Optimisation of processing with excimer laser mask technique

V. SAVA*, C. ILIE[a] , M. POPA[a], S. STANESCU[b], M. I. RUSU[c], M. UDREA[d]
University of Bucharest, Faculty of Physics, Bucharest, Romania
[a]*CPE- CA(National Institute for R&D in Electrical Engineering), Bucharest, Romania*
[b]*"Politehnica" University of Bucharest, Biomedical Engineering Centre*
[c] *National Institute R&D for Optoelectronics INOE 2000, 409 Atomistilor Str., Magurele, Jud. Ilfov, 77125 Romania*
[d]*NIPLR (National Institute for Laser, Plasma and Radiation Physics), Bucharest, Romania*

The quality of laser machined surface and bulk of different materials with applications in micro-technologies is investigated. Machining occurred with a 248 nm KrF excimer laser and a particularly designed optical system. Optimising tests were performed on poly methyl methacrylate (PMMA), which were further applied to poly-ethylene terephthalate (PET), silicon and ferromagnetic material. All the tests were performed in normal atmospheric condition. The experimental results are presented and compared for improving the machining quality of materials.

(Received January 26, 2011; accepted February 17, 2011)

Keywords: Excimer laser, PMMA, MEMS manufacturing, Homogenizer optical systems

1. Introduction

Laser interaction with matter finds many applications in industry, medicine, biology, fundamental science, etc. Micro-processing has attracted a high interest in applications like micro-electro- mechanical systems (MEMS) and micro-optical-electro-mechanical systems (MOEMS). Compact microsystems like micro labs, bio-medical systems with MEMS technology, made by surface or bulk laser processing were manufactured to date [8-12]. A large number of studies in this area have been devoted to achieve miniaturisation and cost effectiveness with such devices [4-6,13]. Almost all types of lasers, such as excimer laser [1-4], CO_2 laser [5-6], solid lasers [7-9] have been used.

In this work, we use a 248 nm excimer laser, a homogenizer-mask system and a projection lens for surface micro-processing into micro-channels, coils, etc. The laser fluence and the repetition rate were varied and tests using different masks were carried out. Comparisons with previously published results [1-4] regarding PMMA and PET processing are made.

The main goal has been to optimise the processing parameters in order to achieve high quality components.

2. Experimental

The schematics of our experiment are given in Fig. 1. The beam delivered by an excimer laser (CompEx 205 F, Coherent Inc.), λ = 248 nm, τ=25 ns, 50 Hz repetition rate, 700 mJ/pulse, arrives on the target through a beam delivery system and a projection lens. The target follows X-Y and rotation movements simultaneously.

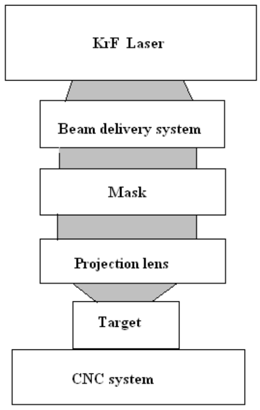


Fig. 1. The experimental block diagram.

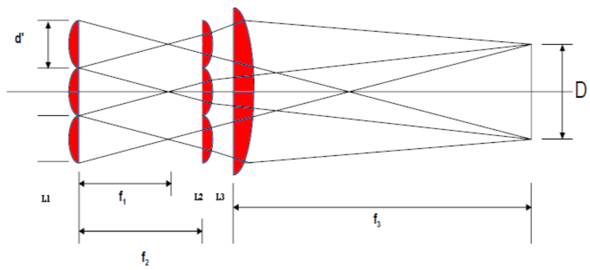


Fig. 2. The homogenizer principle.

It is very important to know the field size of the laser spot in the focal point f_3 of the lens L_3 because there the laser spot is homogenized and from its width and area the energy density on the mask can be derived. By using the imaging formula of an object field d' (here the diameter of the lenses used in the homogenisers) and combining the two focal lengths [14,19] the next formula can be written:

$$D=d' * f_3 / f_2 \quad (1),$$

with d'= 3 mm; f_3 = 900 mm; f_2 = 233 mm for our experiment. We obtained a squared image of the spot in the focal point f_3, with D=11.55 mm. The image is squared because cylindrical lenses with identical width d' are used on the both axes of the homogenizer. It was proved using thermal paper in the focal point f_3 of L3. These results are given in Fig. 3, which depicts a java software simulation, special made for this application, for 10 cylindrical lenses per array of the laser spot at the entrance of the homogenizer and the virtual result in f_3 point (where is measured D). It also shows the laser spot at the entrance (recorded by the producer with a CCD camera) and our homogenized spot (recorded on a thermal paper). One can remark that our calculation of D is correct.

