Journal of Physics: Conference Series **605** (2015) 012023 doi:10.1088/1742-6596/605/1/012023

Fabrication of a microlens array in BK7 through laser ablation and thermal treatment techniques

M Blanco, D Nieto and M T Flores-Arias

Microoptics and GRIN Optics Group, Applied Physics Department, Faculty of Physics, University of Santiago de Compostela, Santiago de Compostela, E15782 Spain

E-mail: maite.flores@usc.es

Abstract. We propose a laser-based method for fabricating microlens on borosilicate glass substrates. The technique is composed by a laser direct-write technique using a $Nd:YVO_4$ for fabricating the microlens arrays and a post thermal treatment with a CO_2 laser for improving its morphological and optical properties. The proposed technique will allow us to obtain microlenses with a broad range of diameters ($50\mu m - 500\mu m$) and focal lengths ($1mm - 5mm$). By combining laser direct-write and the thermal treatment assisted by a CO_2 laser, we are able to obtain good quality elements.

1. Introduction

Micro-optics plays an important role in the industrial production processes, like micro-electronics, laser micro-machining and material processing. Microlens arrays offer an unique enabling technology in critical domains such as sensors, communications, metrology and medical imaging, often providing solutions where other technologies prove unsuitable, unwieldy or cost prohibitive. It can be found in the literature the use of a big variety of methods for fabrication of microlenses: laser direct writing [1, 2, 3], molding or similar thermoforming techniques [4, 5], lithographic methods [6] and wet and dry etching [7]. All of these methods usually need to be done in very controlled enviroments and might be rather expensive. Recently, some of the authors have published a method to fabricate microlenses in commercial substrates using a combination of a $Nd:YVO_4$ laser with a post-thermal oven treatment [8]. This work proposes an improvement of the post-thermal treatment by using a CO_2 laser.

In this paper we report a laser based technique for fabricating a microlens arrays in BK7 glass which combines a Q-switched $Nd:YVO_4$ laser and a thermal treatment CO_2 laser roller furnace [9] that reduces the thermal shock and avoid the complications related to the conventional thermal treatments to be able to melt only the top surface of the glass, on which the array is located.

2. Experimental procedure

The microlenses are fabricated via laser ablation using a Q-switched $Nd:YVO_4$ laser in combination with a galvanometer system for adressing the output laser beam. A flat-field lens, with an effective focal lenght of $100mm$, provides an uniform irradiance distribution over an area of $80 \times 80mm^2$. The most suitable laser parameters for this material and purpose have been found to be a repetition rate of $10kHz$, a wavelength of $1064nm$, a pulse width of 20 ns and a scan speed of $50mm/s$. The structure designed for fabricating the microlenses is composed by a set of concentric rings. Each ring is obtained by a circular trench separated $11\mu m$ from the following one. The laser beam is moved, using a galvanometer system, relatively to the glass sample, being maintained in the same position. The laser fluence used for manufacturing each ring varies from $F = 72(14)J/cm^2$ for the last stage to $F = 189(38)J/cm^2$ for the first stage (see figure 1). After the promoting glass structures are generated in the sample we use a roller furnace combined with a CO_2 laser (see figure 2), for melting the glass and reshape its surface, reducing the damage generated before and softening the morphology of the microlenses.

The scheme used for fabricating the microlens (distance between consecutive rings and laser fluence) are selected individually to avoid extremal thermal effects that lead to breakage of the material.

A visual explanation of the processes involved in the fabrication is shown in figures 1 and 2. As it was said before, figure 1 depicts the experimental setup together with the scheme of fluences applied to the sample, figure 2 shows how the thermal process is done.

