The relationship of the geometric parameters of the surface with its properties (optical, emission, tribological)

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Abstract. This article presents the results of the possibility of manufacturing different types of microstructures. Special surface microreliefs have been created to solve a number of important problems related to the functional properties of the object surface and its relationship with the environment.

1. Introduction
In nature, there are often microstructures in the form of a correct convex four- or hexahedron, having minimum free energy, which provides maximum stability under any external influence – mechanical, chemical, thermal, etc. (figure 1). Such microstructures have important surface properties [1-4], such as increased shape stability (impact resistance) and corrosion resistance, increased contact stiffness, fatigue limit, slip resistance, density and hydraulic density of compounds, electrical strength, etc. The presence of such microstructures increase the adhesion of rubber coatings during prolonged contact "rubber– metal", improve the quality of galvanic coatings, speed up the cleaning of the surface in vacuum conditions, reduces the electron emission to the environment, etc. in the manufacture of a negative image of convex hemispheres by means of forging or rolled, the resulting surface improved adhesion properties. These and many other advantages of convex spherical microstructures make such reliefs in demand in modern industry and research activities.

The authors of the article attempted to recreate such a microstructure using fiber laser radiation and study the relationship of geometric parameters of the surface topography with its various properties.

Figure 1 (a, b, c). Natural analogs of the regular microrelief: (a) sunflower; (b) snakeskin; (c) in the faceted eye of an insect
2. Experiment and results
In our work we used a fiber laser (operating in pulse-periodic mode) with the wavelength of 1070 nm and power up to 18.4 W. As a test sample, steel grade was used 10X9 and 10X18H10T. Surface treatment of metal was held at a room temperature of 23 °C and a relative humidity of air of 55%.

2.1. The relationship of the geometric parameters of the relief surface with its optical properties
The presence of microrelief (roughness) of the surface leads to a number of qualitatively new effects in the reflection of light. First, in addition to the specularly reflected wave, diffusely scattered waves appear. Secondly, when reflected from metal surfaces, the presence of roughness leads to the possibility of converting part of the incident wave into a surface electromagnetic wave (surface plasmon-polariton).

Optical properties of the surface are a priority in a number of applications of functional materials. Of course, in the first place here is photoelectricity, where the problem of weakly reflecting (black) surfaces determines the efficiency and General prospects of the entire direction. Optical properties of the surface play an important role in many products of space and military equipment (anti-reflective surfaces), in the jewelry industry, in the processes of laser marking of products, etc.

It becomes possible to control the spectral reflection coefficient of the incident light wave. Thus, the shape of the microstructure and the slope of the side faces of the pyramids can be adjusted at the stage of ablation, and the thickness of the oxide and its color can be adjusted at the stage of "polishing". For example, in the course of the experiments surface were created microstructures with an oxide layer which having a shade of purple (figure 2). Visually, the color of the microstructure varies from blue to red-purple. This is characterized by the difference in the course of the light wave in the thickness of the oxide layer, depending on the angle of illumination. The microstructure of the surface oxide films of different colors can be used in optical instruments, spectrum analyzers, and reflectors. The problem of controlling the optical properties of the surface can be solved both by creating specific microstructures – periodic reliefs and by chemical processes of obtaining (oxide) coatings on the surface of materials. Both of these methods can be effectively implemented by laser irradiation of the surface of most metals.

Figure 2. An example of oxidization microstructured surface steel grade 9XC

2.2. Connection of geometric parameters of the surface relief with its ability to electron emission
A very important property of the surface for many applications is its ability to enhance (emission reliefs) or suppress (anti-emission – electro-protective reliefs) electronic emission. Emission reliefs are necessary for the manufacture of a large range of specific elements of vacuum technology – cathodes, both metal (tungsten) and oxide.

The ability to control the value of the emission current for the cathode from a given material is associated with the effect of local amplification of the e field near the projections on the surface having the shape of a tip (blade). Field gain:
\[ \beta = \frac{E}{E_0} \]

\( E_0 = \frac{V}{d} \) – the field strength in the absence of the tip at the same potential difference, \( V \) – the potential difference between the electrodes, \( d \) – the distance between them) in the simplest case, the cylindrical tip height \( H \) and the radius of R-vertex \( R \) is estimated from the ratio (when \( d \gg H \gg r \)):

\[ \beta = \frac{H}{r} \]

It follows from the above formula that the smaller the tip radius, the greater the local field gain an emission current. The reduction of \( r \) down to the nanometer size allows detecting currents of field emission by several orders of magnitude larger than for micron-tip-shaped emitter. It should also be noted that the resistive heating of emitters significantly decreases with a decrease in the radius of curvature of the tip, which allows recording record emission currents. Of course, in the transition region of the nanoscale is, in principle, violated the basic assumptions of the theory of Fowler - Nordem (the one-dimensionality of the potential barrier, the uniformity of the field distribution on the surface of the emitter, etc.). Obtaining simple analytical expressions, in this case, is difficult, however, at the qualitative level of the description, the noted regularities remain valid. In this connection, the emission properties of cathode surfaces will be significantly determined by their geometry. Thus for antialiasing terrain is typical that the radius of the protrusions of the relief \( R_1 \) is much greater than the radius of the depressions of the relief \( R_2 \), and for monetary relief on the contrary. Figure 3 and 4 show the reliefs with antiemission and emission properties, which were obtained by surface treatment by laser radiation. For monetary relief best treatment mode corresponds to a power density \( q=1*10^8 \) W/cm\(^2\), and antiemission elevation \( q=0.8*10^8 \) W/cm\(^2\).

