

# LASER MODELING OF THE FORMATION OF NANOPHASE IRON (NP-Fe<sup>0</sup>).

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**Introduction:** The presence of nanophase iron (npFe<sup>0</sup>) 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]. At the same time, the size and number of nanospherules of such iron affect the quantitative and qualitative changes in the spectrum. For example, it is noted that large spherules larger than 40 nm affect the overall darkening of the spectrum, slightly affecting the shape of the spectrum, while spherules smaller than 10 nm affect only redness (that is, the shift in intensity to the long-wavelength region of the spectrum). Intermediate sizes of npFe<sup>0</sup> affect the spectrum differently, depending on their concentration [2, 4, 5, 6]. Researchers are considering two mechanisms of the formation of such iron - in-situ, with the participation of reducing agents, for example, hydrogen ions implanted from the solar wind into the lunar regolith [7]. The second is evaporation during the micrometeorite bombardment and/or sputtering process and reduction in the gas-vapor phase, followed by deposition on neighboring grains and coalescence of reduced iron atoms into nanospherules [1,2,3].

From the point of view of modeling the processes of space weathering, including the growth of npFe<sup>0</sup>, it is convenient to use a laser as an analogue of micrometeorite bombardment [3, 8, 9, 10, 11].

Based on the results of the experiment, the authors of this article proposed a third mechanism of thermal reduction in-situ in the melt.

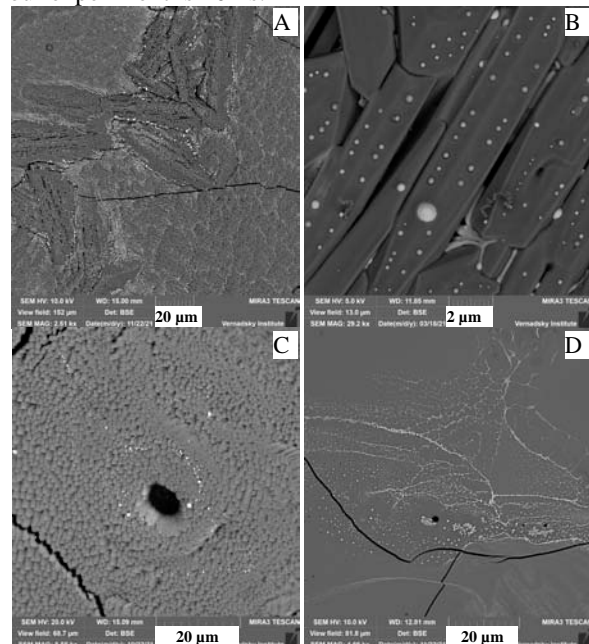
**Experimental methods and technique:** For the experiment a pulsed neodymium glass laser was used. The laser radiation wavelength was 1.06 μm, the pulse duration was 10<sup>-3</sup>s, and the pulse energy was ~600–700 J. The energy flux density was ~10<sup>6</sup>–10<sup>7</sup> W/cm<sup>2</sup>. The 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].

For the experiment, several natural minerals and rocks were selected as targets. The results of the experiment on targets made of basalt glass, crystalline basalt and peridotite were published in the last

publication [12]. Here we present the results with laser “impact” of a target made of olivines with different degrees of iron content (FeO), and pyroxenes. Olivines: chrysolite from Pakistan - 9% FeO, Olivine from Kovdor deposit - 13% FeO and ferrous Olivine from aliwalite - 26% FeO. Pyroxenes: Cr-Diopside and Orthopyroxene.

## Results and discussion:

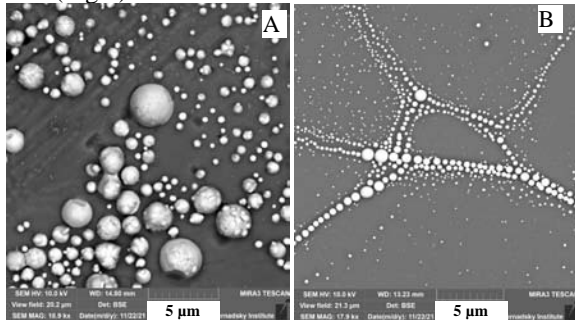
In all targets, after the laser “impact” by scanning electron microscopy, numerous placers of iron nanospherules were revealed (Fig. 1). At the same time, the sizes of some spherules reached the first micrometers (Fig. 2). It should be noted that in the crater of the olivine target, almost all the glass formed during the “impact” was crystallized, also crystallized beads were found everywhere in the products of the ejection from the crater. This may indicate the rapid crystallization of olivine - at the moment of ejection from the crater zone. The duration of the laser pulse in our experiment is 10<sup>-3</sup> s.



**Fig.1.** Images from craters on targets: A) Fe-olivine from aliwalite (26% FeO), B) Olivine from the Kovdor deposit (13% FeO), C) Mg-olivine from Pakistan (9% FeO), D) Ortopyroxen. SEM.

