TECHNOLOGY OF OPTICAL BRAGG'S GRATINGS ON PLANAR WAVEGUIDES FOR ACOUSTOOPTIC APPLICATIONS

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The aim of the presented investigations was to develop a technique of producing Bragg's gratings on planar waveguides for their application in acoustooptic structures. Waveguides are obtained by means of the sol-gel technology and they are deposited on piezoelectric plates. The introduction of a beam of light into the structure of the waveguide is in the case of planar or strip optical systems always an essential technical problem, requiring simple and reproducible solutions without excessive extending the waveguide structure. In the paper the technology of producing grating couplers by impressing the pattern of the network while forming the planar waveguide structure applying the sol-gel method was presented. The results of the investigations on grating couplers obtained in such a way have been discussed, too.

1. METHODS OF LIGHT EXCITING IN ACOUSTOOPTIC WAVEGUIDES

In the works [1] technology of very thin (near 200nm) optical layers for their applications in acoustooptic structures has been presented. The layers were produced by means of low temperature sol-gel technology [2÷7]. The layers of this kind deposited on piezoelectric substrates ensured much effective interaction between acoustic and electromagnetic fields. The light field is concentrated in restricted very thin sol-gel layer and interacts with surface acoustic wave propagated in the piezoelectric waveguide. The optical sol-gel layer is so thin that it practically doesn't decide on the propagation of surface acoustic wave in such the structure [1].

Of essential importance are in acoustooptics as well as in integrated optoelectronics problems concerning the introduction and extraction of the light beam in the planar waveguide.

There are several means of exciting the light in optical waveguides, viz. [8÷11]:

a) from the front (through the normal surface),

b) by means of the skew-cut edge of the waveguide,

c) by prismatic coupler,

d) by means of grating coupler.

The former two methods are characterized by a poor effective coupling (in the order of only some percentages). The prismatic coupler is generally applied in planar optical systems, although in this case the plane structure of the waveguide layer becomes three-dimensional, which may result in an additional restriction of its application.

The application of Bragg's gratings as couplers in planar optics was mentioned for the first time by J.M. White at all [12]. The grating coupler is a structure based on the waveguide, the refractive index of which varies periodically along the path of the propagation of light. An example of the configuration of a grating coupler is shown in Fig.1.

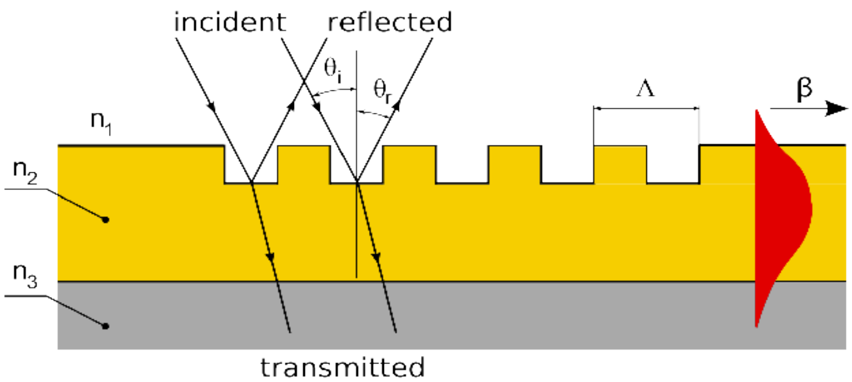

Fig.1 Idea of a light grating coupler

The phase matching condition that must be satisfied in order to couple the incident beam to the guided is [13]:

$$k_1 \cdot \sin \Theta_i - \beta = m \cdot \frac{2\pi}{\Lambda} \qquad \text{where m =0; ±1;±2;±3;...}$$

where: k_I is the wave number of incident light, β - propagation constant of light in planar waveguide, Λ- the grating period, Θ_i the angle of incidence and m an integer.

The analyse of light propagation in grating couplers are presented among others in [8,13]. Due to the factor m , a mode can be excited using various values of the angle of incidence. In reverse this means that guided mode passing the grating can be partly coupled out to multiple beams, each of them radiating into one of these angles.

