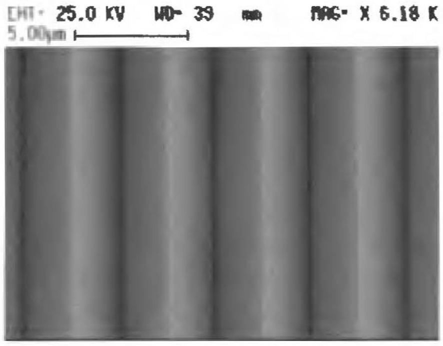

Fig. 2. SEM photograph of an etched silicon grating. The flat top is 0.2 µm.

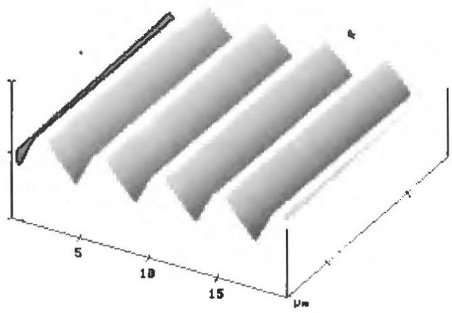

Fig. 3. AFM image of the groove profile of an etched silicon grating. Our sample gratings had a groove spacing of 3.7 µm and flat tops of 0.6 µm.

A perfect grating requires identical parellel grooves without any random or periodic defects. Random defects, which could probably be source of light scattering, were reduced paying special care to the wafer preparation procedure before the lithographic exposure. Periodic errors, that could cause ghosts in the spectra, were almost introduced by the lithographic step. In order to cover a 32x 32 mm area grating, much larger than the exposure field (for this work the electron-beam system was configured with a scanner field of 1.0922 mm^2) we had to repeat the same pattern several times, and all these patterns, which were arrays of parallel lines, needed to be stitched together with precise control. The field stitching accuracy is approximatively 0.02 µm. The resist mask produced in this way was transferred to the thermally grown SiO_2 that covered the silicon wafer by means of dry etching. An immersion of the wafer in KOH-based solution was followed by a very careful cleaning procedure. The result is V-grooves aligned to the [100] direction with very smooth side-walls, as shown in Fig. 2. The groove flat tops range between 0.6 to 0.2 µm. Our final goal is to decrease the flat top width down to 0.1 µm. As we realized our sample gratings from (100) wafers, we obtained symmetric grooves (Fig. 3) corresponding to gratings with a blaze angle of 54.8 °. In order to have proper blaze angles, wafers cut with non-zero angles with respect to {100}plane will be used. The next step in this work will be the fabrication of gratings with the blaze angles as required for the specific astronomical applications [2], and the bonding of such gratings with suitable prisms in order to produce the final grisms.

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MATRIXES OF PLANAR MICROLENSES

Paweł Szeliga, Jerzy Kruszewski

The process of manufacturing planar microlenses matrixes based on the double exchange of ions is described. The results of the microlenses quality assessment are presented and potential applications of the microlenses are given.

1. INTRODUCTION

The development of two-dimensional sets of optoelectronical elements for example matrixes of semiconductor sources of light [1] or detectors [2] and models of optical computers with simultaneous access to two-dimensional structures of data processing [3,4] makes it necessary to have a miniaturised optical elements, especially lenses. The usage of lenses allows the realisation of optical coupling, collimation or focus spotting bunches on many areas of a very small size. Lenses with a size from tens to hundreds of micrometers have been produced for this usage. They are called microlenses. Panels of microlenses are made in different techniques. For example by shaping the geometry of one of the surfaces of the base [5] or by the local change of the refraction coefficient in the defined area in the flat-parallel plate [6]. The process of formation of the single microlens takes place in a small volume of the base comparing to its diameters. Because of that their system is placed within planar structures. They are excellent for co-operation with matrixes of lasers, detectors and optic fibres, which are now more and more widely used.

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2. SHAPES, PARAMETERS, MATERIALS AND TECHNOLOGIES OF MICROLENSES PRODUCTION

Nowadays there are many technologies of microlenses production. There are controlled processes, allowing for obtaining different sizes, shapes and parameters of microlenses depending on their future use. The examples are shown in Fig. 1 [according to 7].

