Excimer laser ablated U-groove alignment structure for optical fibre arrays.

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Abstract.

Laser ablation is extremely well suited for rapid prototyping in a research environment and proves to be a versatile technique delivering high accuracy dimensioning and repeatability of features in a wide diversity of materials. In the paper, we present laser ablation as a fabrication method for micro-machining of arrays of precisely dimensioned U-grooves in dedicated polycarbonate and PMMA plates. The dependency of the performance on various parameters (wavelength, energy density and pulse frequency) will be discussed. The fabricated plates are used to hold optical fibre arrays and are key components in the assembly of 2D optical connectors for short distance optical interconnection.

Introduction.

Today several technologies are at our disposal for micro-machining: embossing, injection-molding and standard micro-electronic manufacturing processes. Most of them are rather mass-fabrication oriented as embossing and injection-molding, allow little degree of freedom in choice of substrate material and suffer from high cost and slow fabrication speed. Excimer laser ablation, a process in which high energy pulses locally remove material in a controlled way (figure 1), offers quite some advantages in comparison to the upper mentioned technologies: speed, numerous substrate materials, low environment requirements, … In other words: the technique is extremely flexible and it is no surprise that since its introduction two decades ago, excimer laser ablation has well acquired the reputation of being a reliable fabrication method of micro-structures and geometries. For large quantity manufacturing however, this technique becomes less appropriate due to the rather small working-area (limited by the excimer beam shape, typically a few square cm) and other technologies will be required.

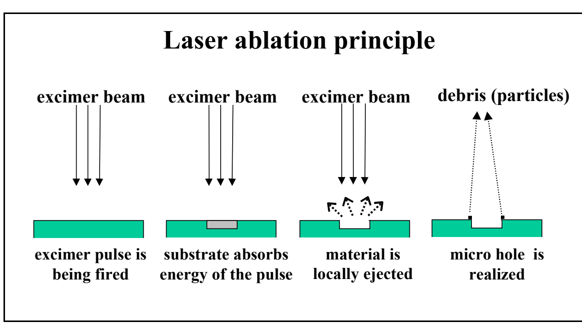

Figure 1: principle of laser ablation.

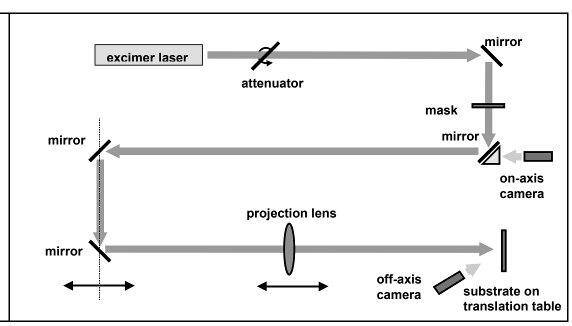

Figure 2: laser ablation set-up.

It is the purpose of this paper to investigate the potential of laser ablation techniques for the fabrication of U-groove alignment structures for (plastic) optical fibre connector purposes on prototyping or low quantity fabrication level. Mass-manufacturing of these alignment components can be succesfully realized with embossing and injection-molding.

Laser ablation of U-groove arrays.

For fabrication of grooves, we investigated two different kind of polymers, PMMA (PolyMethylMethAcrylate) and PC (Polycarbonate) as well as two excimer-laser source wavelengths: 248 nm (KrF) and 193 nm (ArF). PMMA has a rather low absorption coefficient (2000 cm^{-1} and 200 cm^{-1} at 193 and 248 nm[1] respectively) which allows the pulse to penetrate deeper into the material (higher ablation rate) but which is also responsible for the higher threshold of the pulse intensity. Furthermore an incubation effect[2] is observed with PMMA: ablation (defined as physical removal of material) only occurs after a number of pulses have been fired.

