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Precision Micromachining of Metals by CuBr Laser

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***Abstract*—The ability to laser machine materials with high resolution and high throughput is critical in advanced manufacturing for a vast array of applications, from photovoltaic cells to bio-compatible micro-components. Copper bromide (CuBr) lasers with their excellent beam quality promised noticeable advantages and improvements in high precision and material processing at the microscale. The application of the CuBr laser as a precision tool for micromachining of different metals has been demonstrated. That good performance was a result of the combination of high power visible radiation, short pulses, and close to the diffraction-limited laser beam divergence with high-speed galvo scanner beam steering.**

***Keywords*— CuBr vapour laser, laser micromachining, precision micromachining**

Introduction

The world of laser machining production is divided into micro- and macro-machining. This classification is not based on the size of the work piece but rather the fineness of the impact caused by the laser tool. The lasers system used for micromachining employ normally pulsed beams with an average power of well below several watts while those used for macro machining use generally continuous-wave (CW) laser beams ranging up to several kW.

The excellence attributes of laser radiation combined with a high degree of flexibility, contact-less and wear-less machining, the possibility of high automation as well as easy integration allows using this tool in a wide field of macro machining processes for many materials including silicon, ceramics, metal and polymer.

Lasers for micromachining offer a wide range of wavelengths, pulse duration (from femtosecond to microsecond) and repetition rates (from single pulse to Megahertz). These attributes allow micromachining with high resolution in depth and lateral dimensions.

The field of micro-machining includes manufacturing methods like drilling, cutting, welding as well as ablation and material surface texturing, whereby it is possible to achieve very fine surface structures ranging in the micrometer domain. Such processes require a rapid heating, melting and evaporation of the material. The use of extremely short nano- and pico- and even femtosecond pulse durations helps to minimize the thermal effects such as melting and burr formation thus eliminating the need for any post processing measures [1].

Based on today’s approved scan head technologies and software, even processing of three dimensional surfaces is possible. Advantages are simple programmability and the resulting flexibility. In consequence, this process can be easily controlled, permitting a high flexibility.

Compared with traditional mechanical drilling, pulsed laser drilling is characterized by exceptional efficiency, cost-effectiveness, high precision and non-contact processing without tool wear and is particularly suitable for the difficult-to-machine brittle, hard, and flexible materials. With these advantages, it is extensively employed in many industries, including aerospace, automotive, electronics, medical, instrumentation, etc. [2–4]. Pulsed laser drilling is quite a complex process, since materials undergo a series of physical and chemical processes such as heat conduction, melting, boiling, vaporization, and ejection in both liquid and vapour phases, plasma, and even phase explosion [5]. As a thermal ablation process, pulsed laser drilling is inherently associated with thermal defects and poor geometry like recast layer, heat-affected zone, spatter deposition, taper, and circularity, though it can improve the quality of drilling holes by optimizing process parameters such as peak power, pulse duration, pulse frequency, pulse width, repetition rate, focal plane position, and assist gas pressure [6].

High power laser are a widely used in industrial manufacturing applications such as drilling, cutting, welding and surface processing where typically CO_2 and Nd-YAG systems operating in the infrared are used. However, the laser material interactions in many machining cases are more effectively when using lasers operating at shorter wavelengths. For example, micro-machining of many metals is best performed using visible wavelengths. The Cooper Vapour Lasers’ has a good place in this area due to visible wavelength, high pulse repetition rate, high peak and average power, good beam quality, short pulse length [7]. When applied to materials processing, the visible wavelength is found to couple well to most materials, the short pulse length causes ablative material removal, and

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the high repetition rate increases the material removal rate [8]. Another advantage of the copper vapour laser is near diffraction-limited operation allowing good focusing and precise spatial control.

In this paper are presented results in the precise micromachining of several metals using laser system based on CuBr master oscillator and power amplifier connected with computer controlled high- speed scanner system. The goal was to find the best conditions for drilling holes of good circular shape, of minimum heat-affected zone (HAZ).

