SURFACE MODIFICATION OF SILICATES BY ION BOMBARDMENT

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Introduction: Similar to solar wind, cosmic rays reach the surfaces of asteroids, meteorites, the Moon, and other bodies devoid of atmospheres and can, together with meteorite impacts, modify the structure and composition of the surface material**.** Silicates are an important constituent of several cosmic bodies and can be contained in these bodies in amorphous and/or crystalline form. Ionization radiation affects not only the structure but also the phase and chemical composition of silicates in star and interplanetary dust and modifies the chemical and phase composition of lunar regolith particles and particles in regolith at other atmosphere free bodies in the Solar System. Proton and He are the most widely spread components of all types of cosmic rays and solar wind. We present the results of irradiation experiments aimed at simulating thus process.

Experiments: We have experimentally examined the redistributionof ^{54}Fe that was preparatorily implanted in amorphous SiO_2 and crystalline Si after their irradiation with accelerated protons and He ions with subsequent thermal annealing. A Fe admixture was introduced into our samples by the ion implantation technique. Fe ions (^{54}Fe isotope) were implanted in the samples at an Extrion/Varian accelerator at room temperature, energy of 85 keV, and a radiation dose of 5.5×10^{13} ion/cm^2. The density of the ion beam was 0.5 μA/cm^2. After a Fe admixture was introduced into the samples, they were additionally implanted by protons (E = 20 keV and a dose of 5.0×10^{16} H+/cm^2) or He ions (E = 40 keV, dose 1.0×10^{16} He+/cm^2) to induce radiation defects. The irradiated samples were annealed in air at 900°C for 7 h. The profiles of Fe distribution in both the original implanted, irradiated and the annealed samples were measured by secondary ion mass spectrometry (SIMS) on a Cameca IMS_4f. The primary beam for analysis was that of O^+_2 ions with an energy of 8 keV.

We have also investigated experimentally the process of chemical modification of crystalline olivine under deuteron irradiation with 1.43-MeV deuterons with fluence (3-8□*10^{16} cm^2) below the amorphization threshold. We used the Rutherford back-scattering (RBS) method with a deuteron beam from electrostatic accelerator operating at the Institute for Nuclear Research of RAS. Irradiations and measurements were made in situ [1]. Deuterons are preferable in the RBS experimental modeling in comparison to protons due to a better mass resolution. Natural
olivine single crystals were taken from alkaline rocks of the Baikal Rift and from the alkaline basalt nodule of Shavaryn Tsaram (Mongolia). To weaken beam induced luminescence in crystals and to decrease the counting rates of the spectrometer, an aluminized mylar film 4 μm thick, was placed in front of the detector. The energy resolution of the detectors was 30 keV and 24 keV. The spectrum processing was made using the BEAM EXPERT software package, which did not require reference samples [1].

Results: We report the results of study of radiation-stimulated redistribution of implanted Fe atoms in amorphous SiO_2 and crystalline Si which were subsequently irradiated by accelerated protons and He ions at temperatures simulating outer space conditions. The main distinguishing feature of the samples after the experiments is determined by different diffusion behavior of iron in amorphous and crystalline materials under the effect of irradiation and heating. This is likely explained by different mechanisms and parameters of Fe diffusion in amorphous and crystalline materials. Conceivably, iron silicides are formed in crystalline Si under the effect of radiation and thermal processes. This mechanism can operate on the Moon in the course of space weathering. As was mentioned in [2] iron silicides were identified in the Dhofar 280 lunar meteorite and in small particles from Apollo 16 lunar regolith samples. These compounds were thought to be synthesized during the impact recycling of lunar rocks at meteorite bombardment.

The modification of crystalline olivine under irradiation with 1.43-MeV deuterons was studied experimentally. The partial destruction of olivine in the surface layer (100–200 nm) was found at a current density of 5–10 μA/cm^2. This effect is caused by ionization and desorption of Mg and Fe atoms at deuteron fluence (3-8□*10^{16} cm^2) which are substantially below the amorphization threshold. It was suggested that the negative charge of the anion group is neutralized by the interaction with the deuterium ions and Frenkel pairs. The loss of Mg has been observed earlier by [3]. with 20 keV proton irradiation of olivine crystals of Allende meteorite. The mechanism of sputtering of the crystalline olivine surfaces under irradiation with H, D, He and Ar ions was studied using of the SRIM program. We also compared the computed estimates on the sputtering of the surface layer of circumstellar dust particles under irradiation by Ar and He ions with the published experimental results. The fluences required for sputtering the crystalline olivine surfaces under Ar and He ion irradiation were calculated. It was shown that sputtering of a nanometer surface layer of crystalline olivine is not selective.

Our experiments demonstrate that cosmic rays and solar wind can significantly modify mineral phases on the surface of bodies devoid of atmospheres. The study shows that the structure and composition of circumstellar dust particles can be modified by ionizing irradiation.

References: [1].Shilobreeva S.N.and Kuzmin L.E. (1998).*Solar System Research, vol.38, N.1, 59-6.* [2]. Nazarov M. A. et al. (2012).*Petrology* ***20*** *(6), 506–519* . [3] Bradley J. P. (1994). Science, 265, 925-929.