MODELLING OF HELIUM IMPLANTATION INTO ANALOGUES OF LUNAR MINERALS

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Key words: *regolith, solar wind, plasma, helium, implantation*

A process of helium implantation into minerals typical for a lunar regolith is investigated. Samples of volcanic glass (obsidian), irradiated in laboratory conditions by helium plasma in pulsed mode with kinetic energy of ions of about 1 keV were investigated. Exposition time was varied within of 0.3-1.5 μs, thus the temperature of a sample surface at the moment of each pulse action did not exceed of 100°C. The density of helium plasma was estimated as 10^{12} atom cm^{-2} μs^{-1}. The implantation factor of helium into obsidian is low and equal of 3 %.

Introduction

Concentration of the trapped noble gases in particles of lunar regolith depends on chemical and mineral structure of particles, degree of a regolith maturity (lattice defects caused by radiation), and the particle's sizes [1-6]. Concentration of the implanted helium in impact glass or volcanic glass and in major minerals depending on their structure may differ as large as by two orders of magnitude. Selective enrichment depending on mineralogical structure leads to non-uniform regional distribution of concentration of helium isotopes in lunar regolith [7, 8].

Solar wind (SW) is a complex phenomenon characterized in many parameters [9-12]. The major task was research of interaction of helium plasma with terrestrial analogues of lunar minerals and rocks in laboratory conditions. One of research problems is to define of implantation factor (accumulation) of ions, and also to study dependence of that coefficient on ions' energy and material properties.

Materials and techniques

Radiation treatment of samples was to carry out with «plasma focus» PF-5M (IMET of the Russian Academy of Sciences) with energy of 5 kJ with helium as working gas. This device represents the two-electrode sputter-ion unit in which the phenomenon «not cylindrical Z-pinch» [13] is observed. The schematic diagram and photo of device PF-5M are presented in fig. 1.

