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Physics Procedia 41 (2013) 693 – 697

Physics Procedia

Lasers in Manufacturing Conference 2013

Parallel microstructuring using femtosecond laser and spatial light modulator

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Abstract

The spatial light modulator together with the computer generated holograms can be used to shape laser beam to correspond for specific need of the micromachining task. Especially dividing the original laser energy to beam array enables high degree of parallelism in laser micromachining. Spatial light modulator together with femtosecond laser enables fast machining of the complex structures with feature sizes down to a few microns.

Selection and/or peer-review under responsibility of the German Scientific Laser Society (WLT e.V.)

Keywords: Micromachining; Femtosecond laser; Spatial light modulator.

1. Introduction

The spatial light modulator (SLM) can be used for manipulating and shaping of the laser beam in various applications [1-4]. When using laser with relatively high power the original beam can be divided up to hundreds beams and still have the energy of the individual beam above the ablation threshold of the material. This division of the original beam to multiple beams enables the utilization of all laser power regardless of the machining task.

The use of the femtosecond laser enables generation of small spot sizes and ablation features. Ablation of the small features usually requires only a small amount of laser fluence to be delivered to the ablation spot.

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Selection and/or peer-review under responsibility of the German Scientific Laser Society (WLT e.V.)
doi:10.1016/j.phpro.2013.03.135

When using only a one beam for the ablation of the small features this process is bound to be time consuming. In this paper we have demonstrated the splitting the original laser beam to the several beams using SLM in order to speed up the ablation process. The degree of the parallelism that can be obtained in the limits of the power handling of the SLM was studied. Parallel ablation with feature size down to a one micron was also demonstrated.

2. Experimental

Experiments were done using Quantronics Integra-C femtosecond laser providing up to 3 mJ energy per pulse at 1 kHz frequency. Hamamatsu X10468 series LCOS-SLM (Liquid Crystal on Silicon Spatial Light Modulator) was used in the experiments. In practice, the laser energy was limited to 1.5 mJ due to the limited power handling of the SLM. The set-up used in the experiments, consisting computer controlled SLM, imaging system and translation stage, is shown in Fig. 1. The holograms for controlling the SLM were designed and calculated using Matlab and VirtualLab programs. The size of the ablated features can be scaled by changing the magnification of the imaging system. The hologram on SLM is a combination of holograms for the desired intensity distribution and Fresnel-lens in order to get rid of the zero diffraction order.

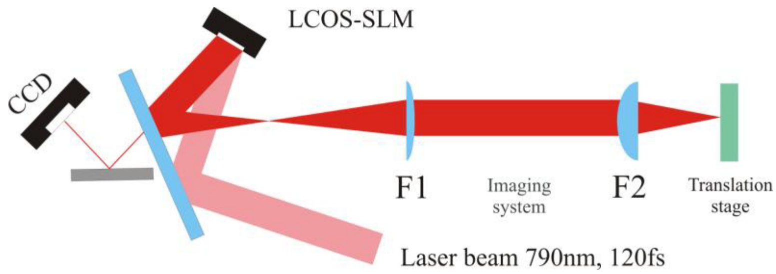

Fig. 1. Optical set-up used in the experiments.

In Fig. 2 are shown scanning electron microscope (SEM) pictures of the ablated University logo made in stainless steel. The logo is made using 3200 pixels with 16 individual holograms each corresponding 200 pixels. The holograms are designed so that the pixels next to each other are made with different hologram. If pixels positioned so close proximity to each other were ablated using same hologram they would interfere with each other. This ablation process took approx. 20 seconds to complete. The feature size, or diameter of the pixel, is 15 µm. As can be seen from the pictures the positioning of the intensity distributions generated using different holograms can be made seamlessly and overall quality of the pixels is good. The noise in the form of the additional diffraction orders and zero order are suppressed using careful hologram designing.

