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Study of the Main Geochemical Characteristics of Phobos' Regolith Using Laser Time-of-Flight Mass Spectrometry

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Abstract—The peculiarities of the airborne LAZMA instrument applied for the measurement of the isotopic and elemental composition of Phobos' regolith by the method of laser time-of-flight mass spectrometry are discussed. These measurements may confirm the assumptions that the material of Phobos is an initial substance with a composition close to carbonaceous chondrites, from which the Earth was formed. The results of the measurements may also confirm the original mechanism of the formation of the anomalous absorption of Phobos' regolith suggested in this study. The obtained results regarding the elemental composition of the regolith may contain information about the conditions of the formation of Phobos, as well as provide information about it age. The scientific tasks of individual experiments and ways for their realization are considered in the paper. A detailed description of the airborne instrument and the principle of its operation is presented. The analytical and technical characteristics of the instrument and the peculiarities of constructive decisions are given. Data on the most important functional assemblies of the instrument, the development and transmission of scientific information to the Earth, are considered. The mass spectra presented in the paper were obtained by airborne instruments during the course of their laboratory test and the selection of the operating regime. It is demonstrated that the LAZMA instrument is the first version of the original next-generation airborne instrument constructed at the Space Research Institute and patented in Russia.

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INTRODUCTION

A detailed and full-scale investigation of the origin of Phobos as presumably an initial body formed from protoplanetary nebula, which also was the main substance for the formation of the planets of the Solar System, is an important problem in modern planetology (Sagdeev et al., 1988). The study of such a multifactor and large-scale problem requires the solution of a large number of different tasks, including numerous complex investigations, the number of which will increase with time. Because of this, it is practically impossible to realize such a program within a single mission; however, there is the real possibility of extracting the main most important tasks from each planned mission, in which case their number will significantly decrease. For this purpose, it is necessary to perform the strict and objective selection of the scientific tasks and exclude those of secondary importance. Only after such a selection will the planned space mission become concrete and informative. In this connection, according to the accumulated experience in the preparation of programs for the investigation of Phobos, the planned *Phobos-Grunt* mission should first of all provide for the obtainment of information on the following important characteristics of this mysterious space object: (1) the origin and age of Phobos; (2) its place in the general classification of small bodies of the Solar System; (3) the elemental, isotopic, and mineralogical composition of its regolith; (4) peculiarities of the optical characteristics of its surface and the reason for the observed anomalies; and (5) previously unknown processes occurring under the influence of external factors.

Such information should be related to basic geochemical information, but it may be considered as astrochemical or astrophysical as well.

Important information regarding Phobos' past is the most completely contained in the "stone chronicle" of this space body. It may be the most completely obtained during the study of the elemental, isotopic, and mineralogical composition of the regolith, including its surface layer. Methods providing for direct measurements of the main characteristics of the studied matter should be considered as the most reliable, informative, and optimal for such kinds of investigations. Direct observations may be remote as well, but, for example, by contrast to the optical methods, they should provide for the direct registration of the material or effect.

The direct registration of the material under the conditions of the vacuum of space may be provided by an airborne mass spectrometry apparatus, which, as it was mentioned above, may be remote in some cases.

Such an approach was realized in the first Phobos mission (1988–1989), during which the remote airborne complexes, namely, the LIMA-D laser distant time-of-flight (TF) mass reflectron (Managadze et al., 1987) and DION secondary ion mass analyzer (Managadze, Sagdeev, 1987), were the instruments that could provide for the obtainment of basic information of abovementioned tasks.

Let us consider some peculiarities of laser instruments. Currently, laser time-of-flight mass spectrometry is one of the most precise and sensitive methods of the analysis of matter. Instruments of this class provide for the synchronous registration of all elements in a sample; do not require sample preparation; provide fractionless evaporation, atomization, and ionization of a sample; and have high analytical characteristics (Managadze G.G., Managadze N.G., 1997).The LAMMA-500 serial mass spectrometer with a laser microprobe was created by the Leybold–Heraues group in 1977 to solve some analytical tasks under laboratory conditions. In 1980, the same group started the production of the more perfect LAMMA-100 mass spectrometer. Later, TF laser mass spectrometers, such as LIMA (KRATOS Analytical) and EMAL (PO Electron), were created. It was demonstrated during the exploitation of these instruments that a number of their characteristics ideally fitted the space conditions of the measurements. Because of this, two variants of airborne instruments were suggested in 1980 during the formation of the complex of the airborne scientific apparatus for the International Project Phobos: first, the LIMA instrument with a weight of ~7–8 kg, and then LIMA-D, a remote instrument with a weight of 84 kg.