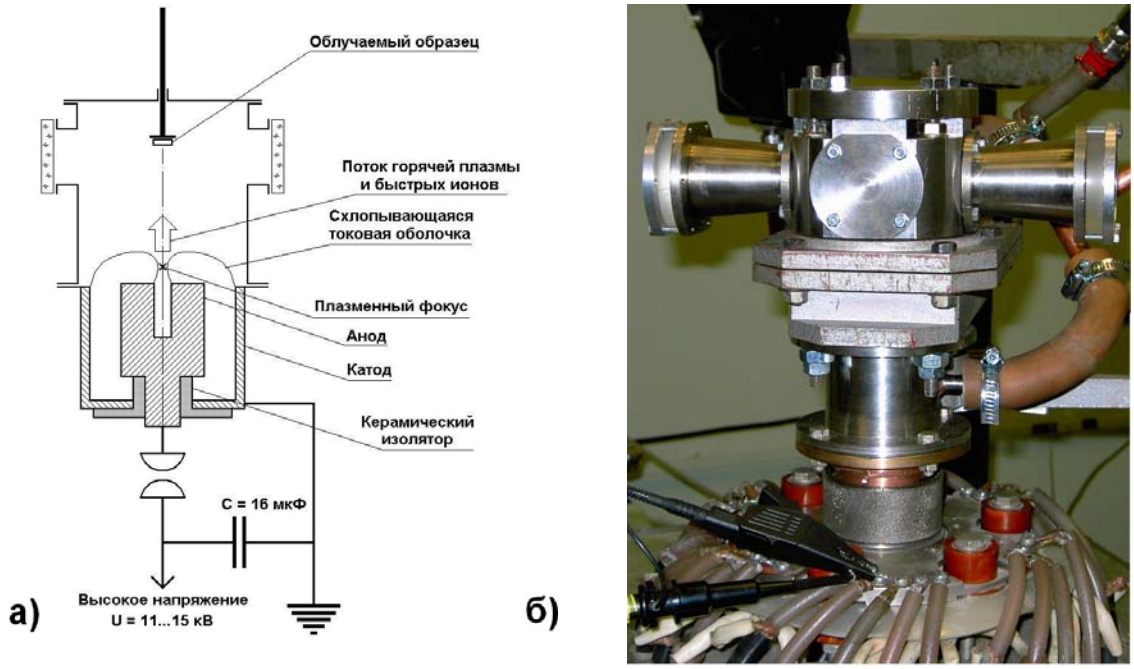

Fig.1. The schematic diagram (a) and photo (b) of device PF-5M

Prominent feature of the device of a given type is formation during the high-voltage discharge near to the anode of the vacuum chamber of dense ($\rho \leq 10^{19}$ particles cm^{-3}), hot (T_i, $e \leq 1$ keV) plasma pinch which moves towards the cathode with a speed of 10^7 cm s^{-1} and with average kinetic energy of

ions (in our case of helium) of $W_i \sim 1$ keV. Temperature and density of plasma in process of its advancement along an axis of the sputter-ion chamber decreases. Speed and the longitudinal size of a pinch ($l \sim 1$ cm) do not vary. Thus, the surface of the sample located on a way of a plasma pinch, is exposed to short-term pulse influence of hot plasma (pulse time for device PF-5M is $\tau \approx 0{,}03$ μs), and energy of interaction of plasma with a target surface strongly depends on the distance which pinch has overcome from the moment of its formation. In our experiments, to modeling of Solar Wind conditions, the distance from the anode of the device to a target has been increased (L = 30 cm), and charging voltage has been reduced down to 11 kV, that corresponds to 970 J. Thus, the temperature of a target surface did not exceed of 100°C.

As a material of targets for the first experiments it was chosen obsidian - rock with amorphous structure. Samples of obsidian were cut in the form of cubes of 5×5×5 mm in size which have been fixed in the holder in the vacuum chamber of PF-5M so, that the side directed to the anode was exposed to the basic irradiation. Thus, the area S of irradiation was 0.5×0.5 cm^2. The irradiation pulses number was varied from 0 (not irradiated, check sample) up to 50 pulses. Maximum total time of an irradiation was of t = 1.5 μs. Further the irradiated samples were taken from plasma device and were located in dumping device of extraction vacuum shielded chamber (FTI, Russian Academy of Sciences), which has been included in a line with a mass spectrometer (MS). The system is designed so, that contains the block of absorbers (getters), neutral to helium and active to chemically active components, which are segregated from samples together with helium. Extraction temperature at which samples of obsidian melted was 1200°C. Heating time was 30 minutes. The scheme of extraction device is shown in fig. 2. The two-beam magnetic resonant mass spectrometer [14, 15] in a mode of the low permission was used.

