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Shaping focal intensity distributions with freeform optics for optimal material processing

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Abstract

The number of applications in material processing that inquirer focal intensity distributions apart from Gaussian shape is growing fast. Of special interest are hereby not only top-hat or donut distributions but also non-rotationally symmetric distributions like squares or ellipses. We present refractive, freeform beam shaping elements to achieve such focal distributions. Moreover, those elements are capable of creating patterns in the focal region with 3x3 or 4x4 spots. The size of all focal distributions is tunable with the NA of the focusing lens employed.

The simulation results are compared with measured intensity profiles to show the good agreement of the results. Furthermore, first single spot experimental results on stainless steel demonstrate the varying impact of the different intensity distribution on the material interaction. Since the beam shaping is all low-dispersion, refractive this opens up new possibilities for material processing, especially, with ultrashort laser pulses.

Keywords: beam shaping; freeform optics; material processing

1. Focal beam shaping

Especially, in the field of laser material processing certain intensity distributions, e.g. top-hat or donut profiles, in the focal plane of an optical system are demanded to achieve different machining tasks. Usually, the required spot sizes reach values in the µm range (< 500 µm). To create those intensity profiles in the focal plane an approach based on Fourier transform correlation is taken (Goodman, 2005; Dickey, 2014).

The beam shaping system consists of two components. The first element is a phase plate comprising a binary structure. This phase plate is used to achieve a collimated Bessel-sinc shaped intensity profile and was derived in a known patent system (Cordingley, 1994). The second element is a focusing optics, which can be a single lens or for example an F-θ lens. The lens basically performs a Fourier transform of the input intensity distribution and the corresponding Fourier counterpart occurs in its focal plane, which is a top-hat intensity distribution in this special case. Combining the phase plate and the focusing optics creates a beam shaping system that performs a Gauss to top-hat transformation, as shown in Fig. 1. Additionally, the size of the resulting top-hat intensity distribution can be scaled by the focal length of the focusing optics (e.g. F-θ lens).

Employing rotationally symmetric top-hat or donut distributions in the focal plane for material processing has already been demonstrated to improve micro-channel quality and speed up processes for nano-structuring like the generation of laser induced periodic surface structures (LIPPS) (Möhl, 2019).

The beam shaping setup, shown in Fig. 1, was investigated with respect of the resulting characteristic beam profiles with the help of a beam profile camera (*Ophir SP928*). Shifting the detection plane, the four depicted intensity distributions were found. What is even better, it is possible to use this type of beam shaping with a conventional scanner system without too much change in the resulting distributions at the edge of the scanning field (Möhl, 2019).

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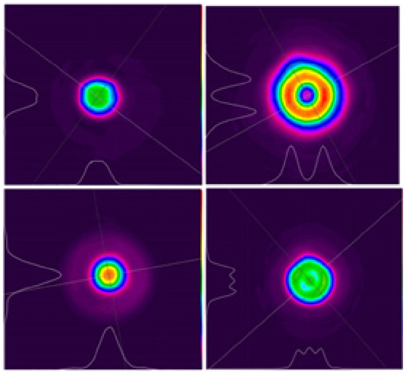

Fig. 1. (left) Principle layout of the focused beam shaping system with corresponding intensity distributions; (right) Measured intensity profiles in the focal region of a lens showing top-hat and donut distributions. The dimension of the profiles depend on the NA of the focusing lens and usually range from 20µm to 500µm.

Since scanning usually has an x-y-symmetry it is an obvious choice to seek beam shaping solutions that incorporate this symmetry. Figure 2 shows such simulated (left) and measured (right) intensity profiles. Besides generating a square top-hat (Fig. 2 upper left), which is assumed to be perfectly suited for scanning with minimal overlap, it is also possible to create much more complex profiles. The beam shaping approach follows the same principle as depicted in Fig. 1 by employing freeform optical elements as phase plates. So far, the very good agreement between simulation and measured results is promising as such elements can withstand much higher intensities as micro-optical structures.

Single spot experiment with ultrashort laser pulses (300fs) on stainless steel will show how those profiles modify the surface structure. Especially those profiles that have a reduced intensity in the middle (Fig. 2 upper right, lower left) are of special interest for further investigation for micro-marking.

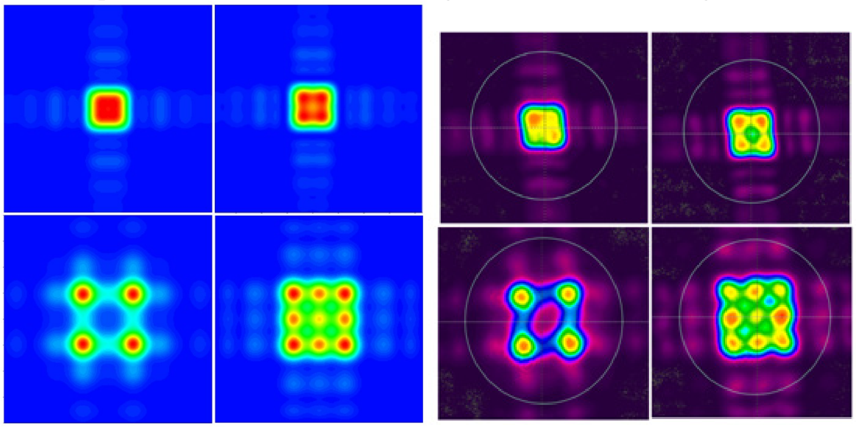

Fig. 2. (left) Simulated intensity profiles in the focal region of a lens as in Fig. 1 employing a freeform optical phase plate; (right) Corresponding measured intensity profiles. The dimension of the profiles depend on the NA of the focusing lens and usually range from 20µm to 500µm.

2. Conclusion

In this paper a new method for converting the Gaussian input beam into a squared top-hat intensity distribution is introduced. Furthermore, other complex intensity distributions are shown, which need further investigation regarding material interaction.

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