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Comparison of the Sensitivity of a Polymer Waveguide in the Classical and Reverse Symmetry System

K. Gut and S. Drewniak

Department of Optoelectronics, Silesian University of Technology
Krzywoustego 2, 44-100 Gliwice, Poland

In this paper an analysis of two types of planar waveguides (with the conventional type of the layer and the reverse symmetry waveguide) is presented. In both types of the structure the polymer SU8 was used. In respect of its properties, this polymer is suitable as a waveguide layer. The analysis presented in this paper describes those structures working as sensors. We made a comparison of both types of configuration. We made a detailed analysis of the sensitivity of the covering layer when the thickness of the waveguide layer is changing and when the length of the wave activating the structure is changing, too.

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1. Introducing

In recent years investigation on planar waveguide sensors [1–11] has been developed considerably, particularly concerning biological applications. The fact that a change of the refractive index n_c involves changes of the effective refractive index of the propagated modes N_eff have been widely used for biochemical detection. In the conventional configuration of the layers, when the covering has a lower refractive index than the refractive index of the substrate, the intensity of the light in the substrate layer is bigger than in the covering. It is a very important fact, when the waveguide is working in the system of sensors. We consider the structure where the refractive index of the covering layer is bigger than the refractive index of the substrate [12]. There we can register that the proportion of the intensity of the light in the covering layer to the intensity of the light in the substrate is considerably higher (in comparison with the conventional structure).

In this paper, we will present two types of the structure — a graphical illustration is in Figs. 1 and 2.

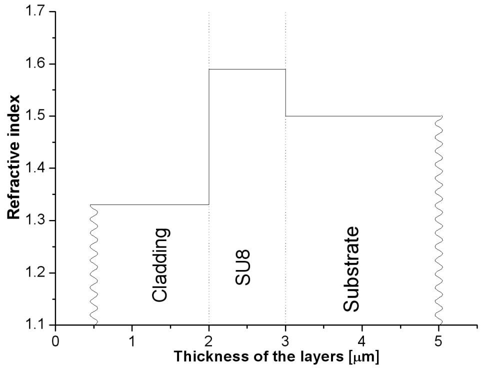

Fig. 1. Scheme of the conventional waveguide.

We propose the polymer SU8 ($n_\mathrm{F} = 1.59$) as the waveguide layer in both types of the structure.. We chose this polymer because of its properties. SU8 is a substance with a good chemical and thermal stability and resistant to damage [13], it is characterized by good adhesion to the substrate [14] and by optical transparency in the infrared wavelength region [13–15]. Water ($n_\mathrm{C} = 1.33$) is the cover in both types of the structures [12]. As a substrate we used glass ($n_\mathrm{S} = 1.50$). In the reverse symmetry waveguide, between the glass layer and the waveguide layer there is mesoporous material (proposed in [16]). This material is characterized by a low refractive index which is equal to $n_0 = 1.2$. In this case, an evanescent field can penetrate deeper into the covering layer than into the layer under the waveguide [16]. This is very important if we want to receive the biggest (possible) sensitivity $S\{n_\mathrm{C}\} \cong \Delta N_\mathrm{eff}/\Delta n_\mathrm{c}$ [12] where ΔN_eff denotes a change of effective refractive index of the cover Δn_c. In this paper we compare the sensitivities $S\{n_\mathrm{C}\}$ of the conventional and the reverse symmetry waveguide. We analyse cases, where the parameters: the thickness of the SU8 layer and the length of the light are changeable.

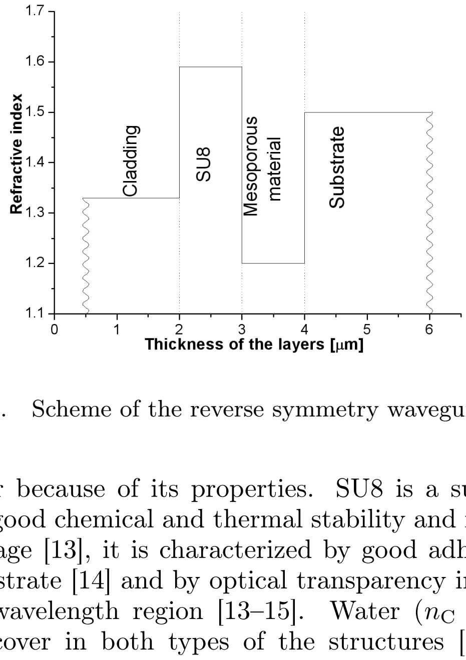

Fig. 2. Scheme of the reverse symmetry waveguide.

