	69.70	72.00
6.487	31.03	22.66	20.00
6.920	30.16	25.55	26.00
7.849	26.53	37.27	38.50
7.602	27.99	32.50	34.00
8.143	27.09	37.12	40.50
8.974	25.47	46.25	49.00

i) All the lenses - with sharp and mild edges - show the negative spherical aberrations. Its value has been estimated for the paraxial rays for the aperture diameter of 2 mm at the height of 1 mm, and for the focal lengths in the range of 20-90 mm. The existence of aberrations is chiefly due to the multimode character of the structure.

ii) Egde chamfering by imposing a toroidal edge shape assures a distinct reduction of the light scattering losses (to their half value) and results in a slight, by 4%, shortening of the focal length.

In Figure 2 an examplified photo of a lens working in an excited lightguide is presented.

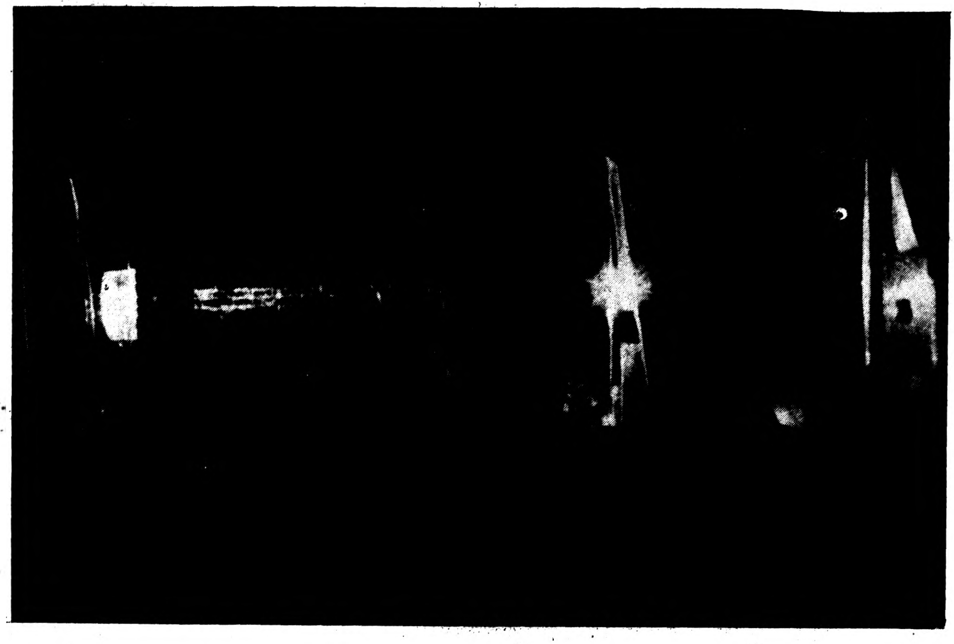

Fig. 2. Geodetic lens in an excited lightguide. Magnification about 2:1

3. Two-layer lens

The structure of a hybride two-layer lens of $N^{*}z$ type is shown schematically in Fig. 3. The lens of this structure has been produced basing on diffusion lightguide on a glass substrate. The realization of the lenses was preceded by examinations aiming at the selection of the best material of light refractive index n_e, creating a structure region modified with respect to its surrounding. Basing on this criterion the oxides ZnO and CeO_2 and the sulphide ZnS have been chosen. These materials have $n_e > 2$ for $\lambda = 5.461$ nm. Next, these dielectrics were examined in the thin film form. The criteria used in this part of examinations concerned the lightguide properties of the layers,

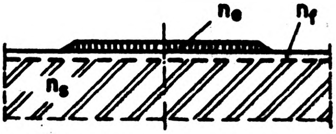

Fig. 3. Scheme of the two-layer structure (n_f, n_s as in Fig. 1), n_e - refractive index of the additional layer deposited on the lightguide within the structure - $n_e > n_f$

i.e., the attenuation and effectiveness of rate of N. In order to determine the attenuation some planar lightguides were produced on the glass substrate by the method of evaporation in vacuum. The values of the refractive indices were determined with the help of an ellipsometric method and the following results have been obtained: 2.5 for ZnS and 2.0 for CeO_2 (all for $\lambda = 5.461$ nm). The attenuation was also measured by the IM spectroscopy method and in layers about 1 μm thick for the fundamental mode TE_0 and $\lambda = 6.328$ nm, and for the sequence of materials as given above the following results have been obtained: 14, 9 and 20 dB/cm.

