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Multi beams fs processing with high power laser

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Abstract

Translating the high available power for industrial lasers in the 100 W range into high throughput micro-processing is of high importance for future industrial applications. Beam divisions into multi beams using diffractive optics is a promising investigation direction. Programmable Spatial Light Modulators (SLM) can bring flexibility while maintaining a high spatial resolution compatible with complex multi spots shaping or user defined beam profiles. The recent technological progress in LCOS based systems enables an optical transmission greater than 95 %, high diffraction efficiency around 80 % but also high average power handling up to at least 100 W. However, the dependence of the shaping performances on laser bandwidth places specific requirements when using ultrafast lasers. The usable field size with respect to the chromatic effects is for instance a specific parameter to manage. Optimization of the machining results by software driving of the SLM phase map can provide original and efficient solutions for parallel processing.

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

1. Introduction

New fiber / crystal hybrid femtosecond lasers [Hönninger *et al.* 2018] are now available with an average power output of up to 500 W, with flexible and controllable pulse repetition rates. For power scaling in multi-100-W or kW, the Innoslab concept [P. Russbueldt *et al.* 2009] allows to develop a new generation of

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amplifiers using the latest advances in components and subsystems, with a very small footprint of only 50 x 20 cm². The condition for obtaining the same high-quality results as for moderate repetition rates and power is to maintain the same energy density on the sample surface. Multiple beams, obtained by diffractive optics or programmable elements, provide a potential direction for high-throughput applications, requiring the conversion of high power to high energy to achieve a high number of separate beams.

High power lasers can thus deliver high energies, from 1mJ up to 20mJ. Since the pioneering works on the field [Z. Kuang, *et al.* 2009, S. Hasegawa *et al.* 2014], user programmable diffractive optics can offer significant advantages for the development and optimization of micro-machining applications. In particular, electrically addressable Spatial Light Modulators (SLMs) add flexibility and ease of use while maintaining a high spatial resolution. Complex optical functions such as multiple beams, non-diffractive beams or multiplexed lenses can be generated. An adequate phase function displayed on a phase modulator results in a custom intensity distribution in the Fourier plane of a lens, and therefore provides a personalized laser tool.

2. Challenges for processing.

2.1 Power handling.

The development of cooled components allows the use 100 W laser power and more, as shown in Figure 1. By implementing laser technologies such as those mentioned above, we can use energies up to 1 mJ for 100 kHz repetition rates. The typical optical transmission can reach 100 %, and the diffraction efficiency is usually near 80 %. Work is being done to further push the power handling limit supported by these new devices [G. Zhu *et al.* 2018], but the main challenges still focus on the implementation of new multi-beam process strategies [J. Li *et al.* 2019].

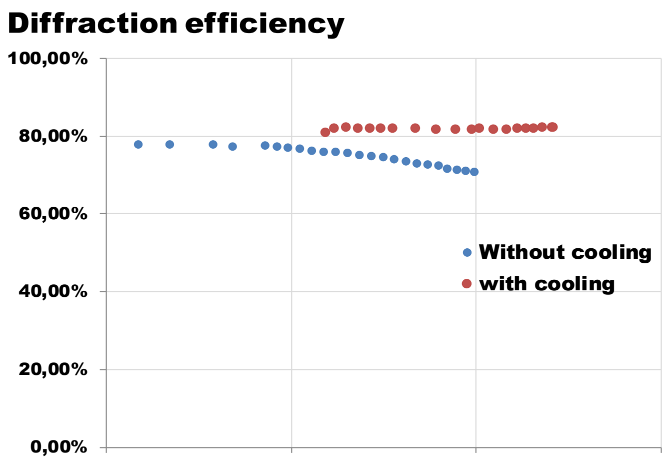

Fig. 1. Power handling of a water-cooled and a passive SLM. The laser used is a Tangor type laser delivering more than 100 W with pulse duration less than 500 fs. The loss of diffraction efficiency indicates the onset of liquid crystal change due to temperature. Under normal conditions of use, the diffraction efficiency of a SLM is typically 80%.

2.2 Usable field.

The key point of using a SLM is the good knowledge of the usable field. A theoretical field is obtained by Fourier transform, knowing the physical dimensions of the component used (pixel size), the focal length and the wavelength of the laser. Table 1 gives typical dimensions of this field.

