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GAP MICRO-LITHOGRAPHY FOR CHALCOGENIDE MICRO-LENS ARRAY FABRICATION

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A newly developed technique, gap micro-lithography, used for the formation of I.R. micro-optical devices such as micro-lens arrays with a very long focal length, is described. The use of a three-component As-S-Se photoresist with a new efficient amine-based selective developer allows for the realization of soft contrast characteristics of the micro-lithographic process with a Xe-light source. Parameters and characteristics of micro-optical devices made using the gap micro-lithography method are discussed.

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1. Introduction

Micro-optical devices such as micro-lens arrays and particularly functioning in the infra-red (I.R.) optical range are increasingly applied in optoelectronics in such fields as micro imaging, optical computing and communication, CCD cameras, beam shaping, and medical tomography [1-4].

Fabrication of micro-optical devices using chalcogenide photoresists is essentially the direct one-step formation of a 3D element array using dependence of the developing rate on illumination intensity. Several techniques for I.R. micro-lens array fabrication based on As-Se and As-S chalcogenide photoresists have been developed previously. The arrays of spherical and cylindrical micro-lenses with a sag of $\leq$ 0.19 μm and a focal length of $\leq$ 31 μm were fabricated by one technique using the modified proximity micro-lithography method [5, 6].

In spite of many advantages, these micro-lens arrays also have some drawbacks. The maximum sag in the micro-lenses is limited to 0.19 μm, which together with the small micro-lens size, limited the achievable focal length. Another drawback is the poor shape of the convex surface obtained, a consequence of the short quasi-linear section of the contrast characteristic (dependence of remaining photoresist thickness on dose irradiation), when using As-Se and As-S chalcogenide photoresists.

Larger micro-lens sag, up to 5 μm, has been realized by using the combined micro-lithography thermal reflow method [7, 8]. However this method has a very serious disadvantage related to the limit of the ratio of the diameter to the sag of a micro-lens. This value should be no more than 10, in order to obtain a properly shaped micro-lens. This ratio limits the achievable focal length to $1.3 \cdot d$, where d is the diameter of a single micro-lens.

The gray scale lithography method [9] uses a unique, very complicated, and expensive mask with a transmission gradient in the contact mode to directly create a designed shape in chalcogenide photoresists. Micro-lens arrays with a very wide range of focal lengths can be produced by this technique. The most important drawbacks of this method are the mask complications and high cost.

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2. Gap micro-lithography method

A new simple and economical technique gap micro-lithography is described in the present letter. The technique is used in the formation of new micro-optical devices: I.R. plano-convex micro-lens arrays with very long focal lengths.

Such arrays were fabricated using ~ a 3.0 μm thick $1As_2S_3 \cdot 1As_2Se_3$ photoresist layer which was deposited by vacuum thermal evaporation onto a glass substrate [10, 11]. The photoresist combines high photosensitivity with the soft contrast characteristic of the micro-lithographic process when used together with a Xe-lamp as the exposure light source and an efficient amine-based selective developer. This contrast characteristic has a long quasi-linear section, which is much longer than in previously used As-Se and As-S chalcogenide photoresists (Fig. 1). The negative-type developer used is characterized by high selectivity, i.e. a high ratio of the dissolution rates in non-irradiated and irradiated areas (γ). A γ value of ~ 40 is achieved with moderate radiation intensity (30 mW/cm^2 at $\lambda = 532$ nm).