Before that time, the TF laser mass spectrometer had not been applied as a space instrument. All the more so, there was no instrument like the LIMA-D that could perform remote measurements. The LIMA-D instrument suggested by researchers of the Laboratory of Active Diagnostics of the Space Research Institute and created in cooperation between the USSR, Germany, Austria, Bulgaria, Finland, and Czechoslovakia possessed unique possibilities and analytical characteristics, in particular, the possibility out of carrying out element and isotopic analysis from the flight apparatus at a distance of 70 m.

After the forced stoppage of work on the poorly known *Phobos* mission (Sagdeev, Zakharov, 1989), the works on the creation of contactless laser mass spectrometers continued. This allowed us to develop the miniature TF mass spectrometer LAZMA (Managadze, 1992; see also Managadze, 2009), a next-generation instrument, in which a high sensitivity was combined with an optimal mass resolution. Being an analog of the LIMA-D, the LAZMA instrument was 40 times smaller than the prototype by weight and size characteristics, but its sensitivity and mass resolution were higher by factors of 100 and 2, respectively (Managadze, Shutyaev, 1993).There are the grounds to expect that in the closest future the most important information on space objects and the processes occurring on them will be obtained with the help of airborne mass spectrometric instruments with a high sensitivity being able to perform direct measurements of the elemental, isotopic, and molecular composition of the environment. The application of mass spectrometric instruments of such a class for the study of the planets and small bodies of the Solar System will provide for the study of their chemical composition, as well as reliable information on the evolution of such bodies and the processes that occurred on them many millions of years ago.

Currently, the abovementioned facts attract the special interest of researchers to mass spectrometric instruments of the airborne type for work in space. In particular, the LAZMA and the MANAGA-F TF mass spectrometer applied for the determination of the mass composition of ion flows may be attributed to such next-generation instruments. Both instruments have the analytical characteristics necessary for the solution of important scientific tasks from space stations and loading modules.

SCIENTIFIC TASKS OF THE EXPERIMENT

As was mentioned above, the LAZMA experiment is applied for the solution of the most important tasks of the *Phobos-Grunt* mission connected with the history of the origin of this poorly studied satellite of Mars. This is clearly evident from Table 1, in which the main scientific tasks of the mission are given and the methods of their solution are presented.

In the consideration of these tasks, it should be noted that the tasks being solved with the LAZMA instrument may be significantly widened if we compare the results with those obtained by the MANAGA-F instrument. The combined analysis of the data obtained by these two mass spectrometers will allow us to significantly increase the reliability of the results of these measurements.

The necessity of comparing the obtained results in this case comes from the fact that LAZMA and MANAGA-F were initially thought to be mutually complementary instruments. They were proposed and created by the same team in the Laboratory of Active Diagnostics of the Space Research Institute.

Let us turn back to the scientific tasks described in Table 1. Considering the scientific tasks presented in the table, we should take into account that their synchronous solution will be difficult within a single mission. This results from the fact that a concrete regolith sample, for example, may not contain the microadmixtures of heavy elements necessary for the solution of point 5 of the task. However, in the case of the successful transport of the sample under the laser beam, the spectra should be registered, and this will allow us to obtain solutions for the main tasks considered in points 1–4 with a high probability. It is also necessary

Table 1. Scientific tasks solved with the help of the LAZMA instrument in the *Phobos-Grunt* project