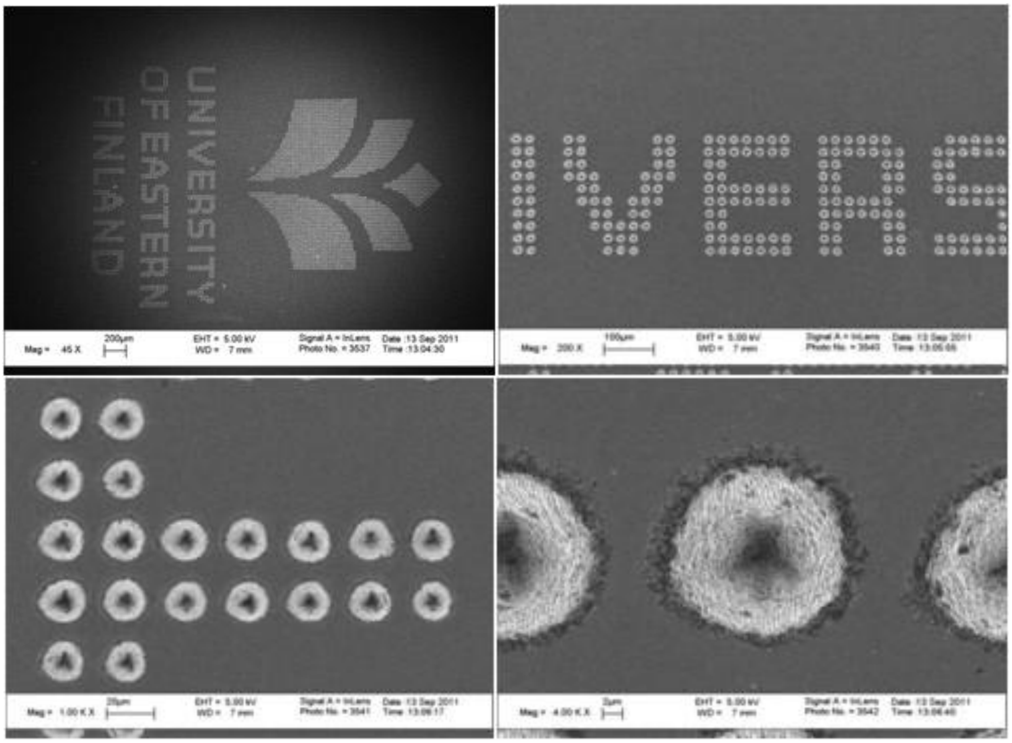

Fig. 2. SEM pictures of ablated University logo on stainless steel with different magnifications. Scale bars on the pictures are 200μm, 100 μm, 20 μm and 2 μm. Diameter of the individual pixel is 15 μm.

The size of the ablated features in our experiments can be controlled by the imaging system shown in the Fig. 1. In the Fig. 3 is demonstrated how small features can be ablated using lens F2 with focal length f = 2.5 cm. Initials of our University are made in silicon using 12 holograms and 160 pixels with each hologram. Diameter of the individual pixel is 3 μm. Using the lens F2 with f = 1 cm the feature size can be further diminished down to 1μm as shown in the Fig. 4. The processing time for the initials was three seconds. Note, that only a few percent of the laser power was used for the ablation process of the initials

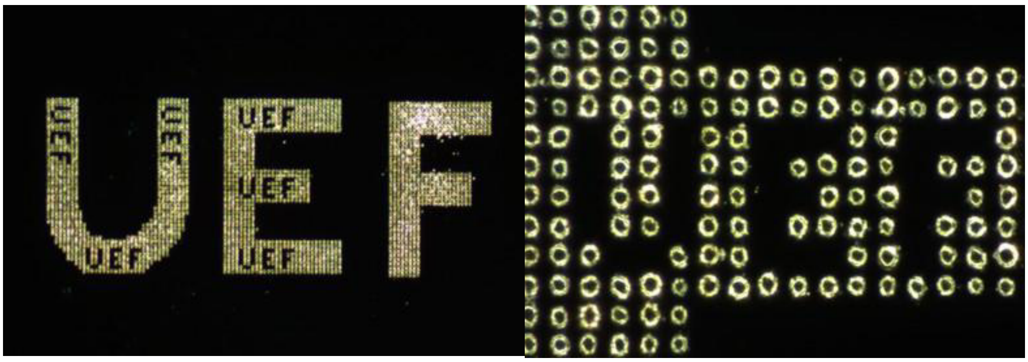

Fig. 3. Microscope pictures of ablated UEF logo in silicon. Size of the logo is 500*200 μm. Diameter of the individual pixel is 3 μm.

