Journal of Nano- and Electronic Physics
Vol. **7** No 4, 04055(3pp) (2015)

Журнал нано- та електронної фізики
Том **7** № 4, 04055(3cc) (2015)

Nonlinear Effects of Laser Surface Modification of Ore Minerals

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(Received 30 September 2015; published online 24 December 2015)

The effect of continuous laser radiation on complex ore minerals objects containing gold, not extracted by monerd methods was investigated. It was established the formation of different structural surfaces of gold, revealed general patterns of sintering and concentration of sub-micron gold.

Keywords: Laser sintering, Ultrafine, Colloidal-ionic, Gold, Gold-bearing mineral products, The structural ordering, SEM, AFM.

PACS numbers: 68.37.Hk, 68.37.Ps

1. INTRODUCTION

High intensity production of many kinds of raw materials leads to the gradual depletion and degradation of its geological and mining conditions of their development. Attempts are being made to use non-conventional energy impact of raw materials, such as electrochemical oxidation, microwave heating, irradiation with accelerated electrons and powerful electromagnetic pulses. Statement of the problem of research is related to the difficulty of extracting fine gold or other heavy metals from mineral raw materials by modern technological methods. The complexity of production associated with both feature crystallography isomorphic minerals, secondary mineralization, and the methods of disclosure splices and minerals [1-3].

The aim of the study is to identify the structural features of a thin and plate gold or other heavy metals (Pb, W et. cet.) from the tailings to the development of methods of extraction of ultrafine gold.

This paper deals with the influence of laser radiation on the gold-bearing mineral medium. Based on the results of the comparative structural, elemental and mineralogical analyzes of starting materials and laser processing products quality physical model was proposed. It describes relevant chemical and structural changes in these materials during the laser processing. It has been shown to occur sintering association nanoscale dimensions of noble metal particles. This has the great practical importance. The experimentally confirmed and patented a laser sintering can be proposed to solve the technological problems of extracting thin and fine gold.

2. EXPERIMENT

Several tens of gold-bearing samples from various deposits were chosen for the study. Electronic images (Fig.1, 2) and elemental compositions of the minerals were obtained by scanning electron microscopy and energy-dispersive X-ray analysis. Topographic distribution of chemical elements in selected sample's area gives a clear idea of structural features in the compositions of the initial products.

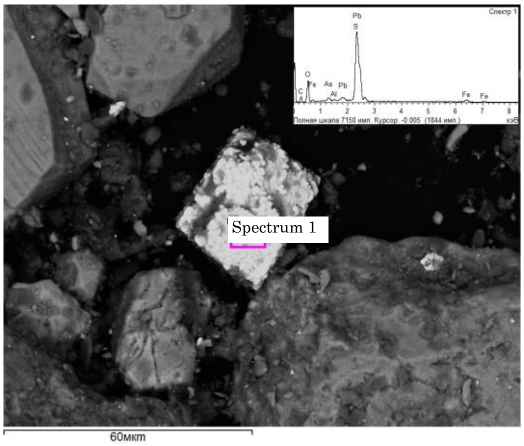

Fig. 1 – Scanning electron images of initial samples of magnetite

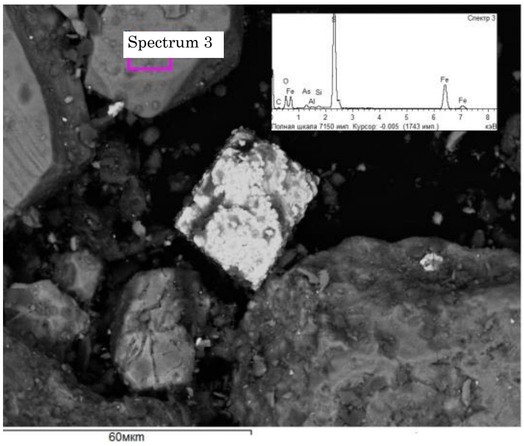

Fig. 2 – Scanning electron images of initial samples of magnetite

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Cluster a structure and the arithmetic-mean roughness are defined. The given parameter characterizes the sizes of clusters. With using topographical analysis it was revealed difference in size of spherical and ellipsoidal formations. Gold of each geographical object has the certain relief and structural features of a surface. It is established, that the sizes of clusters fluctuated from 10 to 400 nanometers [4, 5].