**Figure 3(a, b, c).** The characteristic shape of the experimentally obtained relief of the surface of the steel 10 to give it antiemission properties: (a) 3D model; (b) microstructure of steel; (c) a characteristic type of terrain \( R_1 > R_2 \).

**Figure 4(a, b, c).** Characteristic types of experimentally obtained surface relief of steel grade 10 to give it emission properties (a) 3D model; (b) microstructure of steel; (c) a characteristic type of terrain \( R_1 < R_2 \).
2.3. The relationship of the geometric parameters of the surface topography with its tribological properties

The rear surface of the object has a fairly rich set of topographic characteristics that can be adjusted depending on the requirements of production. They can be divided into two groups, among which:

• Macrogeometry – macro-relief, shape deviation, altitude, step-by-step, lateral, periodic and other surface characteristics.

• Microgeometry – surface roughness, porosity, microdefects, etc.

Each of these characteristics determines the size of the nominal contact area and, as a result, has a significant impact on the tribological behavior, performance and wear resistance of objects.

The proposed technology of microstructuring the metal surface allows you to adjust each of the described parameters: the first stage of metal ablation sets the macrogeometric, and the third stage of "polishing" microgeometric surface parameters. Table 1 presents the main characteristics of the microstructures presented (figure 5 and 6).

|                | The height of the structure h, mkm | Size L, mm | Density N, pcs/cm² | Roughness parameter Rₐ, mkm | Roughness parameter Rₚ, mkm | The thickness of the remote H, mkm | Time of manufacturing t, min |
|----------------|-----------------------------------|------------|---------------------|-----------------------------|-----------------------------|----------------------------------|-------------------------------|
| Cylinders (figure 4) | 950                               | 0.90       | 16                  | 0.26                        | 1.10                        | 1000                             | ~30 (3 step)                 |
| Gutters (figure 5)  | 290                               | 0.03       | 5000                | 1.10                        | 6.94                        | 300                              | ~20 (2 step)                 |
| Untreated surface   | -                                 | -          | -                   | 0.6                         | 2.77                        | -                                | -                            |

The roughness of the surface "polished" by laser radiation was 2.5 times less than the roughness of the untreated surface. This result once again proves the effectiveness of the three-stage laser technology for the formation of microstructures to change the tribological properties of the surface, which is extremely necessary for the production of components of mechanisms in which there is active friction.

Figure 5(a, b). Images of microstructure on the surface of steel grade 10: (a) graphics model of microstructure in the form of a matrix of cylinders (number of objects 16 PCs/cm²); (b) the corresponding photo.
Figure 6(a, b). Images of the microstructure on the surface of steel grade 10: (a) graphical model of the microstructure in the form of a friction plane with gutters; (b) corresponding photo.

The analysis of the obtained results allows us to include that laser irradiation of the surface of steel with a fiber laser can change the shape of the surface topology of the metal by adjusting the surface properties. Figure 7 shows the dependence of the roughness parameters of the manufactured microstructure on the gradual reduction of the pulse duration in the process of polishing the surface of steel 10 by laser emission.

Figure 7. Graph of the dependence of the roughness parameters of the manufactured microstructure on the gradual reduction of the pulse duration in the process of polishing the surface of steel 10 laser radiation (Ra’, Rz’, h’ – roughness parameters of the untreated surface).

3. Conclusion
The article proposes a method for the creation of microstructures on the surface of steel grades 10 and 9HS. The surface reliefs of various types and shapes are obtained: pyramids, cones, hemispheres, cylinders, images, etc., with characteristic dimensions of 30...1000 µm.

It can be concluded that by changing the shape of the surface topology of the metal, you can adjust the properties of the surface: mechanical, optical, electrical, etc. However, to obtain the required accuracy and roughness relief for each material requires the development of individual modes of laser processing.

The main factor affecting the quality of manufactured microstructures is the duration of laser pulses. It is experimentally confirmed that shorter pulse duration is effectively used for surface finishing, which
leads to a decrease in the degree of roughness of the produced microrelief. In this case, the minimum \( \tau = 4 \) ns, which is due to the technical capabilities of the fiber laser used in the work. The proposed method of formation of the microgeometry of the surface using the volume-controlled ablation in the setting with scanning system restores the beam can be used for practicing the basics of laser surface engineering in a variety of industries for research activities.

4. Acknowledgments

The work was carried out with the financial support of the Ministry of education and science of the Russian Federation in the framework of research of the project part of the GZ, project № 16.1750.2017/4.6

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