On the base of these results the further experiments were carried out only for ZnS, for which the modulation effectivity of N coefficient was determined both theoretically and experimentally. For both these methods a model was suggested and the samples of the ZnS layer of thickness t were deposited on the diffusion lightguide produced by the method of exchange of Na^+ ions to Ag^+ ions in the glass substrate. In the model accepted the calculational problem is rather difficult to solve because of the mutual dependence of the two active layers and the complex shape of the refractive index profile. The first layer (starting from the air) is of constant value of n_e, while a jump from n_e-value to n_f-value occurs when passing to the second layer. In the second index-gradient layer the refractive index changes parabolically within the range between the n_f on the surface to n_e. By substituting the WKB integral to the eigenvalue equation for the two-layer structure we obtain the equation which can be solved by numerical methods. The function N(t) has been calculated by introducing the following numerical data: $n_e = 2.3$, $n_{f\ sub} = 1.61$, $n_s = 1512$ (all for $\lambda = 6.328$ nm). The run of N(t) is shown in Fig. 4, where the experimental results were obtained from the sample of different values t changing within the range 0.3–1.9 μm. All the layers ZnS were deposited on a six-mode diffusion lightguide.

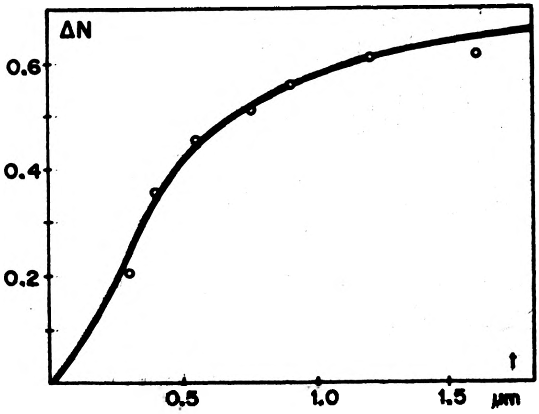

Fig. 4. The run of the function N(t): continuous line - theoretical, dotted line - experimental

The values of the coefficient N were determined by the method of synchronous angle coupling measurement for the fundamental mode TE_0 in different samples. As it may be seen, there exists very good consistence of the calculated and experimental characteristics of N(t). It is easy to notice that the highest modification effectivity $\Delta N/\Delta t$ occurs in the thickness range of 0.2–10 µm. Obviously, this range of ZnS film thickness has been exploited in production of lenses.

Performance of a lens is reduced to production of the two-layer structure of the assumed shape and dimensions in a definite place of the planar lightguide. For the measurement purposes the respective sets of structures have been produced, each composed of 5 round lenses of diameters: 1.7, 2.5, 3.0, 3.5 and 4 mm for each value of t the latter being equal to 0.4, 0.6 and 0.8 µm, respectively. An exemplified set of structures with the thickness $t = 0.6$ µm is presented in Fig. 5. Mechanical masking was employed while producing these samples by evaporation of ZnS. A metal mask with etched windows was placed at a distance of 1 mm from the lightguide plane. In this way wedge transitions t(z) were obtained at the structure boundary. The elements

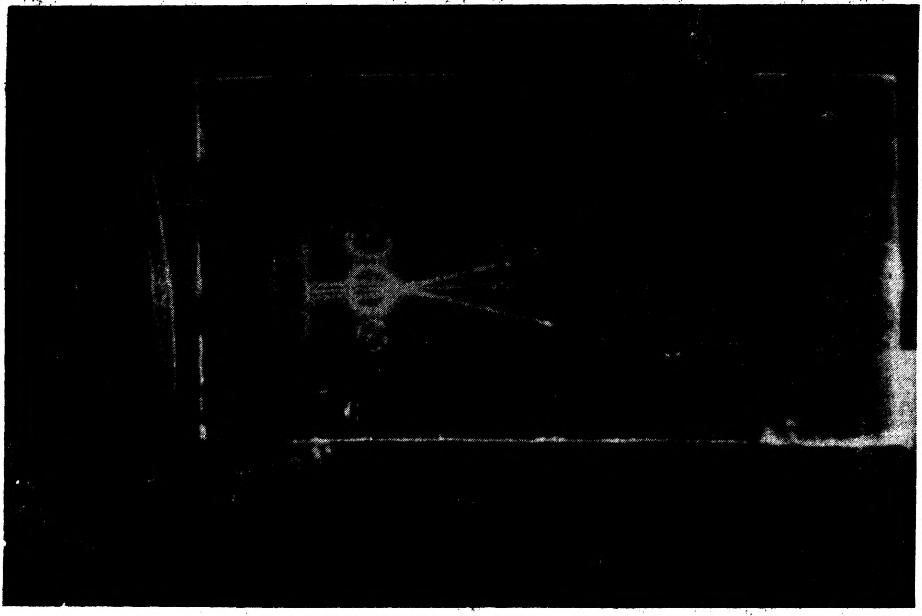

Fig. 5. An image of the sample with a set of lenses, the lens excited is of diameter 3 mm, $t = 0.6$ µm. Magnification 2:1

