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INTEGRATION OF FIBER LASERS IN PROCESSES OF MINERAL RAW MATERIAL PROCESSING

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Annotation. The application of laser technologies (LT) in the economy of the most developed countries. The possibility of using laser technologies for processing technogenic mineral raw materials is considered. The possibilities of integration of fiber-optic lasers into the processes of enrichment and processing of mineral raw materials are explored. The effects of interaction of laser radiation with mineral media - objects of Amur placer technogenic deposits containing submicron gold not extracted by modern gravitational methods are analyzed. The formation of self-organizing gold structures on the surface of a silicate matrix was established, general patterns of agglomeration and concentration of "non-extractable forms" of gold were revealed.

1 Introduction

The wide application and improvement of laser technologies (LT) in the economy of the most developed countries is a global trend of world development. The use of LT is crucial for increasing labor productivity and competitiveness of the national economy, expanding the opportunities for its integration into the world economic system. Laser processing of materials is one of those technologies that determine the current level of production in industrialized countries [1-4]. Distinctive features of the use of lasers in production - high quality of products, high process efficiency, saving of human and material resources, environmental cleanliness. A powerful impetus to the market sector, including laser processing of materials, gave fiber lasers, both small and high power. In 2012, four new companies entered the market - a supplier of such radiation sources, which are trying to compete with the recognized leader in this field - IPG Photonics Corporation. In general, laser technologies (LT) are developed in the EU, USA and Japan, and are reflected in Fig. 1. The countries of South-East Asia (Southeast Asia) are noticeably behind them, but even in these countries the volume of laser sales is about five times higher than in Russia. For example, in China, in Hubei province, which is the concentration of the optical industry in the country, the gross product of laser enterprises in 2005 y. exceeded 75 million $. Laser technologies in the EU countries, in a more general sense - photonics, are viewed only as a locomotive of technological innovations. The photonics market in the world exceeds 150 billion euros, demonstrating a 14% annual growth over the past 10 years.

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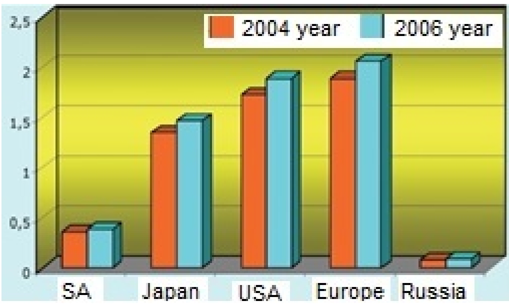

Fig. 1. Sales volume of technological lasers by region the world, bn $ [5]

According to the specialists' research of the general economic conjuncture, the growth rate of world production of laser systems and sources of laser radiation (LI) will remain at the level of 10-15%. Lasers for processing materials sh at present ow the maximum dynamics of growth, both on the international and Russian markets. According to LaserMarketsResearch [5], from 2008 to 2016, the world market for lasers grew from 6.57 to 10.408 billion dollars. The share of lasers was 39%, which used in the processing of materials in the global market in 2016 year: from $ 213 million to $ 1,304.8 million. Lasers for processing materials showed the greatest increase in this time. In 2016, they accounted for 41% of the total market. The table gives a comparison of various technological sources of laser radiation, which are currently used in the processing of materials. At the same time, from the analysis of the problems of processing and extraction of noble metal raw materials, it is known that, a sharp reduction in readily available gold reserves in ores and placers predetermined the search for new low-waste technologies for the extraction of gold and other precious metals from placer technogenic deposits. Involvement in the processing of man-made gold-bearing neo-formations accumulated over a long historical period of gold mining is highly relevant for the Far Eastern region. Such deposits, as a rule, have a high clay content in the sands. The metal is represented in the sludge fractions mainly in dispersed colloidal particles of lamellar or acicular form. The most of particles of gold, of lamellar and dendritic forms, is lost with tails, especially in classes of fineness less than 0.25 mm under gravity enrichment [6, 7]. In mineral media, structural rearrangements occur under the influence of external energy flows on them, so that their state becomes far from thermodynamic equilibrium. Laser treatment of finely dispersed mineral media is one of the promising areas of such studies. This is because laser radiation creates high heat flux densities on both the surface and the volume of the material, sufficient heating, melting and evaporation days. In the work, the processes of interaction of laser radiation with dispersed mineral media have been experimentally investigated with the possible goal of integrating the modern powerful sources of laser radiation into the enrichment and complex processing of mineral raw materials. Among the non-traditional methods of energy impact are: electrochemical, microwave, electroimpulse, electrohydrodynamic, magnetic pulse processing, impact by a stream of accelerated electrons, super-powerful hyper-shock waves and powerful electromagnetic pulses [8]. Laser radiation makes it possible to provide high rates of local changes in temperature in the irradiated medium and temperature gradients, both in narrowly localized sections of surfaces and in the depth of materials due to low temperature conductivity. Such parameters can not be achieved with other methods of exposure. It is known that the properties of micron objects and nanoindivids differ from the properties of their macrohomologists. This is due to the dependence of the specific surface area of the particles on their size and, consequently, to incomparably higher structure perfection and surface effects. Such properties are thermal, electric, magnetic, high aggregative stability. For example, the melting point of the macrograin is 1064 ºC gold, and the nanoindivide value of 4 nm is 427 ºC.