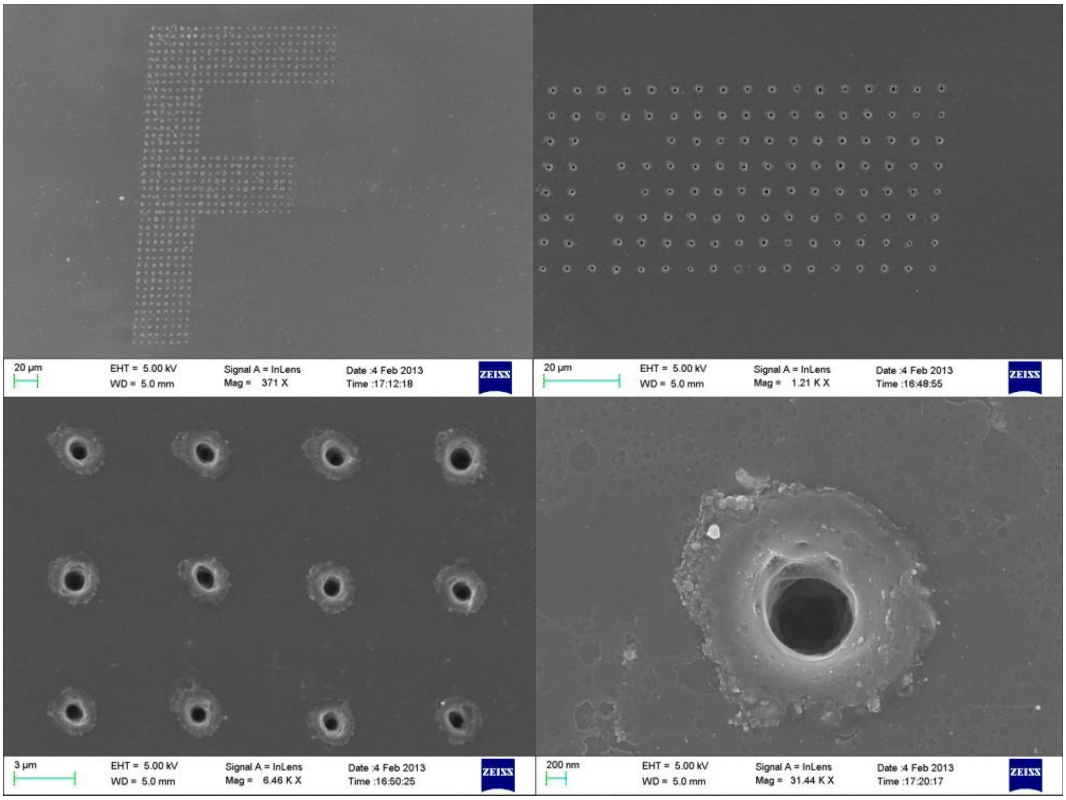

Fig. 4. SEM pictures of ablated UEF logo in silicon. Scale bars on the pictures are 20μm, 10 μm, 3 μm and 200 nm. Diameter of the individual pixel is 1 μm.

The maximum degree of parallelism that can be obtained for specific combination of the laser and SLM is related to various parameters. Laser energy defines how many individual beams can be generated so that they are above ablation threshold of the material. Also desired feature size is related to the amount of the individual beams since smaller features require less energy enabling higher degree of parallelism. The quality of the imaging system defines feature sizes and applicable processing area. When doing small features, around few micrometers, the imaging system can be more restricting to the degree of parallelism than laser energy. In Fig. 5 is shown ablated dot matrix demonstrating the amount of parallelism that can be achieved in our set-up without compromising the processing quality. Using 1 W of input power on SLM the beam can be divided to 576 individual spots that are well above the ablation threshold of silicon. The simultaneously ablated area is 700*700 μm^2 and the diameter of pixel is 8 μm. The matrix is ablated with 100 pulses resulting processing time of 100 ms.

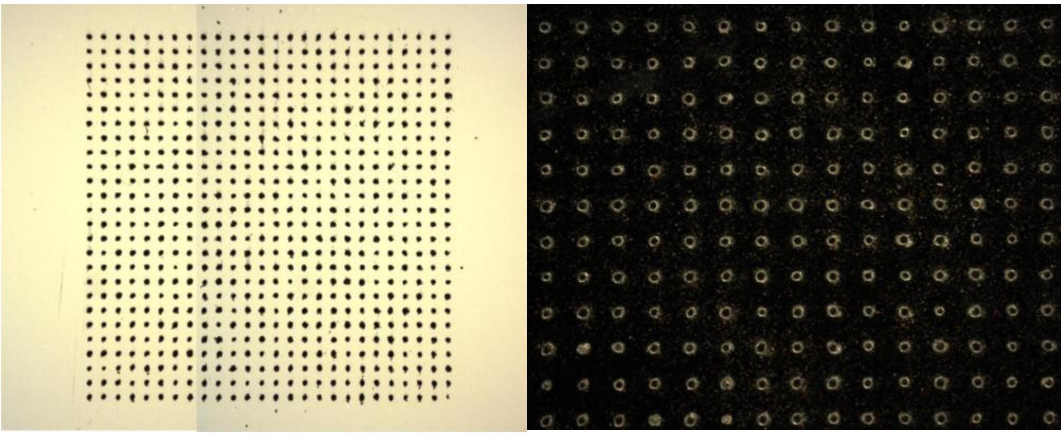

Fig. 5. Microscope pictures from a dot matrix of 576 individual spots ablated simultaneously in silicon. Size of the matrix is 700*700 μm. Diameter of the individual pixel is 8 μm. Processing time was 100 ms.

3. Conclusion

High degree of parallelism in micromachining was demonstrated using combination of femtosecond laser and spatial light modulator. Original laser beam was divided up to 576 individual beams that were used for structuring of silicon and stainless steel. Parallel machining with feature sizes down to a one micron was demonstrated.

Acknowledgements

This work was funded by the Finnish Funding Agency for Technology and Innovation (TEKES).

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