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Investigation of microfluidic topology formation with the use of IR pulse laser

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Abstract. The work considers the possibility of creating microfluidic topology elements on a stainless-steel plate using laser processing. The results of multi-stage exposure of near IR laser radiation to a metal surface in order to create microchannel parts (grooves) with a semicircular profile, as well as through holes that form part of typical microfluidic topologies, are presented. This paper describes the main technological features of the effect of laser radiation on a metal plate, which affect the effectiveness of creating microtopology elements.

Keywords: microfluidics, microfluidic topology, laser processing, laser perforation

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Исследование формирования микрофлюидной топологии с использованием инфракрасного импульсного лазера

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Аннотация. В работе рассматривается возможность создания элементов микрофлюидной топологии на пластине из нержавеющей стали с помощью лазерной обработки. Представлены результаты многоступенчатого воздействия инфракрасного лазерного излучения ближнего диапазона на металлическую поверхность с целью создания элементов, имитирующих микроканалы (канавки) полукруглого профиля, а также сквозных отверстий, которые являются частью типичных микрофлюидных топологий. В данной работе описаны основные технологические особенности воздействия лазерного излучения на металлическую пластину, влияющие на эффективность создания элементов микротопологии.

Ключевые слова: микрофлюидика, микрофлюидная топология, лазерная обработка, лазерная перфорация

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Introduction

Lab-on-a-chip systems are currently one of the fastest growing fields in applied photonics and, in particular, biophotonics. Technologies based on microfluidic systems are very diverse. For instance, they are used by biochemists and medical scientists to analyze biological and chemical liquids, to create new drugs, to manipulate different groups of cells, and even to simulate the work of human and animal organs [1–3]. The main requirements for such systems are high energy and economic efficiency, low weight, compactness, high sensitivity and high operating speed [4].

In a separate group of chips, one can select microfluidic devices for monitoring and analyzing fluids. They can be made from a wide range of materials such as transparent silicone elastomer, photoresist, glass, silicon and various metals. Depending on the material used microfluidic topology can be created using soft lithography, casting, hot stamping, mechanical milling, 3D printing and laser micro-processing [5].

The creation of a microfluidic pattern using laser microprocessing has a number of features and advantages compared to other methods, for example, environmental friendliness, lack of mechanical contact with materials and adaptability to production needs, and the use of metal as a material for the workpiece reduces the cost of manufacturing these products, which makes them more accessible to a wide range of research and applications. However, the process of interaction of laser radiation with metals is very complex and represents a set of physical phenomena such as heating, formation of a liquid phase, evaporation of metal and the effect of shielding the area of exposure with vapor-plasma formation [6]. It requires solving complex technological problems of laser processing of metals, which makes this research relevant and in demand.

The main task of this work is to study the modes of laser surface treatment of steel to obtain geometrically accurate microchannels with low roughness and taper, as well as surface morphology without microcracks.

Materials and Methods

The research was carried out on a 2 mm thick stainless steel metal plate, which was exposed to a precision laser system MiniMarker2 (Laser Center LLC, Russia), based on a fiber ytterbium laser (wavelength of 1064 nm, the beam diameter in the focal plane is 50 μm, the average laser power is up to 30 W, pulse duration from tens to hundreds of nanoseconds, pulse repetition rate up to 100 kHz). The topology elements were designed using specialized software MaxiGraf (Laser Centre LLC) supplied with a laser marker. The laser treatment was performed in several stages, during which processing parameters such as pulse duration, pulse repetition rate, scanning speed of the laser beam and the plane of focus changed.

The transverse dimensions of grooves were measured using an optical microscope NVMicro (NORGAU LLC, Russia). The width of the grooves was measured in three places: in the center and additionally one dimension at the edges of the structure. If an element of the topology had a "threshold", then it was measured in a similar way. This allowed us to find an error in measuring the width of microchannels, which turned out to be about 1%.

The depth of the grooves was measured using a high-precision manual 3D measuring machine Sinowon iTouch (MSP METROLOGY, Malaysia). To obtain an accurate depth value, the surface focusing method was used. The change in focal length when the scan line hit the topology was the value of the groove depth. Five measurements were made on each groove, after which the average depth value was calculated along the entire length of the groove. The measurement error was about 1%.

The roughness of the structures was assessed using an Industrial NSRT-100 profilometer (NORGAU LLC, Russia) with a standard probe installed. The measurement error of Ra parameter was about 5%.

3-D dimensional images of the surface of microchannels were obtained using the NTEGRA II atomic force microscope (NT-MDT LLC, Russia).

Results and Discussion

During multi-stage exposure to a steel plate with a fiber ytterbium laser, it was possible to identify the processing modes of the workpiece to create experimental grooves representing elements of a microfluidic system (Fig. 1, *a*, *b*). Generally one can identify two main parts of processing: hard regimes, which allow penetrating into material, and smoothing final processing regimes for polishing the surface.

