Laser-induced breakdown spectroscopy based detection of lunar soil simulants for moon exploration

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A scientific goal of the moon exploration project is to perform elemental analysis on the moon surface. The assuming of using laser-induced breakdown spectroscopy (LIBS) for this goal has been put forward. The laser plasma used by LIBS is sensitive to the surrounding atmosphere and the moon has very low ambient gas pressure on the surface, so the study of the LIBS capabilities at the low pressure was carried out.

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China is pushing her lunar exploration plan steadily. A scientific goal in the future phase is to perform elemental analysis on the moon. A right selection of the instrument packages for the lunar rover is critical.

Alpha-proton X-ray spectrometer (APXS) and X-ray fluorescence are always the choices for elemental analysis in the past and future space exploration missions. Although proven and developed for the space applications, the APXS and X-ray fluorescence have some significant limitations in terms of the amount of data that can be collected during the limited operational lifetime of the lander. Both methods require that the detector be positioned close to the target (within a centimeter) for analysis to proceed, which limits data acquisition to the area immediately adjacent to the landing site. Another characteristic of the APXS and X-ray fluorescence system is that long counting time (several hours) is required for each measurement. These long counting times, together with the need to position the lander near the target, severely limit the number of measurements that can be made, and so the scientific return from a mission[1].

One elemental analysis method that has great potential as a space exploration tool is the laser-induced breakdown spectroscopy (LIBS)[1−4]. Compared to the APXS and X-ray fluorescence, the method can provide new capabilities that would greatly increase the scientific return of the future missions. One unique capability is the stand-off analysis. That is, the target samples can be analyzed at distances of many meters from the LIBS instrument merely by aiming the optical system at the selected target. Close contact with the target is not necessary, thereby eliminating long travel times required to reach some samples as well as permitting the analysis of samples in the locations impossible to reach with a rover. A second capability is the rapid analysis. That is, one measurement per laser shot is made and the number of shots determines the total analysis time. A third important LIBS capability is the ablation of the target to remove the dusts and the weathered surfaces that may have a different compositions than the underlying rock. The use of the repetitive laser pulses to ablate away the dusts and weathered surfaces will expose the underlying sample to laser interrogation and guarantee the high accuracy of measurement[1].

ChemCam, the laser induced remote sensing for chemistry, has been selected by NASA for the mobile Mars Science Laboratory (MSL) rover, scheduled for launch in 2009. In this paper, we put forward the assuming of using LIBS for China's moon exploration. Because the laser plasma used by LIBS is sensitive to the surrounding atmosphere and the moon has very low ambient gas pressures on the surface, it is important to determine the analysis capabilities under these conditions.

An experimental setup is used to study the analysis capability of LIBS at reduced pressure by focusing the laser pulses on the sample at close distance which is shown in Fig. 1. The pulses (5-ns duration, Gaussian-like spatial profile) were generated by using a Q-switched Nd:YAG laser operating at 1064 nm. The laser pulse energy of 70 mJ was used here for the measurements of the lunar soil simulants. The lunar soil simulants were maintained in a small sealed chamber. The chamber could be connected with a vacuum pump to reduce the pressure to 5×10^{-5} Pa. The laser pulses were focused on the samples using a 180-mm focal length lens which was embeded in the chamber's up-wall. The plasma light was collected by a

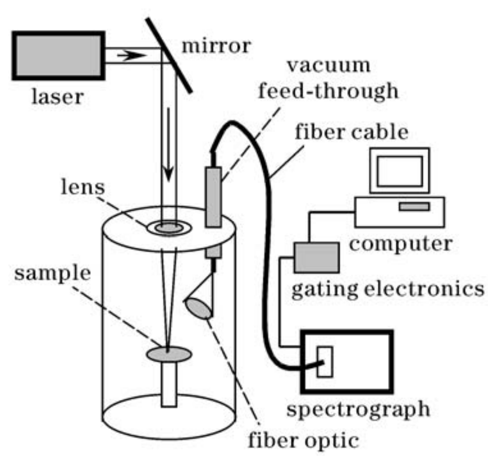

Fig. 1. Experimental setup used to detect lunar soil simulants.