The basic parameters of planar microlenses are their dimensions, length, focus spot, numerical aperture, localisation of the focus spot (whether the focus spot is out of the basis plate, or within the plate, on its back) and transmission. Microlenses matrixes are additionally characterised by such data as the number of elements on 1 mm^2 and the distance between them as well as the differences in focus spot of the lenses from one plate.

The typical dimensions of the lenses are tens of micrometers. In practice it is between 2 micrometers and 2 millimetres. The focus spot is within the range from a few micrometers to tens of millimetres. The light transmission through the plate with the produced structure equals usually about 90%. There are matrixes for which the density of packing the matrixes per plate is up to 100000 microlenses per 1 square millimetre. With the dimension of the single lens of 2.8 micrometer the distance between them equals 0.2 micrometer. The differences between focus spots are about 1%.

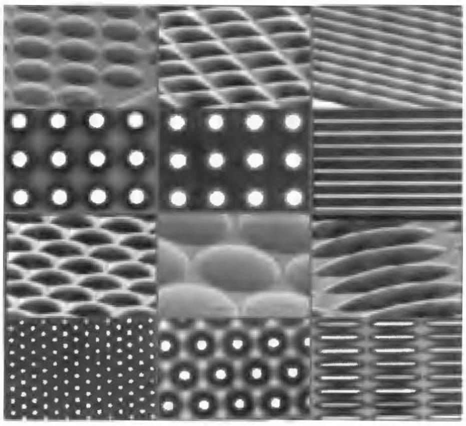

Fig. 1. Microscope picture of microlenses matrixes of different shapes with views of white light passing through.

The kind of the material used for the base of the matrix depends above all on the length of the light wave, which beam is being formed. Apart from glass and polymers there are other material used such as: silicon, germanium, zinc selenium, zinc sulphur etc. The periodical structure is made either in the material of the base [8] for example by chemical etching by the windows in the resist or on its surface [9] *e.g.* by putting drops of polymer on the glass plate and hardening in the ultraviolet. One of the ways of making of microlenses matrix on the glass base is the method of ions exchange [10-12], which has been used by the authors of this project.

3. THE DESCRIPTION OF THE METHOD OF MAKING PLANAR MICROLENSES MATRIXES

The physical basis of the ions exchange have been described in details in many works, among others in this one [6, 10-12]. In this work the method of thermal exchange of ions in two versions, i.e. single and double, has been used [13]. Planar microlenses with the dimensions 50×50×1,5 mm were made on the sodium calcium glass plate with the intrusion about 15% of Na_2O_3. The mask was a thin layer of aluminium deposited in vacuum. Windows with diameter of 1 mm were made by conventional photolithography and etching. They determine the areas of interaction of glass with the bath ions. For increasing the mechanical resistibility the masks underwent oxidation of their surface in the temperature of 360° C for 2 hours.

Single exchange (one step) process Na^+/Ag^+ was done in the solution of dissolved salts: $NaNO_3$ and $AgNO_3$ (5% in weight) in the temperature 350 ± 5°C during 30 hours. The meaningful change of the refraction coefficient by the surface in the exchange zone (Δn equals about 0,09) allows for observation and rough control of the produced structure with a 'naked eye' (Fig. 2).

For the process of double exchange of ions the plates with regularly placed round aluminium masked areas were used. The first exchange Na^+/K^+, taking place in the zones between the expected lenses, was led in the bath of dissolved KNO_3 salt in the temperature of 370 ± 5°C for 5 hours. The process is much shorter than the one-step exchange and the effects of the aluminium mask are much smaller. The areas in which the first exchange was made, form the mask for the second step *i.e.* $Na^+\backslash Ag^+$ exchange. It is done after the aluminium is removed. It should be noticed here that the first exchange in the double process results in narrowing of the windows diminishing the surface of the future details. It also has an influence on the doping distribution. The picture of the plate with matrix of microlenses obtained in the double exchange process is shown in Fig. 3.

4. RESULTS

The introductory observation of the obtained results i.e. assessment of the diameter of the focus spot of the lens, the assessment of the defects and contrast of the projected picture were done on the measurement stand. The stand is equipped with 'fokon', a rod lens with a magnification of 1,4 made in Glass Plant in ITME. Pictures from the surface of the 'fokon' showing the sizes of the lenses on the surface of the plate and their focus spots are shown in Fig. 4. The picture of the light bulb fibre is in Fig. 5.

