Investigation of the influence of the scanning speed and step in laser marking and engraving of aluminum

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Abstract. Marking and engraving of aluminum was carried out by a CuBr (copper bromide) laser operating at the wavelength of 511 nm with a pulse duration of 30 ns. The reflection was investigated of the laser-ablated aluminum surface depending on the laser beam scanning speed and the distance between the laser lines. The changes of the aluminum surface were observed before and after laser processing by an optical microscope and visually. The laser marking quality was estimated by measuring the reflection of the irradiated aluminum surface by an optical spectrometer. The dependence was analyzed of the contrast on the speed for different steps in laser marking of areas of the surface of aluminum samples. Marking by a CuBr laser shows a potential for good quality marking of barcodes and QR codes on aluminum products.

1. Introduction
The laser marking of different materials to rapidly create indelible marks is probably the most widespread of all laser materials processing applications. It is also one of the most well established laser processes and has been employed extensively in industry. It can offer significant benefits over conventional marking techniques, such as stamping and printing, which in many instances can outweigh the greater capital cost of a laser marking system. The benefits of laser marking include excellent contrast, indelibility, cosmetically attractive marks, very high speed, software control, no tooling and versatility. Industrial lasers of all types are used for marking, and virtually all varieties of material can be marked: metals, plastics, natural materials (e.g. wood, paper and even foodstuffs), ceramics and semiconductors [1].

From a practical point of view, it is very important to understand the changes in the surface of the metals in the process of laser marking, scribing and texturing. Laser marking and texturing can be used to enhance system operation indices. Laser scribing and marking on metals has been shown to be economically viable for some engineering applications as well as for part identification in industry. Laser marking systems are currently employed in the electronics, cosmetics, food and beverages, and in many other industries. The engraving of products with alphanumeric or bar codes, logos, symbols and graphics are also useful applications of the lasers. Laser marking compares favorably with other marking systems, when the comparison is based on throughput, performance and flexibility [2].
The process of laser marking is connected with a surface change of the metal target – partial evaporation of the material, and partial melting followed by solidification after laser treatment. From this point of view, it is very important to know the effect of laser irradiation on the chemical state of the surface [3, 4].

We have to note that the process of laser marking is part of the laser ablation technique. The interest in ablation is reasonable because of its application to the synthesis of novel materials or thin films and to the surface patterning of various materials.

In this work, a CuBr laser is used, a member of the family of copper vapor lasers (CVLs). Short-pulse lasers, such as CVLs, have shown a potential in achieving precision machining due to their high pulse power, high repetition rate and good focusing ability. Bergmann et al., considered the scientific and industrial aspects of drilling and cutting with CVLs and compared them with earlier results obtained by using other lasers. The CVL source is one of the best candidates for marking many materials [5].

One of the basic criteria for determining laser marking quality is the contrast. There are several technical parameters that are important for the contrast. They can be separated in three groups in the following way:

- Parameters related to the laser source – surface density of the laser radiation power, pulse energy, pulse repetition rate, duration of pulses;
- Parameters related to material properties – optical and thermo-physical characteristics;
- Parameters related to the technological process of marking – scanning speed, size of step, number of repetitions, defocus.

In the laser marking process, these parameters are in a complex relationship. Their influence has been studied in publications of a number of authors, including the authors of this paper.

In [6], the influence was studied of the speed and frequency on the contrast in laser marking of metal products for mechanical engineering. The results refer to a fiber laser marking system.

In [7], Lazov and Petrov studied the influence of the number of repetitions and defocusing on the contrast in the process of laser marking of tool steel products. Operating intervals were defined for these technological parameters.

It should be noted that engraving of metals with other laser sources, such as CO2, fiber, Nd:YAG, is also widely used in industry [8]. In [9], the authors investigate the influence of the frequency on the depth, width and contrast of the marking. The experiments were performed by a Nd:YAG laser on stainless steel samples.

One of the latest achievements in the engraving technique is the so-called deep color laser engraving. This technique, in addition to laser treatment involves treatment by coloring chemicals. Oxidation of the aluminum surface after laser engraving leads to black etching of the aluminum surface, which is also a new technique of engraving.

There are also a few publications on the influence of the marking speed and step on the laser marking process [10, 11, 12].

The applicability of the CuBr vapor laser for marking and engraving aluminum products have not been thoroughly studied and analyzed. All above considerations justify the need and purpose of conducting research on laser marking of aluminum samples by this type of lasers. This research is focused on the speed v and the step Δx of marking, which is important when writing QR and barcodes on aluminum products for the mechanical engineering needs.

