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FOCUSING SYSTEM BASED ON CHALCOGENIDE MICROLENSES ATTACHED TO OPTICAL FIBERS

D. Savastru*, S. Miclos, R. Savastru

National Institute for Optoelectronics, INOE – 2000, P.D. Box Mg. 5,
077125 Bucharest – Magurele, Romania

Arsenic chalcogenide microlenses (As_2S_3) produced by an original procedure have been used for focusing the red – infrared laser light direct through an optical fiber. The microlenses with diameter in the range 150 – 400 μm were glued on the optical single-mode fiber ends by Canada balm under optical microscope. The focusing effect of the microlenses was investigated in a stereomicroscope, and the focusing quality was studied with the radiation of a He-Ne laser.

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1. Introduction

Amorphous and glassy chalcogenides are of great interest due to their optical properties, that make these materials useful for applications in optoelectronics [1 - 8].

The extremely high resolution capability and high transmission in VIS and IR region of the spectrum enable the chalcogenide glasses (e.g. As_2S_3; refractive index: $n_\infty = 2.39$) to be applied for the production of diffractive optical elements as gratings, lenses, filters, beam couplers and/or beam combiners, etc operating in broad spectral region [9].

These elements have some advantages over conventional refractive/reflective components regarding weight, costs and ease of manufacture and also offer new optical functionalities.

Saitoh et al. [10] reported a micro-lens attached onto fiber ends, which is fabricated using a photolithography technique, i.e. by light illumination and successive etching. Later, the same authors [11] proposed and investigated two new types of micro-lenses. As_2S_3 and He – Ne lasers were employed for the fabrication, since this combination appears to be the most tractable for laboratory experiments. The micro-lenses are produced by laser light, which is coupled into and propagated in single-mode optical fibers. A chalcogenide film covers the other end. Then the light induces photostructural transformations in the film and micro-lenses are formed. Through this process the lenses are automatically and accurately positioned on the fiber core.

Micro–optical lenses (or lenslets) are increasingly considered in free space optical systems providing an optical interconnection between very large scale integrated (VLSI) electronic chips [12], between modules containing chips [13] and in "stacked planar optics" [14].

Ishihara and Tanigachi [15] reported lenslet formation by melting resins deposited on top of a CCD image sensor but precise control of the feature size was cumbersome. A variation of this technique by Popovic et al. [16] involved a multi-step process consisting of metal deposition, photolithography definition of apertures and melting of the deposited resin. Lenslets have also been demonstrated [17] in InP by chemically etching a multilevel MESA followed by mass transport to obtain a smooth curvature.

Arsenic trisulfide glass has some very unique properties. The light red glass transmits from the visible out to 8 μm with no appreciable absorption. For systems operating in the near infrared or

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[*] Corresponding author: dsavas@inoe.inoe.ro

the 3-5 μm window, the glass is extremely useful for lenses or windows. Generally the use in the 8-12 μm range is not recommended because of intrinsic absorption.

Recenly, the photo-expansion (see [18]) and the new photo-plastic phenomenon discovered in As_2S_3 [19,20] opened important ways to applications.

Ramachandran et al. [21] used the photo-expansion phenomenon to optically write lenslets in bulk As_2S_3 glass. The key advantage of this technique is that it is a one-step optical process, which requires no multi-step etching or fixing to get a smooth curvature.

We have developed a procedure for obtaining micron size lenslets in large amount by special processing of the fine grain As_2S_3 powder (under patent). The carefully separated lenslets have been used to be mounted on the optical single-mode fibers with special glue.

This paper reports the results obtained in the investigation of the focusing effect of the As_2S_3 lenslets when He-Ne laser radiation is used in optical single-mode fibers.

2. Experimental

Lenslets with micrometer size were fabricated by a procedure that allows for production of a high amount of lenslets of various diameters and shape. Although, the procedure cannot be disclosed, we can say that powder of As_2S_3 were subjected to heat in dynamic atmosphere. The lenslets with the diameter fitting the optical fibers ends were carefully chosen and controlled regarding the homogeneity and transparency. Sixteen lenslets have been separated and used in this investigation

Micrometer size As_2S_3 lenses were carefully chosen in order to be attached to the open ends of optical single-mode fibers. The attachment (gluing) was made under optical microscope and the glue used was ECCOBOND – 24 (from Emerson & Cumming (n~1.45 – 1.55)).

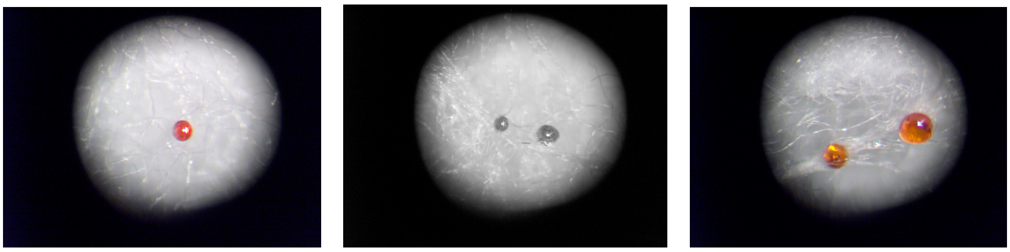

Fig. 1. Some lenslets of different dimensions (— 500 μm)

In the next table we present the diameters and the focal length of 10 of the lenslets we used in our study.

