Flexible Fabrication of Microlenses in Polymers with Excimer Laser Ablation

Kris Naessens, Peter Van Daele, Roel Baets

Abstract– **Excimer laser ablation is a flexible microfabrication technique, suitable for surface structuring of polymers because of their high UV absorption and non-thermal ablation behaviour. Due to the non-contact and direct-write nature of the process, laser ablation is a very attractive technology allowing realization of micro-optical functionality on top of opto-electronic components in a late phase of a heterogeneous assembly.**

In this paper we propose a flexible fabrication technique for microlenses with excimer laser ablation and report on the present status of experimental results on microlenses ablated in polycarbonate. Based on scanning a polymer surface with an excimer beam along well-chosen multiple concentric contours, a microlens of arbitrary shape can be realized. The choice of ablation parameters and the selection of scanning paths are discussed. Optical performance and lens surface quality are evaluated by imaging experiments, scanning electron microscopy and profilometer measurements.

Keywords– **laser ablation, excimer laser, microlens**

I. Introduction

One of the main trends in current opto-electronic device fabrication, is a continuous miniaturization of the components in order to minimize manufacturing costs and maximize operation speed. This tendency has been the main drive to develop micro-optics into a fully fledged discipline handling manipulation, imaging and/or focussing of (arrays of) light beams where the insertion of macro-optics - generally due to a lack of space, is not allowed.

In literature, excimer laser ablation has been reported a viable technology to realize micro-optical components, competiting with other fabrication methods like embossing, injection molding, casting, lithography, micro-jet printing and laser- or e-beam writing. Generally, these technologies suffer from low throughput, little flexibility in choice of material or are unsuitable for direct-writing of microstructures onto opto-electronic heterogeneous assemblies, thus requiring further alignment and preventing full integration of micro-optics and microelectronics.

Excimer laser ablation is a surface structuring technique based on the interaction of intense excimer laser pulses with a material. These lasers operate in the UV where polymers typically show high absorption. This results in electronic excitations which on their turn initiate both thermal and non-thermal processes leading to a dissociation of the polymer and subsequently local ejection of material. The presence of non-thermal reactions are responsible for a clean, well-defined geometry of the ablated zone. The lateral dimensions of the removed polymer are determined by the laser beam size, while the depth of the hole depends on the laser intensity. Typically the lateral resolution is limited to a few micron while the ablation rate can be as low as a few tens of nanometer. These properties make polymers a very suitable substrate material for excimer laser ablation.

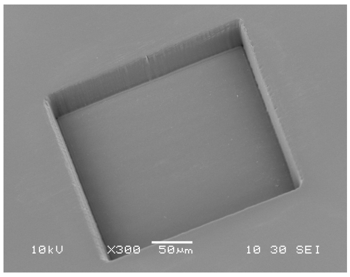

Fig. 1. Excimer laser ablated hole in polycarbonate.

The fabrication approach we propose here is based on ablation with a single circular excimer laser beam for shaping an arbitrary microlens surface. All laser parameters remain invariant during fabrication, no complex and/or moveable masks are used and no additional diffusion or thermal processes are involved, in contrary to previous reported ablation based methods[1,2,3,4,5]. After the lens shape has been realized, additional laser pulses using a larger beam diameter are applied to enhance the surface finish to optical quality.

II. Microlens Fabrication

In this section we describe the fabrication procedure to machine microlenses in a polymer substrate. In essence, the technique is based on ablating several concentric circular trenches with scanning ablation. Each groove is realized by moving the sample stage according to a circular path with diameter D while the excimer laser is firing pulses at a constant pulse frequency and energy (Fig. 2). Every time a trench is finished, the laser stops firing, and the stage is moved in order to ablate a new one with a different diameter. The start position for ablation of a trench is chosen randomly along the contour.

Each trench is determined by its depth, which is proportional to the number of overlapping pulses on every position in the groove, and diameter which will determine the exact profile of the trench as explained below. By ablating several of these concentric trenches with well-chosen depth and diameter, one is able to fabricate an arbitrary, pre-determined circular-symmetric shape. In this paper we will focus on these shapes which realize optical functions: microlenses.