I. MATERIALS AND METHODS

A. Experimental setup

The used laser system is a MOPA (Master Oscillator - Power Amplifier) CuBr laser that generate wavelength 511nm with maximum output power 6W, pulse repetition rate 20kHz, pulse duration 30ns. The master oscillator was formed by a discharge tube placed in an unstable confocal negative-branch resonator with magnification M = 40 and perpendicular optical output through a plane mirror 45-degree tilted, with a small hole (0.5mm) at the center (Fig. 1). The power amplifier was a single pass with the same diameter of the active medium as the oscillator 20mm. The MTS (master timing system) is a computer-controlled tool for synchronizing the laser oscillator and power amplifier [9]. The MTS provides the MOPA power supplies with triggering signals of controlled delay time. Depending on the delay the second laser acts as an amplifier or as an absorber (shutter). The laser beam was focused (spot diameter of about 30µm) by a glass lens (focal length f= 300mm) and directed perpendicularly to the surface of a metal target. The calculated laser fluence at focal spot is 42 J/cm^2.

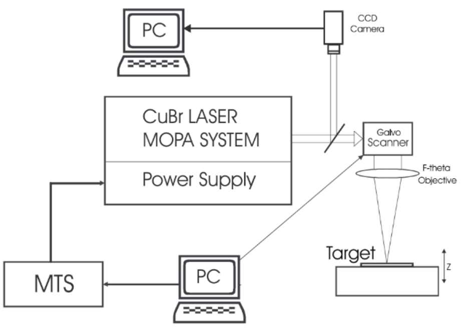

Fig. 1. Schematic of the experimental complex for laser micromachining.

We used Spiricon LBA-300 beam analyser for measuring the profile of the focal spot after focusing with 1m achromatic lens. The obtained intensity distribution was approximated with Gaussian profile. Assuming that, the laser beam diameter is defined at level of 14% of the peak intensity and the dimension of the beam in microns give the divergence in micro radians (Fig. 2). In our case the divergence was approximately 120µrad. In the experiments we used only 14mm of the central part of the laser beam (with diaphragm). It is depends of the input aperture of the scanner. So we lost power but save the divergence and quality of the beam.

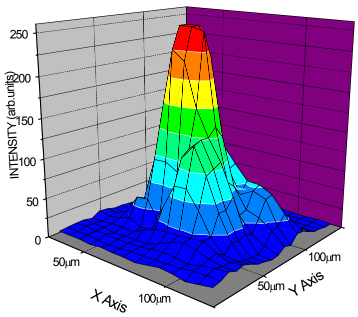

Fig. 2. Spatial distribution of power density at focal point of the laser beam after 1m focusing lens.

Common measure of the beam quality of a laser beam is quality factor M^2 defined by equation (1).

$$M^2 = \frac{\pi \theta D}{4\lambda} \qquad (1),$$

where D is the diameter of the beam, θ – divergence and λ – wavelength. For quality laser material processing is very important to have beam quality factor close to Gaussian beam. In our case it is 2.6 for wavelength 511nm.

B. METHODS

The laser drilling can be done by two ways: by trepanning and by percussion drilling. In the percussion process the laser beam is normally kept still and the hole is punched through the material using multiple pulses. The size and shape of the holes are governed by the size and shape of the focused laser beam (the dimension of the holes is usually the same as the diameter of the beam spot in the focus). The trepanning technique requires a relative beam-target movement during the processing (drill hole cutting, see Fig. 3). In case of trepanning laser drilling the size and shape of holes can be programmed too. In this case, the rotations of the beam spot (or the target) allow making the process as well as the size and shape of holes programmable.

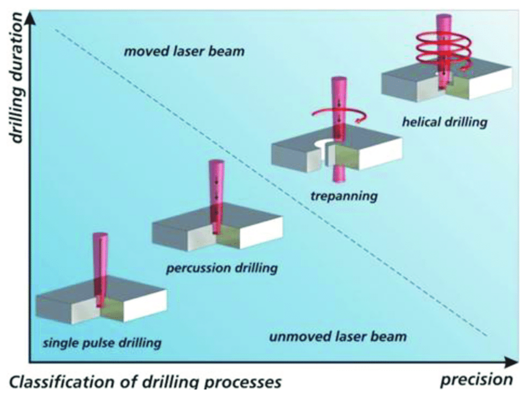

Fig. 3. Classification of drilling processes

Laser percussion and laser trepanning can produce through-holes. The choice comes from the size of hole needed. Laser percussion makes holes of diameter normally less than 50µm. The laser trepanning holes are larger. Laser trepanning is a method by which the laser beam cuts in a circular pattern, taking advantage of high-speed beam positional scanner. There is a limit to the depth of material that can be cut in a single pass, so a number of passes has to be made. The number of the repetitions is defined as a number of passes around the contour of the hole.

