MICROSTRUCTURING IN PLATINUM AND STAINLESS STEEL MATERIAL USING PICOSECOND Nd:YAG LASER

PLATĪNA UN NERŪSĒJOŠĀ TĒRAUDA MIKROAPSTRĀDE AR PIKOSEKUNŽU Nd:YAG LĀZERI

Authors: **Imants ADIJĀNS**, **Ieva KAŽMERE**, e-mail: aston@inbox.lv, ievakazmere@inbox.lv
Scientific supervisor: **Alexander HORN,** Prof. Dr. rer. nat. habil., e-mail: horn4@hs-mittweida.de
Hochschule Mittweida
Laserinstitut
Technikumplatz 17, D-09648 Mittweida, Germany

Abstract. *The number of products manufactured in micro- and nano-size is increasing every year. In electronics, medicine, biology and other industries, because of the rapid development of technologies, is possible to produce new or already used products in very small sizes, maintaining or even improving the efficiency of the product or giving an opportunity to use them for new purposes. Currently available pico- and femtosecond lasers ensure the production of such products in very small sizes. In this study, the treatment of platinum and stainless steel using a picosecond Nd:YAG laser with a wavelength of 1064nm, was considered. The obtained results for the laser ablation process of these materials will be useful for further research in the field of laser microprocessing.*

Keywords: *Laser ablation, picosecond laser, platinum, stainless steel, threshold fluence.*

Introduction

Due to the speed of modern world development, micro-processing of materials plays a very important role. It is important to know the laser and the material characteristics and their interaction. There are several advantages for using ultra short lasers as very precisely definied energy input, insignificant heat affected zone, little debris.

In ultrashort laser ablation processes (using pico-, femtosecond laser pulses) enormous laser intensity leads to absorbtion increse by nonlinear multi-photon absorption processes. It is characterized by pressure, density and temperature extreme increase and accelerate the ionized material to enermous velocities. Using picosecond laser for ablation non-thermal ultrafast processes is dominant [1].

In microtehnologies platinum use in biological conductor path designing and as contact pads for biological sensor chips with evaporation enthalpy [2]. Stainless steel use in many various industries. Fluence is one of the laser parameters which influences kinetics and ablation quality. In stainless steel material ablation efficiency drops with increasing fluence, but ablation efficiency rises with increasing repetition rate. Repetition rate is depend on material thermal-physical properties. The effect of repetition rate depends on the scanning velocity and the material capacity to manage cope with laser beam thermal load increase [3].

The aim of this study is to evaluate and describe the ablation process for platinum and stainless steel materials using optimal power parameters of picosecond Nd:YAG laser.

1. Materials and methods

1.1. Materials

For laser microstructuring used two materials: stainless steel and platinum material. Platinum material thickness was 0,71mm and stainless-steel thickness was 2,96mm.

1.2. Methods

In the study used a picosecond Nd:YAG laser with central wavelength 1064nm, pulse width 10ps and average output power 40W. At the start of this research measured the laser

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average power. On the next part generated single-pulse ablation on a thin platinum layer where needed to determine the effective beam diameter at the processing point. Thirdly, investigated multi pulse ablation in the steel material. In the end of internship generated 3D structures on steel material. Single pulse measurements of ablation diameter per parameter used the Keyence microscope. Generated quadratic pits with different fluences and 3D microstructures evaluated with SEM (scanning electron microscope).

2. Results

2.1. Average power, pulse energy and the fluence measurement and calculation

At the beginning on the computer set the laser device pulse repetition frequency 1MHz and positioned the power meter in the beam path. Laser output power should not be measured in the beam focus. If laser output mean power was P=20W and beam radius in focus was r=14µm then laser pulse power density was 324,8W/cm^2, based on power density equation: Power density= $\frac{P}{A}$, where area A=πr^2 and P-laser mean power. Such high-power density could damage power meter.

2.2. Determination of the beam diameter with the method according to LIU

On a thin platinum layer generated single pulse ablation. For spatially seperating the pulses, pulse repetition frequency reduced to a value of 1kHz. To not overlap a single pulses when laser is in scan regime, traversing speed needed to be $v \geq f_p \cdot D$. If pulse repetition frequency f_p=1Mhz and pulse diameter D=28µm, traversing speed must be v≥28m/s. Reducing the pulse repetition frequency to value f_p=1kHz with pulse diameter D=28µm traversing speed was v≥28mm/s, which results that scan speed was 10^{3}x slower compared to f_p=1MHz. Generated 10 individual pulses with different PoD setting from 8-68% in platinum layer, measured ablation diameter in 3 places for each crater and used the LIU method to determine beam radius and ablation threshold of platinum (see Table 1).

Table 1.

