Laser Induced Breakdown Spectrometer (LIBS) For Chandrayaan-2 Rover

Introduction: One of the fundamental pieces of information about any planetary body is the elemental composition of its surface materials. For in-situ analysis, such an exploration depends on efficient landers and rovers to carry highly specialized instruments to the surface of planetary bodies. Our natural satellite, the Moon, over centuries has been an enthralling scientific aspiration and has aroused a boundless curiosity much more than any other object in the sky. Understanding the Moon provides a pathway to unravel the early evolution of the solar system and that of our home planet, Earth. A precise Moon-elemental mapping demands a sophisticated and simple technique which will be element-specific and element-sensitive. Though the conventional techniques for planetary surface exploration such as APXS (Alpha-Proton X-ray Spectrometer) and XRF (X- Ray Fluorescence) etc. are proven and developed, they have some significant limitations in terms of the amount of data that can be collected during the limited operational lifetime of the rover and also the requirement of the detector to be in contact with the sample (within few centimeters) for the analysis. Due to these limitations, to complement the output data of these techniques there is an absolute necessity of a technique that could overcome all the above-mentioned constraints. LIBS in recent times, has proved to be a powerful laser-based analytical technique for in-situ detection of geological samples, owing to its simplicity and versatility. Specifically, the technique has following advantages:

a. No/minimal sample preparation
b. Rapid and real time analysis.
c. Point detection capability
d. Simultaneous multi-elemental analysis (from low Z to high Z)
e. Elemental composition of dust–covered rocks and samples
f. Suitable for combination with other spectroscopy techniques (like Raman, LIMS etc.)

Existing LIBS instruments are not compact enough to be utilized for planetary surface exploration. In order to perform in-situ elemental analyses on lunar surface, our team at Laboratory for Electro-Optics Systems (LEOS) is currently realizing the development of a 'Miniature Laser Induced Breakdown Spectroscope-(mini-LIBS)' instrument to be flown on Chandrayaan-2 rover, suiting the constraints imposed by the mission. A flight in-situ LIBS instrument is expected to be < 1.0 kg and consume < 5W power.

Science Objectives: Primary objectives of the Instrument are:

1. Qualitative and Quantitative elemental analysis of solids such as Soil, Rock and Ice to infer their elemental composition to further our understanding of lunar-surface composition.
2. Technology demonstration of LIBS for planetary surface exploration.

Context Science

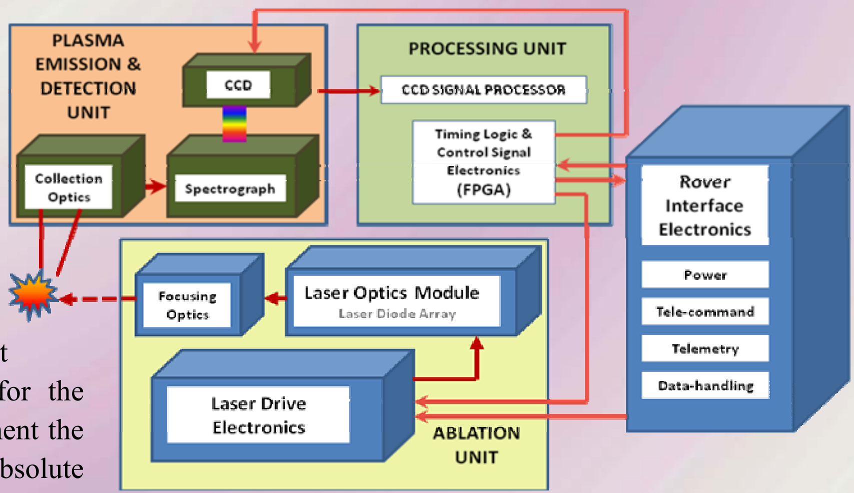

Figure 1 Typical block diagram of the conceptualized LIBS instrument

i. Soil and pebble composition surveys.
ii. Analysis of weathering and depositional coatings or rinds on rocks by observing changes in spectra with depth.

Working Principle: LIBS instrument works by utilizing a high-energy laser pulse as the vaporization, atomization, and excitation source to create a high-temperature micro-plasma at the surface of the target. The elements contained in the sample are vaporized and excited in the hot plasma and emanate their respective transition wavelengths during their decay. The light thus emitted is collected and diverted to a highly sensitive dispersive detection system. The resultant LIBS spectrum contains information describing the elemental composition of the target. Wavelength of the emission line is used to identify the existence of the elements and the background-subtracted peak intensity at the chosen emission line is used to quantify the elemental composition of the target.