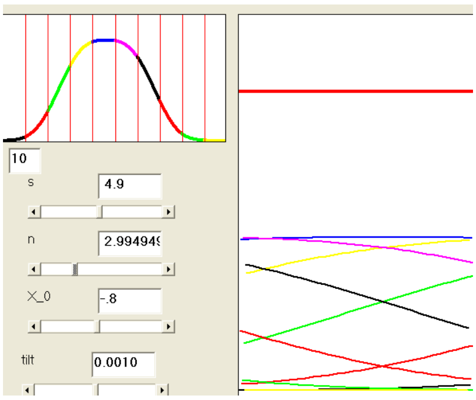
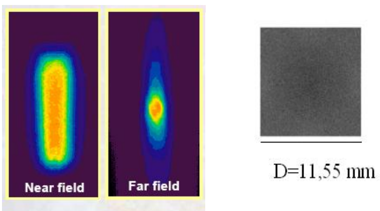


Fig. 3. The software simulation of the laser spot, entrance laser spot and homogenized laser spot (Courtesy of Coherent Inc.).



Fig, 4. Intensity distribution before (a) and after (b) homogenization.

3. Results

We have started by determining the laser spot shape using a single focusing lens. For this purpose we have used Si and a ferromagnetic target. The results are given in Fig. 5, where one can see an irregular shape with a non uniform energy distribution. Therefore, the use of a homogenizer system shows necessary in order to achieve an uniform intensity distribution of the laser beam on a regular shape.

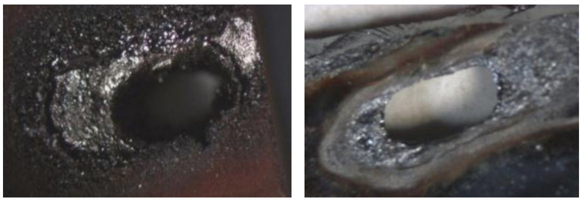
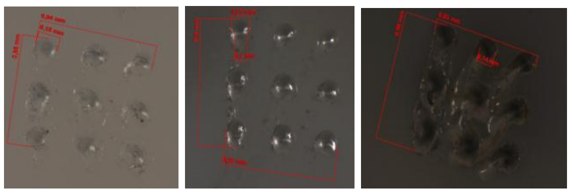


Fig. 5. Non-uniform laser spot shape obtained in Si and ferromagnetic material by using a single plane-convex lens.

Three types of masks were employed in this experimental study in order to improve the quality of the laser beam: a circular one, a rectangular one and a matrix of holes. All masks were designed to fit in a maximum width of 11.55 mm (as we calculated above), not to dim the homogenous laser spot. The circular and rectangular masks are used for surface micro-machining or, with an appropriate CNC system, for bulk micromachining [17-18]. Each mask has had a specific role in this study. First, we used the matrices of holes to find the best repetition rate value for the chosen material. The other two masks were aimed at studying the influence of energy density and repetition rate on the machining quality. At the end we used a special mask to perform different shapes as it will be shown later in this work.

There is a high interest to create micro-channels or micro reservoirs in PMMA with applications in industry, medicine or biology [4], [13], [17-19]. We used a laser energy density between 0.7 J/cm^2 and 2.5 J/cm^2 with a repetition rate in the range 1 Hz to 20 Hz and a total number of shots of 600 (the same total number of pulses for different exposure times and different repetition rates).

The energy density on the target was calculated by measuring the laser energy at the mask plane and the image shape area on the target. Some of the results are displayed in Figs. 6, 7 and 8. The images were taken with an IX51 Olympus microscope.



a b c

Fig. 6. The effect of laser energy density and repetition rate on the PMMA. We used 100 pulses, a fluence of 0.8J/cm^2 and 3 frequencies a)1Hz b) 7Hz c) 15Hz .