The efficiency of the grating coupler amounts theoretically to 60%. Actually, however, such couplers display a practical efficiency of only 30%, because a large part of the energy of the incident beam is refracted and fades in the glass substrate. A higher efficiency of coupling (up to 70%) can be achieved utilising the asymmetric profile of the coupling grate. The grating coupler is less effective than the prismatic one. Its doubtless advantage is, however, its compatibility with the monolithic conception of integrated optoelectronic systems The theory and technology of grating couplers are presented among others in [14-16].

2. PERIODICAL STRUCTURES - METHODS OF THEIR PRODUCTION

Bragg's planar gratings are produced mainly by means of three techniques of periodical perturbation [2,10]:

1. electron technology methods,
2. optical methods,
3. mechanical impressing of the grating on the surface of optical waveguides.

From among the electron methods the focused beams of electrons or ions are utilized to draw the shape of a grating on planar optical waveguides. The advantage of these methods is the possibility of getting structures which period is smaller 300nm and they enable to introduce into the structure the light form the ultraviolet range. To their drawback is that such processes are expensive, requiring special equipment and taking a long time processes. So that the number of users applying them for sensor applications is rather limited.

Optical methods of producing the pattern of the diffraction grating require photo-sensitive waveguide layers or coatings. Periodical structures are produced in these layers by exposing them on ultraviolet light exposition [10]. The grating structures are periodical variations of the refracting index of the layers after their exposition to UV radiation. This methods also require the acquisition of specific (and expensive) devices.

Mechanical impressing of the pattern of the periodical structure is applied in the case of layers susceptible to deformations.

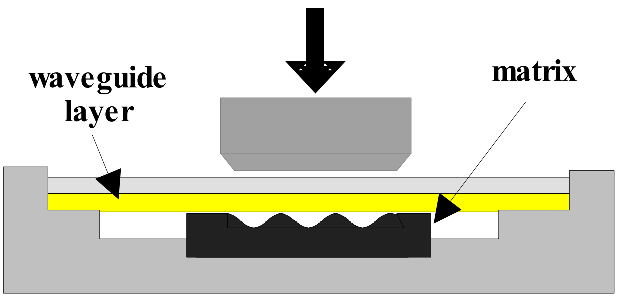

Fig. 2. The idea of the practical realization of the mechanical imprint method.

This method may be used for the activation of periodical disturbances in layers deposited by means of the sol-gel method and also in polymeric layers [10].

The method of mechanical imprinting for the purpose of producing periodical structures in a planar waveguide of the type SiO_2 -TiO_2 was applied by W. Lukosz and K. Tiefenthaler [17]. The obtained structures were used by the authors as Bragg's grating couplers and mirrors. Basing on this method, as I. Szandro suggested in [18], periodical structures of the type: SiO_2, TiO_2, Ta_2O_5, SiO_2-TiO_2 may be performed. Fig. 2 presents the idea of activating a periodical disturbance on a planar sol-gel waveguide by impressing the pattern of the grating [30]. The matrices which are the patterns of the imprinted gratings, have been produced during the process of electron etching on silicon substrates and were performed in Institute of Electron Technology in Warsaw.

The length of one disturbance in the matrix amounted to about 1000 nm. The size of the matrix is a square of 4x4 mm.

In order to obtain periodical structures an adequate mechanical system has been constructed permitting the realization of the imprint method. This system was presented in [2,9].

3. THE PROCESS OF OBTAINING PERIODICAL WAVEGUIDE STRUCTURES

The production of Bragg's grating structures by means of the mechanical imprinting of the grating pattern becomes possible after the technology of producing single-mode planar waveguides by means of the sol-gel method had been mastered.

Numerous grating couplers have been made on many varying substrates with a deposited waveguide layer at various rates of extracting the substrate glass plates from the gel solution. These tests have made it possible to determine the approximate time interval after taking out the plate from sol-gel solution, in which the waveguide layer is elastic enough to permit the periodical structure to be imprinted.