During the work, it was found an oxide film formation at the bottom of the structures (Fig. 1, *a*), which is observed due to the fact that heated ambient gases react with the heated plate material, forming iron oxides and other impurities on its surface.

a) *b*)

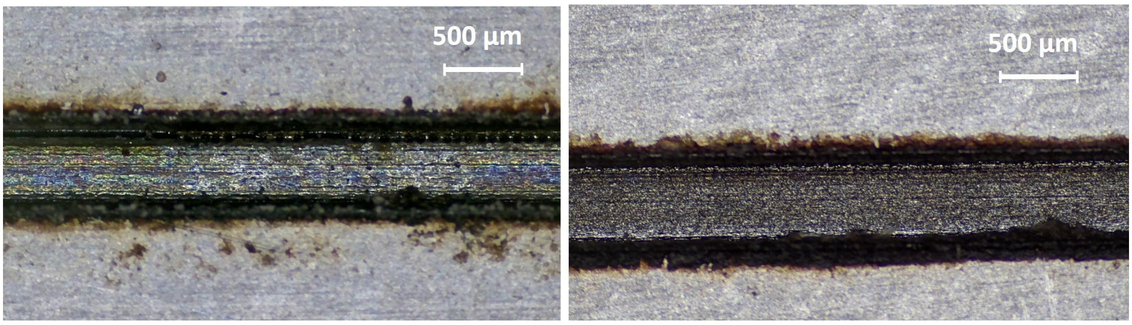

Fig. 1. Photos of grooves with an oxide film (*a*) and with roughness at the bottom (*b*)

To assess the effect of oxide film formation, 12 grooves with different processing modes, which imitated the final polishing step of laser processing, were obtained: 9 of them led to the formation of oxide, each of which was obtained at different power densities, and 3 were purely cellular. The roughness of the obtained structures was measured with profilometer (Table 1).

Table 1

Roughness of structures

Groove	Oxide presence	R_a, μm	Groove	Oxide presence	R_a, μm
1	–	0.382	7	+	0.838
2	–	0.400	8	+	0.744
3	+	0.892	9	+	0.903
4	–	0.409	10	+	0.553
5	+	0.831	11	+	0.544
6	+	0.795	12	+	0.648

From the data obtained, it can be seen that the oxide film leads to increasing the roughness of the structure, and the presence of a metallic luster indicates a lower value of R_a. Thus, the formation of oxide is undesirable for microfluidic purposes.

Also, these processing modes were investigated using AFM, some typical images are shown below (Fig. 2). Nanoscale particles remained in some microchannels (Fig. 2, *a*) after laser treatment, due to the fact that not all the material was able to fall out of the processing area. But in some cases, microcracks appeared during the processing (Fig. 2, *b*), which is a negative effect, since cracks of this size will create additional resistance when liquid flows.

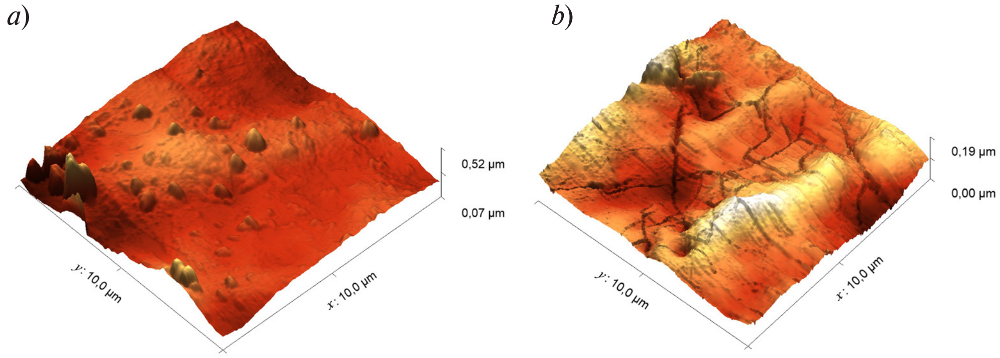

Fig. 2. AFM images of microchannels with the presence of nanopoils (*a*) and microcracks (*b*)

Conclusion

Using laser treatment with IR radiation, it was possible to obtain grooves on the surface of stainless steel with a profile close to a semicircular one, up to 500 microns thick. The experimental data allowed us to identify significant factors affecting the result of microprocessing.

The presence of oxide films, the appearance of which occurred when the power density decreased to 10^6 W/cm^2, increases the surface roughness. On the contrary, when the power density increased to 10^8 W/cm^2, microcracks appeared on the surface of the channels, which can lead to additional resistance when liquid flows. Thus, this study determines that laser power densities from 10^6 W/cm^2 to 10^8 W/cm^2 are most suitable for the final stages of processing and eliminate the main undesirable effects that interfere with obtaining a smooth surface after processing.

REFERENCES

1. **Halimova A.A., Kovalenko A.V., Paramonov G.V.**, Organs-on-a-chip: assessment of prospects for use in the pharmaceutical industry, Medical & pharmaceutical journal "Pulse". 24 (5) (2022) 81–87.

2. **Bovard D., Iskandar A., Luettich K., et. al.,** Organs-on-a-chip: A new paradigm for toxicological assessment and preclinical drug development, Toxicology Research and Application. **1** (2017) 1–16.

3. **Caplin J.D., Granados N.G., James M.R., et. al.,** Microfluidic Organ-on-a-Chip Technology for Advancement of Drug Development and Toxicology, Advanced Healthcare Materials. 4 (10) (2015) 1426–1450.

4. **Zakoyan A.G., Voronkov G.S., Aleksakina Ya.V., et. al.,** Multichannel sensor system for simultaneous polling of several refractometric sensors based on a photonic integrated circuit, Special issue of "Foton-Ekspress-Nauka". 6 (2023) 135–136 (in Russian).

5. **Wlodarczyk K.L., Hand D.P., Maroto-Valer M.M.**, Maskless, rapid manufacturing of glass microfuidic devices using a picosecond pulsed laser, Scientific Reports. 9 (2019) 1–13.

6. **Glotov A.N., Golubenko Yu.V., Desyatskov V.A., Stepanov A.V.**, Some features of the interaction of laser radiation with metals, Vestnik MGTU im. N.E. Baumana. Ser. Priborostroenie. 1 (2020) 15–32 (in Russian).

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