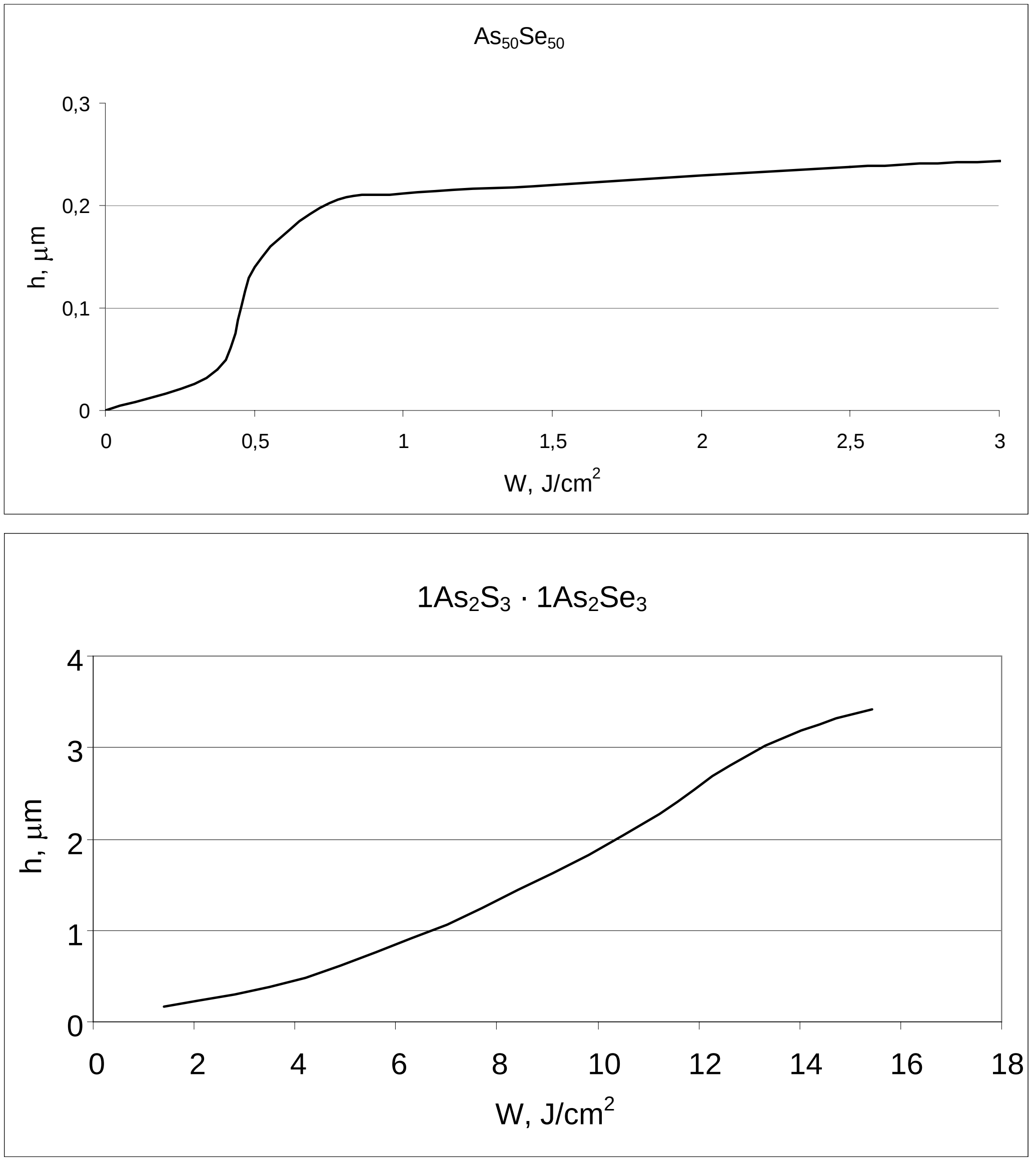


Fig. 1. Contrast characteristics of $As_{50}Se_{50}$ and $1As_2S_3 \cdot 1As_2Se_3$ chalcogenide photoresists.

Arrays of 70 − 100 μm diameter holes in chromium layers on glass substrates were used as binary masks. The micro-lithography process was performed with a gap between a chalcogenide photoresist film and the mask surface (Fig. 2). Changing the distance between the illuminated mask surface and the chalcogenide film modifies the profile of the light distribution from a flat to a rounded one, and the optimum plano-convex shape according to the desired specification (diameter and sag of the micro-lens) can be realized. A 550 μm gap between the binary mask surface and the chalcogenide photoresist film and a 1 minute exposure to a Xe-light source led to the formation of the micro-lens arrays. They were measured using a Zygo Corporation (USA) micro-interferometer. Primary parameters of the micro-lens arrays are shown in the Table.

