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Femtosecond processing with programmable spatial beams

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Abstract

In the frame of the development of flexible micromachining workstations, spatial beam shaping appears to be a significant improvement for femtosecond processes. An adequate phase function displayed on a phase modulator leads to a custom intensity distribution in the Fourier plane of an objective lens, and consequently provides a customized laser tool. Electrically addressed spatial light modulators (SLM) add flexibility and ease-of-use while maintaining a high spatial resolution compatible. We present processing results obtained with an industrial tool coupling femtosecond lasers with beam phase manipulation. Programmable spatial beam shaping contributes to increase the application range of femtosecond processes by enlarging its field from direct surface processing of complex shapes and speeding processing time.

Keywords: femtosecond laser processing, spatial light modulator, parallel processing

1. Multiple beams and fast processing

In recent years, the use of ultrashort pulsed lasers in the field of advanced material processing has considerably increased and it is now a relevant technology for industrial applications requiring a high level of accuracy. Exploiting the specific laser-matter interaction at ultra-short time scales, optimized ablation

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efficiency and high quality machining of nearly any kind of materials are achievable, including metals, semi-conductors, dielectrics, hybrid inorganic-organic materials or biological tissues.

With high power, 100 W and high repetition rate, high throughput is possible with femtosecond lasers. Femtosecond lasers play a key role in these processes, due to their ability to high quality micro processing thanks to their specific shape of deposited energy. The synchronization of operating tools after the laser with the laser is crucial, not only to take advantage of the possibility of high speed processing, but also to prevent new thermal mechanisms occurring when two pulses are either spatially or temporally overlapping.

Indeed, the process set up has to be modified to obtain the same results as in low repetition/low power case, to maintain for instance the pulse overlap defined for the determined process. Two options are then possible depending on laser parameters: to speed also the operating tools using for instance polygonal scanners for keeping the same energy density on sample, or to use multiple beams for distributing the energy on several laser spots. Figure 5 show a schematic view of application field in function of laser pulse repetition and pulse energy.

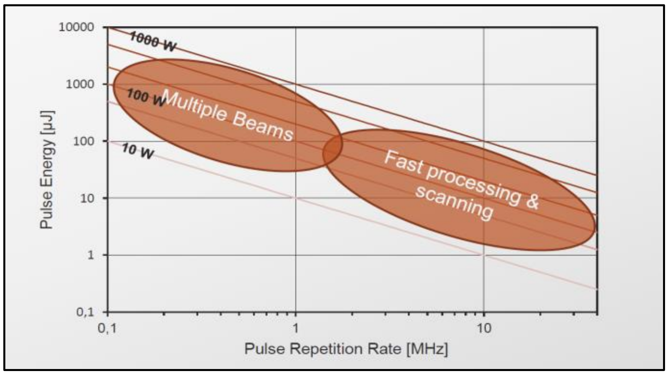


Fig. 1: schematic representation of application field in function of laser parameters

The use of multiple beams allows to distribute a high available energy in several spots. The present work investigates a technical solution with femtosecond lasers developed by Amplitude Systems and multiple beam shaping with an industrial set up developed by Qiova. Programmable spatial beam shaping contributes to increase the application range of femtosecond processes by enlarging its field from direct surface marking of complex shapes to drilling and machining in the surface of metals or in the bulk of transparent materials.

1. Beam shaping using SLM

In the frame of the development of flexible micromachining workstations, spatial beam shaping appears to be a significant improvement for femtosecond processes. An adequate phase function displayed on a phase modulator leads to a custom intensity distribution in the Fourier plane of an objective lens, and consequently provides a customized laser tool. Electrically addressed spatial light modulators (SLM) add flexibility and ease-of-use while maintaining a high spatial resolution compatible with complex optical functions like multi beams, non-diffractive structured beams or multiplexed lenses. The linear set of pulses is a first step for parallel processing when moving beams will be used. Depending on the choice of spatial light modulator, transmission can range from 70 % to 95 %. In all case, a refine treatment of 0-order diffraction has to be managed. Shaping efficiency can range from 60 % to 85 %. An important issue is the strength of SLM materials to high laser energy and high average power. With used devices, average power of 50 W can be easily used and 100 W can be reached with additional cooling systems. Figure 2 show examples of multi beam shaping with a YUJA laser (100 µJ at 100 kHz). The minimum measured spot size of spots is 25 µm, while the expected size corresponding to laser parameters is 21 µm.

(a) (b)

Fig. 2: example of beam intensity distribution after multi spot beam shaping with a YUJA laser from Amplitude Systèmes (100 µJ at 100 kHz) and the Qiova head.

Beam shaping can be obviously realized with fixed diffractive element (DOE). In this case optimization of device with beam characteristics is made only before fabrication of the device and cannot be changed after. With a programmable SLM, an optimizing procedure, using a dedicated computer algorithm to modify the phase map, can be performed for each laser beam used. In the same way, the number of beams can be adapted to the user needs (from the maximum allowed by the beam energy to one beam). The figure 3 shows an example of optimization in the case of eleven beams