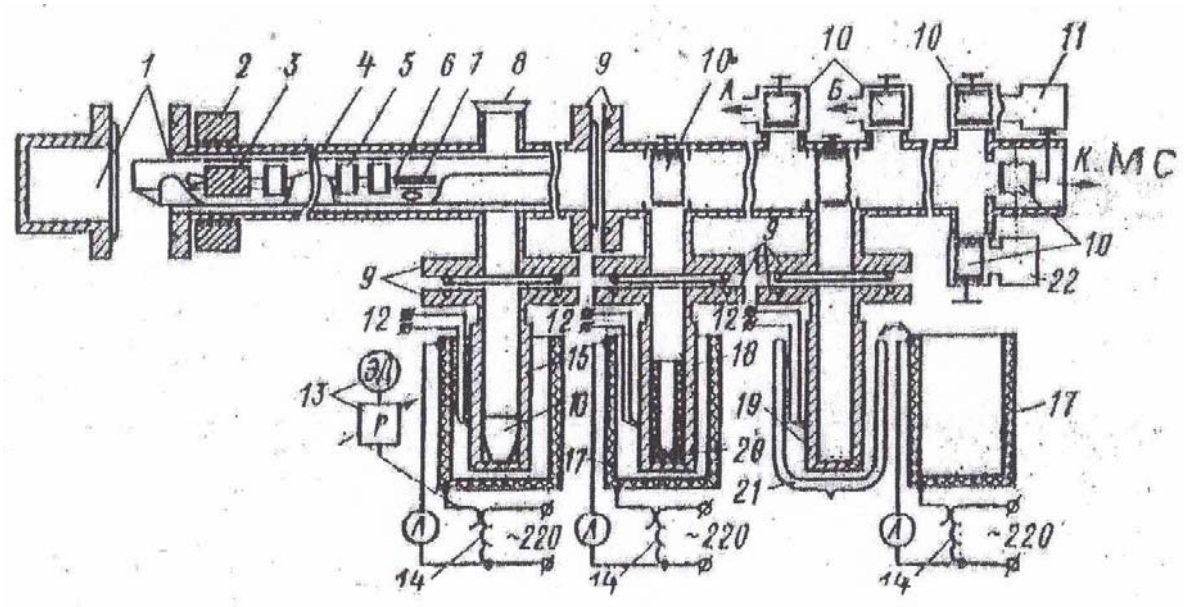

Fig.2. The scheme of all-metal shielded chamber for extraction and clearings of the helium segregated from samples: 1 - butt joint for inserting of samples; 2 - an electromagnet; 3 - a magnetic pusher; 4 - the dumping device; 5 - the cartridge with cells for samples; 6 - thermo-insulation of cutoff plate; 7 - cutoff plate; 8 - inspection window: 9 - connecting flanges; 10 - high-vacuum valves; 11 - the manometrical gauge; 12 - thermocouples; 13 - the electric motor with a reducer; 14-autotransformers; 15 - the case of the vacuum electric furnace; 16-crucible; 17-electric heating units; 18,19 - cases of titanic and coal getters; 20 - glass for titanic getter; 21-Dewar bottle; 22 - additional volume. Connection points of high-vacuum and forevacuum pumps are shown by arrows with indexes of A and B. The place of vacuum connection of extraction chamber with the mass analyzer of mass spectrometer is shown by an arrow with index MC

Eight samples have been investigated in total: one not irradiated (check sample); five samples without any special preliminary treatment of a surface, but with various time of an exposition; two samples with the polished one side of a cube and with various time of an irradiation. All samples have been focused by an irradiated side (both polished, and not polished) to the anode.

Results, calculations, models

The results of measurements and some calculations are shown in tab. 1. The mass of samples (a column 4, tab. 1) considerably varies. The area of an irradiated surface (the area of one side) is accepted constant and equal S = (0.5×0.5) cm^2. The helium segregated at heating of the sample, has various nature. It is background helium ("memory" of an extractor from the previous experiences); the helium formed in obsidian because of decay of natural uranium and thorium; the helium trapped from environment during obsidian formation, and also the implanted helium as a result of an irradiation of samples. It is considered, that concentration of background helium He_{back} which has been not connected with irradiation remains constant value as a first approximation, and concentration variation of helium (He_{impl}) in different samples is caused only by the time variation of an exposition *t.* In this case helium concentration variation depending on exposition time variation may be presented as

$$He_{total}=He_{back}+He_{impl}t, \quad (1)$$

where He_{total} is helium total. The data received are shown in tab. 1 (columns 3 and 6).

Table 1

Results of measurements and calculations*

Sample	Impulses number, N.	Time exposition (*t*), μs	Mass (m), g	^4He, 10^{11} atom/g	^4He, 10^{11} atom/cm^2
1	2	3	4	5	6
1	Non-irradiation sample	0	0.406	5±0.85	8±1.1
5	10	0.3	0.412	5.9±1.0	9.6±1.4
2	20	0.6	0.490	7.35±0.95	14±1.4
3	30	0.9	0.439	6.95±1.4	12±1.9
4	40	1.2	0.473	12.3±1.3	23.2±2
6	50	1.5	0.355	not measured	not measured
11	9	0.27	0.411	10.4±1.0	17.2±1.4
12	20	0.6	0.403	4.9±1.5	8±2

*Samples № 11 and 12 with the polished side

Results are shown in fig. 3 where experimental points are numbered according to tab. 1.

