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Bimodal layers of the polymer SU8 as refractometer

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Abstract

The paper presents the results of investigations concerning measurements of the refractive index and the thickness of planar waveguide structures, obtained by photo polymerization of the polymer SU8. In the paper the mode sensitivity has been calculated as a function of the thickness in a bimodal structure. The differential interference was analyzed concerning modes of the same types TE_0-TE_1 and TM_0-TM_1. The thickness of the layer has been determined when the interferometer is most sensitive to changes of the refractive index of the cover.

Keywords: planar waveguides; interferometers; integrated optical sensors; difference interferometer.

1. Introduction

For the purpose of constructing optical planar sensors various techniques are applied, e.g. ion exchange, plasma-enhanced chemical vapour deposition (PECVD) and spin coating in the case of SU8-polymer waveguides [1-6]. SU8 is a polymer based on epoxy resin, developed in 1989 by IBM. Thanks to its properties it is now one of the most attractive materials used in the optical planar technology. SU8 is rather cheap and displays a high thermal and chemical stability as well as good resistance to mechanical damages and an unusual transparency. Because of its very good optical properties [7, 8] it is utilized in the production of optical sensors operating in the interferometer system.

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For the purpose of investigations a series of planar waveguide structures was prepared for the SU8 polymer of varying thicknesses. The thickness of the layers depended on the velocity of gyration of the centrifuge [7]. In order to determine the refractive index of a step-index waveguide structure, based on the polymer SU8, the numerical method was applied, requiring the determination of the effective refractive indices for each observed mode. By means of mode spectroscopy a set of effective refractive indices was determined for the wavelength 633nm, concerning the planar waveguides [9-10].
The synchronic angle was measured for the polymer waveguides obtained at rotational speeds of 2000rpm, 3000rpm and 5000rpm. Basing on the measured synchronic angle the effective refractive indices were calculated for all modes of each polarization. In the case of waveguides in which not more than two modes could be observed, the denotations 0 and 1 were applied successively, i.e. modes of the zero and first order. Table 1 contains the results of calculations of the thickness of the waveguide layer consisting of SU8. The calculations were based on data resulting from the analysis of mode spectra concerning the respective waveguide and on the previously calculated value of the refractive index.

Table 1. Results of measurements of the refractive index and thickness of waveguide layers at λ=633 nm

Spin speed [rpm]	refractive index	thickness [μm]
2000	1.592	1.38
3000	1.597	1.29
5000	1.594	1.20

2. Bimodal waveguide applied as a refractometer

Knowing the refractive index of the layer SU8 and having the possibility of shaping the thickness of the layer by choosing the angular velocity of spinning, we can optimize the thickness in order to achieve maximum sensitivity to changes in the refractive index of the cover.
For a three-layer system with the following refractive indices: substrate n_S=1.509, waveguide layer n_F=1.592, cover n_C=1.330, the effective refractive indices N were determined depending on the thickness of the layer, concerning both polarizations TE and TM for the wavelength λ=633nm .
In the case of an interferential system the most important parameter is the mode sensitivity $S\{n_C\}$[11-13], determining the changes of the effective refractive index ΔN due to changes of the refractive index of the cover Δn_C.

$$S\{n_C\} \cong \frac{\Delta N}{\Delta n_C} \tag{1}$$

Knowing the effective refractive indices, the mode sensitivity can be determined. [14].
The calculated value of sensitivity has been presented in Fig.1(a).
The differential interferometer is a simple planar waveguide, which can be realized most easily. In the waveguide two modes are excited, and a change of the refractive index of the cover involves changes of the effective refractive indices of the guided modes. The sensitivity of the differential interferometer $S_D\{n_C\}$ can be determined as differences of the mode sensitivity $S_i\{n_C\}$ and $S_j\{n_C\}$ of the guided modes[9]:

$$S_D\{n_C\} = \frac{\Delta\left(N_i - N_j\right)}{\Delta n_c} = \frac{\Delta N_i}{\Delta n_c} - \frac{\Delta N_j}{\Delta n_c} = S_i\{n_C\} - S_j\{n_C\} \tag{2}$$

In the range of thicknesses of the waveguide layer from 0.94μm to 1.54μm the three-layer structure is a bimodal structure for the polarizations TE and TM. In such a structure the modes TE_0, TE_1, TM_0, TM_1 can propagate.