Experimentally investigated and calculated square of average ablation diameter and fluence

No.	Pulse energy [µJ]	Mean power [W]	PoD setting [%]	Ablation diameter 1 [µm]	Ablation diameter 2 [µm]	Ablation diameter 3 [µm]	Average ablation diameter [µm]	Square of average ablation diameter [µm^2]	Fluence [J/cm^2]
1.	2	1,97	8	0,00	0,00	0,00	0,00	0,00	0,65
2.	4	3,96	15	15,36	15,17	14,92	15,15	229,52	1,30
3.	6	6,03	22	20,25	20,43	20,62	20,43	417,52	1,94
4.	8	8,07	29	23,18	23,25	23,85	23,43	548,81	2,59
5.	10	10,07	36	25,39	25,19	25,36	25,31	640,76	3,24
6.	12	12,19	43	26,47	26,23	26,8	26,50	702,25	3,89
7.	14	14,08	49	27,48	27,38	27,52	27,46	754,05	4,54
8.	16	16,35	56	27,83	28,44	28,59	28,29	800,14	5,19
9.	18	18,28	62	28,94	28,85	28,76	28,85	832,32	5,83
10.	20	20,11	68	29,25	29,36	29,78	29,46	868,09	6,48

Single-shot ablation threshold can be determined by measuring the crater diameter as a function of pulse fluence (H). Linear extrapolation of a plot of the squared crater diameter D^2 versus ln(H) yields the ablation threshold fluence H_{th} at D^2=0. The beam radius (r) is obtained as slope of the regression line. Using the formula $m=2 \cdot w_{o,86}^2$, where m=392,85, results with beam radius was $w_{o,86}$=14,015.

The fluence is defined as the time-integrated flux of some radiation. The fluence F of a laser pulse is the optical energy delivered per unit area. Its most common units are J/cm^2. Damage threshold of a material is often specified as a fluence. Ablation threshold fluence for a laser beam with spatial Gaussian distribution calculated based on formula: $H_{th}=\sqrt{\pi} I_0 \tau_{1/e}=\frac{E_P}{\pi w_0^2}$, where I_0-peak laser intensity, $\tau_{1/e}$ - half-width at the level 1/e of the peak laser intensity, E_p – peak pulse energy and w_0 - beam radius at the level 1/e of peak laser intensity. Using logarithmical function y = 392,85ln(x) - 287,89 from Figure 1 and assuming that y=0, ablation threshold x=2,081 was obtained.

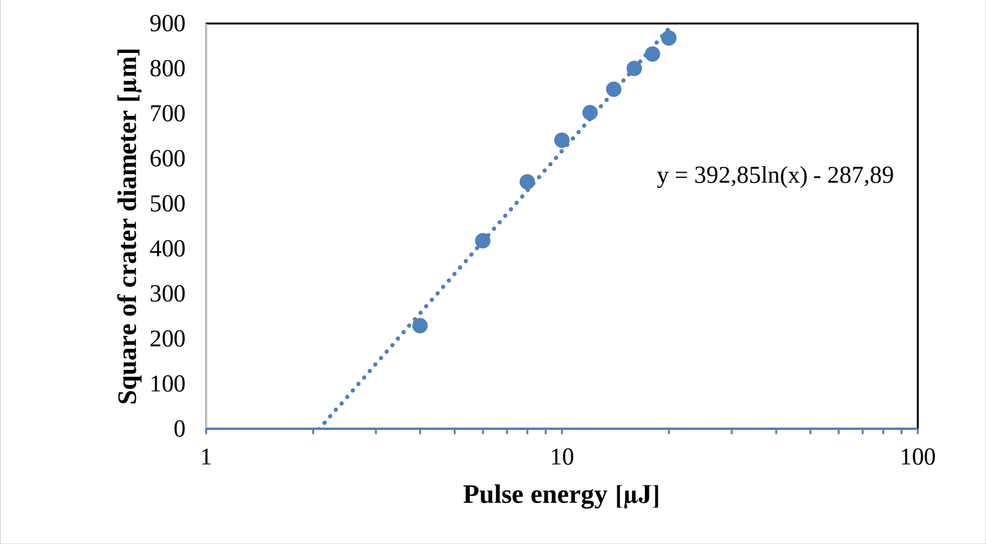

Fig. 1. **LIU plot**

2.3. Generation of quadratic pits with different fluences in steel

In the next internship part generated 8 quadratic pits with pulse energy 2-16μJ to investigate multi-pulse ablation. Processing lines was at a constant distance (6μm) with pulse repetition frequency 200kHz, with lateral pulse distance at a travel speed of 1.2m/s and with 20 passes. To calculate the lateral pulse distance (l) at a travel speed(v) of 1,2 m/s and with pulse repetition frequency(f_p) 200kHz, the formula $l=\frac{v}{f_p}$ was used. Calculated distance between pulses was 6μm.

