TWO-MODE PLANAR AND CHANNEL POLARIMETRIC DIFFERENCE INTERFEROMETER

Kazimierz GUT
Institute of Physics, Silesian University of Technology ul.Krzywoustego 2, 44-100 Gliwice POLAND
kazimierz.gut@polsl.pl

In the paper are presented investigations of planar and channel polarimetric interferometer made by ion exchange in glass for sensor applications. J have determined the dependence of the difference of propagation constants of orthogonal modes of the same order on the refractive index of the cover, for planar waveguides obtained during the ion exchange K^+-Na^+ in the glass BK-7. Similar measurements have been made for the exchange Ag^+-Na^+, determining also for that case the influence of heating time on those parameters.

Keywords: *planar waveguides, ion exchange, waveguide birefringences*

1. INTRODUCTION

Over the last few years we have been witnessing an intensive development of chemical waveguide sensors. One of the group of sensors being subject to such extensive development is constituted by waveguide interferometers [1,2]. The work presents one of the simplest interference systems - the difference interferometer (polarimetric). In the difference interferometer the interference of modes having different polarization states (TE, TM) is applied. Polarization state of the beam at the waveguide's output depends on the difference of the steady phase during the propagation through the waveguide structure. This difference is the function of parameters characterizing waveguide layer and cover. When the cover changes the refractive index in effect of the influence of external factors, it also induces the change of phase difference between the propagating modes [3]. This mechanism is constituting a basis for the functioning of chemical sensors in difference interferometer systems. The system of such sensors can be realized in the planar or channel form. The work presents investigation results involving such a system functioning as refractometer. (The change of refractive index induces the change of polarization state at the output of waveguide system). In the planar system, measurement results were presented involving the change of propagation constants generated by the change of waveguide refractive index in two-mode structures obtained with the use of ion exchange in glass. The determined difference of propagation constants is different for different pairs of ortogonal modes (TE_0-TM_0, and TE_1, TM_1). Two types of ion exchange processes in glass BK7 were presented - Na^+-K^+ and Na^+-Ag^+. The work also presents the investigation results involving the difference interference in channel waveguides obtained using the ion exchange technology K^+-Na^+ in glass BK7.

2. DIFFERENCE INTERFERENCE IN TWO-MODE PLANAR WAVEGUIDES

In two-mode planar waveguides, two modes of polarization TE and two modes of polarization TM can propagate (Figure 1).

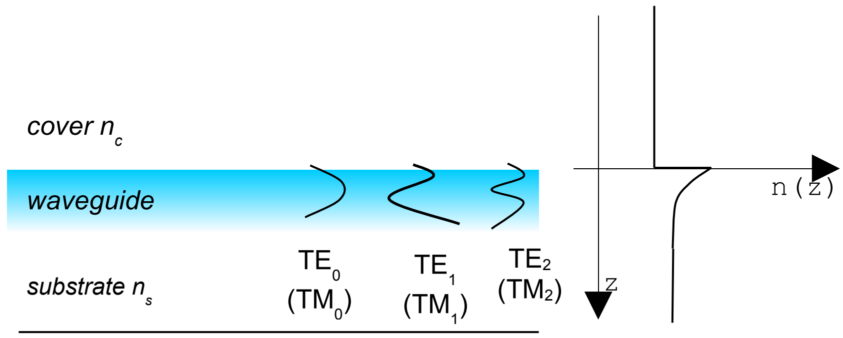

Fig.1 Three-mode planar waveguide

It was presented in works [4,5] that by the application of prism coupler we can excite in the waveguide only one pair of ortogonal modes of the same order. Due to different dispersion equations describing polarizations TE and TM, a phase difference appears between ortogonal waveguide modes of the same order. The change of refractive index of the cover results in the change of phase difference between the guided modes.