Field : typical values	
SLM number of pixel	1272
Field [mm] **@ 1030nm, f=100mm**	8
Resolution [µm] **@ 1030nm, f=100mm**	10

Table 1. typical values for a SLM field in Fourier configuration. Usable field is usually smaller (see text)

However, several parameters generally lead to a significant reduction of this usable field. First, the reduction of the diffraction efficiency is a first limitation to take into account. The third graph of fig. 2 shows the evolution of the diffraction efficiency as a function of the distance to the optical axis. On this graph, the maximum diffraction efficiency obtained on the optical axis is quoted 100%. Depending on a desired energy variation in the chosen diffraction pattern, it will be thus necessary to limit the field. Second, the use of femtosecond lasers, characterized by a spectral width of 1 to 10 nm, may lead to additional precautions for the definition of the usable field. Indeed, a chromatic effect leads to an enlargement of the spot diameter as a function of the distance to the axis. This effect is illustrated in the first graph of Figure 2. This enlargement has consequences on the energy density provided by the different spots. Two strategies are then possible. The chromatism can be taken into account by limiting the field to neglect this effect for the desired variation in energy density. For a given laser + SLM configuration, this variation in diameter can also be corrected by modifying the phase map. Finally, still in the context of the use of femtosecond laser, as shown in the second graph of the figure 2, there is no change in the pulse duration over the entire accessible field.

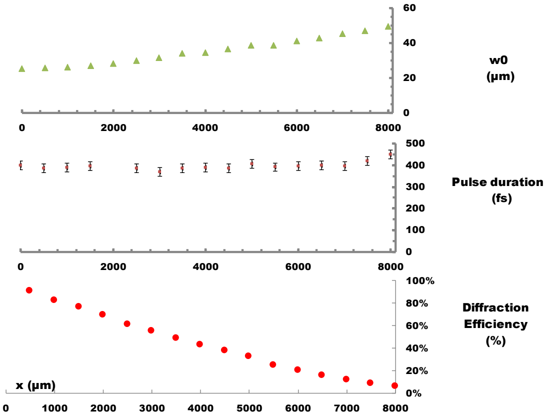

Fig. 2. Variation of the spot size w_0, the pulse duration and the diffraction efficiency as a function of the distance to the optical axis (x). Spectral width of the laser used is 3.3 nm.

2.3 Zero order management.

As mentioned above, the diffraction efficiency of SLM is never 100%, the existence of a zero-order containing the not diffracted energy and collinear with the optical axis is always to consider. As illustrated in figure 3, three strategies are generally considered for the zero-order management. The shaped pattern can be shifted from the optical axis, the zero order can be thus easily stopped. This solution has disadvantages, as only half of the available field can be used. The second strategy aims to achieve the shaping in a different plane of the zero-order focus plane. This solution, which is practical to use, can be questioned if the energy sent in the zero order has always an effect on the processed sample, for example, in the regime of accumulation of multiple shots. The last strategy aims to integrate the zero order in the shaped pattern, if this is possible. Programming the phase map will then optimize the energy available in each spot according to the desired spot energy homogeneity. With respect to the last point mentioned, and more generally, the optimization of the phase map to obtain a controlled energy of each shaped spot is a key point of the implementation of the SLM technology. The flexibility of the SLM versus DOEs may indeed make it possible to compensate by action on the phase map for fluctuations in the laser operation or for variations in the processing conditions. This type of action is intended to be automated and implemented in a control loop, making SLM interesting candidate for the strategy 4.0 suited to laser processing.

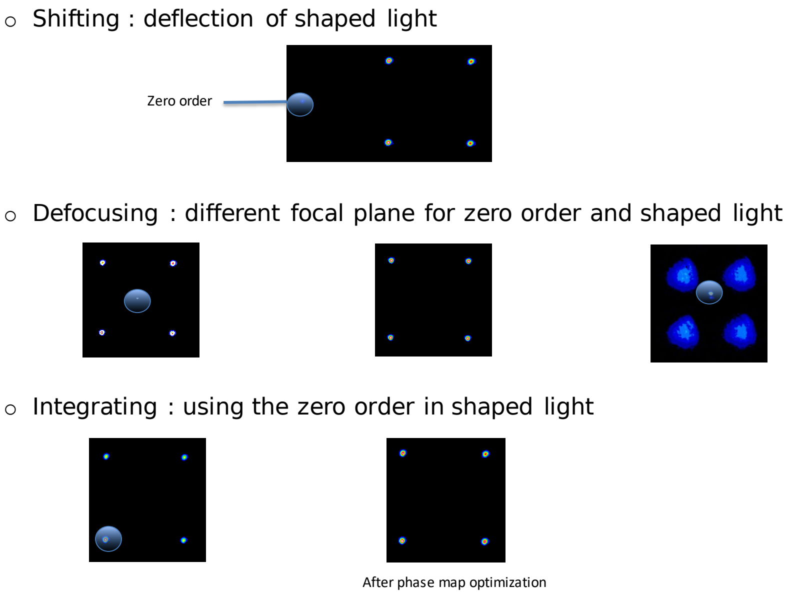

Fig. 3. Different strategies for taking into account the zero order of diffraction.

