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Surface morphological modification induced by low energy ion irradiation

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Abstract

We performed ion irradiation on mineral olivine and ilmenite to simulate ion implantation and sputtering on lunar surface in the present study. The surface morphology and microstructure after ion irradiation was characterized by field emission scanning electron microscopy (FE-SEM).

1. Introduction

Airless bodies of the Solar System, such as Moon and Mercury, are continuously exposed to the bombardments of photons, meteorites of different size, cosmic rays and solar particles (ions from flares and solar wind, a rarefied plasma made of electrons, protons, heavier ions and magnetic fields streaming radially from the Sun). Space weathering is the physical and chemical alteration of surfaces of airless bodies exposed to the space environment. Several irradiation experiments have been performed and shown that irradiation of a few to tens KeV H^+ and He^+ ions can effectively cause amorphization of olivine and enstatite [1, 2, 3]. Irradiation of He^+ or H^+ ions forms bubbles inside the target material and a high dose irradiation deforms surface structures of the target observed on silicates as orange skins [1, 2, 3] or blisters [4]. In the present study, we perform ion irradiation on mineral olivine and ilmenite to simulate ion implantation and sputtering on lunar surface. The surface morphology and microstructure after ion irradiation was characterized by field emission scanning electron microscopy (FE-SEM).

2. Experiments

Nature mineral olivine and ilmenite were chosed as the samples in the experiments. Olivine is one of the most significant rock-forming minerals on Moon, Mercury, S-type asteroids. Ilmenite is composed of titanium and iron oxide, which is the most abundant opaque mineral in lunar rocks. Luobusha olivine (~Fo80) is picked from the formation of dunites in the Luobusha ophiolite, Southern Tibet. Panzhihua ilmenite is sampled from Panzhihua ilmenite deposit in south-western Sichuan Province of China.

$^4He^+$ implantation was performed using LC-4 high-energy ion implanter at the Institute of Semiconductors, Chinese Academy of Sciences. The experiments were carried out at room temperature, in an ion pumped ultra-high vacuum (UHV) chamber with residual pressure of 10^{-7} mbar. The energy of ^4He ions is 50 keV. The irradiation dose is 5×10^{16} ion/cm^2. Beam current density is maintained below 45 μA/cm^2 and ion beam was scanned homogeneously over the target in order to prevent heating during implantation. The rise in surface temperature of the target during irradiation was not measured. We estimate the temperature is no higher than 50 °C. More details are available from [5].

The samples were observed using FE-SEM (Carl Zeiss SUPRA 55 at National Astronomical Observatories, China Academy of Science) before and after the irradiation to examine the morphological changes of irradiated mineral grain. Most of the samples were coated with carbon or gold to avoid charge up effect during the FE-SEM observation and obtain high-spatial resolution image. Some were not coated with any electric conductor but observed with a low accelerating voltage (<3 kV) with SE2 and InLens detectors.

3. Results and discussions

Figure 1 shows the second electron image of irradiated Luobusha olivine. Cleavage is easy to recognize on the surface of olivine grain. But there are no significant changes between origin and irradiated olivine surface. Matsumoto et al. (2013) noted that olivine samples irradiated with He^+ ions at dose of 1×10^{18} ions/cm^2 showed numerous blister structures on their surfaces[4]. The bubble and void have been observed in irradiated San Carlos olivine by TEM. Helium tends to aggregate into bubbles and the diameter of bubble increases with ion dose. Ion dose in the present study is 20 times lower than the

Saturated fluence of $10^{18}/cm^{2}$[6], which should explain no noticeable morphological changes for irradiated Luobusha olivine.

However, the sharp edge of Luobusha olivine grain seems disappears after ion irradiation. We compared the images under low magnification (<100x) of olivine grain before and after irradiation. All origin grains display acute angle and sharp edges while irradiated are smooth and round. And the cleavage crack of olivine surface became wider grooves after irradiation, with the width about 0.5 microns. Both of these could be attributed to sputtering erosion due to solar wind, which had been found in Apollo soil.

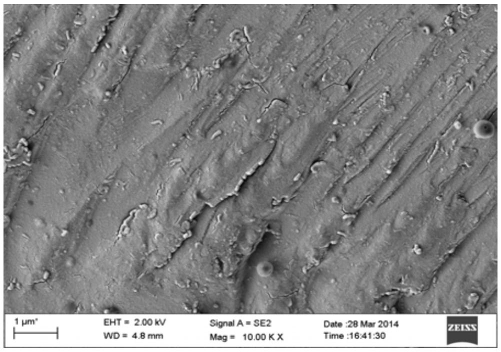

Figure 1: Second electron image of irradiated Luobusha olivine grain.

For ilmenite, morphological changes due to ion irradiate are distinguished with silicates. Irradiated ilmenite did not show blister structure on the surface but all covered with smooth flakes with the thickness about 200 nanometers. Futagami et al. (1993) interpreted that the surface layer flaked off due to gas pressure in large bubbles[6]. However, there are not so many bubbles on the irradiated Panzhihua ilmenite surface but several bubbles are found near the edge of ilmenite grain. Except this, temperature rise during ion implantation may also contribute to the formation of flake layers. The rise in surface temperature of the target during irradiation was not measure and we estimated the temperature is not higher than 50°C. It is impossible for such low temperature to result in any melting or other thermal alteration.

EDS analysis revealed no chemical composition difference between flake and the hos mineral. The smooth flakes are quite different in surface roughness with the host.

In addition, some mineral-like particles are found at the flaked off surface of irradiated Panzhihua ilmenite. But more work is necessary to identify what these particles are and explain how they form.

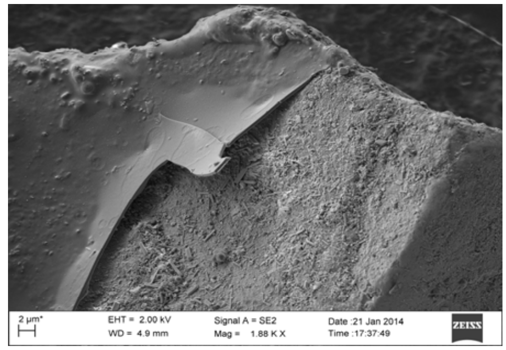

Figure 2: Second electron image of irradiated Panzhihua ilmenite grain.

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