The basic characteristic which describes difference interferometer working as refractometer is the change of phase difference as the function of refractive index of the cover $f(n_c)= |\Delta(\phi_{TE} -\phi_{TM})|$

$$\Delta(\phi_{TE} - \phi_{TM})=[\phi_{TE}(n_c) - \phi_{TM}(n_c)]-[\phi_{TE}(n_c=1) - \phi_{TM}(n_c=1)] \quad (1)$$

where $\phi_{TE}(n_c)$, $\phi_{TM}(n_c)$ describe the phase of modes TE, TM for refractive index of the cover n_c. Fig.2 presents the measured change of phase difference $|\Delta(\phi_{TE}-\phi_{TM}|$ along the propagation length of 1cm for both pairs of ortogonal modes TE_0-TM_0 and TE_1-TM_1. Two-mode planar waveguide (for the wavelength λ=670nm) was produced in the ion exchange process Na^+-K^+ (process time 5h, temperature 400°C, glass BK7). The change of phase difference is rising faster for fundamental modes as compared with the modes of the first order. Fig.3 presents the measured change of phase difference for two-mode planar waveguide (for wavelength λ =690nm) made in ion exchange process Na^+-Ag^+ (process time 1h, temperature 300°C, glass

BK7). In this case the change of phase difference is a few times higher (as compared with the two-mode waveguide made in the ion exchange process Na+-K+) and the change of phase difference is rising faster for the first order modes than for fundamental modes. In some sensor applications the change of phase at the end of optical line can be too high (e.g. if we want to work within the range of phase difference 0-π). The sensitivity of difference interferometer can be easily changed by heating the waveguide in the atmosphere of air. Figures 4 and 5 present the characteristics of the waveguides produced in ion exchange process Na^+-Ag^+ (process time 1h, temperature 300°C, glass BK7) and subjected to heating respectively over 0.25h and 0.75h. With the increase of heating time the characteristics are becoming flatter. By choosing appropriate heating time we can modify the sensitivity of the sensor. Two-mode waveguides make it possible to obtain two interference signals of different sensitivity values, and hence we can define the phase changes higher than π.

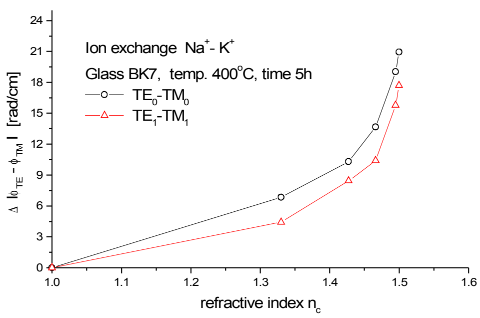

Fig.2 Waveguide characteristics (exchange Na^+-K^+)

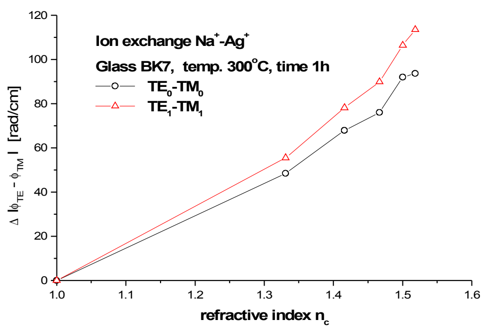

Fig.3 Waveguide characteristics (exchange Na^+-Ag^+)

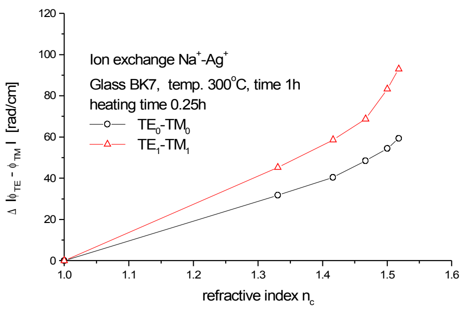

Fig.4 Waveguide characteristics (exchange Na^+-Ag^+ and heating 0.25h)

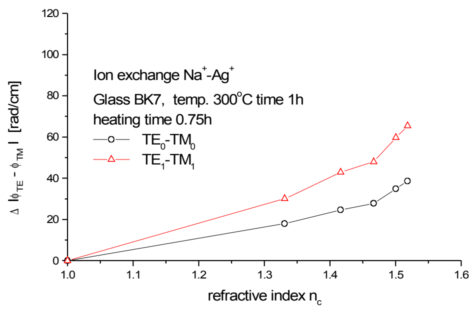

Fig.5 Waveguide characteristics (exchange Na^+-Ag^+ and heating 0.75h)

3. DIFFERENCE INTERFERENCE IN STRIP WAVEGUIDES

Fig.6 presents the diagram of the set-up which was used to record the modal interference in strip waveguides. The light from laser diode LD, after it has passed through polarizer P and objective O_1, is introduced to the strip waveguide.

