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Simulation of the neutral particle converter of the ARIES-L device

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Abstract

This paper presents the concept of Lunar regolith surface layer composition analysis using solar wind bombardment and registration of the sputtered and knocked out atoms converted into ions with solid-state converters and subsequent registration of ions by high-aperture electrostatic analyzer. Monte Carlo binary collision approximation code is used to calculate angular and energy distributions of scattered and sputtered atoms. Literature data are used for evaluation of charged fractions of scattered and sputtered components and SIMION code is used for calculation of charged particles trajectories in electrostatic deflector. The total sensitivity of the proposed scheme is evaluated.

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Keywords: solar wind; lunar regolith; ion optics; binary collision simulaions.

1. Introduction

Russian spacecraft Luna-Resource, which is designed to land on the Moon, is to be launched around 2017 [http://www.lr.cosmos.ru/devices]. It will be Russia's first mission to land on the Moon since the Luna 24 mission in August 1976. Scientific program of Luna-Resource includes study of solar wind influence on the lunar surface and composition of the lunar soil.

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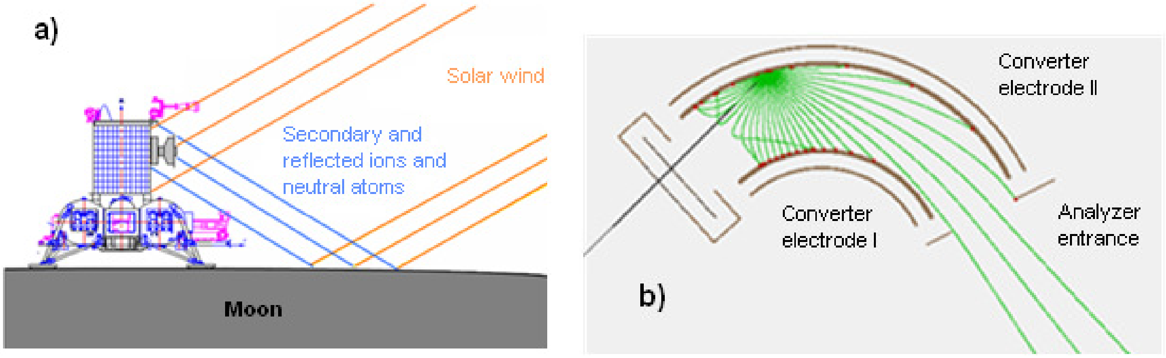
Moon surface composition and structure analysis comprises an essential part of Moon origin and evolution research, which also concerns the Solar System. One of the possibilities of lunar regolith analysis is the direct using of solar wind as natural source of keV ions bombarding lunar surface layer with subsequent analysis of sputtered atoms. Solar wind primarily consists of H^+ (~96%) and He^{++} (~4%) ions with characteristic energies of 1 keV and 4 keV, respectively, and with flux density of 3×10^8 ions/cm^{2}sec [Elphic et al. (1991)].

For analysis of atoms sputtered from the Moon surface by solar wind it is convenient to use a solid-state converter of neutral atoms into ions [Wurz (2000), Wurz et al. (2006)] and high-aperture electrostatic analyzer [Gott et al. (2008)]. Schematic view of the apparatus on the Moon surface is shown in fig. 1.

2. Geometry of analysis

At the planned spacecraft landing place near the Moon pole the angle of incidence of solar wind on the surface is close to 80° (sliding incidence). Part of the atoms sputtered from the surface enters aperture of analyzer and partially is converted into ions. The latter are deflected in electric field and enter an input slit of the analyzer. Thus, the registered flux depends on: a) probability of sputtered atoms to enter an input aperture of the analyzer, b) probability of incoming neutral atoms to be reflected from the converter surface in charged state and c) probability that ions reflected at different angles reach the analyzer slit at several different potentials on converter electrodes. Efficiency of ions registration with MCP can be close to unity and is not considered.



a *b*

Fig. 1. Scheme of measurements: a) position of the analyzer at the apparatus, b) semi-spherical deflector with outer more positive electrode operating as a converter (semi-spherical neutral particle converter and trajectories of ions reflected from the electrode are shown).

The aperture of the analyzer allows registration of sputtered particles within polar angle of ~500 and azimuth angle of ~ 0°.

3. Algorithm of simulations and results

3.1. Computer codes used

Two codes were used in this work. The SIMION8 [http://simion.com/] calculates electric fields for electrodes and ion trajectories in those fields. The SCATTER [Koborov et al. (1997)] is the binary collision code identical to well known TRIM, but improved for the acceleration of calculations and tested many times for different cases of atomic particles interactions with condensed matter. The SCATTER allows calculations of both the energy and angular distributions of reflected and sputtered particles without regard for their charge state.

