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Elemental analysis instrument for landed lunar and planetary explorations: Laser-induced breakdown spectrometer (LIBS)

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In general, lunar and planetary explorations are carried out through the processes of remote sensing by orbiting satellites, in-situ observation by landers and rovers, sample return, and manned exploration. Lunar and planetary explorations of each country will shift to a sample return phase. However, the results of past remote-sensing explorations show that moons and planets in the solar system have complicated and various surfaces. This clearly indicates that we cannot know the origin and evolution of a planetary body from a sample that is recovered from anywhere on it. The necessity of in-situ observations by landing to multiple sites and the importance of understanding the geological context of landing sites are suggested from the experience of the past planetary explorations, especially the landed explorations on Mars. Therefore, a landed geological exploration as a prior phase of sample return is indispensable. In such a case, a wide range of movability by a rover with a quick and efficient elemental analysis method is necessary. Laser-induced breakdown spectrometer (LIBS) is an elemental analysis instrument that is appropriate to such lunar and planetary surface explorations.

The measuring principle of LIBS is as follows: Samples are irradiated with pulsed laser beams in order to generate plasmas of a small amount of a sample. When atomic and ionic species excited in the plasmas are deexcited, the emission of lights occurs according to the difference in energy levels before and after the deexcitation. These lights are measured with a spectrometer as emission lines on spectra. The wavelength of emission lines is unique to each element, and the intensity of emission lines is correlated with the elemental abundance. Both qualitative and quantitative analyses, such as elemental abundance determination and mineral classification, are carried out by analyzing the acquired spectra.

LIBS has several advantages such as (i) capability of remote analysis (up to ten meters or more depending on laser intensity), (ii) rapid data acquisition (a few second to a few minutes), (iii) ability to analyze almost all elements including light elements, (iv) high spatial resolution (several tens to several hundred of micrometers), (v) unnecessity of sample preprocessing, and (vi) unnecessity of an radiation source. On the other hand, LIBS have a weak point of slightly worse determination precision than other elemental analysis methods usually used. However, recent studies show that the use of multivariate analysis methods such as partial least squares regression as a spectral analysis method improve the determination precision.

LIBS is basically composed of a laser, a spectrometer, and optical system. Various configurations are possible according to the size of a landing explorer (a rover or a lander) or the objective of an exploration. For example, "Measured-distance-variable remote LIBS", in which focusing of both the laser beams and emitted lights are conducted through a measured-distance-variable telescope, can measure distant samples. Rapid data acquisition for multiple samples is possible without moving a rover or a lander. Since this configuration requires a telescope with large diameter lens, a drive mechanism for the telescope, and a laser with high output power, the size and weight of this type of LIBS tends to be large. "Measured-distance-fixed near LIBS" measures samples with small laser and simple optical system equipped on a robot arm of a rover or a lander. Since neither a telescope with large diameter lens nor drive mechanism for the telescope are needed, this type of LIBS can be small and lightweight.

LIBS exerts its capability when it is equipped on a rover. Rapid analysis of distant samples makes the selection of interesting sites where a rover moves to possible. In a future sample return mission LIBS will be a suitable instrument for searching appropriate samples to recover.

Keywords: elemental analysis, geological exploration, planetary exploration, LIBS, Moon, Mars