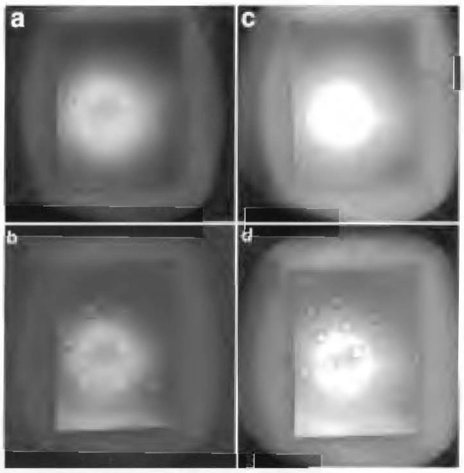

Fig. 4. The picture of the matrix of lenses obtained on the surface of 'fokon': a - picture of the matrix of microlenses made in the process of one - step exchange of ions, b - picture of the microlenses' focus spots from a, c - picture of the matrix of microlenses made in the process of double exchange of ions, d - picture of microlenses' focus spots from matrix from c.

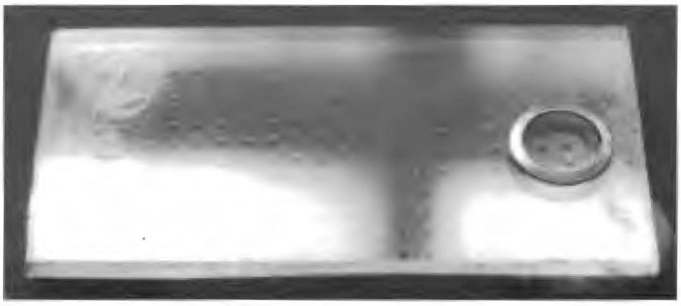

Fig. 2. Picture of the planar microlenses obtained in the process of one-step exchange.

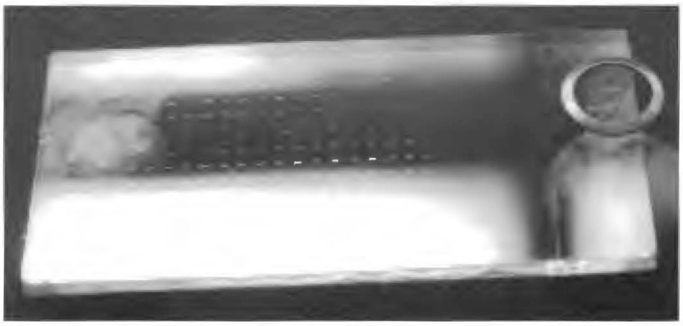

Fig. 3. Picture of the matrix of microlenses obtained in the double exchange process.

The precise assessment of focus spot and the influence of the defects were done by the intensity of illumination

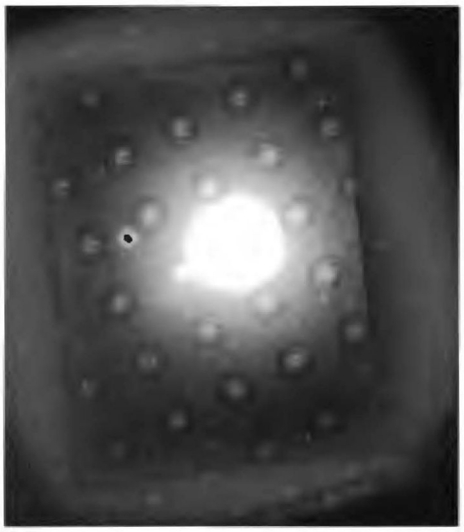

Fig. 5. Pictures of the light bulb fibre as appeared in microlenses made in the process of double exchange, presented on the surface of 'fokon'.