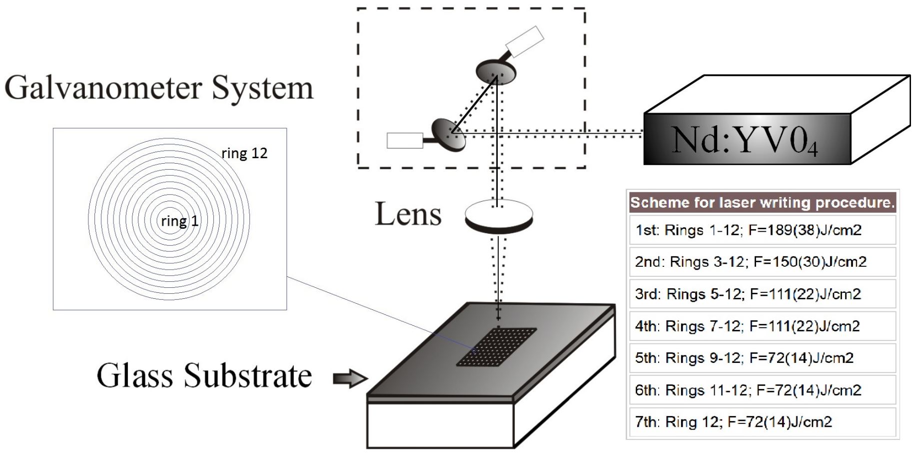

Figure 1. Setup of the ablative process. The applied structure is depicted by the rings on the left side. The scheme of fluences is shown in a table on the right, in which we explain for every step of the process what is the fluence and over which rings it acts.

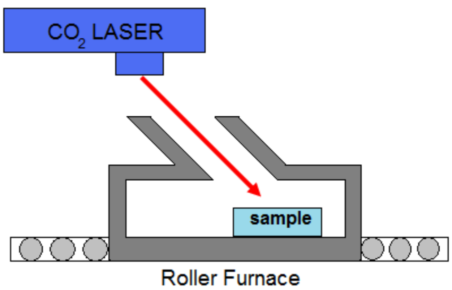

Figure 2. Representation of the thermal treatment composed by a dinamic furnace and a CO_2 laser.

Journal of Physics: Conference Series **605** (2015) 012023 doi:10.1088/1742-6596/605/1/012023

3. Results and characterization

In this section we analize the fabricated microlens array. Measurements of diameter and height have been obtained using an optical microscope Nikon MM400. Images of a top and lateral view of the carved structure can be seen in 3 and 4 respectively. In figure 3 it can be seen the annular structure defined in the previous section and how the separation between rings is optimal to avoid walls of material between two consecutive lines, figure 4 supports this conclusions and also gives a measurement of the height of the profile. Microlenses with diameter $290\mu m$ and height of $\sim 7\mu m$ are presented.

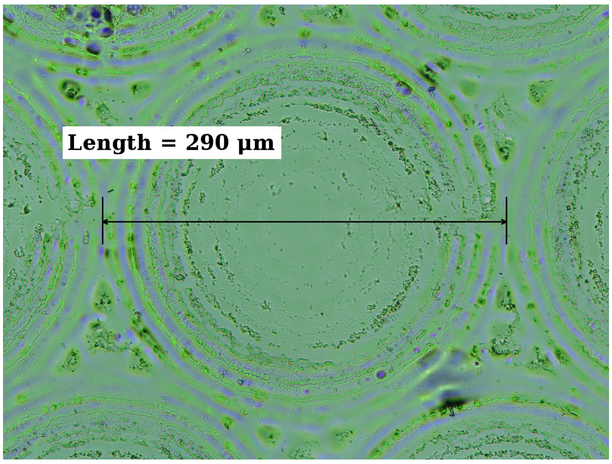

Figure 3. Microscope image of the top view of the direct carving process. The ring structure can be noticed perfectly in the outer regions. The diameter of the microlens was measured using the microscope commercial software. The measurement precision is $\sim 10\mu m$.

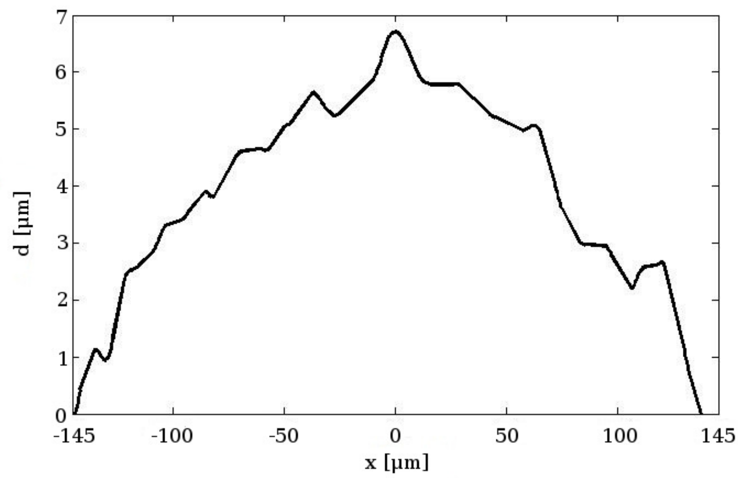

Figure 4. Lateral view of the carved structure. It can be seen that the shape is very irregular but it can be improved by a melting procedure.