No.	Scientific task	Method of the solution
1	Determination of the type, class, group, and subgroup of Phobos' regolith material within the general meteorite classification	Mass spectrometric measurements of the relationships of the main elements in the regolith composition (C, O, Mg, Al, Si, Ca, and Fe) are performed. These data are used for classification
2	Study of the regolith's mineralogical composition averaged by the surface and depth	Qualitative analysis of the major element composition without a standard is performed. The spectra are compared with the spectra of minerals from the database
3	Study of the isotopic anomalies of the A, B, and C classes for stable isotopes	Measurement of the isotopic composition of matrix elements of the regolith after their averaging allows us to determine the anomalies of stable isotopes exceeding ~1%
4	Study of the local surface and volumetric regolith heterogeneities and the determination of their characteristic sizes	Fine shift of the beam with a step of ~50–100 μm over the surface and ~1–3 μm to the depth will allow us to reveal these heterogeneities. It is important that the instrument configuration allow us to perform the analysis by layers without depth limitation
5	Study of the agglomeration temperature	Direct qualitative mass spectroscopic measurements of microadmixture concentrations for Pb, Bi, Tl, Zn, and Cd will allow us to determine this value
6	Quantitative measurements of the presence and volumetric distribution of coupled water	Quantitative mass spectroscopic measurements of hydrogen in the low-energy range at the deepening of the focus plane and high-power density
7	Search for carbon excess providing an anomalously low albedo of Phobos' regolith in the thin surface layer	Comparative element analysis of regolith samples during their collection from the surface and depth
8	Study of the unstable isotopes formed under the influence of cosmic rays.	Mass spectrometric measurements of the minor components; mass resolution allows us to register these isotopes and perform a quantitative estimation of their concentration

to take into account that the observation of new, not preliminarily planned effects is not excluded, and such effects are usually of significant interest.

It might be expected that a comparison of the results obtained by LAZMA and MANAGA-F will allow us to explain the reason for the anomalously high absorption of Phobos' regolith and determine the mechanisms of the formation of this effect. The observed anomalous absorption of the regolith was explained (Managadze et al., 2007) by the enrichment of its surface layer with carbon occurring in the composition of the material of Phobos. This paper suggests the original mechanism providing for such enrichment. This mechanism is based on the anomalous properties of carbon, which is able to form secondary ions with low energy and negative polarity under the influence of ion bombardment (Cherepin, 1992). It is known that the surface of Phobos gets a positive potential of 5–6 V under the influence of UV solar radiation. That is why a significant portion of the secondary carbon ions can overcome the potential barrier and "return back" to the surface.

The suggested mechanism under the conditions of the environment of space may be indirectly confirmed by the laboratory modeling of the optical characteristics of Phobos' surface performed in (Starukhina, Shkuratov, 1997). According to the results of this study, analogs of carbonaceous chondrites provide spectra similar to those of Phobos only after they are covered by carbon film with a thickness of 130 nm.

It is necessary to mention that the enrichment of carbon appearing in the secondary ion processes in a thin surface layer with a thickness of 1 nm may be redistributed to a depth of up to 1–3 cm under the influence of micrometeoritic bombardment. In this case, the carbon excess may be registered by LAZMA, whereas the high carbon concentration will not be revealed in the mass spectra obtained by MANAGA-F from a distance, as well as after the landing because of the negative charge of the generated secondary ions of this material. Consequently, such results obtained in two independent measurements will significantly confirm the capability of the suggested mechanism, resulting in the anomalously high light absorption by the surface of Phobos' regolith.

DESCRIPTION OF THE EXPERIMENTAL TECHNIQUES

The LAZMA Laser TF mass reflectron shown in Fig. 1 is applied for the elemental and isotopic analysis of the surface regolith layer of atmosphere-free space bodies, on which the landing of a spacecraft is possible.

The method of investigation, as evident from Fig. 2, includes the following: after loading the regolith sample onto a rotating disc at a given distance corresponding to the focal length of the laser radiator, the impulse action proceeds on it with a duration of 7 ns and a power density of ~10^9 W/cm^2. Such an action results in