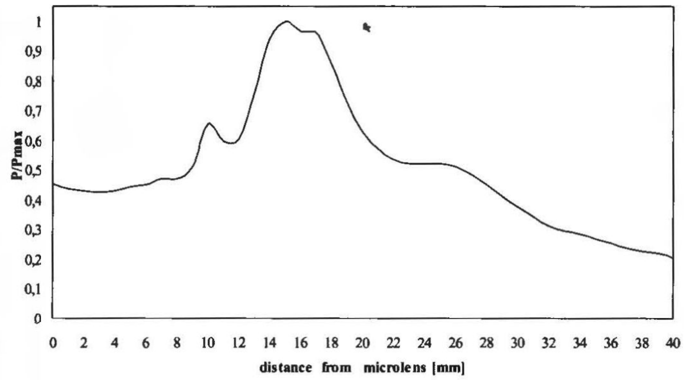

Fig. 6. The distribution of light intensity behind the microlens made by the two-step ion exchange along its axis. Horizontal lines mark the light illumination values before the plate with the matrix of microlenses was positioned in the beam of the laser light.

measurement function of the distance from the surface of the plate(Fig. 6). In Fig. 7 intensity distribution along the picture plane at the focal distance from microlens is shown.

5. THE EXAMPLES OF THE USAGE OF PLANAR MICROLENSES

The basic functions played by the matrixes of microlenses in optoelectronics are: formation of light beams, light coupling in different technical devices or optical connections between functional blocks in open space. The use of microlenses in coupling of semiconductor matrixes (sources of light or detectors) with optical fibres, is schematically shown in Fig. 8.

Similar usage of the optic switch was shown in Fig. 9. The microlens selected from the matrix forms collimated beam moving between two-dimensional switch structures.

Microlenses matrixes have many uses in the devices which are on the market *e.g.* in the wave front disturbances sensor DETECT 16 WAVEFRONT SENSOR by Optical Test Instruments, which idea was shown in Fig. 10.

Moreover microlenses are used in the system of parallel optic recognition of patterns [3], in parallel recording with the high-speed data transmission [14], in microdisplays to compensate dispersion effects [15], in optical techniques of strength testing of materials with contouring of the surface, [16] etc. Planar microlenses made within this project were used in the input signal channel in the optic fibre detector of the change in illumination [17], which can be installed without any disturbances in the monitored area.

6. CONCLUSIONS

The microlenses can find implementation in a form of matrixes and single elements with their dimensions matched to other elements of the optic fibre chan-

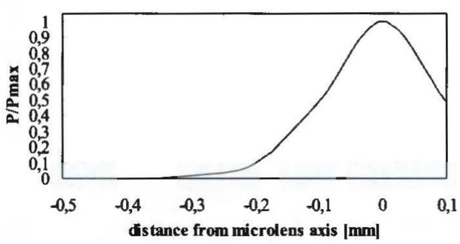

Fig. 7. Distribution of light illumination behind microlens in the picture plane.

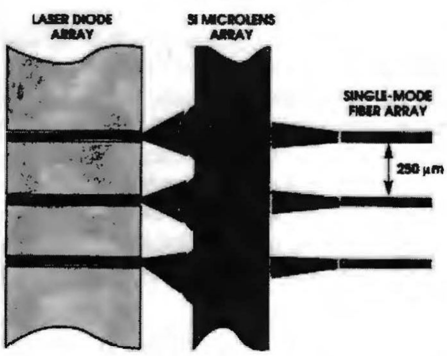

Fig. 8. The diagram of microlasers matrix connection with the bunch of optic fibres.

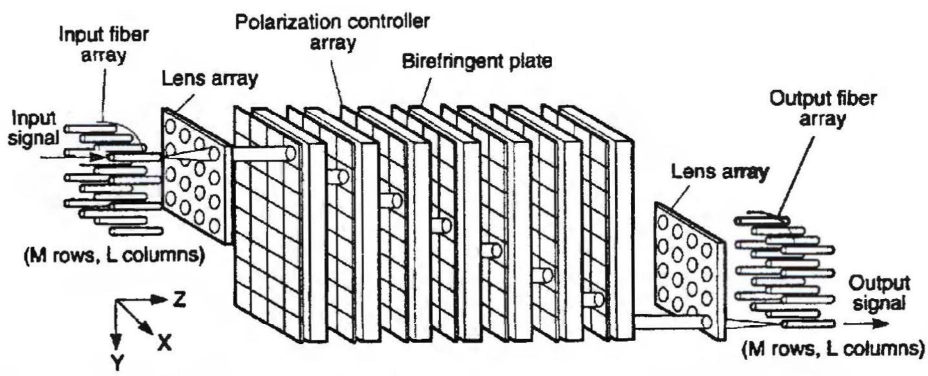

Fig. 9. Diagram of the optic switch structure with the use of the microlenses matrix.