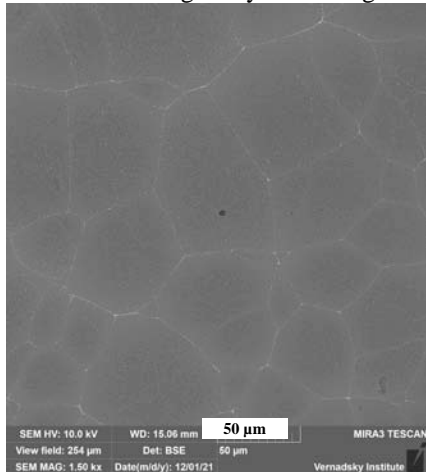
In general, there was an abundant precipitation of nanospherules on all targets, but there were also

variations in the amount depending on the target material and, in particular, on the FeO content. In olivines, placers are more pronounced than in pyroxenes, and in the olivines themselves, the number of nanospherules depends on the FeO content. The thickest and most numerous placers were found in Olivine from aliwalite (26% FeO). In addition, very large varieties up to 5 microns in visible diameter are also noted here (Fig.2).



**Fig.2.** (A) Large heterogeneous metallic iron spherules in the ferrous-olivine target crater (26% FeO). (B) Large spherules of metallic iron in the crater of a Cr-diopside (clinopyroxene) target, here large spherules formed at the junctions of polyhedrons composed of chains of  $\text{npFe}^0$ . SEM.

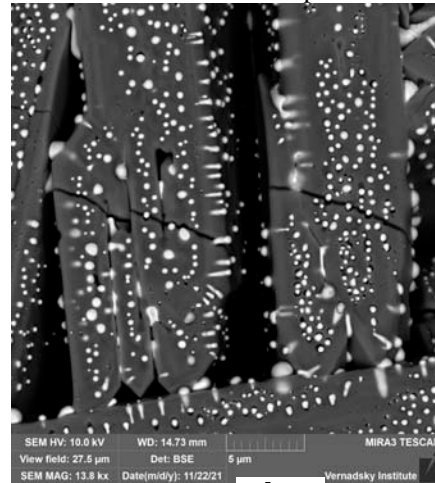
In pyroxenes, crystallization is not noted; here, the crater material is mainly represented by glass. At the same time, trains of nanospherules are represented here by relatively ordered forms close to polygons in the center of which there are chaotic placers (Fig. 3). This probably corresponds to the inhomogeneity in the redistribution of the heat received from the laser and/or from the inhomogeneity of the target material density.



**Fig.3.** Polygons built from  $\text{npFe}^0$  chains in Cr-diopside. Chaotic placers can be traced in the center of such polygons. SEM.

There is also a feature in olivines, apparently, due to the synchronous growth of spherules and olivine crystals (Fig.4.). Here you can see how "holes" with

elongated iron crystals ending in spherical heads appeared on elongated needle-like olivine crystals. Such heads on the surface look like spherules.



**Fig.4.** Needle crystals of olivine with "holes" with elongated crystals of iron. SEM.

#### Conclusion:

Our experiment has confidently demonstrated the possibility of simulating the appearance of  $\text{npFe}^0$  under conditions close to those of a micrometeorite bombardment on the lunar surface. In addition, in our experiment, there were no reducing agents, and also, the results indicate the absence of an evaporation-condensation mechanism. Thus, a third mechanism for the formation of  $\text{npFe}^0$  has been suggested - in situ in the melt by thermal reduction. In addition, the number of placers, their abundance and the size of  $\text{npFe}^0$  may depend on the target material and, in particular, on the FeO content. Fe-olivine contains a large number of placers, as well as large spherules up to 5  $\mu\text{m}$ . Also, different textures (for example, irregular polyhedrons) are noted, which form chains and placers on the surface of the craters.

**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] Pieters C.M. et al. (1993) *J. Geophys. Res.*, 98, 20817-20824. [5] Keller, L., et al. (1998) *In: Proc. 29th Lunar Planetary Science Conference*, Abstract 1762. [6] Noble, S. K., et al. (2007) *Icarus*, 192(2), 629-642. [7] Housley, R. M., et al. (1975) *In: Proc. 6th Lunar Sci. Conf.* 3173-3186. [8] Moroz L.V. et al. (1996) *Icarus*, 122, 366-382. [9] Moroz L.V. et al. (2014) *Icarus*, 235, 187-206. [10] Gerasimov M.V. et al. (1999) *Lab. Astrophys. Space Res.*, 236, 279-330. [11] Sasaki S. et al. (2001) *Nature*, 410, 555-557. [12] Sorokin E. M. et al. (2021) *In: Proc. 52nd Lunar and Planetary Sci.Conf.* #1975.