It can be seen in the images 1 and 2 the obtained annular structure, as well as the total abscense of crackings or breakage of any kind on the material.

Journal of Physics: Conference Series **605** (2015) 012023 doi:10.1088/1742-6596/605/1/012023

The obtained array has an efficiency (ratio between the power in the focuses and the total incident power) of $\varepsilon = 69.2(6.3)\%$ at $\lambda = 633nm$. The focal length obtained is $5.2(1.2)mm$ via direct measurement, which is in accordance with the curvature ($R = 2066.1(0.1)\mu m$) obtained via measurement with a Zeta-20 True Color 3D Optical Profiler, shown in figure 5 according to:

$$f = \frac{R}{n-1} \tag{1}$$

In this equation f is the focal length, R is the curvature radius and n the refractive index.

In figure 5 we can observe how a central region ($\sim 200\mu m$) of the lens is effectively spherical with a small deviation in the edges.

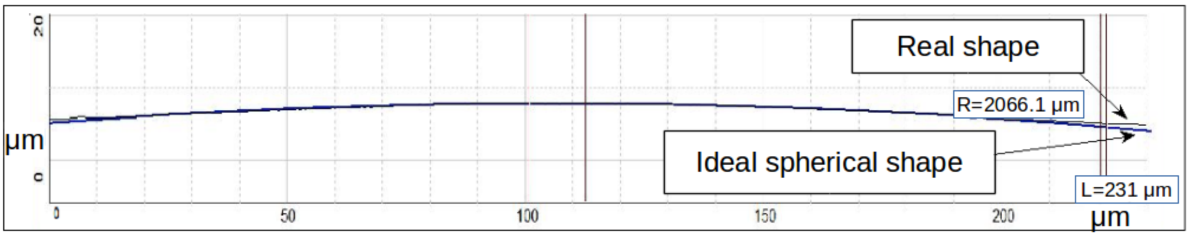

Figure 5. Lateral profile of a microlens obtained with a Zeta-20 True Color 3D Optical Profiler. It can be seen how a central region of $\sim 220\mu m$ clearly fits to a theoretical parabolical/spherical shape with a small deviation on the edges.

Analizing this profile we can obtain a diameter value of $\sim 220\mu m$ and a curvature radius of ($R = 2066.1(0.1)\mu m$), which in combination with the equation 1 and assuming a refractive index of $n = 1.5$ returns a focal length of $4.1322(0.0001)mm$.

The dimensions of the spot of light are wider than the real ones due to magnification because of the use of a microscope objective in our measurements. Taking this into account, the spot can be fitted to the theoretical Airy disk formula (equation 2) obtained for a circular lens. The irradiance distribution of a spot produced by a microlens in its focal length has been measured by a Thorlabs BP100VIS beam profiler (see figure 6). The fit presents a regression coefficient of $r^2 = 0.92$.

$$I = I_0 \left(\pi r^2\right)^2 \left[\frac{2J_1\left(\frac{2\pi x r}{\lambda f}\right)}{\frac{2\pi x r}{\lambda f}}\right]^2 \tag{2}$$

In this equation, I_0 is the peak irradiance, r the microlens radius, x is the position coordinate, f the focal length of the microlens, λ the wavelength of the light source and $J_1(x)$ is the Bessel spherical function of first order.

Figure 6 shows a fit of the theoretical formula in equation 2 to the measured data, it can be seen the very good agreement between them, reflected on the previously mentioned regression coefficient of $r^2 = 0.92$.