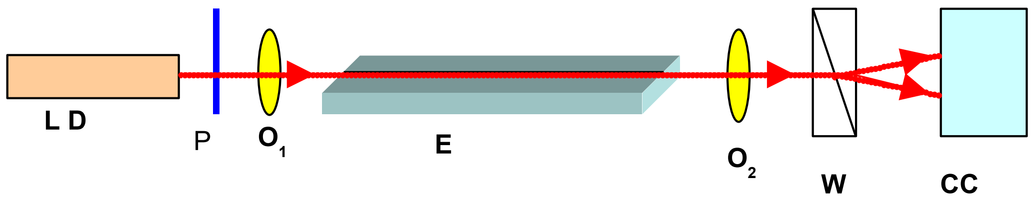

Fig.6 Set-up used to measure phase difference between the modes
LD-laser diode, P-polarizer, O-microscope objective, E-channel waveguide, W-Wollaston's prism, CCD-camera.

The investigated waveguides were made using the ion exchange technology K^+Na^+ in glass BK7. The polarizer P allows to determine the distribution of power in the excited modes TE and TM (more precisely quasi TE and quasi TM). After the optical waveguide has passed through the waveguide it is recorded by cameras CCD. The objective O_2 containing Wollaston's prism W splits and forms the output beam. The prism W can be rotated around the axis of the optical system. If the plane in which the split beams are located is perpendicular or parallel to the surface of the plate in which the waveguide was made, angular separation of modes TE and TM is taking place.
The camera CCD is recording the picture (Fig.7), and by using respective software we can determine the total intensity of light in particular beams. Spatial distribution of modal field in the strip waveguide is presented in Fig.8.

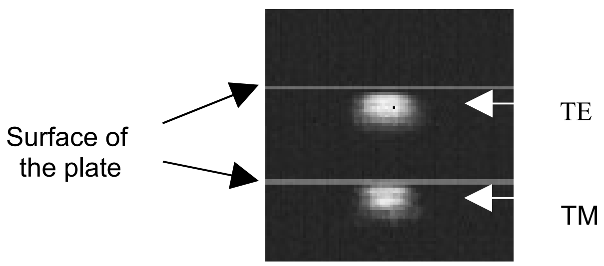

Fig.7 Picture of modes TE and TM recorded by the camera CCD for strip waveguide. (Ion exchange Na^+-K^+ in glass BK7, T=400°C, t=1h, width of mask window 7µm, wavelength λ =670nm).

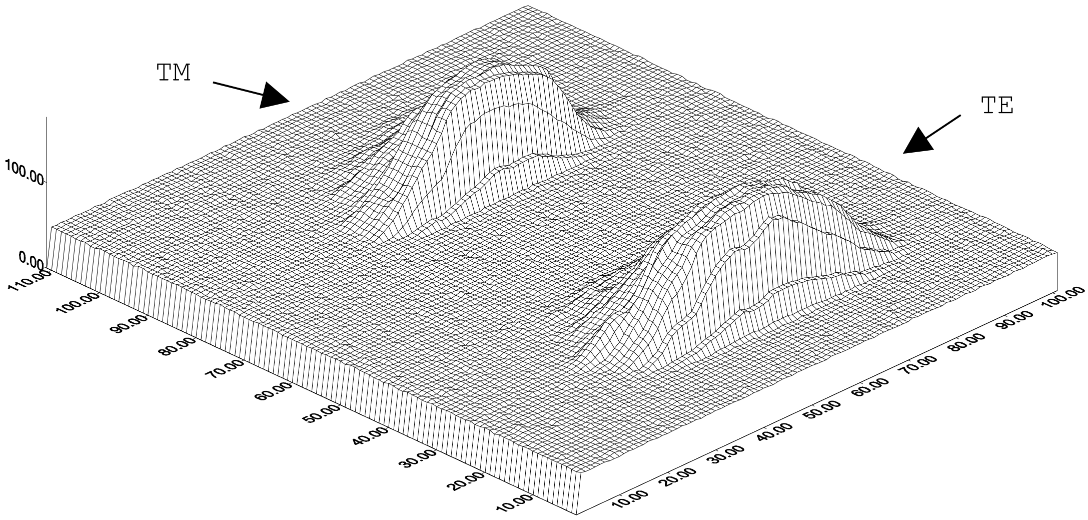

Fig.8 Distribution of light intensity in modes TE and TM in strip waveguide.