In the most of cases the industry is usually interested in through-holes with a diameter in the range of 50μm up to 1000μm. So we chose the laser trepanning for the realization of precise and reproducible through holes. Another reason for choosing this method is because it allows a fast modification of the processing parameters: scanning speed of the laser focal spot and the number of repetitions. Changing the scanning speed we can control overlapping of the adjacent pulses (see Fig. 4).

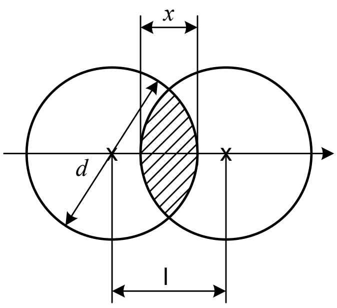

Fig. 4. A schema of the overlapping two consecutive pulses.

Table I shows the scanning speeds employed in order to attain the different overlapping percentages and necessary repetitions to make hole in the foil.

TABLE I. Scanning speeds/overlapping coefficients and number of repetitions needed to drill 100μm hole

Scanning speed, mm/s	**Overlap-ping coefficient, %**	**Number of repetitions for drilling of 100μm hole in foil thickness of** Al, 100μm	Cu, 150μm	SS316, 150μm
20	97	3	2	6
50	92	6	3	20
100	83	12	5	39
200	67	27	11	88
400	33	55	24	190
600	0	95	70	320
800	-33	200	150	660

Overlapping coefficient of the laser pulses overlapping is a complex factor that gives relation between scanning speed (factor related to the technological process) and pulse repetition rate and laser fluence of laser beam by diameter of focal spot (parameters of the laser). It is defined by the expression

$$k = \frac{x}{d}.100\% = \left(1 - \frac{l}{d}\right).100\% \qquad (2),$$

where d is the diameter of focal spot, x is the width of the overlapped area of two consecutive pulses, l - the distance between two consecutive pulses. Taking into account ratio

$$l = \frac{V}{\nu} \qquad (3),$$

where V is the scanning speed and ν – pulse repetition rate and making substitution in equation (2) is obtained:

$$k = (1 - \frac{V}{\nu.d}).100\% \qquad (4).$$

Negative or zero overlapping coefficients means no overlapping of pulses.

II. Results and discussion

The targets in our experiments were copper, aluminium and stainless steel (SS316) metal foils.

Fig.5 and Fig. 6 presents pictures of drilling of micro holes in Al and Cu using trepanning technique.

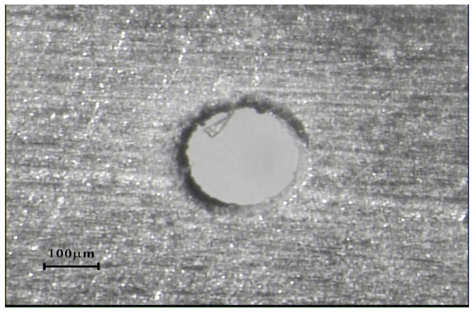

Fig. 5. Al foil, thickness 100μm, scanning speed -20mm/s and number of repetitions – 3.

In this case the edge is clear and sharp and there is no evident thermal distortion. We drilled successful holes also with lower speeds with less repetitions but in this case the HAZ was significant and a small zone of melting materials around the holes was observed. The same unsatisfying results we had for scanner speed more than 600mm/s, i.e. without overlapping of laser pulses. For the drilling the same hole in this case we needed to make a lot of repetitions.

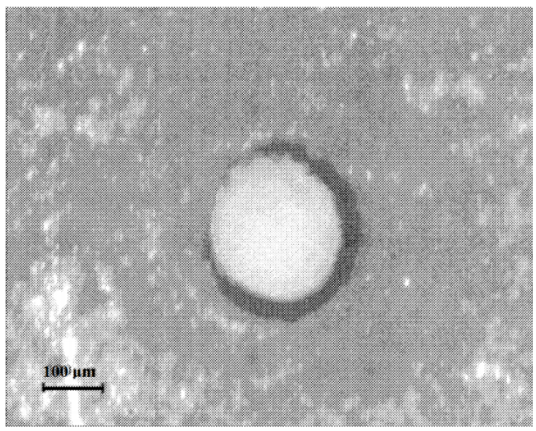

Fig. 6. Cu foil, thickness 150μm, scanning speed - 20mm/s, number of repetitions – 2.