2. Experimental
The experimental setup used for marking surface of an Al (aluminum) plate is shown in figure 1. The laser system is a MOPA (master oscillator-power amplifier) copper bromide laser oscillating at 511 nm with a fixed output power of 6 W, a beam divergence of 100 μrad, a pulse repetition rate up to 20 kHz and a 30-ns pulse duration [13]. The laser scanning of the aluminum surface is realized with the help of two galvanometer mirrors. The laser beam was focused (spot diameter of about 30 μm) by a glass lens (focal length f = 30 cm) and directed perpendicularly to the surface of an Al workpiece.
The laser beam motion in parallel lines with a pitch of 15 μm, 30 μm, 45 μm and 60 μm was achieved by an Arges scanner head. The treatment was conducted at a fluence of 35 J/cm² and the following scanning beam speeds: 6 mm/s, 12.5 m/s, 25 mm/s, 50 mm/s, 100 mm/s, 250 mm/s and 300 mm/s. All experiments were performed at room temperature in air. No post processing was required for any of the samples.

Figure 1. Experimental setup of MOPA laser marking system.

| Table 1. Parameters of MOPA laser system. |
|-----------------------------------------|
| Laser parameter | Value                  |
|-----------------|------------------------|
| Wavelength, λ   | 511 nm & 578 nm        |
| Output power, P | 6 W                    |
| Pulse duration, τ| 30 ns                  |
| Frequency, ν    | 20 kHz                 |
| Beam quality, M²| 1.5                    |

The reflection from the aluminium surface was measured by an Ocean Optics HR 4000 spectrometer as follows: the light emitted from the spectrometer (in the VIS / UV range) is directed perpendicularly to the aluminium surface via an optical fiber and the reflected part of the light is captured by the same fiber. The reflection spectrum was obtained for each surface treated by different laser marking parameters (scanning speed and step). On this basis, the marking contrast for each of the marked surfaces was calculated according to equation (1). This gives an estimate for comparison with the untreated aluminium surface, which has 85% reflection. When calculating the contrast, the value of the reflection of each marked surface was taken at 555 nm, corresponding to the maximum sensitivity of the human eye [14].
3. Results and discussion

A laser marked sample is created with a grid of $8 \times 8$ mm squares. Two technical parameters of the laser system are varied within this grid – scanning speed ($6 - 300$ mm/s) and distance between parallel raster lines ($\Delta x$, from 15 $\mu$m to 60 $\mu$m). The surface of an Al sample thus treated is shown in figure 2; it shows how the laser-marked surface changes for each square in the matrix. A decrease in reflection is observed as the scanning speed and the distance between the laser-marked lines are decreased.

![Figure 2. Laser marking of the aluminum plate surface.](image)

The contrast in the case of dark markings on a lighter background is defined as

$$k = \frac{J_f - J_x}{J_f} \cdot 100\%$$

(1),

where $J_f$ is the intensity of the light reflected from the untreated surface of the sample (from the background), $J_x$ is the intensity of the light reflected from the affected zone on the sample.

![Figure 3. Contrast $k$ dependence on the scanning speed $v \Delta x = \text{const}$ (15; 30; 45; 60) $\mu$m.](image)
Analyzing the above graph, we find that the contrast reduction is exponential at the low scan speeds of 5 mm/s to 100 mm/s, and linear for high speeds, from 100 mm/s to 300 mm/s for all steps from 15 µm to 60 microns. This difference in contrast is due to the change in the degree of overlap of the successive laser pulses incident on the surface of aluminum.

In general, the scanning speed and the step of the laser beam determine the overlapping of the pulses (figure 4). Increasing the scanning speed and the step leads to a decrease in the overlapping of the successive pulses. As seen in figure 3, the contrast decreases with the increasing speed and step; therefore, the contrast increases as the scanning speed and the step of the laser beam are reduced.

![Figure 4. Schematic illustration of laser raster marking.](image)

Comparing figures 5 (a) and 5 (b), which differ in the size of the step (60 µm and 30 µm), one can see that the distance between the marked lines affects significantly the visible light reflection – it decreases with the decrease of the size of the step.

![Figure 5. (a) Laser marking of aluminum with scanning speed 6 mm/s and size of step 60 µm, microscope magnification ×60 times (right-hand part is laser marked).](image)

![Figure 5. (b) Laser marking of aluminum with scanning speed 6 mm/s and size of step 30 µm, microscope magnification ×60 (right-hand part is laser marked).](image)
Figures 6 (a) and 6 (b) show a barcode and a QR-code, both fully scanner readable, produced at the optimized settings using a CuBr laser in a MOPA system. These barcodes are commonly used to mark ultra-fragile and miniature items in electronics, as well as very hard tools and engineering products at Max Lasers Ltd. using the optimal parameters for laser marking.

4. Conclusions
We investigated the use of a CuBr laser in a MOPA configuration emitting the fundamental visible wavelength for marking and engraving of aluminum. The laser and scanner parameters were optimized in view of achieving marking suitable for producing scanner readable barcodes, QR codes and other information by changing the surface reflection of an aluminum plate.

The light reflection from the aluminum surface was measured using a spectrometer, on the basis of which the contrast was calculated. The dependences of the contrast on the scanning speed and step of the laser beam were determined.

It was demonstrated that MOPA CuBr laser systems can be employed in an industrial environment to make scanner readable, high quality, indelible marks upon a metal that is one of the most widely used in industry. We believe this technique may find many applications, particularly in the automotive industry, for traceability and security of components, sub-assemblies, electronics, cosmetics, food and beverages.

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