Using the presented system we can uniformly excite both ortogonal modes through setting the polarizer P in appropriate angular position. If the prism W is set in such a way that the plane of the split beams forms the angle of 45° with the surface of the plate from which the waveguide was made, then in each of linearly polarized beams there occur components of light vector from the mode TE and from the mode TM. The pictures recorded by the camera for the above cases are presented in Figs. 9a and 9b.

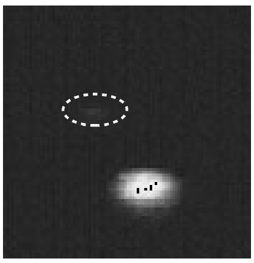

Fig.9a Picture recorded after rotating the Wollaston's prism by the angle 45°

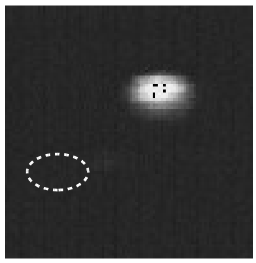

Fig.9b Picture recorded after rotating the Wollaston's prism by the angle (-45°)

In the places marked in the figures (9a and 9b) with broken line, the waves coming from both modes meet in the opposite phases and their quench is taking place. By coating the waveguide surface with fast evaporating liquid, (this method was used to change the phase difference between the modes at the end of optical line), alternate brightening and quench of respective areas of the picture recorded by the CCD camera was observed (Fig.10).

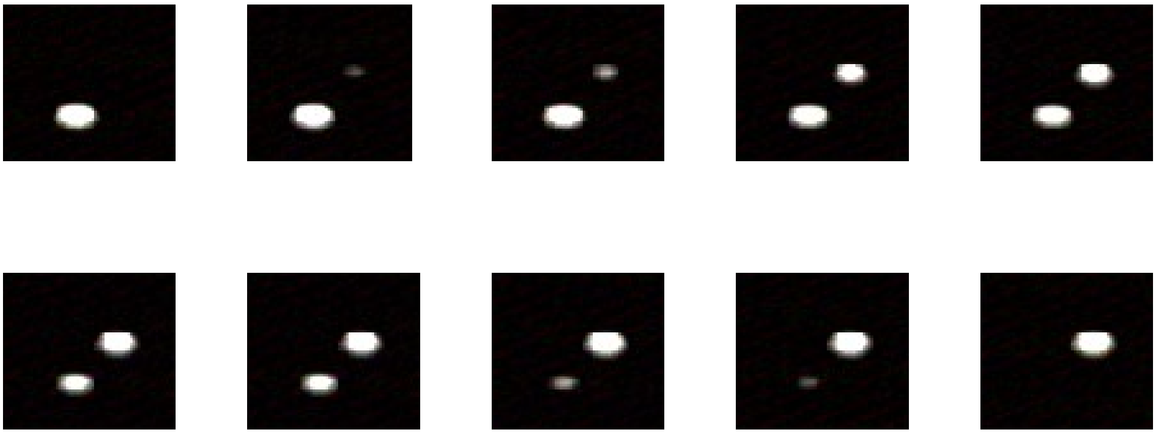

Fig.10 Difference interference in single-mode strip waveguide. Phase change from 0 to π was recorded between the guided modes.

Figure 11 presents the recorded interference picture for the case when the interference involves the modes of different orders and the same polarizations. The plane of angular separation of the beams is perpendicular to the surface of the plate with the waveguide.

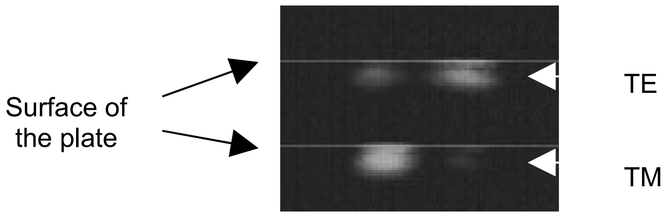

Fig.11 Interference picture recorded by the CCD camera at the end of strip waveguide. (Ion exchange Na^{+}-K^{+} in glass BK7, T=400°C, t=1h, window mask width 20μm, wavelength=670nm).