For detailed examination of the holes we used SEM (scanning electronic microscope). Typical holes in aluminium and copper with diameters of 100μm are presented in Fig. 7 and Fig. 8.

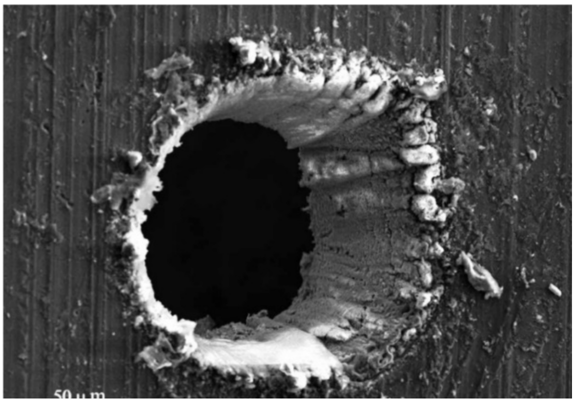

Fig. 7. SEM of the surface of Aluminium foil, thickness 100µm, scanning speed - 20mm/s, number of repetitions – 3.

We found that the trepanning reduces significantly the visible heat-affected zone when the motion velocity of the laser beam spot is more than 50mm/s. By overlapping, the leading edge of the second pulse meets surface temperature higher than the first pulse. So, we have an accumulation temperature effect that conduces to the sample surface high temperature [10].

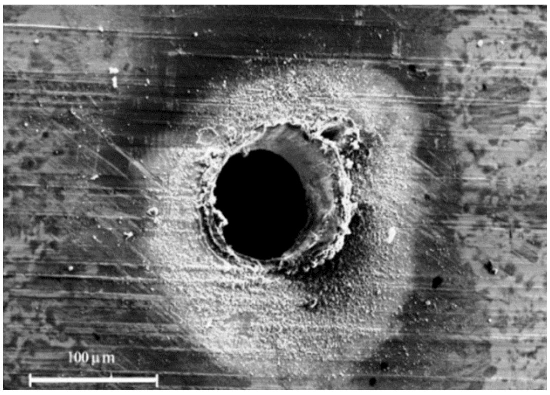

Fig. 8. SEM of the surface of Cupper foil, thickness 150µm, scanning speed - 20mm/s, number of repetitions – 2.

On the other side, the target temperature increase is important because the reflectivity of the metals normally decreases as the surface temperature goes up, and the overall efficiency of the laser processing increases too [11]. This case is presented in the Fig. 7, where the drilling of Al foil is with good efficiency and negligible HAZ. Without overlapping, when the velocity is too high (in our case, more than 800 mm/s), the HAZ is negligible but the efficiency of the drilling decreases sharply (we had to increase greatly the number of repetition cycles) –Table 1.

A series of sieve holes were made in Stainless steel foil. The desire configuration was achieved as 3x3 matrix with distance between the centres of two adjacent holes 200µm. Again was used trepanning technique to drill holes one by one i.e. laser focus sport does not start second hole before finish of first one. Non-spherical shape of holes is due to a technical problem in one axes of xy-galvanometric scanner head (Fig. 9 and Fig. 10).

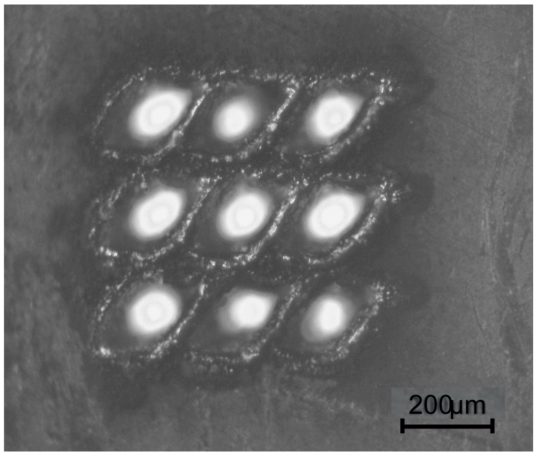

Fig. 9. Sieve on Stainless steel, thickness 150µm, scanning speed 150mm/s, number of repetitions - 65

It has been experimentally found the optimal parameters of trepanning drilling of holes in sieve on stainless steel. The best quality we achieved at scanning speed 50mm/s of laser beam, number of repetitions 20 and pulse repetition rate 20kHz (Fig. 10).

