CHEMICAL COMPOSITION OF THE NANOPHASE IRON (NPFE0) OBTAINED IN THE LASER EXPERIMENT.

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Introduction: As a result of micrometeorite bombardment, nano- and submicroscopic spherules of metallic iron ($npFe^0$) are formed in regolith grains of airless bodies. The presence of nanophase iron ($npFe^0$) significantly changes the spectrum of reflection from airless bodies - it subdued the characteristic absorption bands in the visible and near-IR ranges, shifts the intensity of reflected light toward longer wavelengths and reduces the total albedo [1,2,3]. During micrometeorite bombardment, it is formed as a result of condensation of vapor arising from the shock evaporation of lunar rocks. Especially often, nanophase iron can be observed in a thin amorphous film on the surface of mineral particles [4,5].

Moreover, the study of these formations is interesting from the point of view of using regolith in terms of building material for additive manufactures [6]. In this regard, it seems promising to use a laser for modeling the processes of space weathering of airless bodies [3, 7-11].

Experimental methods, technique and study of the samples: For the experiment a pulsed neodymium glass laser was used. The laser radiation wavelength was 1.06 μm, the pulse duration was 10^{-3}s, and the pulse energy was ~600–700 J. The energy flux density was ~10^6–10^7 W/cm^2. The temperature at the “impact” point was of the order of 4000–5000 K, which corresponded to the evaporation temperature during high-speed impact processes with collision velocities of the order of 10–15 km/s [10]. The initial heating temperature of the substance is determined by the power density of the laser pulse, and the pressure corresponds to the pressure of saturated vapors at a given temperature. When the vapor cloud expands, condensation occurs and, consequently, pressure and temperature evolve along the boiling curve, as in the case of an evaporative process with a high-speed impact. The high temperature and density in the vapor cloud ensure the rapid establishment of thermodynamic quasi-equilibrium at the initial stage [11]. With a drop in temperature and pressure in the process of cloud expansion, the rate of establishment of quasi-equilibrium decreases, and at some point in time it becomes less than the characteristic time of cloud expansion. There comes the so-called "hardening", after which the chemical composition of the cloud does not change with its further expansion. The temperature at which “hardening” occurs depends on the rate of change in the parameters of the cloud during its expansion and the higher, the smaller the scale of the cloud. In the experiment, we used several types of targets - tholeiite recrystallized basalt, basalt glass, several types of olivines, several pyroxenes, and peridotite. Numerous placers of iron nanospherules with different shapes and textures were found in all targets. Spherules up to 5 μm in size were analyzed by the EDS method. To determine the chemical composition of submicron iron spherules, we analyzed craters in targets made of ferruginous olivine and basalt glass. When studying the composition of large spherules, the method of sequential fourfold rotation of the sample and the direct determination method of oxygen was used.

The analysis was performed on a TESCAN MIRA 3 scanning electron microscope with an X-MAX 80 EDS analyzer (Vernadsky institute).

Results: In our experiments, very large spherules with sizes of a few microns up to 5 were obtained: in the basalt glass 19 spherules, in the Fe-olivine - 36 spherules. Such spherules are amenable to analysis in a scanning electron microscope (Fig. 1). Although the determination of oxygen by the EDS method occurs at a semi-quantitative level, and taking into account the effect of the oxidation of the metal phase in air and even in the chamber of a scanning electron microscope. For example, up to 1.5% oxygen is found in the cobalt standard, that is, an oxide film is formed. We can indirectly show that high abundances of elements in the reduced state are found (table 1); even taking into account the possible contamination from condensate material that could be deposited from the vapor cloud above the crater.

Among the impurity elements in such micron spherules, Ni (<1%), Si (up to 5%), P (up to 14%), S (up to 0.2%) and some other elements were found (table 1). The content of elements such as Al, Mg, Ca show a direct correlation with the content of oxygen, while the content of P, Si, Ni does not (Fig. 2).