For fabrication of grooves we applied two different methods (both common in micro-machining) which we will call moving-aperture and mask method. The first implies the use of a suitable single aperture that is imaged onto a substrate that is translated between two or more pulses. The latter involves a more complex mask pattern that is imaged onto the substrate. Depending on the pattern size, translation might not be necessary anymore, although it may be beneficial to the resulting ablation quality of the trenches: by partially overlapping pulses (slow translation of the substrate), one averages depth variations of the ablated surface due to spatial inhomogeneity of the laser beam. This is only possible when the ablated geometry is translation invariant (e.g. a groove).
After ablation of the grooves, a cleaning step with alcohol and pressed air is necessary to remove debris (macroscopic particles which did not vaporize and remained in or close to the ablated region) on the polymer surface.
The experiments were carried out with a Lumonics Pulse Master 848 (suitable for both KrF and ArF gas mixtures) and by means of an optical set-up as in figure 2. A Molectron J3 pyroelectric joulemeter was used for accurate energy density calculations.
Figure 3 and table 1 illustrate the results. Both arrays consist of 8 grooves of 125 micron depth and 9 mm length with a pitch of 250 micron. The width has been optimized for carrying an optical plastic fibre taking the finite steepness of the trench into account. Fabrication time for the structure in polycarbonate with the moving aperture method (on the left) is approximately 11 hours while the one on the right (the same array in PMMA with the mask method) takes only 27 minutes. The mask pattern consists of 4 grooves of length 2.5 mm (500 micron on substrate level, taking an imaging from mask to sample with demagnification 5 into account) and is limited in size by the aperture of the projection lens. It consists of a quartz substrate (transparent for both excimer wavelengths) on which a metal pattern has been deposited. The maximum allowed energy density is about 100 mJ/cm^2. Note that a mask with the full array geometry would result in a fabrication time of only a few minutes.
A number of parameters are at our disposal for ablating this structure: on-substrate energy density and pulse frequency. Both illustrated structures were fabricated at a low pulse frequency (10 Hz) and energy (lower than 200 mJ/cm^2). Although increasing each

or both parameters speeds up the process, this is not very beneficial to the quality of the structure (roughness and morphology of the groove bottom): at high frequencies and energies we observed the creation of large macroscopic particles at the bottom (several microns to tens of microns) which cannot be removed anymore and a brown-like colour shift of the polymer which suggests the material has been thermally damaged. Ablation at 248 nm seems more sensitive to this phenomenon in comparison to the ArF wavelength.
The ablated trench does not have vertical walls due to the principle of imaging of an aperture or mask. However, the steepness of the latter can be controlled to a certain extent by the pulse energy density: we observed angles as low as 69 (low pulse intensity) up to almost 81 degrees (high energy densities).

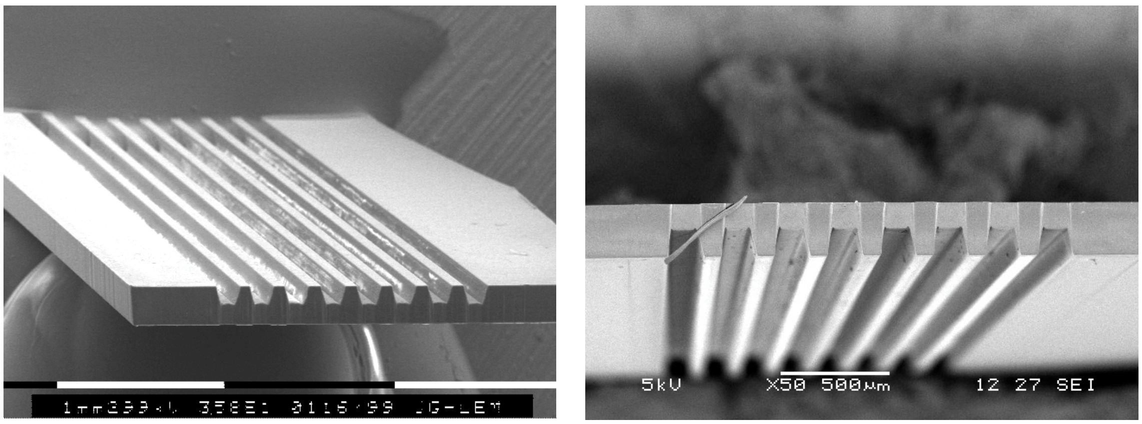

Figure 3: array fabricated with moving aperture method in PC at 248 nm (left), array with mask method in PMMA at 193 nm.

	moving aperture method at 248 nm in PC	**mask method at 193 nm in PMMA**
on-substrate energy density	178 mJ/cm^2	160 mJ/cm^2
pulse frequency	10 Hz	10 Hz
steepness	72 degrees	78 degrees
number of pulses per spot	282×3	224×2
RMS roughness	0.40 µm	0.33 µm
Fabrication time	11 hours	27 minutes

Table 1: ablation parameters and experimental results.