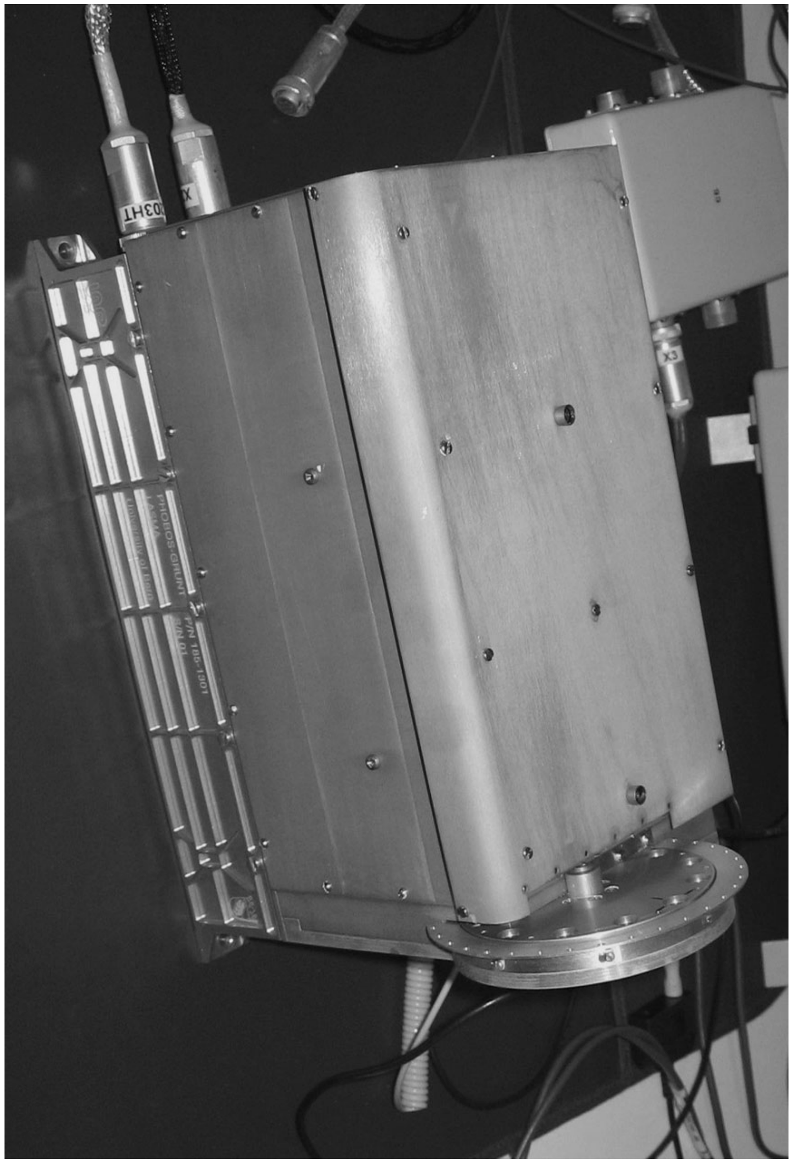

Fig. 1. LAZMA mass spectrometer.

the complete atomization and ionization of the sample material and strong overheating from the ejection of the formed ions in the composition of the target in the form of a plasma torch. The high-speed ions emitted from the formed plasma in the regime of free scattering enter into the time-of-flight mass analyzer separated by the flight time according to the formula

$$T = L(M/2E)^{1/2},$$

where T is the flight time of ions with an energy E and a weight M over the field-free distance L. Ions separated in time after their reflection in the decelerating field of the electrostatic reflector are registered by a secondary electron multiplier (SEM). From the exit of the SEM, the signal comes to the high-speed analog–digital transformer (ADT) and is saved in the instrument's memory as a single spectrum.

The weight of the ions may be determined by the flight time with a high degree of accuracy. A chemical element may be recognized according to the distribution and amplitude of the isotopes, and then the intensity of the mass peaks of the elements may provide the chemical, elemental, and isotopic composition of the studied material. The relationships between the main or matrix elements allow us to reliably determine the type of meteorites to which Phobos may be related and evaluate the similarity of its composition to the protoplanetary nebula and its age. Furthermore, the analysis of the relationships between the intensities of the mass peaks of individual elements by the corresponding data of preliminary calibrations included in the