Based on the structure dimensions, where edge length a=1mm, and d is ablation depth, can derive the formula for total removed value $V=a^2 \cdot d$. Expressing formula for total number of pulses (M): $M=\left(\frac{a}{pd}\right)\cdot\left(\frac{a}{pd}\right)\cdot N$, where N was number of 20 laser pulse passes and pulse distance(pd) was 6 μm. From these equations can calculate ablation volume per pulse energy: $V_{Pulse}=\frac{V}{M}=\frac{pd^2 \cdot d}{N}$ (see Table 2).

Regard to the efficiency of the ablation process can notice that at lower pulse energy efficiency of ablation process was higher. From Figure 2 can notice that increasing pulse fluence increased volume removed per pulse. By increasing fluence, roughness of the generated surfaces increases. Surface modification and feature size increased with higher fluences.

At the edges of the structure laser beam scanning speed decreased because of acceleration and deceleration. These changes of scanning speed led to shorter distances between pulses and as a result higher deepness at the edges of the structures.

Table 2.

Volume removed per pulse and efficiency

No.	Pulse energy [µJ]	Ablation depth [µm]	Average roughness [µm]	Volume removed per pulse [µm^3]	Efficiency [µm^3/µJ]
1.	2	2,20	0,31	3,97	1,98
2.	4	3,95	0,69	7,12	1,78
3.	6	4,92	1,15	8,85	1,48
4.	8	5,86	1,76	10,55	1,32
5.	10	6,71	2,29	12,07	1,21
6.	12	7,45	2,65	13,42	1,12
7.	14	7,85	3,13	14,13	1,01
8.	16	8,96	3,71	16,13	1,01

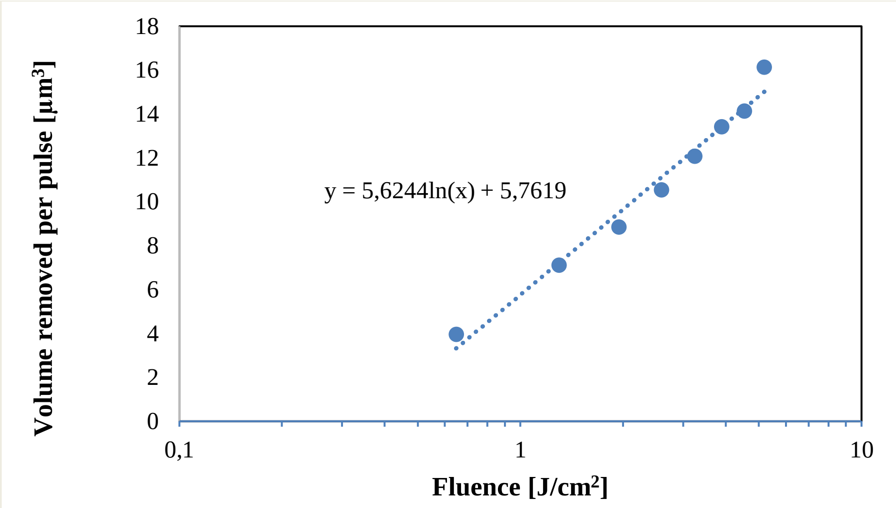

Fig. 2. **The volume of material removed per pulse of different fluences**

2.4. Generation of 3D microstructures using a post-processor

In last part generated different 3D microstructures with number of 500 crossings, 100 crossings and burst pulses with crossing count 100. Comparing SEM images of the structures can be observed differences in their roughness. The best quality showed structures created by burst-mode. They had the smoothest surface and well-structured shape (see Figure 3).

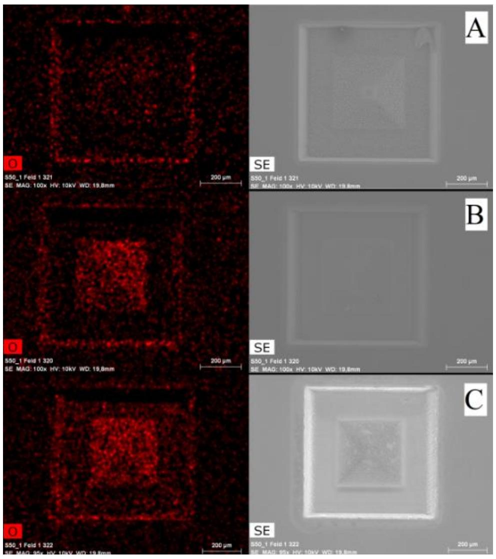

Fig. 3. **(A) Microstructure pyramid with 100 scans; (B) Microstructure pyramid with 500 scans; (C) Microstructure pyramid with burst-mode**