Investigations have proved that if the layer is too hard or to soft imprinting of a grating is either impossible because the obtained structures are very intensive deformed.

Basing on tests that have been carried out it can be assessed that in the presented system the periodical structure can be imprinted in the course of about 3-4 minutes after the waveguide layer has been deposited on the glass substrate by means of its rating from the sol-gel solution. It has been found that after the elapse of about 4 minutes the layer has become too hard for getting a periodical structure with satisfying optical properties.

In our situation, the periodical structure was imprinted up to 3 minutes after the deposition of the waveguide layer.

The quality of the obtained periodical structure depend on forces with which the matrix is pressed to the layer. If the exerted force is too high (per surface unit) or too small, the layers adhere to the matrix and their fragments are torn off from sol-gel solution, what leads to a permanent deformation of the periodical structure. In our first processes the applied pressure amounted to about 0.1 Mpa.

The sol-gel waveguides with obtained grating structures were then kept for two hours at temperatures of 200ºC, 250ºC, 300ºC and even 400ºC for their hardening.

The obtained periodical structures were subjected to investigations by the atomic force microscope in order checking quality of the obtained gratings and determining the accurate value of constant Λ

Measurements have shown that Λ=1000±1 μm (and is fully conforming with value determining by the grating matrix producer).

4. INVESTIGATIONS OF GRATING COUPLERS

The obtained grating couplers were tested in the set-up presented in Fig. 3.

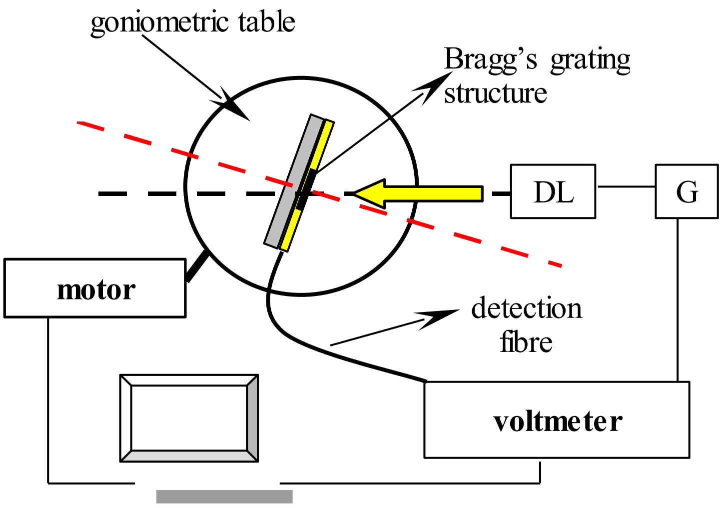

Fig. 3. Diagram of the set-up for the testing of grating couplers (DL - laser diode, G - generator)

In order to position the periodical waveguide structure versus the direction of the laser beam precisely, a goniometric table was used. The tested structure was illuminated by a laser diode (DL) with a wavelength of 677 nm and modulated by a signal from a generator with a frequency of 1000 Hz. The applied goniometric table permitted the introduction of a light beam with a known polarization into the waveguide. The rotation of the goniometric table forced the step motor, controlled by a computer. The accuracy of rotation of the goniometric table was a 2" angle. The optical modes which propagated in the waveguide structure were transmitted to the photodiode by the optical fiber. The testing of the waveguide consisted in measurements of the light propagated in it as a function of the angles of its activation. In the detection system a homodyne nanovoltmeter was used, from which the output signal was directed towards the measurement card in the computer.

5. RESULTS OF INVESTIGATIONS CONCERNING GRATING COUPLERS

In order to continue further attempts of getting grating couplers the previous technological process some times was modified. The best grating couples were obtained for following technology. The solutions were prepared in these same proportions as presented in part 1. Duration of a partial TEOS hydrolysis lasted 75 minutes. The final solution, after the addition of TET, was obtained after 3 hours its mixing in ultrasonic washer at 60^0. From this solution the waveguide layers were extracted and deposited on glass substrates. Next, by means of the designed imprinting system the structures of the grating couplers could be imprinted. The imprinting processes have been starting 2 minutes after taking out the cover glass plate from the sol-gel solution. Imprinting pressures were above 1MPa. The obtained samples were divided into three similar series, differing temperatures and times of their heating. The samples were held at temperature of 200°C, 250°C and 300°C for 3, 2.5 and 2 hours, respectively.