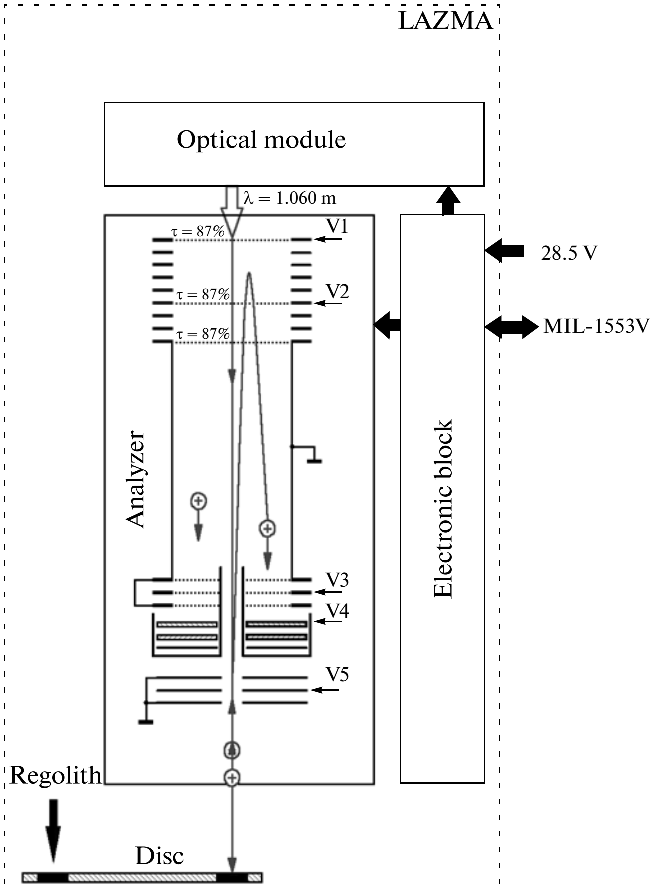

Fig. 2. Functional scheme of the LAZMA mass spectrometer.

spectrum database may allow us to determine the mineral providing the mass spectrum registered by the instrument, i.e., determine its mineral composition.

The most important instrumental peculiarity for the considered task is that the laser source may provide for the synchronous release of all elements of the periodical system with a practically equal probability during a single action and, consequently, their registration with equal probability and the high permitting ability of the analyzer (Managadze, G.G. and Managadze, N.G., 1999).

Table 2. Electric characteristics of the LAZMA instrument

Number of power supply feeders (+28.5 V)	1
Successive interface MILSTD-1553V	1
Number of functional commands	0
Number of telemetric channels	0
Average power consumption of the feeder, W	5
Number of UKS	14
Volume of the internal memory of the instrument, MB	4
Volume of the digital massif, MB	4
Information volume, MB/h	2

The instrument allows us to study materials with variable physical properties, including finely dispersed powder. The development of the spectrum after its transmission to the Earth will proceed automatically by the preliminarily created program. The application of the disc with precise movement will allow us to control the position of the laser beam, which may be moved over the surface of the sample to study local heterogeneities. The instrument also allows us to perform the surface analysis with a resolution of 30–50 μm. The configuration of the instrument provides the unique possibility of the layered analysis of the sample up to a depth of 1 mm.

The LAZMA instrument was created by joint efforts of researchers from the Space Research Institute, University of Bern, and SKB KP of the Space Research Institute. The contribution to the instrument's design was made by researchers of the Laboratory of Active Diagnostics of the Space Research Institute, namely, A.I. Kuznetsov, L.V. Romanova, and D.A. Moiseenko. The electronic block was developed and constructed by researchers from the University of Bern, namely, J. Jürg, D. Piazza, U. Jenzer, and D.A. Abplanalp. The development of the functional mechanisms and the construction of the instrument were performed in the SKB KP of the Space Research Institute under the technical leadership of A.S. Belousov and the leader of the instrument B.T. Karimov with the participation of V.A. Kotlov.

INSTRUMENT DESCRIPTION

Main Characteristics of the Instrument

The LAZMA instrument has the following main technical characteristics:

Mass range, 1–250 amu.

Resolution, 380.

Relative sensitivity in one spectrum, 10^{-4}.

Absolute detection limit by mass in a single analysis, 5×10^{-14} g.

Speed of the instrument for 1 amu, 200 ns.

Dynamic range, 10^5.

Rate of ADT registration, 15 ns.

Accuracy, 10%.

Weight, 2.6 kg.

The main electrical and informational characteristics of the LAZMA instrument are given in Table 2. The instrument consists of the following functional assemblies (Fig. 2): optical module, analyzer, unit receiving regolith samples, and electronic block.

Optical Module

The optical module of the LAZMA instrument includes the following: a Nd:YAG laser with a wavelength of 1.06 μm, an optical system consisting of a focusing objective, an attenuator of laser radiation, and an assembly for the control of laser radiation and synchronization.

The Nd:YAG laser with a passive Q modulation has dimensions of $2.5 \times 3 \times 13$ cm and provides a release energy of 20 mJ at an impulse duration of 7 ns. The maximal laser frequency is 0.1 Hz. Its weight is 100 g without a power supply unit and ~700 g with the power supply unit and optical system. The serviceability of the laser is retained within a wide temperature range from −50°C to +50°C. The service life may reach 1 000 000 impulses or four months of continuous work, which will be sufficient within the safety margin to fulfill its tasks.