3.2. Lunar regolith sputtering

Lunar regolith mainly consists of O, Si, Al and Ca (44.6, 21.0, 13.3, and 10.7 %, accordingly), the rest elements represented by Fe, Mg, Na, K, S (4.9, 4.6, 0.48, 0.073 and 0.07%, respectively) [Tsymbalnikova et al. (1975)]. As used for modeling code SCATTER can only account for 5 components in the target, simulations were carried out in two stages at total number of impinging solar wing ions equal to 10^7. For solar wind simulation we used monoenergetic H^+ (~96%) and He^{++} (~4%) ions with characteristic energies of 1 keV and 4 keV, respectively, with total flux density of 3×10^8 ions/cm^{2}sec and incident angles of 80°, 75°, and 70° (sliding angles 10°, 15° and 20°, respectively).

The angle distributions of sputtered particles (fig. 2a) demonstrate that for solar wind the main contribution in sputtering is due to hydrogen. The largest sputtering yield is achieved at the sliding angle of 10° to the moon surface (fig. 2, b).

Calculated energy distributions demonstrate that regolith atoms sputtered by solar wind hydrogen ions have energy below 200 eV, and atoms sputtered by solar wind helium ions have energy up to 1 keV, although their number is much smaller. To accelerate calculations, the energy spectra of sputtered particles was divided into ten intervals.

As particles emitted at different azimuthal, φ, and polar, ψ, angles have different energies *E*, to take it into account the coefficient $S_{el}(\varphi,\psi,E)$ indicating the amount of particles of certain element emitted at certain azimuthal and polar angles with certain energy was used.

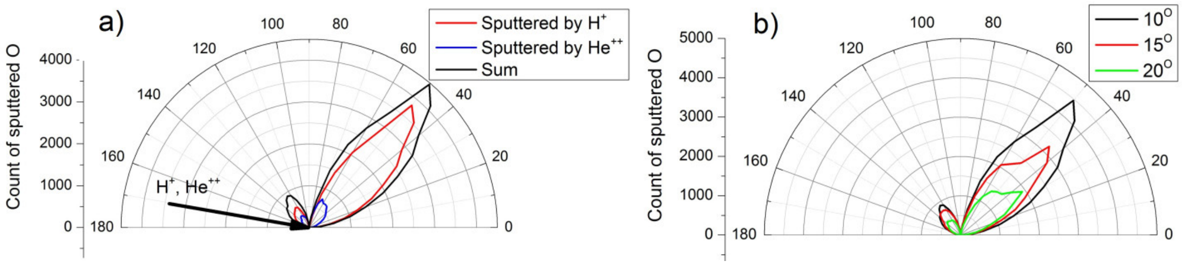


Fig. 2. The polar angle distributions of sputtered oxygen: a) sputtering by hydrogen and helium at the incident angle 80°, b) sputtering at different sliding angles of solar wind ions.

3.3. Model sources

As particles can get to the converter from different areas of the moon surface, to consider the spatial distribution of sputtered atoms over moon surface near apparatus, the grid of sources was set (fig. 3). So, every spot of the grid represents the source from the respective area of the surface.

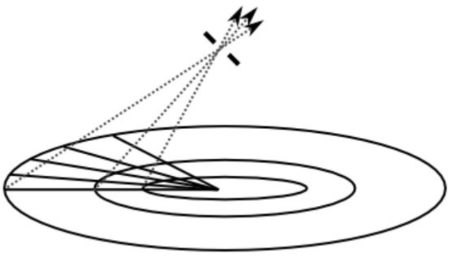


Fig. 3. The scheme of the sources grid. Dotted lines indicate trajectories of particles, which came into the converter from three sources with azimuthal angle φ=0° and different polar angles.

Particles emitted from every source have identical energy and angle distributions derived by SCATTER calculation.

It should be noted that sources with different polar angles correspond to different areas of moon surface irradiated by solar wind. A polar increment is constant, but distance between adjacent sources increases with polar angle decreasing. The source area difference leads to different amount of particles corresponding to different sources. It is taken into account by using an “area” coefficient $S(\psi)$.

3.4. Reflection of particles from converter surface

SCATTER was used to determine parameters of particles reflected from converter surface. The average incident angle of sputtering particle 30° was used. The energy and angle distributions of reflected particles were obtained. The angular distribution of different particles over the whole energy range is close to the cosine one (fig. 4).