3. Parallel processing

The figure 4 illustrates the results obtained by parallel processing in the context of the implementation of SLM technology in industrial conditions (Fs laser machine, Irepa Laser, Strasbourg, France), under low power conditions (20W, 110 µJ) with a relatively large fs laser spectral bandwidth (8 nm). Under these conditions, the division of the beam up to 10 spots of 28 µm in diameter is possible excluding the chromatic effect. In addition, the phase maps are optimized to obtain a homogeneous distribution of energy both in the different spots and inside the spots. The material used is stainless steel, the configuration of equivalent spots allows a controlled laser fluence at a target of 1 J/cm^2, which represents the optimal fluence for stainless steel. The results presented in fig. 4 illustrate the implementation of a collinear parallel method, the multi-spots being aligned in the direction of the movement of the sample and separated by 56 µm. The measurements of the grooves profiles show equivalent depths for the three presented tests (1 spot, 3 spots, 6 spots), but with a reduction of the processing time in the same ratio as the number of spots, since the number of passes has been divided by the same amount (/ 3 and / 6) compared to the mono spot processing.

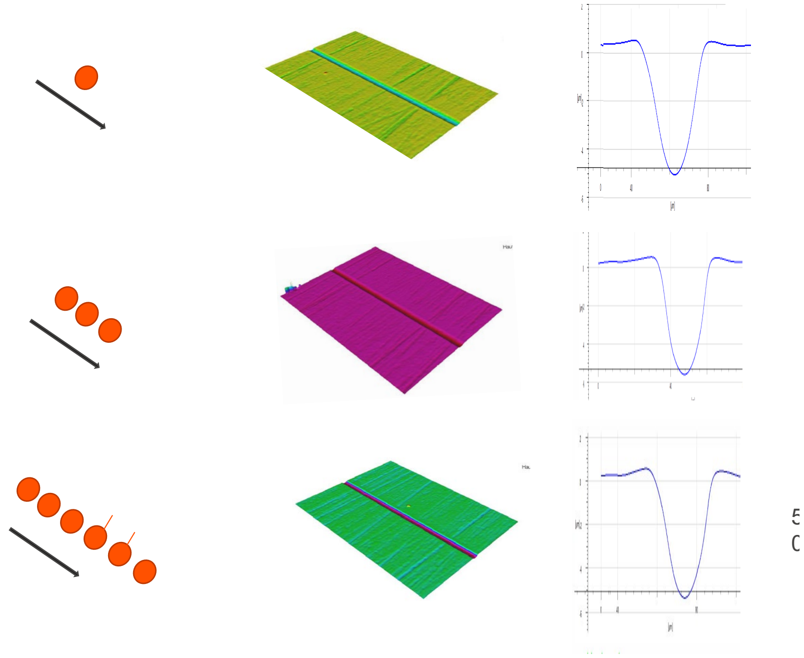

Fig. 4. Reduction of the process time by multisport parallel machining colinear to the movement of the sample. Left: multi-spot configuration used, medium: view of the grooves created, Right: depth of the grooves and processing time measurement. The material used is stainless steel, the fluence of each spot is maintained at 1 J/cm^2.

4. Conclusion: Evaluation of the implementation of SLM technology

SLM technology has shown renewed interest in recent years for processing with high power lasers. The advantage of a programmable diffractive optics is based on the potential adaptation to technical changes in industrial needs. Beam division is now one of the recognized ways to increase productivity with high power lasers and the new components are more credible in terms of reliability and power handling. Their flexibility of use makes them candidates for future "4.0" approaches to process control. On the other hand, the presented results show the necessity of a well-controlled development of integrated SLM fs solution, to take into account the specific effects of diffractive optics. In particular, the chromaticism should be considered for the use of femtosecond lasers with large spectrum. Depending on the results that will be obtained during the more widespread use of this type of component, it will be possible to identify whether SLMs can be used not only for the development of innovative processes in an R&D framework and if they are also suitable for production.

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