The optical system carries out the function of adjustment according to the energy and space characteristics of laser radiation on the target surface.

The attenuator of laser radiation is an elecrooptical shutter based on a lithium niobate crystal and allows us to change the energy of laser radiation within the range of 40 dB gradually or with a small step of discretion that is necessary for the accurate adjustment of the laser ion source during the production of singly charged ions, as well as for the compensation of the energy change of the laser radiator depending on the temperature.

The focusing system provides for the concentration of laser radiation to a spot with a diameter of 30 μm on the target surface at a power density of 10^9 W/cm^2 and a distance of 18 cm from the output lens of the objective. Such a spot size is optimal for time-of-flight mass spectrometry and allows us to analyze the composition of small heterogeneities on a sample's surface, which may provide additional information on the regolith's homogeneity.

The total dimensions of the optical system, including the power supply unit, are $15 \times 6 \times 7$ cm for the summer modification of the instrument.

The development and construction of the optical module was carried out at the Stel'makh FGUP NII POLYUS under the leadership of M.B. Zhitkova.

Analyzer

The analyzer of the TF mass spectrometer is an axially symmetric construction (Fig. 2) consisting of an electrostatic reflector and detector.

Ions formed due to the action of the laser passing the first field-free area with a length of 15 cm enter the reflector in which the spatial–time focusing of the ions in the detector plane is performed.

The dispersal of the initial speeds of the ions formed in the same source plane is the main physical reason limiting the instrument's resolution. In the case of an anomalously high dispersal of the initial energies of the ions (tens of eV, as typical for laser sources), the instrument without the reflector cannot obtain the resolution of practical interest. A reflector providing for the focusing of ion packets in the flight time allows us to obtain a high resolution while maintaining all other advantages of the instrument.

Assume that an ion packet with a given M/Z ratio (where M is the ion weight and Z is its charge) focused near the source contains ions with energies from $E_{\min}$ to $E_{\max}$.. Motion in the field-free space results in the widening of the packet due to the ion speed diversity, and the time of ion movement is proportional to $1/E^{0.5}$, where E is the ion energy. The focusing of ion packets in the detector plane requires the same time of movement for ions with a given M/Z ratio. To follow this condition, the reflector is placed at the end of the first field-free area of ion movement as a homogeneous decelerating electrostatic field in which the time of ion motion is proportional to $E^{1/2}$. Ion packets with a thickness close to the initial thickness of the packets in the ion formation area may be obtained during the corresponding selection of the reflector parameters at the detector's entrance. Thus, if the resolution in the TF mass spectrometer of a common scheme cannot be increased by the simple elongation of the movement, since this increases the motion time and packet thickness in the detector plane as well, in mass reflectron it increases proportionally to the motion length. We selected a double-gap reflector with a diameter of 4 cm and a total depth of 32 mm to provide the necessary resolution. The power supply of the detector was performed by a stabilized voltage source of 100 V. Being reflected in the reflector and passing the second field-free area of the analyzer with a length of 10 cm, ions reached the detector with a net construction on the entrance, cutting off the low-energy ion flow. The detector was represented by a chevron construction of two microchannel plates and a double-channel anode. The power supply of the detector was performed by a high voltage from −1800 to −2200 V (100 μA in the operating regime), which allowed us to work in the area below the plate's saturation limit at a total strengthening of 10^6. Having minimal dimensions of $14 \times 4 \times 4$ cm and a weight of ~200 g, the geometrical and electrical construction of the mass analyzer allowed us to register the ions formed in the laser source and collect them in thin packets effectively.

Unit Receiving Regolith Samples

The unit is represented by a disc with twelve holes and applied for the fixation and introduction of the samples to the area of the action of laser radiation and their transportation during the analysis. The presence of twelve holes allows us to carry out the analysis of eleven samples collected in different places on the surface of Phobos, because one hole is reserved for the standard target.

After the regolith is loaded into the accepting hole of the instrument by the collecting device, it is transported on command to the area of laser action. The removal of the excess regolith and the packing of the sample proceed incidentally in such a way that the surface of the analyzed sample lies on the focusing plane of the optical system. After the sample is placed, a periodical shift of the target by a value of 50 μm is performed during the analysis to exclude the effect of crater influence on plasma formation and to study the whole surface of the sample. The control for the positioning of the disc was performed by Hall indicators.