In the top part the interference of modes TE_{10} and TE_{11} was recorded. In the bottom part the interference of modes TM_{10} and TM_{11} was recorded. By coating the waveguide surface with fast evaporating liquid, alternate brightening and quench of the left-hand and right-hand part of the picture was observed (Fig.12).

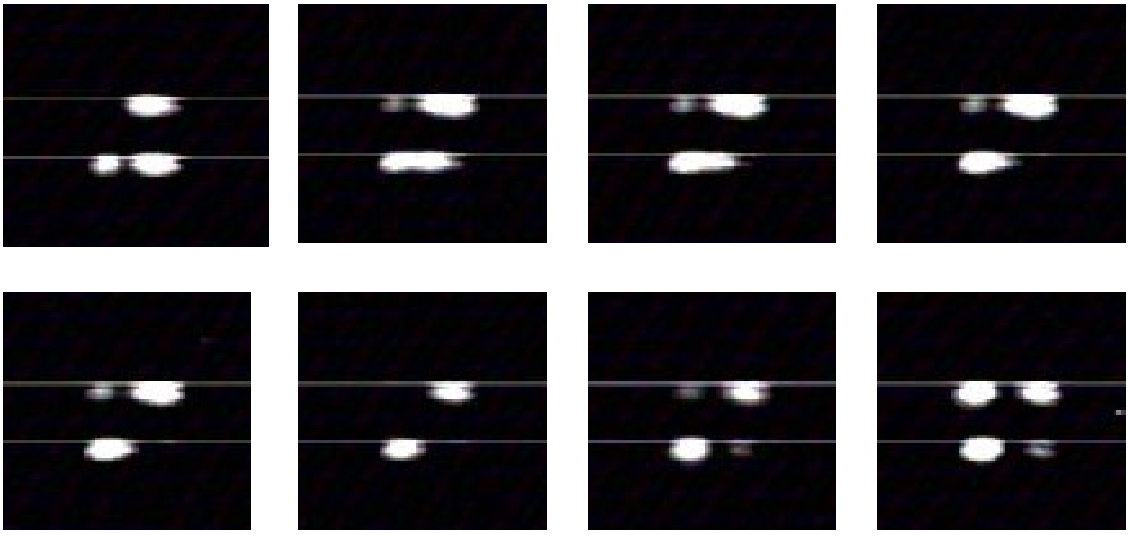

Fig.12 Difference interference in two-mode strip waveguide. (Ion exchange Na^{+}-K^{+} in glass BK7, T=400°C, t=1h, mask window width 20μm).

Strip waveguides develop the potentials offered by the ion exchange technology. The diameter of strip waveguides and the distribution of refractive index are comparable with optical telecommunications fibres. Therefore strip waveguides and telecommunications fibres can be coupled with relatively low loss.

4. CONCLUSIONS

The interferometer presented in the paper can work both in the planar system and in the strip system. Simple production technology of the waveguide is definitely an advantage of the planar structure. By using the strip structure, a few single and two-mode lines can be produced on the common substrate in one technological process, which is important in the designing process of matrixes of optical sensors.

ACKOWLEDGMENTS

The work has been co-sponsored within the research grant KBN No. 3T11B 07126

REFERENCES

1. L. Ross, "Ion -exchanded glass waveguide sensors", SPIE Proc.Vol. CR 53 (1994)
2. W. Lukosz, Ch. Stamm, H.R.Moser, R. Ryf, j. Dubendorfer „Difference interferometer with new phase-measurement method as integrated-optical refractometer, humidity sensor and biosensor" Sensor and Actuators B 38-39 (1997) pp. 316-323

3. K. Gut, P.Karasiński, W. T. Wójcik R. Rogoziński, Z. Opilski A. Opilski, „Applicability of interference TE_0-$TM_)$ and TE_0-TE_1 modes to the construction of waveguide sensors” Optica Applicata Vol. XXIX, No. 1-2 pp. 101-110 (1999)

4. K. Gut, A. Opilski, **„**Mode beat measurement of planar optical waveguide using the immersion coupler” Proc. SPIE Vol. 3744, pp.430-440, (1999)

5. K. Gut, M. Błahut, R. Rogoziński, Z. Opilski, A. Opilski, "Integrated optical difference interferometer" Proc. SPIE Vol. 3058, pp. 137-144, (1997)