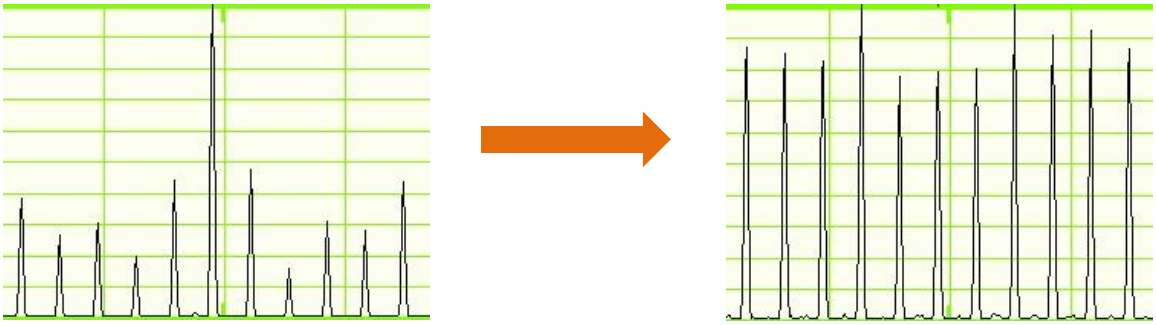
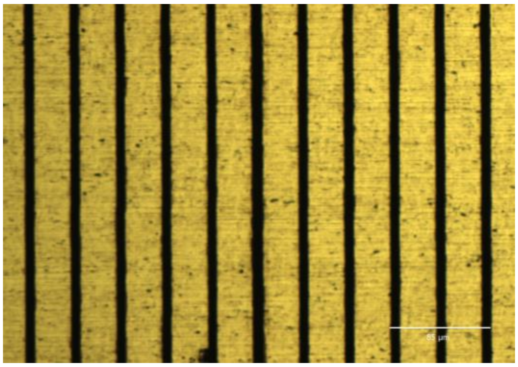


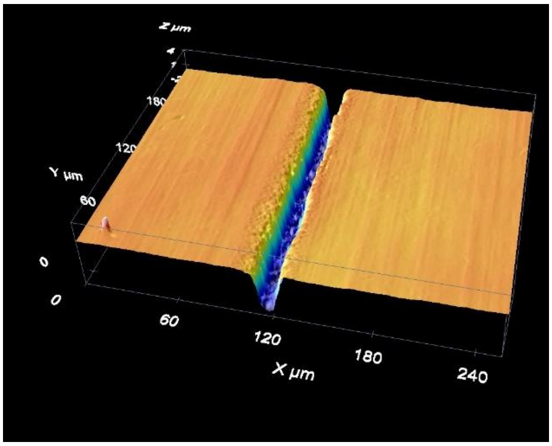
Fig. 3: example of results for phase map optimization with the used laser beam in fig. 2

2. Processing with programable beam shaping

A consequence of the weak extension of surrounding damages is that the shape of the processed area is very close to the intensity distribution in the focal spot. This has motivated some efforts in the field of femtosecond laser beam shaping. Amplitude masks or diffractive optical elements (DOE) have already been used with success for femtosecond micro-machining applications, but amplitude filtering suffers from high transmission losses, and DOE deliver only one pattern for each device, thus highlighting the need for a dynamic and programmable system. By using a versatile beam shaping set-up which generates custom beam shapes in the focal plane of a lens by spatial phase modulation, we demonstrate direct fabrication of complex micro-structures in material. The specificities of femtosecond light pulses interaction with metals have been widely studied and put forward especially in the field of micro processing. Micro grooves with a high degree of precision can thus be realized by translating the focused femtosecond spot on the surface of the sample. The dimension of the machined structures depends on the focusing strength and the interplay of the energetic conditions and the physical properties of the irradiated material. Demultiplication of the focal spot into several foci enables parallel processing greatly reducing the processing time and cost.



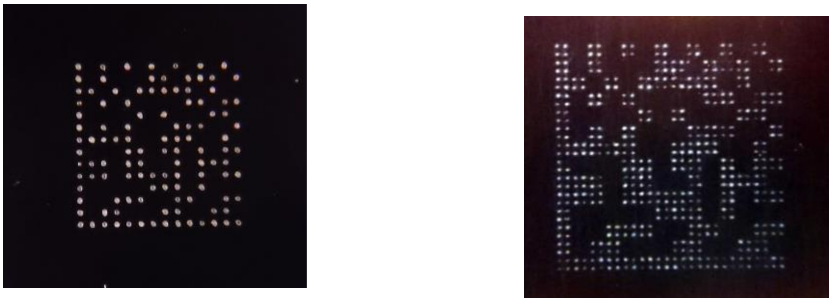
(a)



(b)

Fig. 3: example of parallel processing on stainless steel (11 grooves with one initial laser beam). The laser used is a SATSUMA laser (50W at 1,3 MHz). (a) view of machined grooves with optical microscope, (b) profile of one groove with a profilometer.

To test the number of possible spot in one pulse, we have also used high energy laser (up to 5 mJ) at low repetition rate (100 Hz). This rate is close the refresh time needed (around 60 Hz, depending on the computer interface) for the phase map. The objective is to print a data matrix in one pulse, containing information that can be modified between each pulses. Figure 4 shows some examples on silicium an stainless steel



(a) (b)

Fig. 4: example of multi spot marking with one laser pulse of 5 mJ. (a) silicium, (b) stainless steel for spot density x4

3. Coupling SLM with lasers

Amplitude and Qiova are associated to propose a unique solution integrating very compact laser and beam shaping solutions. In the following illustration, the integrated laser system (YUJA) delivers more than 10 W average power, with pulses energy more than 100 µJ, and pulse duration less than 500 fs. The laser dimensions are 36x23x12 cm while The Qiova head dimensions are 24x16x15 cm.