2. Numerical analysis

The sensitivities $S\{n_\mathrm{C}\}$ depend on the effective refractive index N_eff. It was necessary to enumerate N_eff. We did this by using Optiwave Software. The sensitivity $S\{n_{\mathrm{C}}\}$ [17] is determined by the formula

$$S\{n_{\mathrm{C}}\} = \frac{n_{\mathrm{C}}}{N_{\mathrm{eff}}} \frac{n_{\mathrm{F}}^2 - N_{\mathrm{eff}}^2}{n_{\mathrm{F}}^2 - n_{\mathrm{C}}^2} \frac{\Delta z_{\mathrm{C}}}{d_{\mathrm{eff}}} \left(\frac{2N_{\mathrm{eff}}^2}{n_{\mathrm{C}}^2} - 1 \right)^{\rho}, \tag{1}$$

where

$$d_{\mathrm{eff}} = d_{\mathrm{F}} + \Delta z_{\mathrm{C}} + \Delta z_{\mathrm{S}}, \tag{2}$$

$$\Delta z_J^{(\mathrm{TE})} = \frac{\lambda}{2\pi} \frac{1}{\sqrt{N_{\mathrm{eff}}^2 - n_J^2}}, \tag{3}$$

$$\Delta z_J^{(\mathrm{TM})} = \frac{\lambda}{2\pi} \frac{1}{\sqrt{N_{\mathrm{eff}}^2 - n_J^2}} \times \left[\left(\frac{N_{\mathrm{eff}}}{n_{\mathrm{F}}} \right)^2 + \left(\frac{N_{\mathrm{eff}}}{n_J} \right)^2 - 1 \right]^{-1}. \tag{4}$$

The index J means C for the covering layer and S for the substrating layer. The index ρ is equal to 0 for the TE type of polarization ($\rho = 1$ for the TM type of polarization). The length of the wave is marked as λ, the refractive index of the waveguide layer is marked as n_{F}. Effective thickness d_{eff} (Eq. (2)) is marked as total depth of light penetration. Equations (3) and (4) describe the depth of the evanescent field in the covering/substrate layer for the TE and TM polarization, respectively.

3. Sensitivity $S\{n_{\mathrm{C}}\}$ dependent on the thickness of the waveguide layer

We calculate the effective refractive index for both types of the structures in the case when waveguide layer is changing (for $\lambda = 365$ nm).

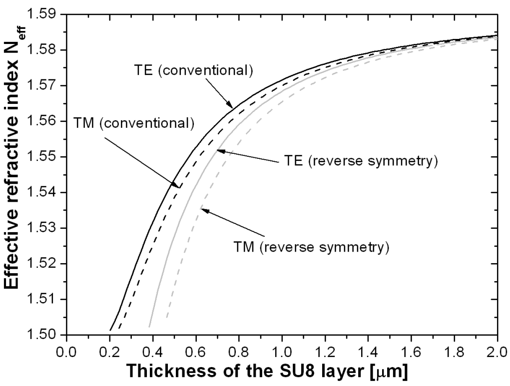

Fig. 3. Effective refractive index in the function of the changeable thickness of the SU8 layer.

Result of calculations for the mode 0 is shown in Fig. 3. There it is visible that the effective refractive indices of the reverse symmetry structure are smaller than N_{eff} of the conventional structure (at a constant thickness of the waveguide layer). Moreover, in the case of TE polarization, the effective refractive indices are higher in comparison with TM polarization.

The dependence of the sensitivity $S\{n_{\mathrm{C}}\}$ on the thickness of the SU8 layer is shown in Figs. 4–6. The sensitivity of the reverse symmetry structure is larger than of the conventional waveguide. At the smallest thickness of the SU8 layer, that the mode is propagating, the sensitivity $S\{n_{\mathrm{C}}\}$ reaches its maximum (in the reverse symmetry structure).

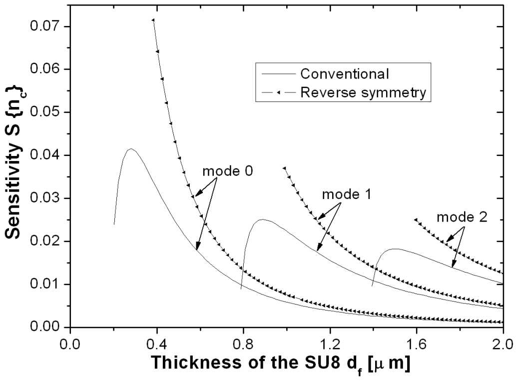

Fig. 4. Sensitivities $S\{n_{\mathrm{C}}\}$ in the function of the thickness of the SU8 layer for TE polarization.