Table 1. Comparison of different types of lasers. Advantages of fiber lasers*

Parameters	Required for use in industry	CO_2	YAG-Nd with lamp pumping	YAG-Nd with diode pumping	diode lasers	Fiber lasers
Output power,кW	1...30	1...30	1...5	1...4	1...4	1...30
Wavelength, mkm	as less as possible	10,6	1,064	1,064 or 1,03	0,8...0,98	1,07
Beam Parameter Product, BPP, mm x mrad	< 10	3...6	22	22	> 200	1,3...14
Effectiveness, %	> 20	8...10	2...3	4...6	25...30	20...25
Range of radiation delivery by fiber, m	10...300	absent	20...40	20...40	10...50	10..300
Output Power Stability	as high as possible	low	low	low	high	very high
Sensitivity to back reflection	as low as possible	high	high	high	low	low
Footprint, m^2	as less as possible	10...20	11	9	4	0,5
Cost of installation, relative unit.	as less as possible	1	1	0,8	0,2	< 0,05
Cost of operation, relative unit	as less as possible	0,5	1	0,6	0,2	0,13
Cost of service, relative unit	as less as possible	1...1,5	1	4...12	4...10	0,1
Periodicity of replacement of lamps or laser diodes, hour.	as high as possible	-	300...500	2000...5000	2000...5000	> 50 000

*http://www.ntoire-polus.ru/apps_lasers.html

2 Materials and methods

Experimental data were obtained on the ytterbium laser radiation sources LS-06 with a fiber transmission system. The coefficient of efficiency of such an installation is 30%. On the ytterbium fiber-optic installation LS-06, it is possible to control both the radiation power from 0 to 600 W. and the diameter of the local processing zone by placing the optical head over the material being processed. The operating mode of the radiation source is continuous, the modulation frequency of the output power is 5 kHz. The spectral width is 10 nm. The wavelength λ = 1070 nm. Natural gold-bearing dispersed images of mineral raw materials from high-clay technogenic objects of Far Eastern alluvial deposits with the particle size of 71 μm, 40 μm and 20 μm were prepared for research. Gold-containing high-clay aluminosilicate samples in loose form, with a layer thickness of 3 mm, were placed on a special graphite substrate. The optical head was placed above the graphite substrate. It was possible to specify the parameters of defocused radiation. Laser radiation, passing through the ytterbium optical fiber fixed at the input of the optical head, and through the optical head placed vertically and rigidly on the tripod, fell on the samples under study. The substrate was moved at a speed of 1 mm / s. The diameter of the defocused radiation was chosen empirically and was 7 mm.

The material composition of the directed change in the properties of the samples was studied with the help of electron and atomic force microscopy. The images were examined before and after laser treatment. As a result of laser action, the formation of enlarged gold of spherically agglomerated forms on an aluminosilicate matrix was recorded from microscopic analysis data.

Electron microscopic examination of the samples was carried out with a scanning electron microscope LEO EVO 40HV (Karl Zeiss, Germany) equipped with an energy dispersive analyzer INCA-ENERGY. The study of mineralogical objects using a secondary electron detector (SE detector) made it possible to obtain information on the topography of the samples. In addition to the detector of secondary electrons (SE detector), a backscattered electron detector (QBS detector) is used. With the aid of a QBS detector, phases with a higher average atomic number are more pronounced in contrast when the images are obtained than in phases with a lower atomic number. Since the difference in atomic weights of gold and minerals contained in the studied mineralogical objects is large, a more contrasting image is obtained, which makes it possible to visually reveal gold. The relief difference of agglomerated gold surfaces is revealed under the action of continuous energy laser radiation (LI). The sensitivity of the method is ~ 0.1%. The width of the electron beam is ~ 20-30 nm. The penetration depth of the electron beam is ~ 1 μm. The local spectral analysis confirms the agglomeration of gold. When laser processing of gold-bearing mineral raw materials, the character of fast-flowing processes is established, leading to the formation of various structural surfaces of gold, and general patterns of agglomeration and concentration of ultradispersed gold not extracted by gravitational methods are revealed. Figures 2-4 show images of optical, electron, and atomic force microscopy, respectively.