Description: The basic components of any LIBS system are similar but their specifications are tailored to at particular application. Fig. 1 shows the typical block diagram of the conceptualized LIBS instrument. As shown in the figure it consists of primarily 3 units. ***1) Ablation Unit (AU):*** It consists of a laser source and focusing optics system. This unit serves the purpose of surface ablation and plasma generation. ***2) Plasma Emission Detection Unit (PEDU)*** that includes collection optics unit (to collect the resultant emission from the decaying plasma) with a high resolution, high sensitive dispersive element and a detector (for spectral acquisition). ***3) Processing Unit (PU)*** that includes FPGA based electronic cards to process the plasma signals in micro-second levels. These three units will be interfaced to rover to execute on-board operations. Table 1 presented below lists the specifications of the instrument.

Table 1: List of Instrument Parameters

Specification	**Value (SI Units)**
Size	180 mm x 150 mm x 80 mm
Power	Total Consumption ~4 W
Weight	Total Weight $\leq$ 1kg
Laser Transmitter	1.54 µm, 7 ns, $\leq$ 1 MW peak power, 1-5 Hz PRF
Coupling Optics Focusing Optics i) Spot size Collection Optics ii) F# iii) FOV	Lens Coupled Mechanism 3-lens system < 40 µm 2.2 $\pm$ 14^0
Detection Assembly	Flat-field Holographic Grating based Spectrometer
Range	190 – 800 nm

Design and Realization Aspects: Space environment being harsh and hands-off-free, the design and development choices of the instrument were tightly constrained from the outset, principally by schedule, space-craft mass and power budgets and rover accommodation. The major challenges to be met for LIBS instrument development are: lunar surface temperatures that may range from - 60 °C to - 90 °C, depending on landing latitude (close to lunar poles) and season, a planned operational lifetime of 6 months, a volume equivalent to that of 180 mm x 150 mm x 80 mm, weight of <1 kg, energy consumption < 5W, storage temperatures of -60 ^{0}C to +70 ^{0}C and operating temperatures of -10 ^{0}C to + 60 ^{0}C. Such are the stringent constraints the instrument must meet, raising many technical challenges, pushing current know-how to its limits. These stringent space mission requirements call for the development of a lightweight LIBS instrument. Fig.2 shows the CAD model of the LIBS prototype instrument (meeting all the above explained restrains) that is under realization.

Realization of LIBS instrument as a payload involves

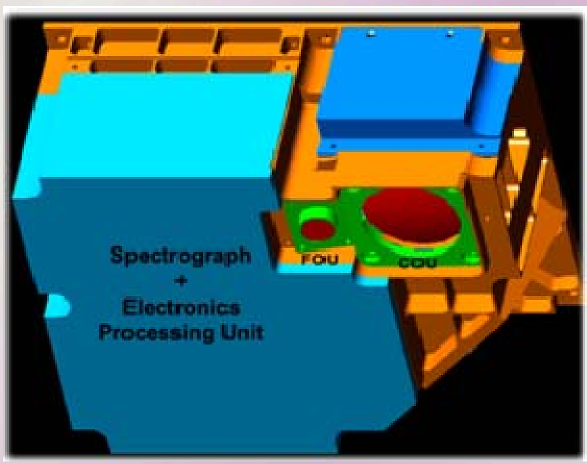

Figure 2. ***3D-CAD model of LIBS prototype instrument***

development of various modules as fore-mentioned.

Laser: The class of laser source being used for LIBS payload is Er: Glass (Erbium Glass) laser of average energy 2.5mJ and pulse duration of 7 ns. This laser offers compactness as well as low weight. The peak power being < 1 MW, with a moderate focusing of laser pulse one can achieve desired power density required to generate plasma.

Focusing and Collection Optics : The FOU (Focusing Optics Unit) optimized as per the theoretical analysis is a 3-lens system that can focus the laser to a spot size of < 40 µm so as to cause the ablation of all elements of interest. The conceptualized COU (Collection Optics Unit) is a single lens system, followed by 2- fold mirror geometry with F# 2.2 and FOV of $\pm$ 14^0.

Spectrograph: LIBS proto-model comprises of an indigenously developed spectrograph basing on flat-field reflective (concave) aberration corrected holographic grating configuration. The wavelength range of detection is 190-800 nm with a resolution of <1 nm. Such type of grating combines optical imaging and diffraction into one device. The selected detector to capture microsecond plasma events is a 2048 element linear CCD with a pixel size of 14 µm x 200 µm. This detector supports to process the data as per the instructions given by the Processing Unit (PU).