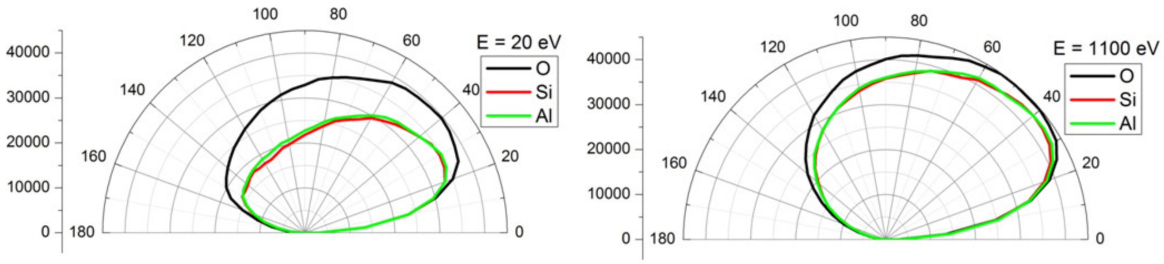


Fig. 4. The angular distribution of O, Si and Al atoms reflected from Au converter surface at incident energy 20 eV (a) and 1100 eV (b).

The energy distribution of reflected particles is close to monoenergetic one. As a first approximation, it was considered that the energy of the reflected particles did not change after collision with the target. The results of this simulation allows to find the reflection coefficient $R_{el}(\alpha,E)$ depending on the particle type, the reflection angle α, and the particle energy E.

3.5. SIMION simulation

The trajectories of particles after reflection and conversion into ions (fig. 1b) were simulated in SIMION for a converter with two torus-shaped electrodes. The coefficient of atoms conversion into the positive charge (ion fraction) was set to be $\eta = 3\times10^{-4}$ for all kinds of impinging atoms. The simulations were performed for different potentials on electrodes I and II (respectively 0, 0 V; 15, 90 V; 30, 90 V; 45, 90 V; 50, 300 V; 100, 300 V; 150, 300 V; 150, 900 V; 300, 900 V; 450, 900 V). Then parameters of ions that get to the analyzer entrance slit were monitored.

3.6. Simulation results

The total current of each regolith element that gets to the analyzer entrance slit can be calculated using proper sputtering S_{el} and reflection R_{el} coefficients for this element, moon surface area S corresponding to one model source with fixes source coordinates, solar wind flux Ψ, can be expressed as:

$$I_1 = \Psi \cdot S(\psi) \cdot S_{el}(\varphi,\psi,E) \cdot R_{el}(\alpha,E) \cdot \eta \,. \tag{1}$$

Summing currents from individual model sources over moon surface (see fig.3); we obtain the total current for different elements and the total current of all particles. The maximum current is achieved when the angle of incidence of solar wind is 80°, due to the larger sputtering coefficient in this case. The data for different values of converter electrodes potentials for the incident angle of 80° is shown in Table 1. The maximum current matches to the potentials at the converter electrodes, which are equal to 30 and 90 V, correspondingly.

Table 1. The current on the entrance slit of the energy analyzer at different converter electrodes potentials for the solar wind incident angle of 10°.

Potentials, V		The current, ions/sec			
		O	Si	Al	All elements
0	0	50.1	9.9	9.9	83.6
15	90	50.7	10.9	7.6	80.6
30	90	75.4	17.7	14	126.5
45	90	73.4	16.5	13.7	122.9
50	300	11.9	4	2.6	22.6
100	300	15.2	5.1	3.3	29
150	300	17.9	6	4.1	34.5
150	900	1.8	0.4	0.2	2.7
300	900	2.3	0.4	0.3	3.5

4. Conclusions

The sensitivity of ARIES-L device designed to investigate the effect of the solar wind on the lunar surface and the composition of the lunar soil is roughly estimated. The simulation of this device’s neutral particle converter operation is performed using the computer code SCATTER for calculating of energy and angular distributions of sputtered from lunar surface under the solar wing impact and scattering at the converter surface. To calculate the total flux of different sputtered regolith atoms, which can reach convertor surface from the moon surface near apparatus position, the model of the surface source of sputtered particles is proposed. The partial contribution of different regolith atoms in total incoming flux is evaluated. The converter electrodes potentials effect on the ion flux at the analyzer entrance is also investigated with SIMION code and optimal value of 30 and 90 V is obtained.

The probability of atoms conversion to positively charged ions at Au converter surface is set to be equal (3×10^{-4}) for different atoms in the energy range of sputtered atoms up to 200 eV. This is a very rough estimate, corresponding to the average value of secondary ion-ion emission coefficient. Unfortunately, the data on conversion coefficients for regolith atoms (O, Si, Al and others) on Au surface are unknown. This may be the main error in the estimation of converter efficiency. It is also necessary to take into account that the real relief of lunar surface can be very rough, which influences parameters of both scattering [Bandurko et al. (1990)] and sputtering [Roth (2012)]. While in our calculations, only smooth surfaces have been considered. This also may be the reason of overestimation of obtained maximal ion flux ($\sim10^2$ s^{-1}).

In general, the main result of this work is the development of global algorithm for estimation of sensitivity of detecting the composition of cosmic bodies using solar wind as a source of analyzing beam and solid state targets converting neutrals to ions.

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