realized in this way have been examined. First, with the help of an interference microscope, the real thickness t of the ZnS layer, edge profile and diameter were determined. It turned out that the wedge profile is almost linear and - therefore only its length along the z-axis (direction of propagation) in the lightguide plane was determined accurately. These measurements pointed out that for all the above thicknesses of the ZnS layer this thickness amounted to about 0.1 mm, i.e., to about 166 wavelengths.

The numerical results obtained from the measurements allowed to calculate the focal lengths of all the lenses. Tacking account of small length of the transition with respect to the diameter, for the paraxial rays the formula $f = N_f \Phi/4(N_e - N_f)$ (where N_f - effective refractive index of the lightguide - in the lens surrounding, N_e - effective refractive index of the two-layer structure - in the region t = const, and Φ - lens diameter).

Figure 6 shows exemplified runs of $f(\Phi)$ for lenses with the ZnS layer 0.6 µm thick. For this value of t we have: $N_f = 1.58$, $N_e = 1.92$. Obviously, the linear characteristic presents a theoretical run of the function $f(\Phi)$.

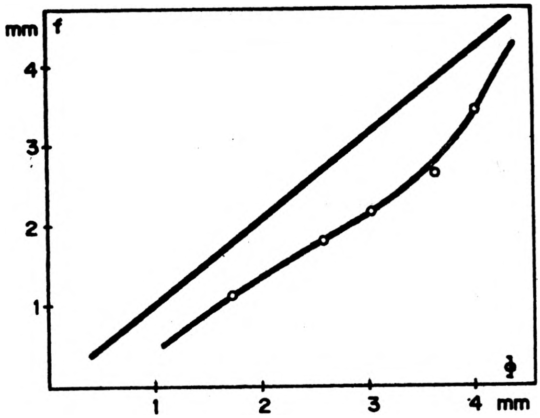

Fig. 6. Runs of $f(\Phi)$: theoretical (linear), and experimental

The curvilinear relation, marked with points, has been determined experimentally from the focal length measurements carried out on the base of the photographs analogical to these shown in Fig. 5. The discrepancies between the theoretical and experimental relations of $f(\Phi)$ appear mainly due to the presence of spherical aberration. The latter, in turn, is caused by the multimode character of the structure, similarly as it was the case for the geodetic lens. As it follows from the analysis of Fig.6 the spherical aberration shortens to a greater degree the focal length of the small diameter lenses. The measurements discussed allowed to state that the aberration is mainly negative and changes within the limits 0.4-0.9 mm, depending on the lens diameter, but that its value does not depend upon the parameter t of the structure. The value of the focal length f determined experimentally ranged between 1-4 mm depending on the lens diameter (see Fig. 6).

4. Conclusions

As it may be easily seen, the results presented have been obtained during preliminary work concerning the practical realization of optical thin-film elements. The trial structures obtained practically are loaded with defects defined above. The reference level for those results may be the achievements obtained in the advanced research centres working in this field. One of those is Instituto Sulle Onde Elettromagnetiche, Firenze, Italy. The works [5, 6] from this Institute present the newest achievements in the design and production of the geodetic lenses. The reason for the technological and experimental works in this field, undertaken by our group and resulting in the examination of the above structures, was of some importance since it gave us real possibilities of carrying out the further works oriented toward the elimination of the said defects, perfectioning and modification of these structures and exploitation of other materials of better optical properties and useful in creating of definite functional system of integrated optics.

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ГЕОДЕЗИЧЕСКАЯ И ДВУПЛЕНОЧНАЯ ЛИНЗЫ, ОСУЩЕСТВЛЕННЫЕ НА ОСНОВЕ ДИЭЛЕКТРИЧЕСКОГО ДИФФУЗИОННОГО СВЕТОВОДА

Описаны методы осуществления двух типов линз, применяемых в интегральной оптике - геодезической и гибридной двупленочной. Приведены также параметры этих линз.