Advanced technologies of microlenses production for robot system camcorders

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Abstract. The processes of formation of microlenses in photosensitive silicate and germanate glasses have been studied. A series of successive operations with samples of photosensitive glass activated by silver and cerium ions: irradiation, photolithography, secondary heat treatment, diffusion and ion exchange lead to the formation of various profiles on the glass surface, including convex or concave lens surfaces. On the basis of this effect, a promising technology for the production of raster microlenses and lenses for various optical devices and video cameras of a robotic system was developed.

1. Introduction

Up-to-date techniques of the ion-exchange technology provide production of the glassy materials with the predetermined properties [1], [2]. Glass and glassy materials are pertained to either of the most complex and interesting objects of research due to the large variety of processes that progress within those ones during synthesis, crystallization, secondary thermal treatment, radiation effect, ion-exchanging processes. At the present time, the activated glasses represent the greatest interest for practical use in the field of the raster, fiber optics and microoptics [2].

The task of this research consisted in production of the convex and concave microlenses for the optical systems and camcorders for robotics. Objectives of such vision facilities should consist of a set of microlenses, when each microlens forms image of the object under the certain visual angle. Array of the microlenses (raster) of the objective simulates the arrangement of an insect oculus, and allows one to get the high-quality 3D-images [3], [4].

This paper presents the results of investigation of the formations of microlenses in photosensitive glasses.

2. Materials and methods

The photosensitive glass compositions were used as materials for investigation. To achieve these goals, the photosensitive glasses of various compositions have been synthesized and researched (Table 1). Silicate glasses were activated by ions of silver, cerium and antimony in the amount of up to 0.05 mol %. And up to 10 mol % of the oxide of the gallium was introduced into germanate glasses.

From the viewpoint of optical properties, composition 1 (silicate glass) has been found to be optimal for microlenses production [5], and the further research has been proceeded with that one. This glass composition was distinguished by the simultaneous content of potassium and sodium ions, which apparently leads to the manifestation of poly-alkaline effects. For production of the microlens rasters, the ion-exchange diffusion method has been used in regard to the system of glass – melt - salts.
underlies in the basis of the industrial production of the gradient optics elements [4], [6].

Ion exchange diffusion is a chemical strengthening process where large ions are “stuffed” into the glass surface, creating a state of compression. The glass is placed in a hot bath of molten salt at a temperature of approximately 400 degrees C. Smaller lithium ions leave the glass, and larger potassium and sodium ions from the salt bath replace them. These large ions take up more room and are pressed together when the glass cools, producing a layer of compressive stress on the surface of the glass [7].

### Table 1. Photosensitive glass compositions

| Components | Components content, mol % |
|------------|---------------------------|
|            | Silicate glasses (1-5)    | Germanate glass |
| SiO₂       | 70-80 71.70 71.70 71.70 71.70 71.70 – |
| GeO₂       | – – – – – 70 |
| Li₂O       | 12-20 19.82 12.18 19.36 19.39 24.36 20 |
| Na₂O       | 1-2 1.07 12.18 5.00 – – – |
| K₂O        | 2-4 3.47 – – 5.00 – – |
| Al₂O₃      | 1-3 2.98 2.98 2.98 2.98 2.98 – |
| Ga₂O₃      | – – – – – 10 |
| ZnO        | 0-2 0.79 0.79 0.79 0.79 0.79 – |
| Ag         | 0.05 0.05 0.05 0.05 0.05 0.05 – |
| CeO₂       | 0.05 0.026 0.026 0.026 0.026 0.026 – |
| Sb₂O₃      | 0.05 0.058 0.058 0.058 0.058 0.058 – |

### 3. Results and Discussion

The operation sequence that provides production of the microlens rasters is illustrated in Figure 1. At the first stage of the technological process (Figure 1, a), the exposure of the photosensitive glass plate is performed, 4-8 mm thick, under the short-wave radiation field of the nitrogen laser, through the photomask.

During the follow-up thermal treatment (the second stage), at the temperature of 873 K (Figure 1, b), the crystallization is caused of the exposed areas, that is accompanied with squeezing-out of the transparent areas. At that, the non-exposed areas remain transparent. The difference between the density amounts of crystallized and non-crystallized areas results in the compression and buckling stresses initiation of the transparent areas above the glass surface, being followed with the spherical segments forming, due to the surface tension forces. Height of the convex areas above the surface does not exceed 25 micrometers, whereas diameter of the lenses – 300 µm. After that, grinding-out is performed (Figure 1, c) of the convex areas.

At the third stage, the glass exposed and crystallized, according to the photomask geometry, is subjected to the ion-exchange treatment within molten salts of the nitrates of the alkaline metals. Due to mole volume changing of the glass, the non-crystallized cylindrical domains of the glass are occurred to be extruded above surfaces (Figure 1, d) or embedded inside those (Figure 1, e) forming at that the convex or concave surfaces on both sides of the glass plate.
For production of the collecting microlenses, sodium or potassium nitrates have been used, or their mixtures. At that, the extrusion of the non-crystallized areas of the glass surface takes place due to extension of the mole volume during the ion changing Li$^+$glass $\leftrightarrow$ Na$^+$, K$^+$melt. In the case of the whole exchange of the Li$^+$cations with the Na$^+$ and K$^+$ cations, an extension of the mole volume could be anticipated, accordingly, 1.07 and 1.22 times. The light scattering microlenses have been produced using the molten salt mixtures of sodium and lithium.

The sample of the microlens raster is shown in Figure 2, for production of which the plate 30 × 30 × 4 mm in size has been used that has been exposed to exposition under the radiation field of the nitrogen laser through the photomask with disk diameters of 500 µm. The secondary thermal treatment and ion exchange (melt KNO$_3$, $T = 873$ K, duration 2 hours) have provided formation of convex segment $38 \pm 1$ µm high on the surface of the plate (Figure 2).

Figure 2. Photo of microlens raster sample: lens diameter is 500 µm, lens height is 38 µm

The microlenses produced have the focal length of $f \approx 2.47$ mm (at estimation of $f$ value, possible inaccuracy makes up 0.03 mm). The interference pattern on the sample surface, with convex segments, is shown in Figure 3, along with its computerized processing. As one can see, the lens surface could be approximated with the
spherical surface - on condition that the segment height is much less than the radius of curvature.

Figure 3. The interference pattern on the sample surface of the microlens raster (a), b – computerized processing of the interference pattern of the substrate of the microlens raster: microlenses diameter - 310 µm, microlenses height - 5 µm

4. Conclusion
The technology developed for production of the microlens rasters for the optical systems represents integrated use of photolithography, secondary thermal treatments, along with the ion-changing diffusion method, and practically allows realizing the properties of the photosensitive silicate glasses. The combination of the methods applied allows creating successfully the 3D relief of the microlenses profile required and their configuration on the surface of the photosensitive glasses. In this case, the relief produced provides maintenance of the photomask image parameters on the substrate material.

References
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