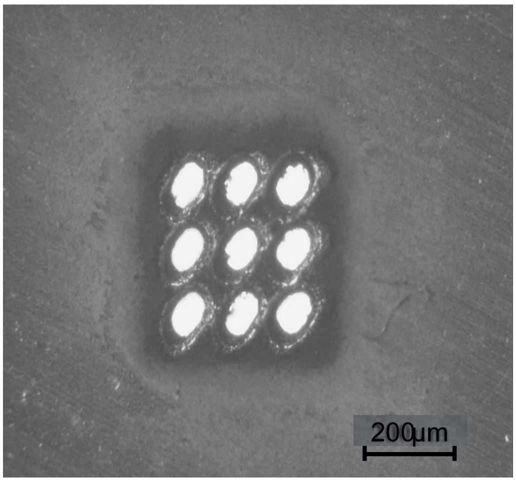

Fig. 10. Sieve on Stainless steel, thickness 150µm, scanning speed 50mm/s, number of repetitions - 20

III. Conclusions

MOPA copper bromide vapour laser system, made in Bulgaria, combined with computer controlled xy - galvanometric scanner was used to investigate process of laser drilling of micro holes using trepanning of aluminium, copper and stainless steel metal foils. Although the quantity of removed material per pulse is small for these processes, the high repetition rate of CuBr laser allows material processing at high speeds.

The experimental results show that our system is a good tool for high - speed laser drilling and cutting. The trepanning method for drilling or cutting with kilohertz repetition rates laser pulses allows better control of high-speed machining with good quality.

References

[1] W. Steen and J. Mazumder, “Laser Material Processing,” Springer-Verlag London, 2010, pp. 131–198.

[2] S. Mishra, V. Yadava, “Laser beam micromachining (LBMM) – a review,” Opt. Lasers Eng., vol. 73, pp. 89–122, 2015.

[3] D. Ganguly, B. Acherjee, A. Kuar, S. Mitra, “Hole characteristics optimization in Nd:YAG laser micro-drilling of zirconium oxide by grey relation analysis,” Int. J. Adv. Manuf. Technol., vol. 61, pp. 1255–1262, 2012.

[4] R. Biswas, A. Kuar, S. Sarkar, S. Mitra, “A parametric study of pulsed Nd:YAG laser micro-drilling of gamma-titanium aluminide,” Opt. Laser Technol., vol. 42(1), pp. 23–31, 2010.

[5] Y. M. Zhang, Z. H. Shen, X.W. Li “Modeling and simulation on long pulse laser drilling processing,” Int. J. Heat Mass Transf., vol. 73, pp. 429– 437, 2014.

[6] M. Ghoreishi, “Statistical analysis of repeatability in laser percussion drilling.” Int. J. Adv. Manuf. Technol.”, vol. 29, pp. 70–78, 2006.

[7] N. V. Sabotinov, “Pulsed Metal Vapour Lasers,” NATO ASI Series 1ed, vol. 5, C. E. Little and N. V. Sabotinov Eds., Springer Netherlands, Kluwer Academic Press, 1996, pp. 113–124.

[8] J. S. Lash and R. M. Gilgenbach, “Copper vapour laser drilling of copper, iron and titanium foils in atmospheric pressure air and argon,” Rev. Sci. Instrum. 64, 1993, pp. 3308–3313.

[9] H. W. Bergmann, C. Korner, M. Hartmann and R. Mayerhofer, “Pulsed Metal Vapour Lasers,” NATO ASI Series 1/5, Kluwer Academic Press, 1996, pp. 317–330.

[10] H. Lei, L. Lijun, “A study of laser cutting engineering ceramics”, Optics & Laser Technology, vol. 31, pp. 531–538, 1999.

[11] G. Andra, E. Glauche, “Real time investigation of the interaction of a CuBr laser beam with solid surfaces” Appl. Surf. Sci. 109/110 133–136, 1997.