fiber optic pointed at the plasma and then transported to the entrance slit of the spectrograph. The ocean optics vacuum feed-through channeled plasma light out of the vacuum chamber. The grating of 1200 lines/mm and the slit of 14 μm were used to obtain the spectral coverage of 200—600 nm and the optical resolution of 0.5 nm. The spectra were recorded by a Sony ILX511 2048-pixel CCD linear image sensor. The time-gated detect of the laser-induced plasma was realized by using a gating electronics to eliminate the strong continuum emission and increase the signal-to-noise ratio (SNR).

The effect of the pressure on LIBS emission signal has been investigated previously[1−3]. It appears that the emission signals increased significantly as the pressure was reduced from the atmospheric pressure to about 10 torr (1 torr = 133.3 Pa) because of the decrease in shielding of the surface by the plasma formed above the target at the higher pressure. As the pressure was reduced from about 10 torr the emission signals decreased significantly because the laser-induced plasma expands into a larger volume and the number of collisions between atomic species decreases. At pressures below about 0.003 torr, no further decrease in emissions was observed with decreasing pressure because there is no strong cyclic excitation of atomic species in the plasma at such a low pressure.

Fig. 2. Photo of lunar soil simulants.

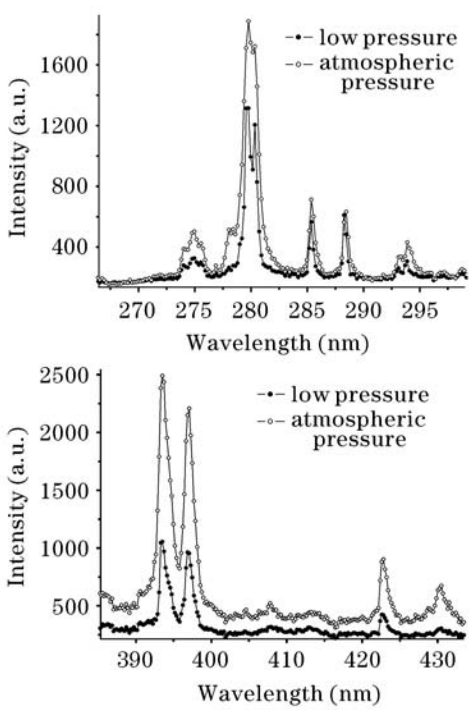

Fig. 3. Experimental results of LIBS measurement at low pressure and atmospheric pressure.

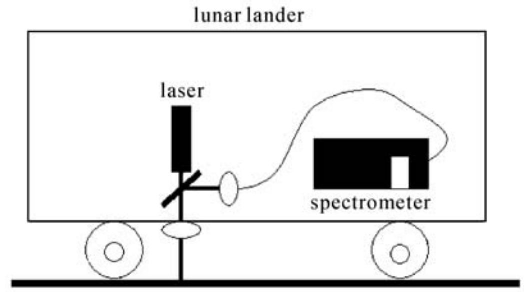

Fig. 4. LIBS instrument on the lunar lander.

The results of the study of LIBS capabilities at the low pressure are presented here for in-situ analysis of the lunar soil simulants which are shown in Fig. 2. The same laser pulse energy was used to carry out the LIBS measurements of the simulant sample at the pressure condition from the atmospheric pressure to the low pressure of 5×10^{-5} Pa. As shown in Fig. 3, the emission signals at the low pressure are weaker than that at the atmospheric pressure but can still be detected.

Therefore, it appears that at the low pressure characteristic of the Moon, LIBS should be able to provide elemental analysis at least at close range. We can board the LIBS instrument on the bottom of the lunar lander to carry out the close range detection on the moon surface just like what is shown in Fig. 4.

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