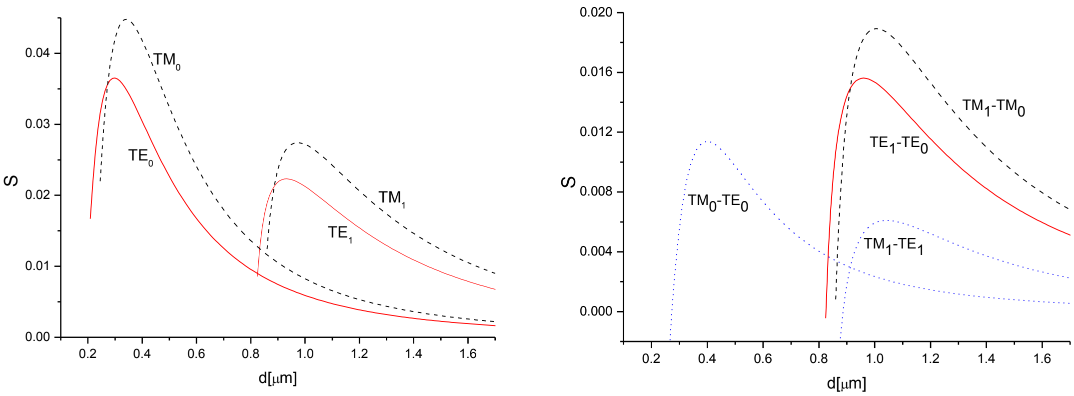

Fig. 1. (a) sensitivities as a function of the thickness of the waveguide layer; (b) sensitivities as a function of the thickness of the waveguide layer concerning various pairs of modes.

In the course of recent years the application of various orders in the construction of a differential interferometer has been suggested [15-18]. Changes of the refractive index of the cover may be monitored by any arbitrary pair of modes. A high sensitivity can be achieved when modes of the same types TE_0 – TE_1 or TM_0 –TM_1 are applied. Fig.1.(a) presents the sensitivity of the modes TE_0 and TE_1, Fig.1.(b) presents the sensitivity of a differential interferometer which operates basing on these modes. In the bimodal range of the waveguide thickness (0.94μm to 1.54μm) the sensitivity of the mode TE_0 is rather small, decreasing with the growth of the thickness, whereas the sensitivity of the mode TE_1 first increases and after reaching its maximum decreases with the growing thickness of the waveguide. The characteristics of the sensitivity of the differential interferometer are in this case similar to those of the sensitivity of the mode TE_1. The differential interferometer has the highest sensitivity equal to 0.016 at the thickness of the waveguide layer d=0.96 μm. Considering the interferences of the modes TM_0–TM_1, we see (Fig.1.(b)) that the respective characteristics are similar. In such a case the differential interferometer achieves the highest sensitivity equal to 0.019 at a thickness of the waveguide layer d=1.01 μm.

Fig. 1b. presents the sensitivities of the differential interferometer as a function of the thickness of the waveguide concerning modes of the same type (TE_0–TE_1, TM_0–TM_1) and modes of the same order (TE_0 – TM_0, TE_1–TM_1).In the case of modes of the same type a higher sensitivity can be achieved than in the case of mode of the same order. The highest sensitivity is achieved by applying the interference of the modes TM_0–TM_1.

3. Conclusion

The investigations concerning the achievement of planar waveguides on a glass substrate. For the investigations waveguides were chosen obtained at rotational speeds of 2000, 3000 and 5000 rpm, in which two modes of polarization TE and two with TM polarization were propagated. The application of modes of the same types (TE_0–TE_1 or TM_0–TM_1) permits to achieve a higher sensitivity than in the case of modes of the same orders (TE_0– TM_0, TE_1–TM_1). The highest sensitivity is obtained by applying the interference of the modes TM_0–TM_1.

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