Electronic Block

The electronic block of the LAZMA instrument created in the University of Bern is the "brain" of the instrument. It provides the complete control of the operation of the mass spectrometer; the registration, saving, and transmission of spectral data and telemetry; and the power supply of all mechanisms of the instrument.

The registration system is a four-channel (8 bit, 64 MHz) ADT with analog amplifiers connected directly to the SEM exits. The synchronous application of four channels allows us to provide the parallel registration of elements of the matrix and admixture with a dynamic range of 10^{-5}. This also increases the reliability, since the failure of one of the channels will not result in the complete loss of the serviceability of the instrument. ADT synchronization during spectrum registration is done by an external TTL impulse produced by the optical system by generating laser radiation. The volume of the single four-channel spectrum, including the telemetric data, is 15 kb. The saving and storage of the data is carried out in 4 Mb flash memory.

In addition to the provision of the mass spectrometer units with a low-voltage supply, the system of the supply of the electronic block has three high-voltage channels:

—regulated (12 bit ADT), from 30 to 3600 V for the supply of the optical attenuator;

—nonregulated stabilized voltage of 100 V to supply the analyzer nets; and

—regulated (12 bit ADT), from –20 to –2200 V for the SEM supply.

Calibration and Standard Measurements

Tungsten alloy containing carbon, titanium, cobalt, niobium, and tantalum was selected as the standard for the adjustment of the regime and the calibration of the mass scale of the instrument. The choice of such an alloy is explained by the high stability and reproducibility of the spectra obtained on the given sample. Matrix peaks of the elements within the whole mass scale allowed us to adjust the instrument for the obtainment of the optimal mass resolution in the whole registration range.

After the adjustment of the apparatus for the obtainment of the maximal resolution and the fixation of the measurement regime, the averaging of ten individual spectra was performed. Then, the characteristic of the mass dependence on the peak registration time was determined by the averaged time peak position (Fig. 3). As this took place, the accuracy of the mass determination was ±0.3 amu. This seems to be quite sufficient for our task.

After the laboratory calibration of the mass scale, we performed the analysis of the standard of JSC-1 lunar regolith imitation (David, McKay, 1994) to check the instrument's serviceability on real regolith samples and to measure the sensitivity of the flight instrument. Figure 4 demonstrates one of the spectra obtained for this sample. The concentration (ppm) is indicated above the element isotope symbol. As is evident from the spectrum, the instrument allows us to register elements with concentrations of tens of ppm reliably, and at the expense of sample heterogeneity, register elements with a lower concentration.

PERSPECTIVES AND CONCLUSIONS

From the very beginning, the selection of the method of the laser TF spectrometer for the study of the elemental and isotopic composition of different materials occurring as solid phases on the planets and small bodies of the Solar System was explained by the universal character of such instruments. Further multistage investigations of the analytical characteristics of such instruments demonstrated that these properties were not illusory. In this connection, the patented, completely axially symmetric instrument configuration (Managadze, 1988) attracted special interest in many research centers in the world. The first results obtained during laboratory experiments of this version of the instrument were reported to P. Wurz in 1985 during the visit of G.G. Managadze to the University of Bern before the application of the proposal for the patent. The new construction attracted the interest of researchers from the University and in some time, the "Switzerland version" of LAZMA was created (Rohner et al., 2003). In the following years, LASMA was applied in the Isotope company, as well as in analytical laboratories of the Universities of Kaiserslautern and Mainz in Germany. Within the treaty on cooperation, the prototype of the LAZMA–LAMS instrument was applied in the Johns Hopkins University Applied Physics Laboratory in the United States. Joint research with that organization was successfully performed over the course of 17 years (Brinckerhoff et al., 2000). Currently, it participates in the application of the airborne version of the LASMA instrument in NASA's Goddard Space Center. These works are aimed at the application of the instrument for planetary studies and creating a spectral database for the *Phobos-Grunt* project.