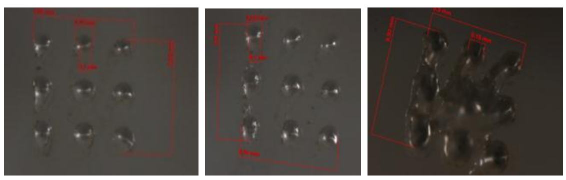


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Fig. 7. The effect of laser energy density and repetition rate on the PMMA for 100 pulses, at a fluence of 1.5 J/cm^2 and 3 frequencies a)1Hz b) 5Hz c) 10Hz .

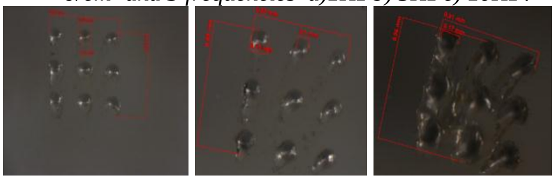

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Fig. 8. The effect of laser energy density and repetition rate on the PMMA for 100 pulses, a fluence of 2 J/cm^2 and 3 frequencies a)1Hz b) 4Hz c) 10Hz .

When comparing the results the conclusion comes out that the optimum frequency for PMMA is: < 7Hz for 0.8-1.2 J/cm^2; < 5 Hz for 1.2- 1.5 J/cm^2 and < 4Hz for 1.5 - 2 J/cm^2. Thus, at higher fluences lower frequencies should be used. Once the best repetition rate for this material was determined, the next step has been to study the effect of the fluence and of the number of pulses for the tapper angle by using a square mask. The results can be seen in the Fig. 9.

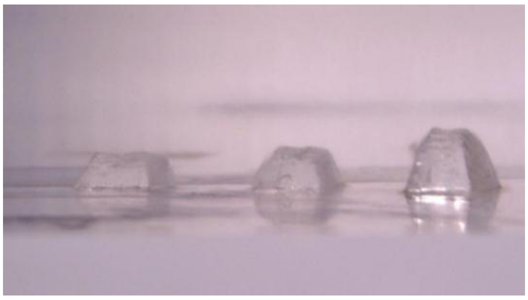


Fig. 9. Some results of testing the influence of number of pulses over the hole's wall for 300,400 and 550 pulses. The more the pulses the closer to 90 deg the angle between the surface andthe hole wall.

For determining the influence of the total pulse number over the hole angle we used a fluence of 2 J/cm^2, 3Hz rep rate and a total pulse number between 300 and 600 pulses. All the results are shown in the graph in Fig. 10:

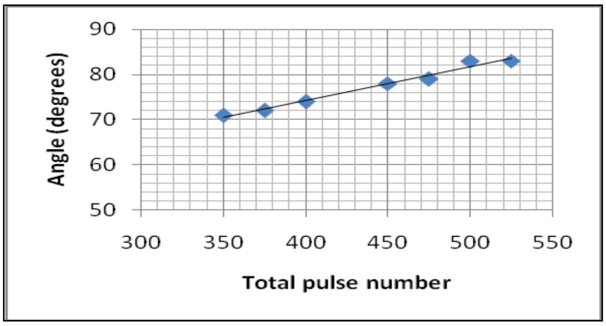
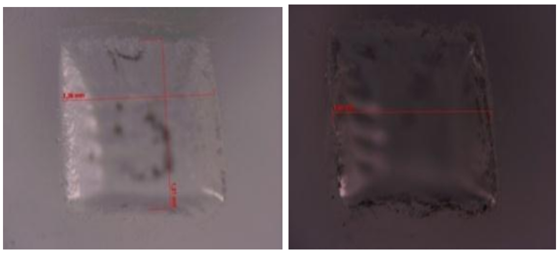
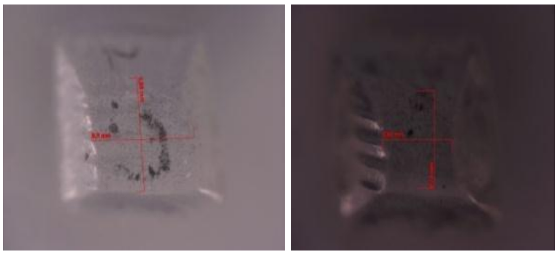


Fig. 10. Influence of the total number of pulses on the angle between hole's wall and entrance surface.