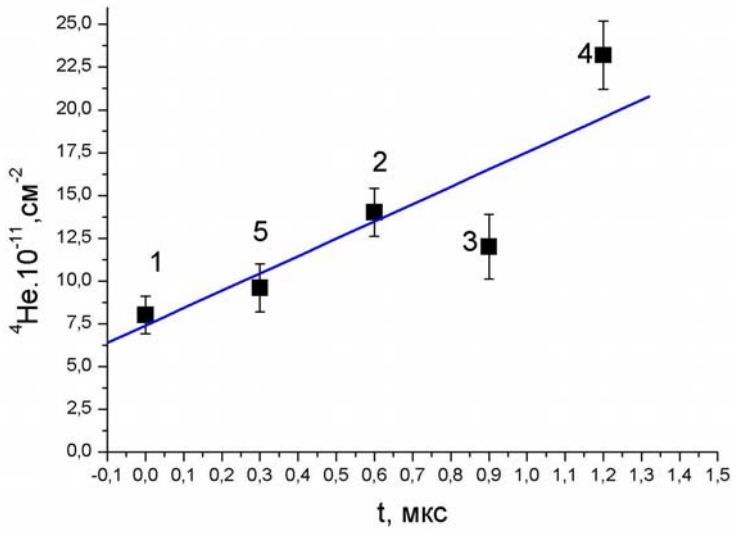

Fig.3. Dependence of the implanted helium quantity on exposition time of samples (tab. 1)

Taking into account dimension of axes is:

$$^4He\times10^{-11}= (7.4\pm0.94)+(10\pm1.6)t, \quad (2)$$

where t is microseconds, ^4He is in units of atom cm^{-2}.

Thus, the average value of background helium He_{back} is 7.4×10^{11} atoms per surface unit. The error is equal approximately 15%. The density of stream F_I of the implanted helium according to (2) is estimated to 1×10^{12} atom cm^{-2} μs or 10^{18} atom cm^{-2} s. The error is also about 15%. It is to be noted, that random errors of MS-analyses are included only. The correlation coefficient is R = 0.9, i.e. is high enough. Background helium is normalized by mass of the sample. Thus, $He_{back} = 4.6\times10^{11}$ atom g^{-1} (1 cm^3 (STP) g^{-1}) with an error of ≅ 15 %. Thus, natural helium in the investigated obsidian is $\leq 4.6\cdot10^{11}$ atoms per gram. Subtraction of background helium reduces the resulted value approximately twice.

Summary

Models and computer calculation are offered to identify natural (constant) and implanted (variable, time-dependent expositions), helium components. For model it is necessary to use some samples with various time of an exposition. This circumstance allows lowering a random error of a stream of implantation F_I. The quantity of the implanted helium can be expressed by implantation coefficient K which is equal to the relation of implanted helium F_I to a density of helium plasma stream F. This coefficient is:

$$K = \frac{10^{12}}{3{,}3\cdot10^{16}} = 3\cdot10^{-5} \quad (3)$$

Thus, the helium implantation coefficient K for obsidian with energy of ions $E \approx 1$ keV and temperature of the sample of about 100°C is equal 3, that is less, than 0.01 %.

Distinct dependence of quantity of the implanted helium on exposition time is observed. Experiment has shown that even rather soft parameters of an irradiation of the material, close to parameters of a solar wind on distance of a terrestrial orbit, have appeared quite sufficient for the implantation of necessary concentration of helium accessible to the analysis.

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Electronic Scientific Information Journal "Vestnik Otdelenia nauk o Zemle RAN" № 1(27)'2009
ISSN 1819 – 6586
Informational Bulletin of the Annual Seminar of Experimental Mineralogy, Petrology and Geochemistry – 2009
URL: http://www.scgis.ru/russian/cp1251/h_dgggms/1-2009/informbul-1_2009/planet-5e.pdf

Published on July, 1, 2009