In recent years, we managed to develop a modern model of the surface version of the LAZMA instrument with automatic programs of instrument control,

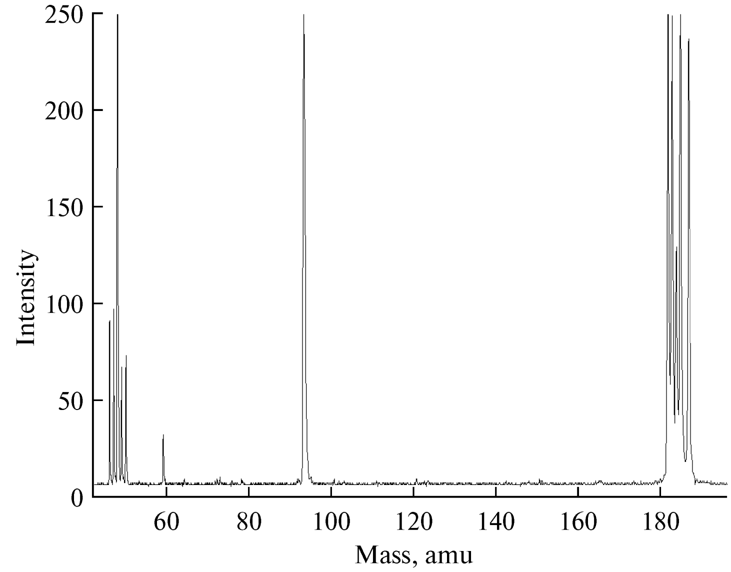

Fig. 3. Fragment of the single spectrum of standard tungsten alloy after the calibration of the mass scale.

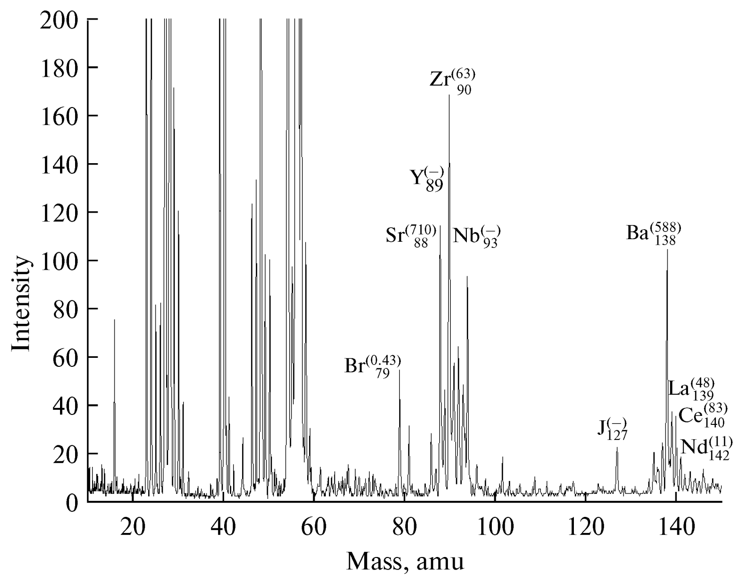

Fig. 4. Mass spectrum of the standard sample of the JSC-1 lunar regolith imitation.

measurements, and the development of obtained information. This allowed us to construct the laboratory model of an airborne complex based on the laboratory instrument within the research program "Perspective" supported by the Space Research Institute. This complex is able to enrich a sample by a factor of no less than 10^3 and then determine the age of the geological rocks on the planets and small bodies of the Solar System from the landing module by the measurement of the ratios of lead isotopes. Clearly, the accuracy of the age determination by the airborne complex is significantly lower than its laboratory analogs, but it is quite sufficient for the solution of the main geochemical tasks for many space objects.

The development of the landing module on the surface of Europa is currently being carried out based on the LAZMA instrument (Managadze, 2009). The planned complex will be able to determine the existence of life with a high probability by the relationships of the main elements in the case of the presence of organic compounds of biological origin or biomass extracted from Jupiter's satellite if the discovered form of space life is similar to that on the Earth.

It is important that the miniaturization of the LAZMA instrument carried out for the *Phobos-Grunt* project was successfully performed without the loss of the main analytical characteristics of the instrument. This opened very wide possibilities for the application of this instrument for various measurements of the mass and isotopic composition of the regolith from space objects. This is evident from the applications for the use of the instrument in Moon investigations within the state program and the interest of NASA in creating an instrument with autonomous evacuation for further investigations of Mars based on the new miniature LAZMA version. The creation of a distant instrument for the investigations of asteroids from a time-of-flight apparatus and landing module is being discussed.

The potential possibilities of the application of a surface version of the LAZMA instrument for a wide class of research and technological tasks including metallurgy, geology, and medicine are not limited. It has been written about significantly thus far; thus, we confine ourselves to the material presented above.

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