Experimental Studies: To demonstrate the feasibility of LIBS for in situ analysis of lunar soils and rocks, a laboratory setup made with commercial components was

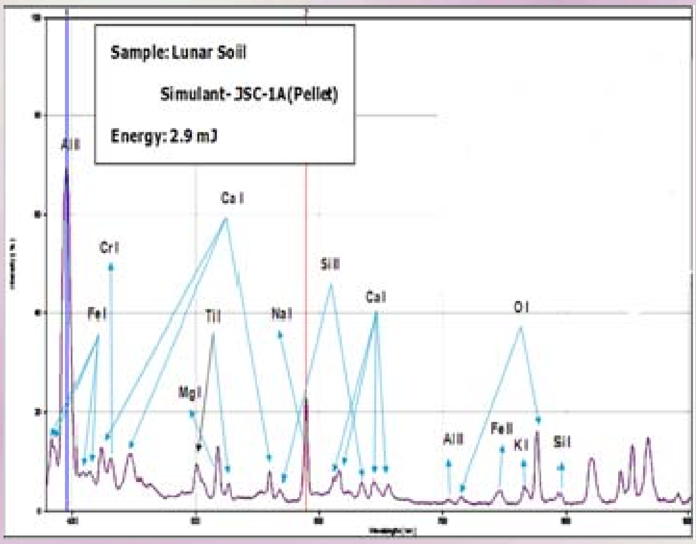

Figure 3. ***LIBS spectra of lunar soil simulant (JSC-1A)***

used to determine the specific characteristics of the laser, the optical components, and the detection system that could be mounted on a rover. Several samples were analyzed under these experimental trials. These include locally collected soils (i.e. marine soil, fly-ash (Class-C and Class-F)) and lunar soil simulant (JSC-1A). Experiments were carried out under various pressure levels ranging from 760 Torr to 0.00006 Torr employing a miniature laser (3 mJ, 7 ns and 1 Hz @ 1.54 micron) and a compact array spectrometer (CAS 140B, Analytical Instruments) equipped with back-illuminated CCD detector system. Fig.3 shows the lunar soil simulant pellet (JSC 1A) spectra originating from single laser shot whereas Fig.4 shows the comparison plot of LIBS spectra at various pressure levels. At pressures below about 10^{-3} torr, no further decrease in emission with decreased pressure is observed.

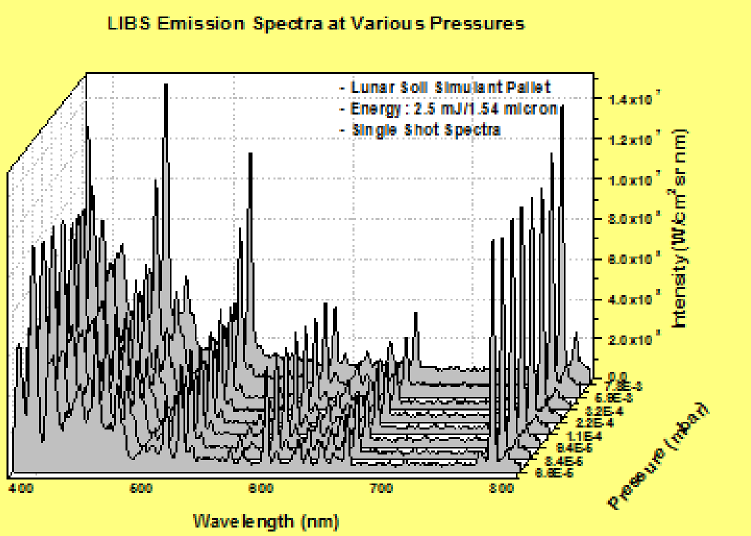

Figure 4. ***LIBS spectra at various pressure levels***

Experiments were also carried out employing spectrograph of 0.1 nm resolution and further the aberration corrected holographic grating being utilized for LIBS prototype model was characterized using Fairchild CCD detector circuit and the read out electronics.

Conclusion: Laser-induced spectroscopy technique has opened a new door for simultaneous multi-elemental detection and has revolutionized the area of on-line analysis technologies by rapid material characterization. Our present study clearly reveals that LIBS technique can be utilized for elemental analyses of planetary surfaces. Theoretical modeling, ablation dynamics estimations and experiments under vacuum conditions have further assured the LIBS suitability.

Further Reading:

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Mr. Laxmiprasad A.S
Email: aslp@leos.gov.in


Mr. V.L.N. Sridhar Raja
Email: sriraj@leos.gov.in


Mr. Adwaita Goswami
Email: adwaita@leos.gov.in


Ms. Surya Menon
Email: surya.menon@leos.gov.in


Mr. M.V.H. Rao
Email: mvhrao@leos.gov.in


Mr. K.A. Lohar
Email: lohar_ka@leos.gov.in

Contact: +91-(0)80-2839 6470
Laboratory for Electro-Optics Systems
Indian Space Research Organisation (ISRO)
Bangalore