The grooves were not ablated to full depth at one go. Experiments pointed out that a process in two or more steps allows faster ablation and smoother structures than when ablated at once. This can be explained by the steepness of the surface which undergoes ablation: in the first case this angle is much smaller than in the latter. Thus the energy density at this surface remains higher and ablation still takes place without much loss of speed.
Finally the experiments indicated that from an ablation speed and surface morphology point of view, PMMA ablates better at 193 nm (figure 4) while PC performs better at 248 nm.

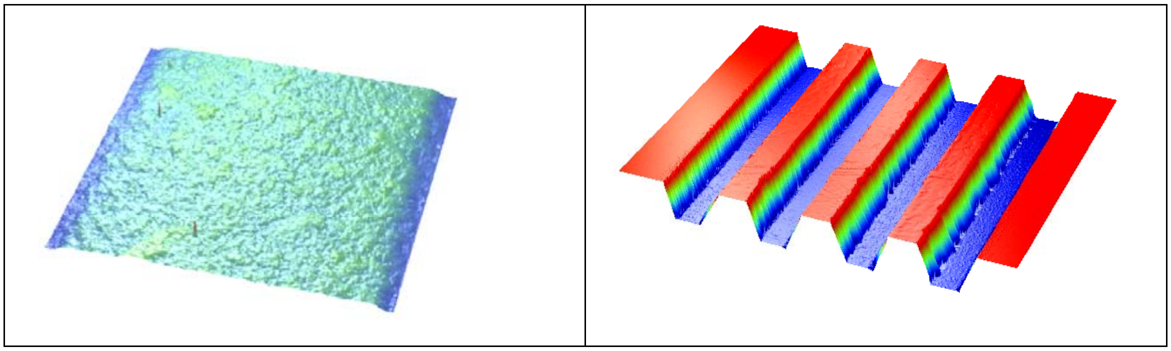
figure 4: surface scan (WYKO) of the groove bottom (left) and a part of the array (right) in PMMA.

Assembly of an optical fibre array 2D-connector.

The ablated grooves allow plastic optical fibres (POFs) to be aligned and fixed in the PMMA dedicated plates. Before doing this, the facets of the PMMA plates are prepared to obtain the accurate dimensions in combination with smooth end facets. This is realized by cutting the plates with a heated sharp knife due to a simultaneous cutting and melting process. After fixation of the fibres with a UV-curable adhesive on a ribbonisation set-up and cutting the fibres one by one with the hot knife technique (figure 5), the plates can be stacked to build a 2D fibre-array connector in which the spacing between all fibres is 250 micron.

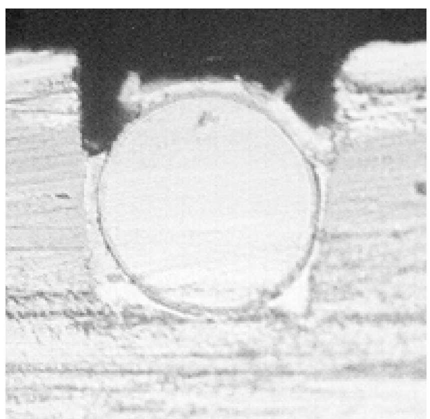
Figure 5: plastic optical fibres fixated in the grooves.

Conclusion.

Laser ablation proves to be a very suitable candidate for the prototyping of precise fibre-alignment structures. Groove arrays in dedicated polymer plates haven been produced for optical fibre alignment purposes in a precise, fast and reproducible way. The quality of these structures has been evaluated for different substrate materials (PMMA and PC) as well as for different laser source wavelengths and the importance of parameters as energy density and pulse frequency has been discussed.

Acknowledgements: the authors would like to thank the Flemish IWT for equipment support as well as the Belgian DWTC project IUAP-13 and European ESPRIT project OIIC.

[1] R. Srinivasan and B. Braren, Appl. Phys. A 45, p. 289-292 (1988)

[2] R. Srinivasan, B. Braren and K. G. Casey, J. Appl. Phys. 68 (4), p. 1842-1847 (1990)