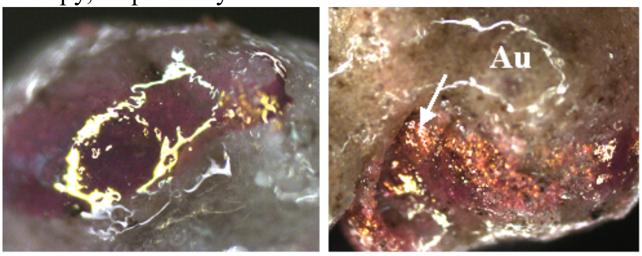

Fig. 2. Images of optical microscopy: micron forms of agglomerated gold, less than 1 mm, on aluminosilicate spectra, samples from technogenic deposits

3 Results and discussion

It was shown in [9-11] that thermocapillary forces make the dominant contribution to the process of coarsening from nanoparticles to sizes of practical importance, up to hundreds of microns. Thus, under the influence of laser radiation, a thermal process of disintegration of the crystal lattice of the mineral occurs, followed by a rapid thermal process of recrystallization, defragmentation and sintering due to a laser exposure of a second duration. Due to this scenario, the chemical homogeneity of dispersed mineral objects increases.

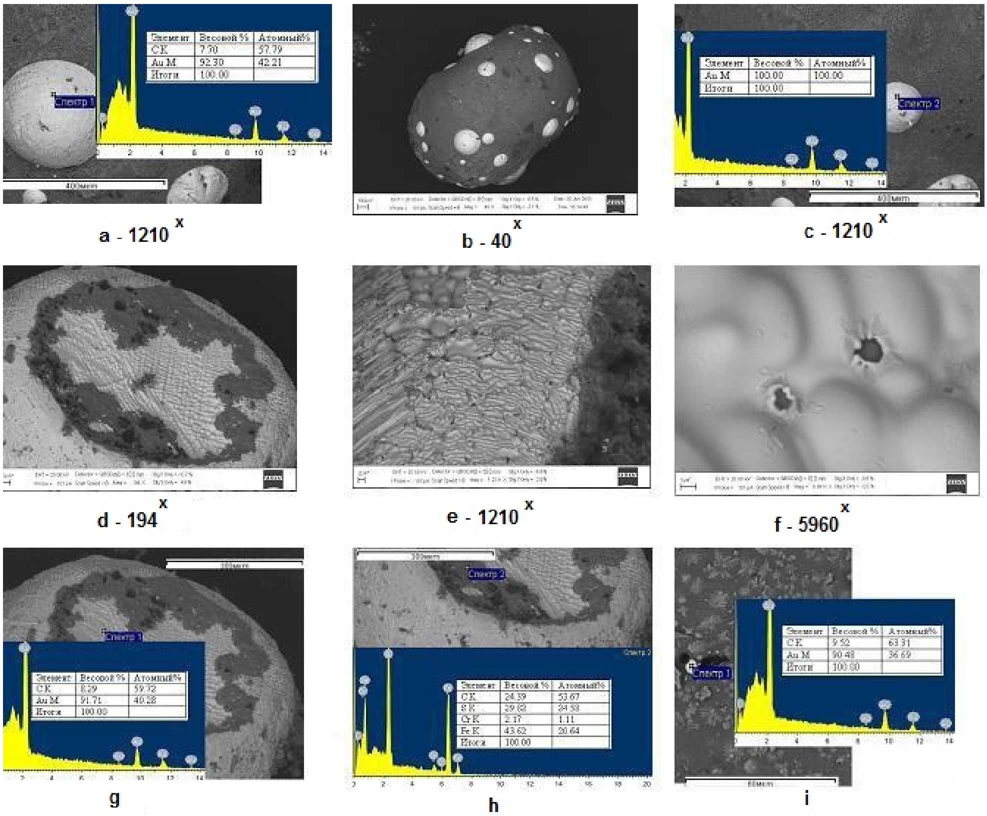

Fig. 3. Images of raster of agglomerated gold of spherical shape and the investigated areas of its surface after exposure to a continuous source of laser radiation LS-06. Risks: 400 mkm – a, c; 300 mkm – g, h; 100 mkm – b; 60 mkm – i; 20 mkm – d; 2 mkm – e, 1 mkm – f.