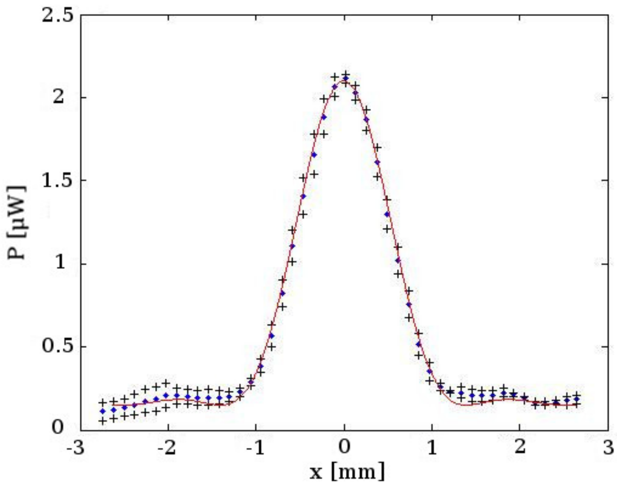

Figure 6. Fit of one of the spots to the Airy disk formula. The fit is made numerically in Matlab with the *cftool* package, leaving as parameters the diameter and the focal length in the Airy equation in 2. The quality of the fit is ensured by the squared regression factor $r^2 = 0.92$.

The fit of this equation is made numerically in Matlab, and it returns a value for the diameter of $264(12)\mu m$ and a value of focal length of $f = 4.48(0.95)mm$.

One last method to measure the diameter and the focal length of the fabricated microlenses is based on the use of a He-Ne laser ($\lambda = 632.8nm$), and a microscope objective, as depicted in figure 7. In order to determine the focal distance of the tested microlenses, we focused the microscope objective on the surface of the microlenses. Then, this was moved until observing the focal plane of the microlens array, the difference between the two positions gives us the focal distance of the fabricated microlenses. Figure 7 shows a close look of the experimental setup.

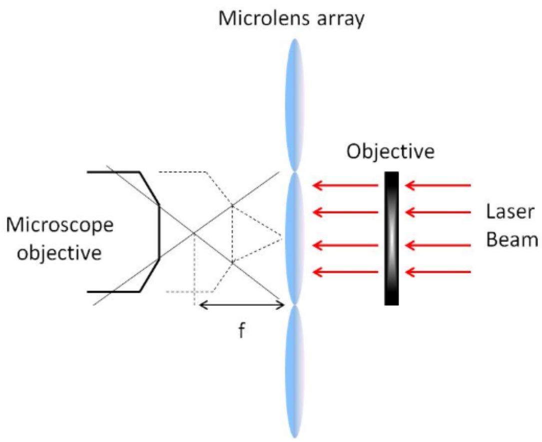

Figure 7. Setup for measuring the microlens focal length.

The value measured for the focal length was $5.2(1.2)mm$, that seems to be in good agreement with the previous ones.

4. Conclusions

The proposed technique will allow us to obtain microlenses with a broad range of diameters ($50\mu m \rightarrow 500\mu m$) and focal lengths ($1mm \rightarrow 5mm$) and opens a new window for generating different kind of surfaces in optical materials through a cheap laser process. By combining laser direct- write and the thermal treatment, we are able to obtain good quality elements using a common laser in industrial processes, which makes this technique competitive with other methods.

Acknowledgments

This work was supported by Xunta de Galicia, Spain, under project EM2012/019.

References

[1] Nieto D, Flores-Arias M T, O'Connor G M and Gomez-Reino C 2010 *Appl. Op.* **49** 4979
[2] Nieto D, Arines J, Gomez-Reino C, O'Connor G M and Flores-Arias M T 2011 *Proc. SPIE.* **8011** 80110T-6
[3] Smuka A Y and Lawandy N M 2000 *J. Appl. Ph* **87** 4026
[4] Huang C Y, Hsiao W T, Huang K C, Chang K S, Chou H Y and Chou C P 2011 *J. Micromech. Microeng.* **21** 085020
[5] Wu M H and Whitesides G M 2002 *J. Micromech. Microeng.* **12** 747
[6] Kim J, Kim K M, Jeon S K, Moonjung K, Park E H and Kwon Y S 2003 *Int. Conf. on Indium Phosphide and Related Materials.* 175
[7] Kunnavakkam M V, Houlihan F M, Schlax M, Liddle J A, Kolodner P, Nalamasu O, and Rogers J A 2003 *Appl. Phys. Lett.* **82** 1152
[8] Nieto D, Arines J, Gomez-Reino C, O'Connor G M and Flores-Arias M T 2010 *J. Appl. Phys.* **110** 023108
[9] Estepa L C and De la Fuente G F 2006, "Continuous Furnace with Coupled Laser for the Surface Treatment of Materials", Patent No. 200600560