Structures created using 1.2 µm distances between pulses and number of crossings 100 had the worst quality. These structures were very rough compared to other. Quality of structures with 6 µm pulse spacing and 500 crossings was worse compared to constructions created using burst-mode, but better than constructions created using 1.2 µm spacing between impulses. Where ablation quality was better, the oxigen quantity in the material was higher (lowest oxigen quantity was with 100 crossing number, but highest-using the burst pulses). Analyzing stainless steel sample, it basically consisted of Fe(87,87%) and C(6,38%), also from Cr(3,36%), S(1,03%), O(0,82%) and Si(0,54%) (see Figure 4).

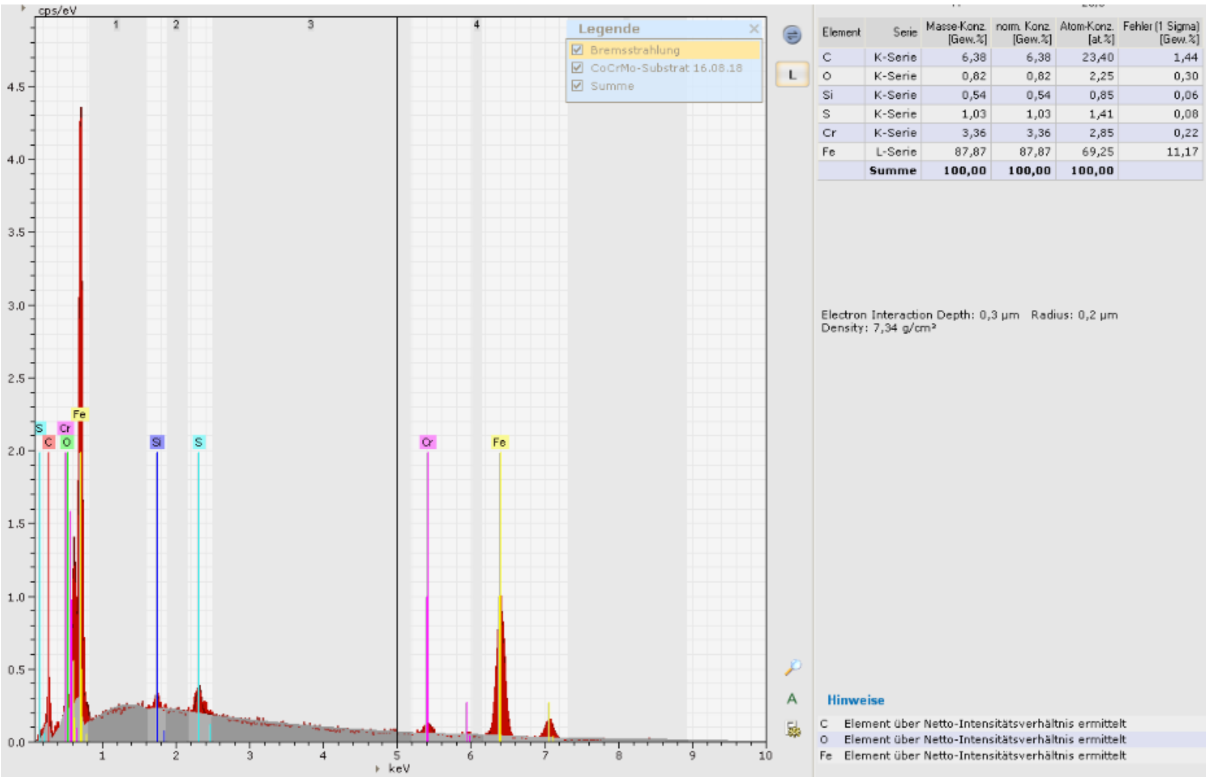

Fig. 4. **Stainless steel chemical composition**

This stainless steel composition influence ablation roughness based on SEM images, where can see that using laser pulses with pulse energy >8µJ ablation on stainless steel layer was with non-homogeneous roughness, at different locations making smoother laser processed dots.

3. Conclusions

1. Using method presented by LIU the beam radius (r) was calculated r=14,015µm and obtained ablation threshold x=2,081.
2. Efficiency of the ablation process was higher at lower pulse energy.
3. Increasing of pulse fluence incresed volume removed per pulse and roughness of generated surfaces. Surface modification and feature size increased with higher fluences.
4. Higher deepness can be observed at the edges of the structures.
5. Structures created by burst-mode had the smoothest surface and well-structured shape. Burst-mode showed high influence to the surface roughness quality.

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