In optical planar waveguides can propagate only two types of optical modes - first modes for which the electric component of electromagnetic wave is parallel to a propagation plate (so called Transverse Electric modes, marked as TE modes) and second modes in which the magnetic component is parallel to a propagation plate (so called Transverse Magnetic modes, marked as TM modes) [ ]. The first modes, with the smallest values of propagation constants β are called zero order TE_o and TM_o modes. Modes of higher orders are signed as TE_i and TM_i ones.

Due to the fact that the TE_o and TM_o modes propagating in the structure display various effective propagating constants, the various synchronical angles (angles of incidence of the laser beam on the structure, at which the appropriate mode is excited) are observed for various modes.

Fig. 3 illustrates the characteristics of the selected grating coupler obtained on planar waveguides applying the sol-gel method. For this purpose a pressure of the order of 1.5 MPa was exerted. After imprinting, the samples were held at a temperature of 250°C for 3 hours.

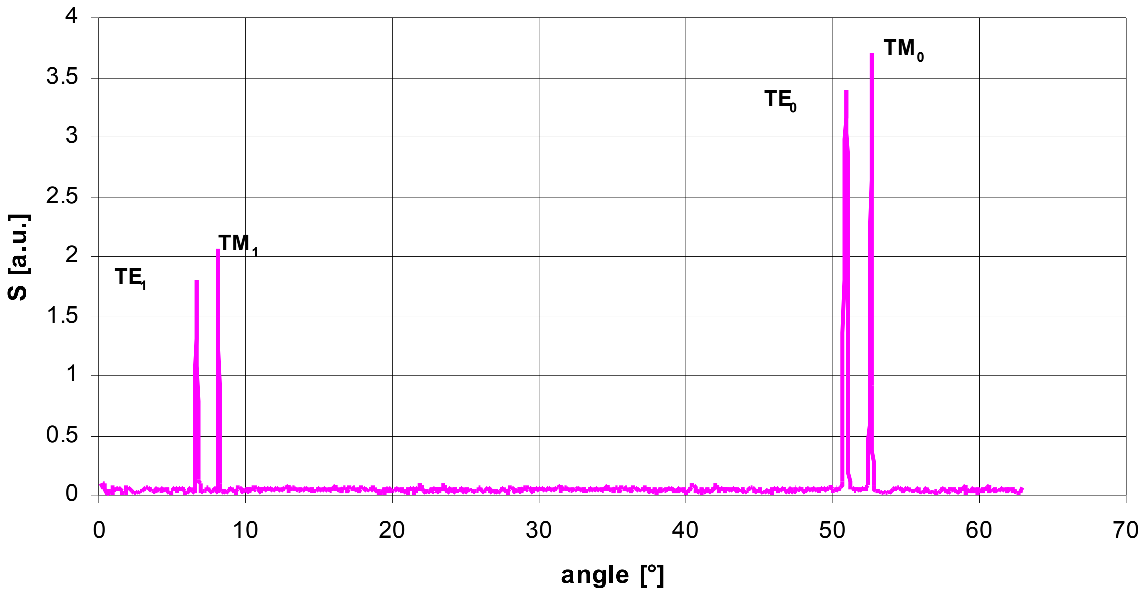

Fig. 3. Mode characteristics of a grating coupler

As Fig. 3 shows, in planar waveguides obtained by sol-gel method can propagate the zero order mode (TE_0 and TM_0) and first order mode (TE_1 and TM_1). For this same order of mode the effective propagation constant of TEi mode is smaller than for TMi mode. Therefore the TE modes are excited at smaller values of incident angle than TM modes. In the waveguide structure excited by means of grating coupler only one mode can propagate in it at given angle of incident of light.