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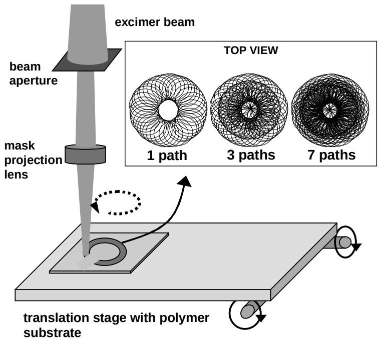

Fig. 2. Lens fabrication procedure.

A. *Theoretical analysis*

We assume that the beam diameter ρ is homogeneous and that ablation results in a hole with equal depth over its entire area. In the case of scanning ablation, the depth of ablation at a certain position on the sample will be determined by the number of pulses which overlap on that location. Assuming that the scanning speed and ablation depth per pulse is sufficiently low, a smooth ablated surface avoiding a staircase pattern can be achieved. Both assumptions allow an analytic expression for the ablated trenches. For a typical beam diameter of 100 µm, an etch depth of 0.1 µm per pulse and a contour velocity of 10 µm/s for the sample stage, the resulting profile is illustrated in Fig. 3 for 3 values of D: 50, 100 and 200 µm, respectively D < ρ, D = ρ and D > ρ.

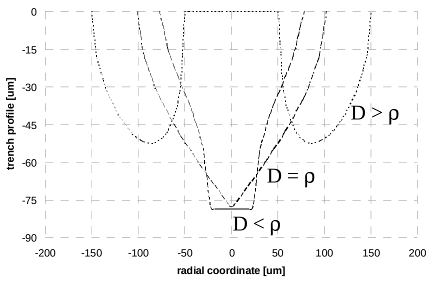

Fig. 3. Trench profiles.

Next we assume that a well-considered combination of trenches can result in the fabrication of an arbitrary pre-determined circular-symmetric microlens. Given a number of concentric circular channels, we require an optimization of their contour diameters which determine the overlap between the neighbouring channels and can be chosen to achieve a smooth surface in accordance with the intended microlens shape. The scan velocities, which determine the depth per channel, will not be optimized since this would most probably result in values which might lead to staircase or ripple patterns on the ablated surface due to respectively too high or too low velocities[6].

The optimization is performed by a simulated annealing algorithm, calculating the optimum contour diameters in order to approximate the desired microlens shape according to a least squares law.

B. *Experimental results*

The experiments are carried out with an excimer ArF laser (λ = 193 nm) by means of an optical set-up given in Fig. 4. The substrate is a polycarbonate film of 250 µm thickness. The ablated profiles have been measured by means of Scanning Electron Microscopy and confocal microscopy (3D profilometry) as illustrated in Fig. 5.

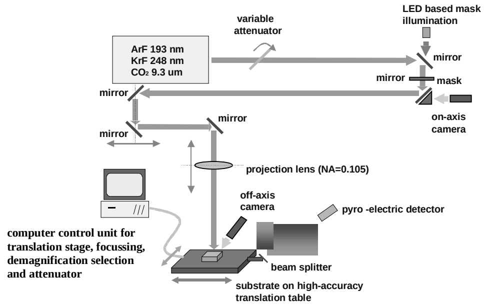

Fig. 4. Excimer laser ablation set-up

After ablation of the microlens, a large excimer beam is used to ablate a thin layer away from the whole lens area at once. In this way, we accomplish an ultimate removal of debris - ejected particles which did not evaporate and remained on the surface in or close to the ablated region - and reduce ripples which might have been introduced during ablation of the lens shape due to non-perfect overlap of neighboring trenches.

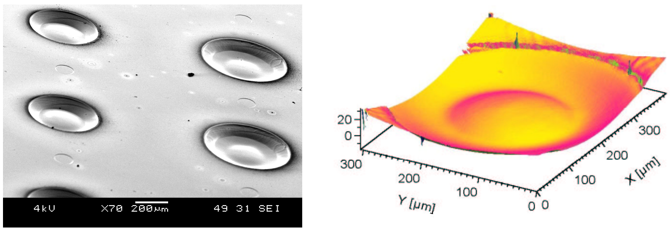

Fig. 4. SEM image of a microlens array (*left*), 3D profilometer measurement of a single microlens (*right*).

CONCLUSIONS

We developed a method to ablate microlenses using a simple laser ablation set-up. The measured surface finish and imaging properties of the ablated lenses are very encouraging in term of roughness and optical quality.

Further research is now focussed on fabrication of (arrays of) microlenses, integrated in an opto-electronic assembly.

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