Lenslet	d [μm]	f [μm]
#1	212	66
#2	172	54
#3	234	73
#4	179	56
#5	282	88
#6	268	84
#7	279	87
#8	254	79
#9	301	94
#10	398	124

As it may be easily remarked, the focal lengths that can be obtained vary in a wide range, from about 50 μm up to 125 μm.

Fig. 2 shows the typical combination of fiber and lenslet made of As_2S_3. The picture was taken without laser light penetration of the system The diameter of the lenslet

(200-400 micrometers) corresponds to the outer diameter of the optical fiber. The laser radiation is fed through the other end of the fiber. At the end of the fiber it can be seen the lenslet (red color) with smooth curvature approaching the spherical shape. The fiber extends to the right hand of the picture and, looks as white tube due to the reflection of the light on the external walls of silica composition fiber.

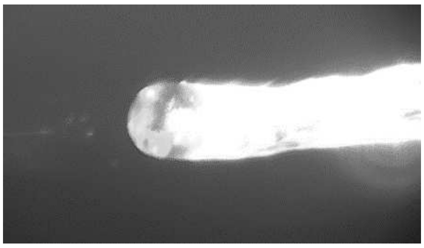

Fig. 2. Typical combination of fiber and lenslet.

The focusing effect of some lenses has been followed in a stereomicroscope. The radiation emitted by a He-Ne laser was used in the experiments.

3. Results

The focusing effect of As_2S_3 lenslets depends on their size and type.

Figs. 3 - 5 show the focusing of the He-Ne radiation propagated along an IR optical fiber based on silicon oxide. The focal distance and the quality of focusing depend on the type of the lens and on the quality of gluing of the As_2S_3 lenslet on the fiber's end. The refraction index of ECCOBOND glue permits the passing of the light without scattering and without high optical losses. In order to point out the focusing effect the pictures have been taken for different positions of a white screen (made of paper sheet) situated behind the system: optical fiber + lenslet at the end.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 3 a and b shows the focusing effect of the lenslet consisting in the change of the profile of the laser beam on the screen for different distances to that screen. The screen being very tilted the projection of the laser beam has an elliptical shape and exhibits a large extension in the vertical direction. The image b of the figure shows a position closer to the focus than the image a.

Fig. 4 a, b shows the defocusing effect for a spherical lenslet attached at the end of an other optical fiber. In this case the light is concentrated through the lenslet at larger distances than in the first case.

Fig. 5 a, b shows an other example of beam concentration through the system lenslet-optical fiber.

4. Discussion

The size of the focused spot may be different as a function of the wavelength of the radiation. For example the size of the focused spot is wider for the near infrared radiation and this may be due to the effect of light diffraction. Two types of lenslets have been used: plano-convex and spherical.

The geometrical optics shows that the focal length of a plano-convex lens is given by

$$F = \frac{r}{(n-1)} \tag{1}$$

where n is the refractive index of lens material and r is the curvature radius of the lens. Microlenses with short focal lengths can be produced easily.

Assuming the lenslets are spherical in profile, the focal length may be calculated by

$$F = \frac{h^2 + \frac{d^2}{4}}{(n-1)\cdot 2\cdot h} \tag{2}$$

where h is the height and d is the diameter of the lenslet and n is the index of refraction. For infrared light with the wavelength of 1550 nm the refractive index is n = 2.4380. This gives a focal length of ~ 0.77 mm [18]. The chalcogenide glass is characterized by photo-structural transformations. During illumination with a gap or above-gap light the absorption edge is shifted toward higher wavelengths (photo-darkening). Consequently, the refractive index is changed and the focal length, as calculated from the above formula, is changed.

It is interesting to remark the characteristic differences between chalcogenide and organic microlenses. The first one is the difference of refractive index. The chalcogenide glasses exhibit indices of refraction in the range 2.0 – 2.6, while the organic materials have n ~ 1.5. The chalcogenides are transparent at around (near) infrared, while the organic lenses are transparent in visible wavelengths region.

The lenslets prepared in our procedure are, probably, stressed. Therefore, the annealing under T_g will stabilize the glass, and its characteristics.

Chalcogenide micronlenslets attached to optical fibers could be compared to the lenses formed through photostructural transformation induced by He-Ne laser light, which is propagated in the fibers so that the lenses are automatically positioned at the center of fiber cores. The last lenses were proposed for red and infrared wavelenghts with a minimal focal length of ~ 10 μm [22-24].

The advantage of the new lenslets consists in the possibility to choose easily the best combination lens+fiber and the mechanical resistance of the device.

5. Conclusions

Chalcogenide-glass microlenses (lenslets) appear to be promising for controlling red and infrared light emitted through optical fibers

The procedure of gluing As_2S_3 lenslets on the optical fiber's ends gives rise to an efficient system of light focusing. The focusing system is easy to produce, is mechanically resistant and can be extended to other systems lenslet-fibre. The application in the ophtalmological laser surgery microscope could be of interest.

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