In the next phase of the study, all samples are processed by continuous irradiation of fiber laser LC-06. As a result, formation of dark burnt sphere with a diameter from 500 to 3000 microns was observed. Forming of molten gold particles with spherical shape drop in range from 50 to 500 microns were observed on these surfaces. It is established changes of structure of the surface in the agglomerated particles of gold. In the case of magnetite on the surface of the cake were found conglomerates of lead (Fig. 3, 4).

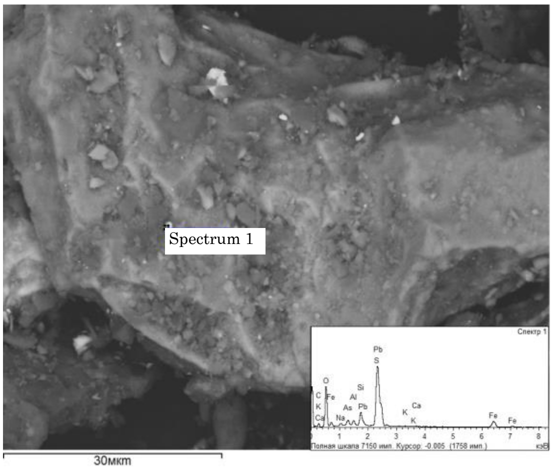

Fig. 3 – A conglomerate of lead on the surface of magnetite after laser treatment

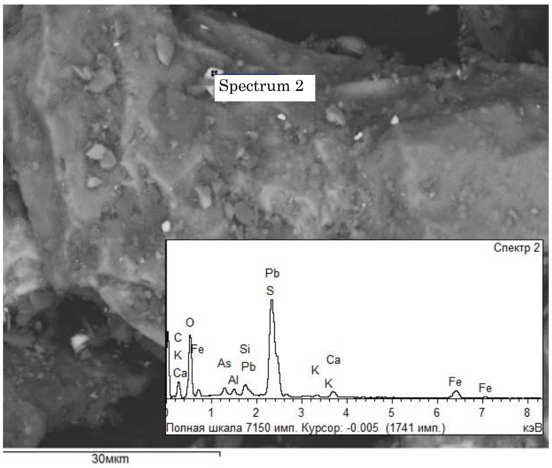

Fig. 4 – A conglomerate of lead on the surface of magnetite after laser treatment

The gold is in the inside of break up melt agglomerates (Fig. 5).

3. RESULTS AND DISCUSSION

The temperature field in mineral products under the influence of laser radiation is described by the heat equation. Distribution of temperature field is considered for a case of one-dimensional distribution of a stream of heat in the sample. Such approximation is possible if radius of a laser hot spot of essentially more than thickness of zone of laser action. The heat equation thus looks like:

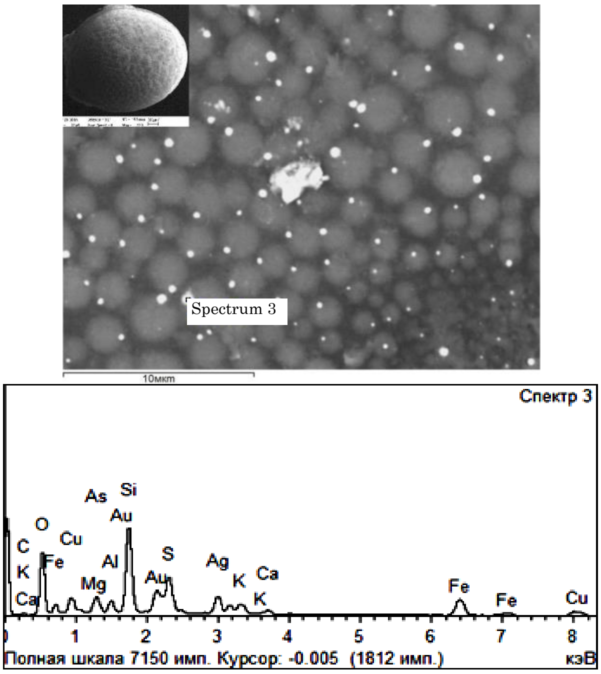

Fig. 5 – A conglomerate of gold in magnetite after laser treatment

$$\frac{\partial T}{\partial t} = a^2 \frac{\partial^2 T}{\partial x^2}, \tag{3.1}$$

where $a^2 = \lambda / c\rho$ is the thermal diffusivity, λ is the thermal conductivity coefficient, c is the specific heat capacity, ρ is the density of the sample.