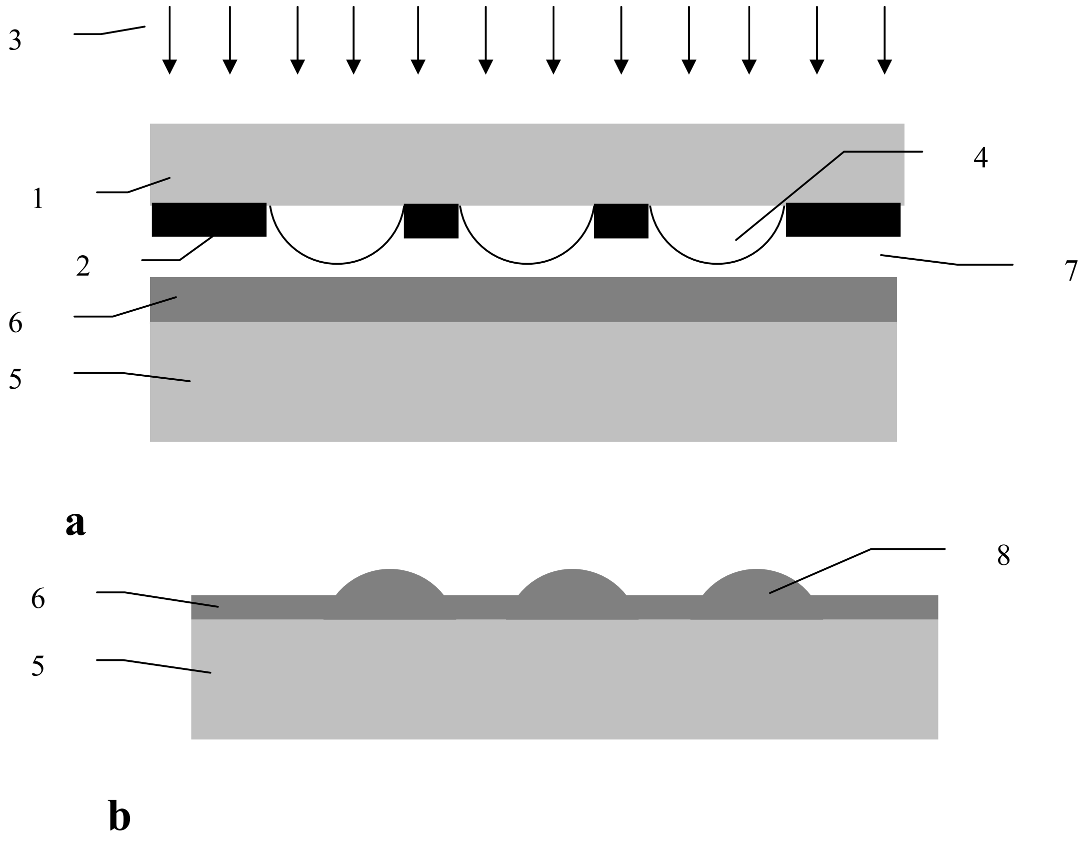
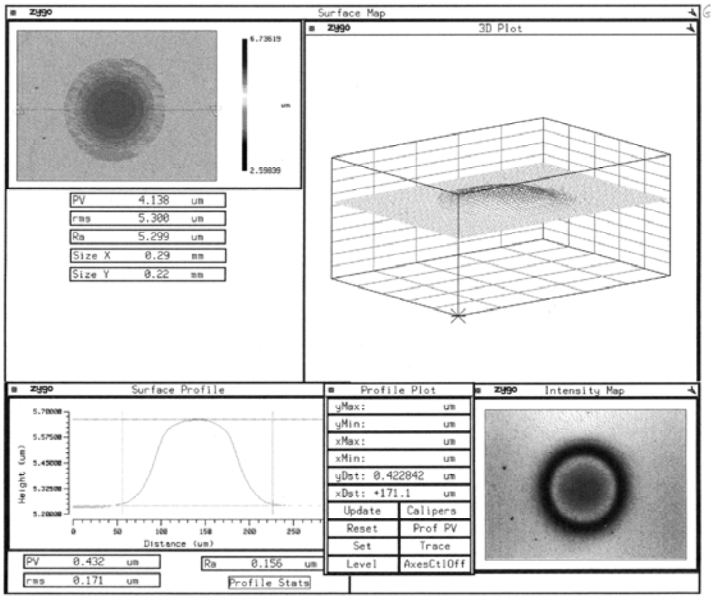


Fig. 2. A proposed gap micro-lithography method for plano-convex micro-lens array fabrication: a. exposure of a chalcogenide film through a binary mask with a gap between the mask and chalcogenide surfaces. b. development of the chalcogenide film and micro-lens array formation. 1 – binary mask substrate; 2 – chromium; 3 – light exposure; 4 – form of light intensity distribution; 5 – glass substrate; 6 – chalcogenide film; 7 – gap between a binary mask and chalcogenide surfaces; 8 – fabricated micro-lens array.

Table. Primary parameters of the plano-convex micro-lens arrays fabricated.

Micro-lens diameter, μm	114.8 − 171.1
Micro-lens sag, μm	0.42 − 0.85
Radius of curvature, μm	1,940 − 8,710
Focal length, μm	1,227 − 5,634
Micro-lens array pitch, μm	300 x 300
Micro-lens array size, mm	12 x 12
Roughness, nm	0.5



PV 4.138 um
rms 5.300 um
Ra 5.299 um
Size X 0.29 mm
Size Y 0.22 mm

PV 0.432 um
rms 0.171 um
Ra 0.156 um

yMax: um
yMin: um
xMax: um
xMin: um
yDst: 0.422842 um
xDst: +171.1 um

Fig. 3. Plano-convex micro-lens with a diameter of 171.1 µm and sag of 0.42 µm.

Fig. 3 shows a single plano-convex micro-lens of an array. The surface quality of all fabricated micro-devices (shape, roughness) was extremely high with good reproducibility of their parameters.

3. Conclusion

In this letter, a newly developed technique, gap micro-lithography for fabrication of I.R. plano-convex micro-lens arrays with very long focal lengths of 1,227 − 5,634 µm was reported. Simple binary masks, $1As_2S_3 \cdot 1As_2Se_3$ chalcogenide photoresist films with a thickness of ~ 3.0 µm, and an efficient amine-based selective developer were used in the fabrication of these micro-lens arrays.

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