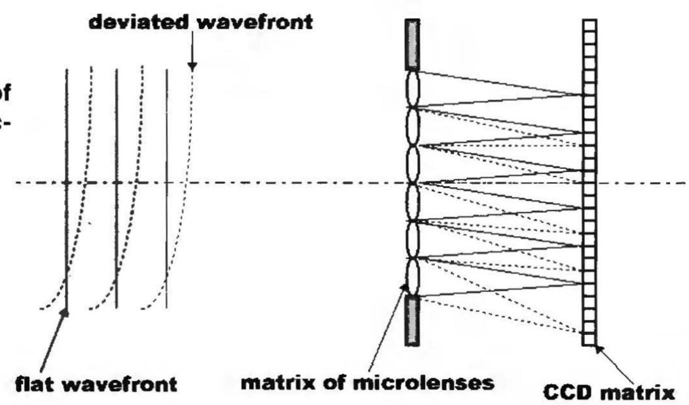

Fig. 10. The ideas of the wavefront detector.

nel. The lenses made with the method of two-step ion exchange have significantly better parameters from those made with one-step exchange. It results from the decrease of the faults of the surface and from the narrowing of the window, through which the exchange Na/Ag is made. Narrowing of the window and volume character of the 'ion mask' results in the shape of the area doped with silver which is more spherical and in consequence diminishes the spot dimension at the focus, and improves the quality of the picture.

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POLYMER MICROLENSES REALISED BY A MODIFIED LIGA-PROCESS

Patrick Ruther, Jürgen Mohr

A fabrication process for high aperture polymer microlenses developed at the Research Centre in Karlsruhe is described. The technology combines the standard LIGA process with an additional synchrotron irradiation step and a melting process [1].

In a first step PMMA microcylinders with a height of several 100 µm are realised by X-ray lithography. In an additional step the PMMA micro-cylinders are flood exposed by synchrotron radiation through a filter membrane. This results in a change of the glass transition temperature T_g of PMMA as a function of the structural height. Due to the different T_g it is possible to partially melt the top of the microstructures which is deformed to a spherical surface by the action of surface tension. By heating the PMMA microcylinders it is possible to produce hemispheres on top of remaining cylinders. The resulting front focal length *ffl* of the lenses is therefore proportional to the radius of the cylinders. In an additional aligned exposure step it is possible to define the lateral geometry

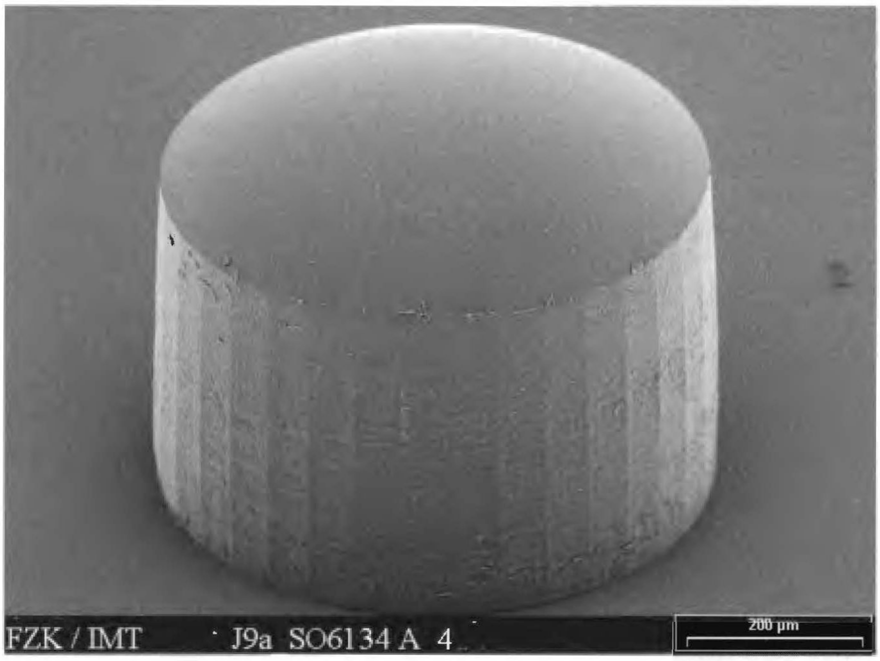

Fig. 1. Moulded PMMA lens with 1000 µm back focal length *ffl*.

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