The initial condition: before the beginning of an irradiation the temperature in all points of the sample is identical and equal to an ambient temperature T_0, i.e.

$$T\big|_{t=0} = T_0 = \text{const}. \tag{3.2}$$

The boundary condition: from the beginning and during all process of irradiation the thermal source of the round form works on a sample's surface. The power density q of surface source is completely spent for heating of the sample, i.e.

$$-\lambda \left(\frac{\partial T}{\partial x} \right)\Bigg|_{x=0} = q. \tag{3.3}$$

Power density q is the most important parameter of thermal action. It's equal to the ratio of the laser power P to the area of laser hot spot on surface of the sample S: $q = P / S$.

The analytical solution of the heat equation (3.1) in one dimension with the given initial (3.2) and the boundary (3.33) the condition will be:

$$T(x,t) = \frac{q}{c\rho L}\left[1 + 2\sum_{n=1}^{x} \cos\left(\frac{n\pi x}{L}\right) \exp\left(\frac{n^2\pi^2}{L^2} at\right)\right]. \tag{3.4}$$

Solution of heat equation with the initial and boundary conditions allows to define such parameters of temperature field as temperature of mineral samples, rate of change of temperature both during laser action, and after it's finishing, space distribution and temperature gradients. The optimal characteristics of laser action can be defined on the base of these parameters.

Also it is well known that, two types of capillary mechanisms exist, which are proportional to the surface tension gradient: thermocapillary and thermogravitational. Which will dominate depends on the Bond number that is equal to the ratio of the Rayleigh to the Maragoni number: $\rho g \beta h^4/\sigma$, where ρ is the density, g is the acceleration of gravity, β is the thermal diffusivity, h is the layer thickness, σ is the surface tension. For the thermocapillary mechanism to be dominant the value of this ratio must be less than unity. For noble metals, as mentioned, σ is anomalously large (for example gold 1100 din/cm^2), making the thermocapillary mechanism the major for thin layers which are given in the experimental results [6].

The appearance of deformations on the sphere surface of gold is due to the thermocapillary mechanism. The surface tension forces direct perpendicular to the free surface or to the melt surface. The occurrence of the thermocapillary convection is necessarily accompanied by the variation in the normal stress of a surface layer, its curvature. In our case the deformations were found to be indeed comparable with the foil thickness. They range from parts of a micrometer to micrometers. The products of the laser melt can be heterophase and heterogeneous [7-8].

4. CONCLUSIONS

Such a formation during laser melting is likely explained by surface tension. Spherical surfaces of gold are characterized by minimized in energy. Variations in granulometric compositions of mineral gold-bearing associations derived due to laser agglomeration make it possible to extract gold by using conventional gravity methods. It testifies to the practical importance of the method. It was proposed to make particles of noble metals larger by reasonably effective and an environmentally friendly means. It may find using for preliminary concentration of noble metals not extracted with conventional techniques in order that subsequently extract those using traditional means. During laser processing formation of self-organized colloid-ionic gold occurs. Melted particles have size from 50 to 500 μm.

Based on the obtained temperature field distribution (3.4) can determine the optimum conditions for laser irradiation source and mineral compounds and adjust such parameters of the laser radiation as exposure duration, pulse energy, beam diameter, focal length, exposure time. It is necessary to obtain maximum size of the gold particles, which facilitates their subsequent extract.

This article was prepared with the support of grant of the Russian Foundation for Basic Research No 13-05-00586 «Nonlinear effects in the interaction of laser radiation with rocks and mineral media with a view to integrating the technology of fiber lasers in the mining industry» in 2015.

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