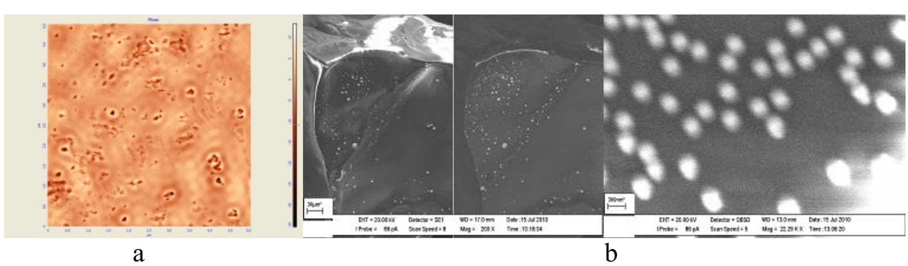

Fig. 4. Image of phase contrast of aluminosilicate cake with submicron gold after laser treatment, a - atomic force microscopy, scanning area 5x5 μm, b - electron microscopy, nanometer size objects of gold 300 nm.

Concentration and agglomeration of metals occurs under the action of laser radiation, in particular, gold in larger formations, which are distinguished by greater chemical purity than the original mineral associations. These studies are the scientific basis for developing new technologies for extracting submicron and nanometric forms of gold and other useful components. On this basis, a sufficiently effective and environmentally safe method of coarsening noble metal particles not extracted by traditional methods based on laser treatment of natural materials of anthropogenic character can be proposed [12]. It is possible that the use of modern laser radiation power sources with fiber-optic ytterbium energy transmission lines will make it possible to solve in the future purely practical tasks related to optimization of industrial technological processes of deep processing of man-made raw materials and extraction of valuable components. This testifies to the practical significance of the method.

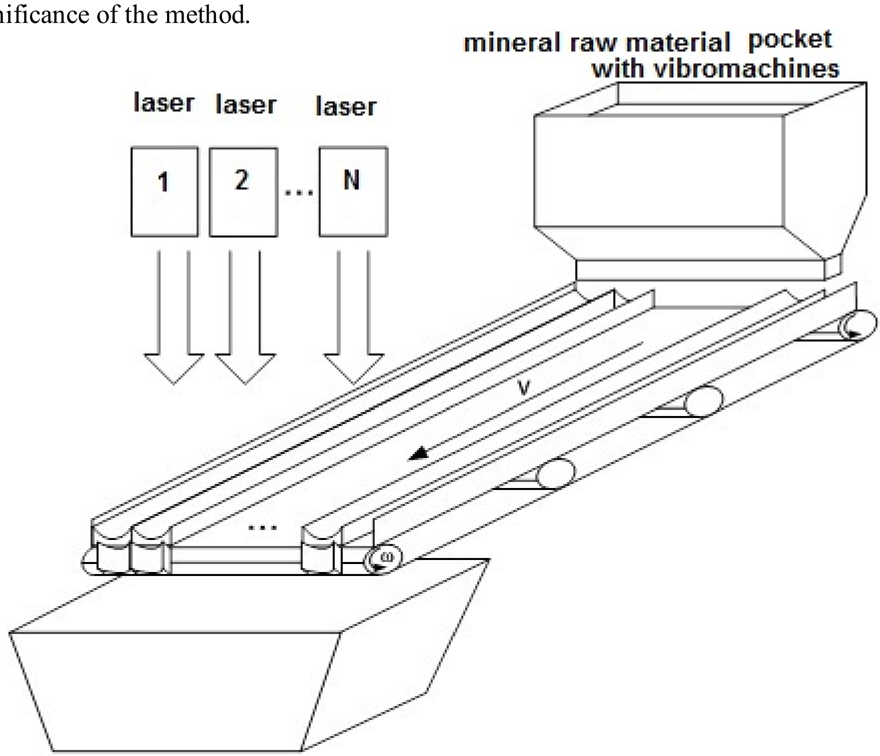

Fig. 5. Scheme of continuous flow technology for the extraction of submicron and ultradispersed gold particles on the basis of power laser fiber technology

4 Conclusion

The given examples of application of non-traditional technologies for extraction of ultradisperse and submicron gold particles allow us to consider that the solution of the problem of hard-to-extract forms of precious metals is possible. The method of laser treatment of gold-bearing high-argillaceous sands is approved. As a result, there is a redistribution of the substance with concentration and agglomeration of gold, which makes it possible to further integrate laser devices in the technology of mineral processing and processing of mineral raw materials. Figure 5 shows a patented scheme of continuous, on-time technology for the extraction of submicron and ultradispersed gold particles based on power laser fiber technology [13].

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