Physics and chemistry of minerals under laser processing

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Abstract. New experimental data of the influence of laser irradiation on the phase composition minerals of bauxite and red mud and their technological features have been represented. The mechanisms of formation of micro- and nanophases on mineral surfaces under the influence of laser irradiation were shown. It is underlined that changes of condition of surface atoms, concentration of metals, agglomeration of titanium minerals and new phase formation occurred under laser irradiation on bauxites and red mud.

1. Introduction
The interaction of laser irradiation with mineral substance is characterized by many important factors compared to, e.g., mechanical processing. The degree of influence of laser irradiation on mineral (ore) depends on the ability of the latter to absorb the irradiation on of the given laser wavelength. It can be compared to mechanical processing based on such features as hardness and viscosity. It is considered that main energy output during utilization of mineral resources is connected with ore degradation to expose minerals. Such an approach is not sufficient enough due to variety of entry of metals into host minerals, besides the excessive crushing is negative. The laser processing allows avoiding excessive crushing of the material, new 0.1 mm phase formation and metal agglomeration are observed on mineral surface.

The main task of the paper - to show mechanisms of laser processing of minerals (ore), which open the perspective of new material creation, utilization of “invisible” gold and other valuable metals stimulating transition to the industry of laser technologies.

2. Materials and Methods
The objects of studies – natural and technogenic mineral systems of bauxite and iron-containing concentrate from red mud (Russia). The sample processing was conducted with the use of ytterbium fiberoptical continuous wave laser LS-06 with wavelength $\lambda = 1060$ nm. The power of output irradiation varied from 100 to 400 W. The samples were studied by scanning electron microscopy. Element analysis of initial composition of the studied sample, study of structural and element chemical changes under laser irradiation were conducted with LEO EVO 40HV scanning electron microscope (Carl Zeiss, Germany) with INCA-ENERGY energy dispersive analyzer. The imaging of the studied objects was supported by SE-detector, which gives information about sample topography. Additionally QBS-detector was used. Localization of sensing beam to the spot with diameter approximately $3 \times 10^{-5}$ mm with the depth of penetration of beam $\sim 10^{-3}$ mm allowed to obtain data on qualitative and quantitative distribution of chemical elements in the studied mineralogical objects.
3. Results and discussions

Low-iron bauxites. The method of low-iron bauxites treatment for processing is suggested. The discovery is related to the sphere of low-iron bauxite concentration and can be applied for preliminary preparation for processing, e.g., during bauxite processing for titanium, which allows increasing integrity and efficiency of bauxite processing. The integrity of bauxite processing is realized not to full extent, mainly for rare earth elements. The technical result is achieved due to the method of preparation of low-iron bauxites includes rough preparation of the surface and subsequent irradiation.

Laser irradiation will be absorbed by mineral phases with greater absorption capacity (absorption depends also on melting and evaporation temperature, volatility etc.). The absorption capacity of mineral increases during laser impulse due to thermal emission and photoeffect. These processes result in electron emission, which increases absorption.

Before processing the sample represented rocks with boehmite predomination, which was seen on the diffraction pattern of non-irradiated sample (Fig.1).

Initially the sample surface represented grained boehmite matrix (Fig.2(a)) with titanium in the form of rutile and ilmenite. However titanium can be isomorphically included in lattices of other minerals. According to Belyaev with co-authors [1] up to 3.5 % TiO$_2$ is included in the lattice of boehmite. During our micro X-ray studies of bauxites, titanium is absent (or beyond sensitivity) in boehmite matrix.

The conducted studies showed that redistribution of bauxite substance is observed with titanium concentration in sinter during laser processing of kaolinite-boehmite bauxites (according to statistical interpretation of microprobe scanning the content of titanium increases in average at 1.7 times), at that titanium concentration is observed at certain values of energy density of laser irradiation. During the experiment the optimal parameters of energy density of laser irradiation were determined, at which a new phase crystallization was observed.

Iron-containing concentrate from red mud. Figure 3 shows the surface of initial sample (-0.071 mm fraction) and element microanalysis of local zone of iron-containing concentrate from red mud.

![Figure 1. Diffraction patterns of initial and laser-processed bauxite](image-url)
Iron content was 50\% (wt\%) according to the chemical analysis. The element analysis of iron-containing concentrate from red mud showed the presence of iron, titanium, calcium, silica, aluminum and oxygen in the following ratio: Fe_{10.8}Ti_{1.7}Ca_{5.4}Si_{3.4}Al_{2.6}O_{9.9}.

During the experiments a sample of iron-containing concentrate from red mud (fraction - 0.071 mm) was placed on a special graphite base. The rate of laser process was continuous up to 1 mm/sec. As a result of laser processing the obtained samples were of spherical shape with chemical non-homogeneity. The laser processing with power from 100 to 400 W resulted in the agglomerated pellets of iron-containing concentrate from red mud (Fig.4).
The size of the pellets varied from 0.5 mm to 2.0 mm. The pellets were represented by glass-like spherical structures with a high degree of hardness, which were very difficult to crush in agate mortar. The hardness was 6-7 by Mohs scale. The surface of the sinters (Fig.2) showed local zones of gold and platinum concentration: \( \text{Au}_{547}\text{Pt}_{536}\text{Rb}_{103}\text{Fe}_{47}\text{Ca}_{29}\text{O}_{4} \) and \( \text{Au}_{753}\text{Pt}_{738}\text{Fe}_{61}\text{Ca}_{31}\text{O}_{5} \) (Fig.5).

Figure 6 represents the element analysis of the following composition: a - \( \text{Au}_{434}\text{Pt}_{426}\text{Fe}_{35}\text{Ca}_{18}\text{O}_{3} \), b - \( \text{Au}_{336}\text{Pt}_{330}\text{Fe}_{27}\text{O}_{2} \).

![Figure 5. Gold and platinum on the agglomerated pellet surface of iron-containing concentrate from red mud (laser power 100 W)](image1)

![Figure 6. Gold and platinum on the agglomerated pellet surface of iron-containing concentrate from red mud (laser power: a – 125 W and b -150 W)](image2)

We observed various surface structures depending on the laser power and irradiation density at given parameters. E.g., figure 7 represents images of modified surface structures with element analysis and identification of gold, platinum, zircon, tungsten at laser processing from 100 to 400 W.

4. Conclusion
The method of bauxite laser processing has been developed, which resulted in redistribution of substance with agglomeration of titanium minerals and new phase formation, which are recoverable by conventional methods of concentration.

The laser processing results in the thermal disintegration of crystal lattices of finely disseminated minerals of iron-containing concentrate from red mud, then fast thermal recrystallization, defragmentation and sintering due to laser exposition of second duration. This scenario leads to increasing chemical homogeneity of dispersive mineral objects. The concentration and agglomeration of metals, particularly gold and platinum, into larger formations occurs under the influence of laser irradiation. Apart from gold and platinum, under laser processing at 125 W hafnium, zircon, and at 200 W - bismuth, at 400 W – tungsten are identified on the surface of sinters of iron-containing concentrates from red mud. However it should be noted that we did not find platinum on the surface at power more than 200 W.

Studies presented above can be a scientific base to develop new technologies of extraction of submicron and nanometer forms of noble metals and other valuable components.
Figure 7. Images of modified surface structures with element analysis and identification of gold, platinum, zircon, tungsten (laser power from 100 to 400 W)

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