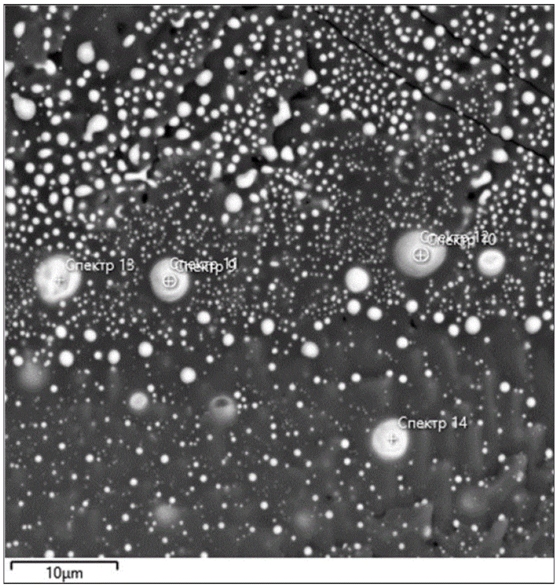

Fig.1. Large spherules of metallic iron in a crater of ferruginous olivine, scanning electron microscope.

Table 1. Average content of chemical elements in submicrospherules in targets made of ferruginous olivine and basalt glass.

Element	Fe-olivine	Basalt glass
O	1,90	6,91
Na	0,00	0,71
Mg	1,95	1,32
Al	0,06	1,74
Si	1,44	9,23
S	0,01	0,00
P	0,00	3,86
Ca	0,03	1,03
Mn	0,04	0,45
Fe	90,39	70,76
Ni	0,27	0,19
Total	96,10	96,41

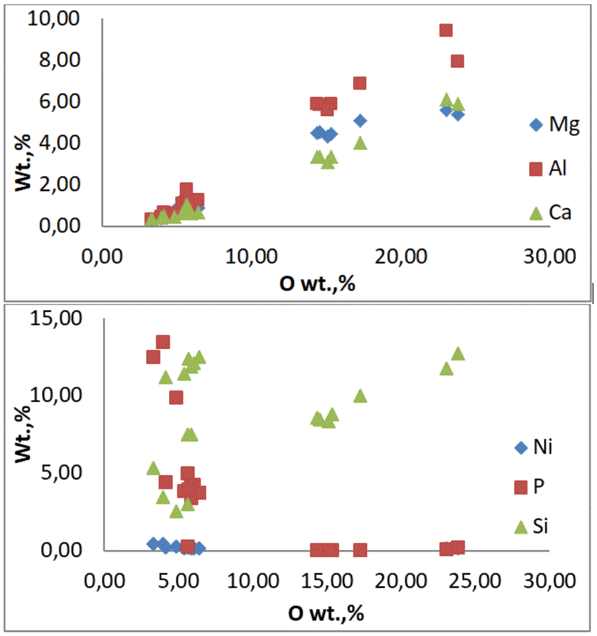

Fig.2. Contents of various elements in iron submicrospherules with respect to oxygen, for a basalt glass target.

Conclusion: Metallic iron spherules were obtained in a laser experiment. The largest ones were measured by the EDS method on a scanning electron microscope. The analyzes performed indirectly showed that in a short time of the experiment, on the order of a millisecond, not only the thermal reduction of iron oxide, but also silica, with subsequent dissolution of silicon in the iron melt, as well as enrichment in siderophilic elements (P,S) of this melt, has time to occur.

References: [1] Hapke B. (2001) *J. Geophys. Res., 106*, 10039-10073. [2] Pieters, C. M. et al.(2000) *Meteorit. Planet. Sci*., 35(5), 1101–1107. [3] Pieters C. M. and Noble S. K. (2016), *J. Geophys. Res. Planets, 10*, 121. [4] Keller L. P. and McKay D. S. (1993) *Science, 261*, 1305–1307. [5] Keller L. P. and McKay D. S. (1997) *Geochim. Cosm. Acta, 61*, 1–11. [6] Taylor,L.A., and Meeks T.T. (2005) *Jour.Aerosp.Engr., 18*,188–196. [7] Sasaki S. et al. (2001) *Nature, 410*, 555–557. [8] Hapke B. (2001) *J. Geophys. Res., 106*, 10039-10073. [9] Moroz L.V. et al. (2014*) Icarus, 235*, 187–206. [10] Sorokin E. M. et al. (2021) *In: Proc. 52nd Lunar and Planetary Sci.Conf*. #1975. [11] Gerasimov M.V. et al. (1999) *Lab. Astrophys. Space Res., 236*, 279—330.