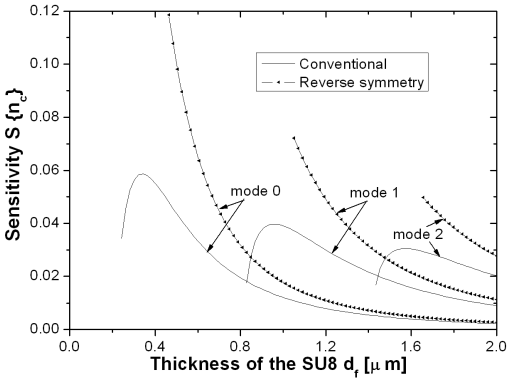

Fig. 5. Sensitivities $S\{n_{\mathrm{C}}\}$ in the function of the thickness of the SU8 layer for TM polarization.

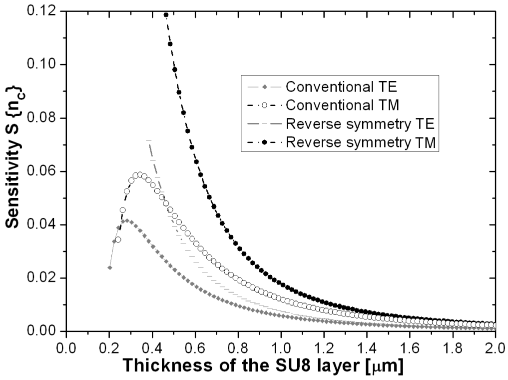

Fig. 6. Sensitivities $S\{n_{\mathrm{C}}\}$ in the function of the thickness of the SU8 layer for the mode 0 (for both types of the structure).

4. Sensitivity $S\{n_{\mathrm{C}}\}$ dependent on the wavelength of light

The effective refractive indices were calculated when the wavelength was changing ($d_{\mathrm{F}} = 1$ μm). Figure 7 compares the values N_{eff} (mode 0) in both types of the structures for TE and TM polarization. Figure 8 shows the dependence of $S\{n_{\mathrm{C}}\}$ in the mode 0.

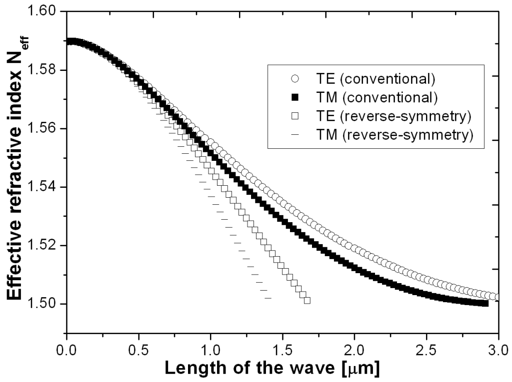

Fig. 7. Effective refractive indices in the case where the length of the light is changing (mode 0).

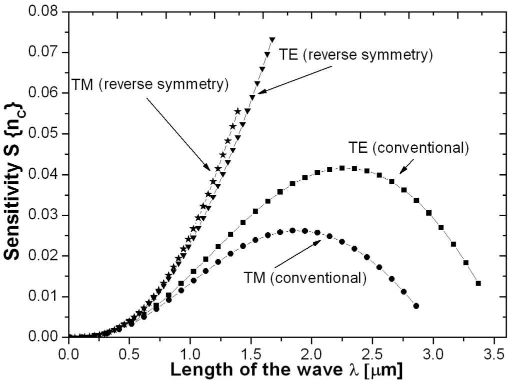

Fig. 8. Sensitivities $S\{n_{\mathrm{C}}\}$ in the case where length of the light λ is changing (mode 0).

If we want to achieve the maximum sensitivity in conventional structures, we must use a longer length of light than in the structure with reverse symmetry. The maximum of the sensitivities (for the TE polarization) is bigger in reverse symmetry structure (0.073) than in the conventional structure (0.042). The situation is similar for the TM polarization.

5. Summary

The value of the sensitivity $S\{n_{\mathrm{C}}\}$ is higher for reverse symmetry structure than in the conventional structure (both for the case when the thickness of the waveguide layer is changing and for the case when the length of the light is changing). It is very important information when the waveguide is a part of the sensor system. By choosing the layer between the substrate and the waveguide layer we get an impact on value of the sensitivity.

Acknowledgments

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