Laser Power Stabilization for Improved Ablation Depth Uniformity

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In this proceeding we report about a laser power stabilization system, which was developed for a higher output power stability of a ps-laser for enhanced precision in micromaching experiments. With the fabrication of a sinusoidal grating in copper using a direct ps laser ablation process we demonstrate the functionality of the designed and implemented system.

1 Introduction

For a precisely controlled ps-laser ablation process stable machining conditions are required. Typical OEM-lasers for this purpose have an output power stability of about 0.5% RMS. The remaining power fluctuations result in a depth variation of the fabricated microstructures. To improve the fabrication process we exploit the linear polarized output radiation of our ps-laser and stabilize the output power via polarization optics. With our stabilization system we aim for an output power stability of better than 1 per mill RMS.

2 Laser source and environmental conditions

The laser source we use, is a frequency tripled Nd:YOV$_4$ ps-laser with a wavelength of 355 nm and a linearly polarized output radiation. The average pulse duration is 15 ps and repetition-rates between 10 to 640 kHz are provided. The maximum output power at a repetition rate of 100 kHz is about 500 mW. The laser source shows a power stability of 0.5748% RMS during a long time measurement of 10 hours.

The ps-laser is integrated in a 5-axis ultraprecision micromachining center. In this machining center several tools for the micro fabrication of optical elements are integrated. In addition to mechanical machining tools, like the fly cutting or micro milling tool, the ps laser is used for the fabrication of micro optical structures as well as for finishing processes like polishing. The machine position accuracy is about 100 nm for the 3 translational axes and 1 mrad for the 2 rotational axes. The machine is located in a temperature and humidity stabilized lab with a separate basement to disconnect the machining center from the building vibrations.

3 Concept and functional principle

According to the linearly polarized output radiation of the ps laser source and the high pulse peak power the principle of the stabilization system is based on a manipulation of the polarization direction and a decoupling of fluctuating laser power portions.

In a first step the laser power is measured and averaged to obtain a mean value. After this initialization phase the measured power values are compared to the determined mean power value. In a case differentiation step the stabilization system has to react in three different ways. If the measured power is in target range everything is fine. Only in the two other cases, if the power value is higher than a minimum or maximum value the system has to counteract.

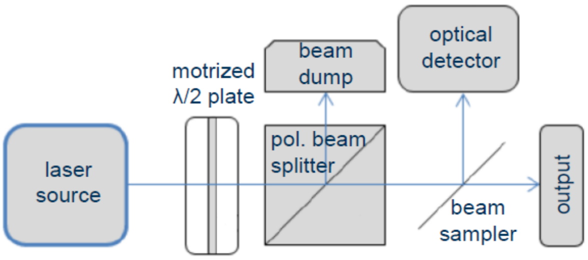

Fig. 1 *Functional principle of the stabilization system.*

In figure 1 the functional principle of the stabilization system is shown. From the left hand side the laser radiation passes a motorized rotational half wave plate. In combination with the polarizing beam splitter laser power portions can be decoupled. The laser power is measured by means of an optical detector via a beam sampler. The optical detector and the motorized half wave plate are connected to a computer with a stabilization routine implemented to control the rotation direction and the increment of the motorized half wave plate. Thus the detector can measure the fluctuating power of the laser source and control the smoothing by the stabilization system.

4 Setup and verification process

Figure 2 shows the experimentally realized stabilization system.