Fig. 4 shows the image of the grating coupler, obtained while using the microscope of atomic forces (AFM).

During the measurement, humidity in the laboratory compartment was equal to 30%. The investigations showed that the angles Θ_i at which the modes are excited in the waveguide by means of grating coupler depend on the surrounding atmosphere.

The investigation showed also that the TM modes are more sensitive then TE ones to alterations of external conditions.

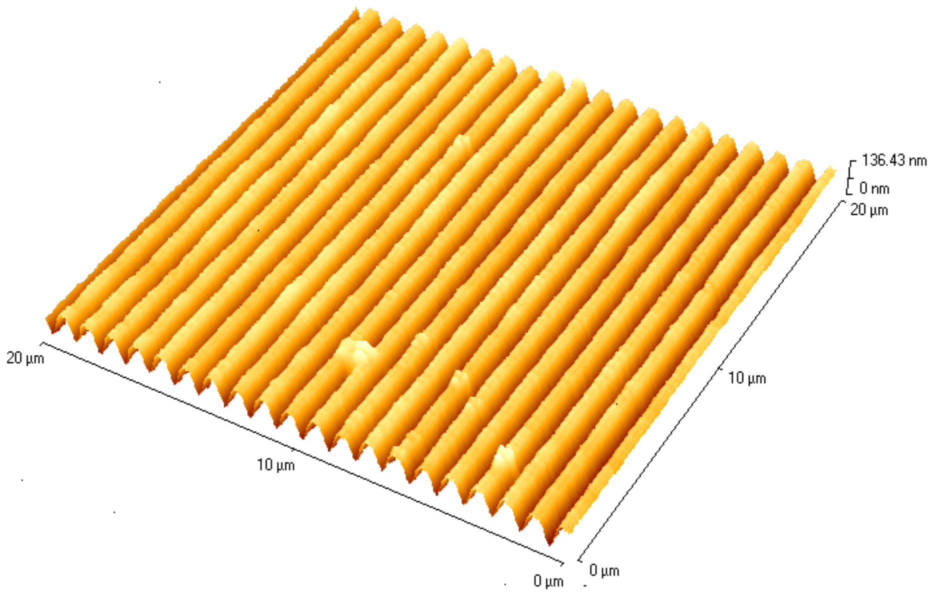

Fig. 4. Periodical grating coupler structure (image by an atomic forces microscope)

6. SOME REMARKS

The made investigations have been shown that grating couplers and single-mode waveguides can be obtained in the course of one technological process. In result of the investigations the parameters of the process were determined, in which it is beneficially to produce periodical structures by mechanical impressing the pattern of the mask on the surface of the waveguide. Experimental investigations have been carried out concerning the influence of the stress exerted in a specially designed system of imprinting the pattern of the mask on the waveguide substrate upon its optical properties and on the geometrical shape of the structure, as well as on the degree of its damage. The mechanical pressure permitting the performance of high-quality periodical structures exerts a stress of the order to $1.5 \cdot 10^6$Pa.

The investigations have shown that the technological conditions of grating couplers realization decided in very great step on optical properties of those structures, both on energy guided modes and on generation of undesirable modes. The process of mechanical imprinting of grating couplers on planar waveguides obtained by sol-gel method requires of adhering the sharply technological regimes. The process of waveguide production by means of sol-gel method for sensor applications is not so as much technologically rigorous.

The assessment of the results of these investigations leads to the conclusion that the developed grating couplers are characterized by a high effectiveness of coupling, amounting to some tens of percents.

Such couplers will be applied in gas sensors, including sensors of toxic industrial substances.

The light has been propagating in very thin layer (order of 200nm or even smaller) and for this reason its density of energy may be rally very high. The system of this kind was applied for investigations of non linear acoustooptic interactions. Investigations shown that the results of acoustooptic interactions in this structure are sensitive on the external conditions, e.g. on the type of atmosphere surrounding the acoustooptic structure. For this reason the structures will be applied in acoustooptic sensors of toxic gases.

The results of those investigations will be published.

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