Another topic of high interest is the study of the evolution of the hole's depth under the effect of the laser energy density. On this purpose we used the same square mask module and a fluence between 1.2J/cm^2 and 2.2J/cm^2 with a repetition rate of 1Hz and a total pulse number of 100 for each hole.



a) The entrance surface



b) The bottom surface

Fig. 11. Comparison between two results for the variation of the laser shape with laser energy.

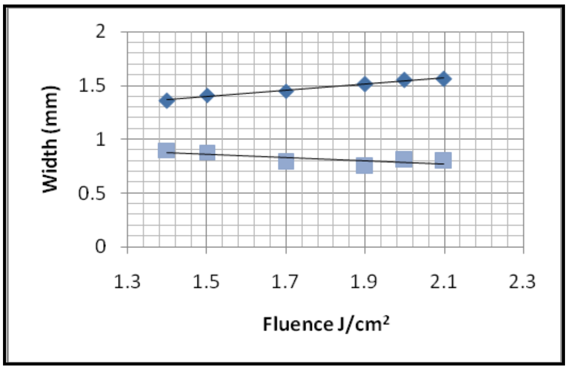


Fig. 12. Evolution of width in the top and bottom side channels as a function of laser's fluence.

4. Discussion

Both graphs (Fig. 10 and Fig. 12) show the high importance in choosing the machining parameters, e.g. laser fluence, repetition rate and total number of pulses, especially for PMMA. A controversial discussion could still arise because of the compromise one should accept between increasing the laser energy and increasing the total number of pulses when making a hole of a fixed depth. From our experiments it is clear that for higher laser fluence a lower repetition rate is suggested and to obtain well shaped channels or holes is better to choose lower laser energy and a larger total number of pulses. This can be an impediment to create some longer channels or more complicated drawings by using a single hole mask, so that it cannot be an acceptable solution. From references [1-8] and [18] the solution would be the use of a mask with a shape as complex as possible, to choose the proper energy and repetition rate controlling also the ablation depth.

For example, by using the same system and a more complicated mask we made a wheel-like structure ablated into PMMA. This can be used to further create an electroformed replica.

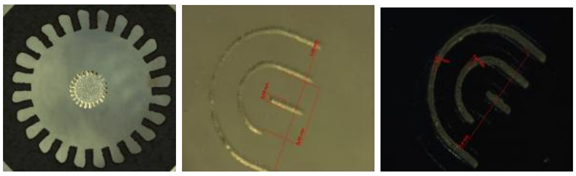


Fig. 13. A wheel structure made in PMMA and ~ 100 um channel structure made in PMMA and Si.

Also, this kind of system can be used for holes drilling, for example in 100 μm thin PET by using the same mask we have described above.

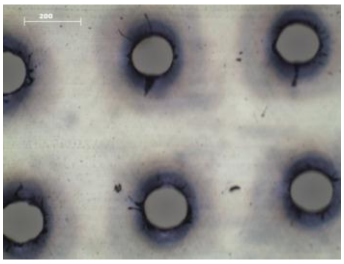


Fig. 15. The same hole matrices used this time for drilling holes in PET.

5. Conclusions

Excimer laser processing can produce various types of structures in planar or non-planar materials if it is used with a suitable CNC system. Careful consideration should be taken on the repetition rate. As the using of excimer laser processing systems become more common, we believe that is very important to make some improvements for this systems in developing it not only as a stationary tool but also as a more complex system through combinations with chemical etching, ion-beam milling or photolithography, thus creating new ways of micro engineering to design a greater range of materials and shapes.

Laser fluence, optical system used, total number of pulses and work piece motion with co-ordinate CNC laser firing are all important in creating good micro-piece at high efficiency. Polymers are the most changeable and efficient materials to be ablated with excimer lasers through photochemical interaction. Other materials can be machined by the system described in this work and further development using a vacuum chamber may increase the efficiency and hence reduce the cost of processing materials such as copper, steel, silicon and others. Polymer structures can be machined down to depths of the order of 800 to 1000 μm with good spatial resolution. The control of ablated wall angle is in close connection with the fluence, repetition rate and total number of laser shots but may also be controlled by appropriate choices of mask and processing method, for example by using a mobile mask.

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*Corresponding author: vasile.sava@apellaser.ro