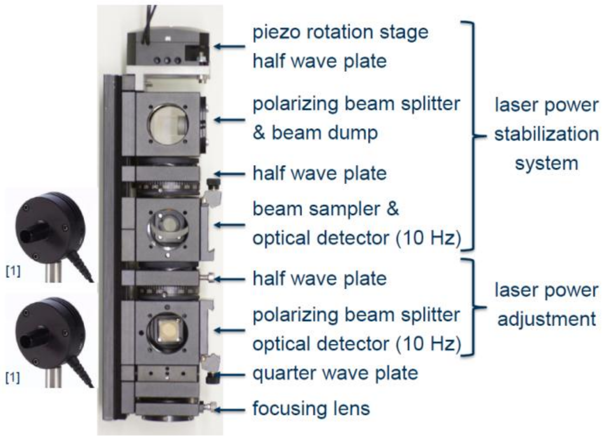

Fig. 2 *On-axis hardware setup.*

At the top a half wave plate is mounted in a piezo driven rotation stage. By an incremental rotation of the plate the system can react to laser power fluctuations. The second half wave plate adjusts the amount of power, which hits the detector behind the beam sampler. The beam sampler is a plane parallel piece of glass with an antireflection coating on the backside. Thus only the Fresnel losses are detected. These components act as the laser power stabilization system whereas the components below are used for the laser power adjustment at the workpiece.

In figure 3 two power measurements of our laser source with and without the stabilization system over an interval of 10 hours are shown.

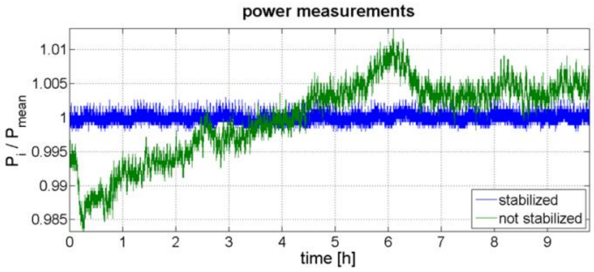

Fig. 3 *Power measurements of the ps laser source.*

The standard deviation from the not stabilized laser source of 0.5748% RMS was improved to less than 1 per mill and exactly to 0.0681% RMS.

To check the functionality of the system we fabricated two gratings in copper, one with and the other grating without the stabilization system. To hit an average target depth of 284 nm (zero order ≈ 0% @ 532 nm and 45° angle of incident) we apply a repetition rate of 100 kHz, a laser power of 20 mW and a scanning speed of 900 $^{mm}/_{min}$. With a 1/e²-focus diameter of 9 µm we get a grating period of 6.5 µm.

In figure 4 a three-dimensional profile recorded with an interferometric measurement of the stabilized fabricated grating is shown. This section from the whole surface measurement shows the sinusoidal profile with a period of 6.5 µm and an average grating depth of 287.1 nm.

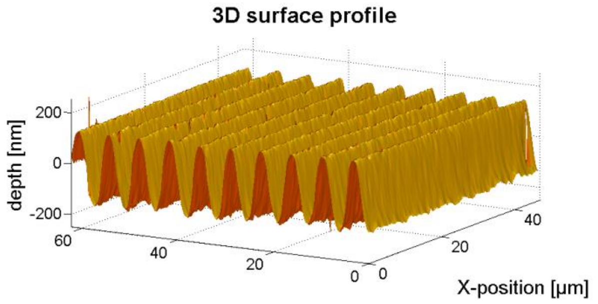

Fig. 4 *Surface profile of the grating.*

5 Results

Both gratings cover an area of 50 x 24 mm^2, which results in a fabrication time of 10 hours per grating. The surface profiles of both gratings were analyzed by a white light interferometric setup and the results are shown in Tab. 1.

grating (power)	avg. depth	R_a @ ground	STDV (depth)	STDV (power)
not stabilized	270.4 nm	5 nm	±18 nm	± 0.5748%
stabilized	287.1 nm	5 nm	±9 nm	± 0.0681%

Tab. 1 *Results of the fabrication process.*

The depth, period and roughness of each grating were measured at different positions and the results are averaged. A roughness at the ground of 5 nm was achieved in both cases. Only the grating, which was fabricated with the stabilization system, reaches nearly the target depth of 284 nm and a 50 % improvement of the standard deviation of the depth was obtained. Simultaneously to the grating fabrication process the laser power was measured which showed an enhanced stability. With these results we have proven the suitability of the developed stabilization system for enhanced ps ablation processes and many other applications.

Acknowledgements

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6 References

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