Development of X-Ray Fluorescence Spectrometer onboard SELENE. K. Ogawa[1,2], T. Okada[1,3], K. Shirai[1], Y. Yamamoto[1], T. Arai[1,4], H. Shiraishi[1], K. Hosono[1,3], T. Inoue[1,3], T. Inoue[1,3], Y. Maruyama[1,3], M. Arakawa[1,5], and M. Kato[1,2,3], ogawa@planeta.sci.isas.jaxa.jp, [1]ISAS/JAXA, Yoshinodai 3-1-1, Sagamihara, Kanagawa 229-8510, Japan, [2]Tokyo Institute of Technology, [3]University of Tokyo, [4]Graduate University for Advanced Studies (SOKENDAI), [5]Nagoya University.

Introduction: An x-ray fluorescence spectrometer (XRS) onboard SELENE, a Japanese lunar polar orbiter mission that will be launched in 2007, is being developed for lunar surface x-ray exploration. XRS has been designed to detect x-rays from the lunar surface with improved energy resolution, high detection efficiency, and less than 20 km of spatial resolution, for global mapping of lunar surface major elemental composition [1]. The composition map will cover approximately 90% of lunar surface except for the polar regions through the normal mission term of 1 year.

The remote x-ray fluorescence spectrometry from spacecraft' orbits is an available method for determination of elemental composition of atmosphere-free planetary surfaces. Electrons in atoms composing uppermost surface less than 1 mm deep are able to be excited by solar x-rays, and generate characteristic x-rays to space while moving back toward the ground state immediately. Energy spectra of these fluorescent x-rays directly indicate the elemental composition ratio on the surface. Typical major elements on the lunar and planetary surface, Mg, Al, Si, S, Ca, Ti, and Fe, emit soft x-rays of energies in 1-8 keV as the result of above process.

Instruments: XRS system consists of three instruments. Those are XRF-A, the main sensor for x-rays from lunar surface, SOL-BC, solar x-ray monitors, and XRS-E, an electronic circuit. XRF-A consists of units, while each unit includes four CCDs for x-rays (Si-CCD, full-frame transfer, one inch square, one million pixels, 125 kHz readout clock, Hamamatsu Photonics K.K.). Total 16 CCDs on XRF-A provide large detection area of 100 cm^2 and high energy resolution of $<$ 160 eV at 5.9 keV. It is possible to identify Kα and Kβ of Fe fluorescent x-rays with this high energy resolution for instance. Ultra-thin beryllium filters of 5 μm in thickness, which shield low energy photons such as visible light, and lattice collimators, which set FOV to 12 $\times$ 12 deg, are placed in front of the CCDs. Observation footprint of 20 $\times$ 20 km on the lunar surface is given by the limited FOV for the actual XRF-A missions. SOL-BC is a component including solar x-ray monitors SOL-B and SOL-C. Intensity and spectral profiles of solar x-rays at the time of operations are fundamental information to more detailed lunar surface elemental composition analyses and their quantitative studies. SOL-B will detect 1-20 keV direct solar x-rays by two Si-PIN x-ray detectors (Amptek) with hemispherical wide FOV and energy resolution of $<$ 500 eV at 5.9 keV. SOL-C performs calibrator for XRF-A data. Single CCD same to that on XRF-A is used for the x-ray detector on SOL-C, and detects fluorescent x-rays from the reference material sample which is lunar basalt like

Figure 1: XRF-A and SOL-BC. Left: XRF-A the main sensor for fluorescent x-rays from lunar surface. Four CCDs and collimators are equipped in each bores. Right: SOL-B (right part) and SOL-C (left part). SOL-B has two Si-PIN x-ray detectors under 1 mmϕ pinholes for monitoring of direct solar x-rays. SOL-C perform calibrator for XRF-A. A reference material sample is mounted on the platform in front of CCD that is equipped in the hole.

composition glass placed near the sensor, exposed to the sun. The elemental composition ratio with $< 10\%$ error will be achieved by the calibrator. XRS-E perform a controller including command receiver, telemetry sender, and data handler. 60 MHz SH-OBC and 16 MB DRAM are equipped on the electronic circuit.

Onboard data process: Observation data of XRF-A and SOL-BC are processed by FPGAs on each component and SH-OBC in XRS-E. They perform data analysis and reduction along the total telemetry rate limit 4 kbps for normal operation [2]. For CCD data from XRF-A and SOL-C, three major handling mode are used to send data on downlinks: *event*, *spectrum*, and *image* mode. SOL-B has only *spectrum* mode for its operation. *Event* is the mode which outputs for each detection event of x-ray photon. The data set for an event includes information of three pixels with a central focus on the pixel where a x-ray event is occurred, those are energy values, background values, and the pixel address. *Spectrum* outputs data as spectra histogram format through grade classification, which is frequent method to identify x-ray detection events for CCD, and integration for a given length of time. Eventual data size on this mode is less big than *event*, while detailed information of each x-ray event is lost. These two observation modes are commonly used for normal operations, and XRS is programed as automatically selects the observation mode in these according to the frequency of x-ray events and subsequent data size. *Image* will be used for periodical diagnoses of CCD, outputs full CCD image data at the time.

Function and Performance Tests: We have been examining functions and performance, and optimizing electrical parameters and onboard software for XRS in the laboratory. Hardware and software functions for XRS work quite well, output clear data through the onboard data process. The XRS have satisfied also in performance to be applied to the lunar x-ray analysis. Here we show some recent results of the tests.

For the performance tests, thermal behaviour of XRS sensors was especially investigated in the temperature controlled bath since the CCD is highly sensitive to thermal noise. As the result, CCDs works with less enough noise under the temperature of < -40 degC at which CCDs will be operated in space. Fig. 2 (left) shows typical x-ray spectrum by one of CCDs mounted on XRF-A acquired at -45 degC with inputting fluorescent x-rays of Fe. The spectrum was made from *event* mode data; one is histogram for x-ray events before grade classification, and the other includes only grade-0 event after applying grade classification. The grade classification process cancels split x-ray events. We are able to identify Kα (6.4 keV) and Kβ (7.1 keV) pearks with FWHM < 200 eV after simple data handling. More accurate data analyses will enable the energy resolution to make high. Fig 2 (right) shows a histogram of SOL-B by inputting fluorescent x-rays of Cu with cooling by Peltier device placed behind the sensor. Clear two peaks of Cu Kα (8.0 keV) and Kβ (8.9 keV) are found in the spectrum with FWHM < 500 eV. It has enough performance to determine the continuum shape of the solar x-rays.

References:

[1] T. Okada, *et al.*, Lunar x-ray spectrometer experiment on the selene mission, *Adv. Space Res.*, 30, 2002.
[2] T. Arai, *et al.*, Onboard software analysis of SELENE XRS, *36th LPSC*, 2005.

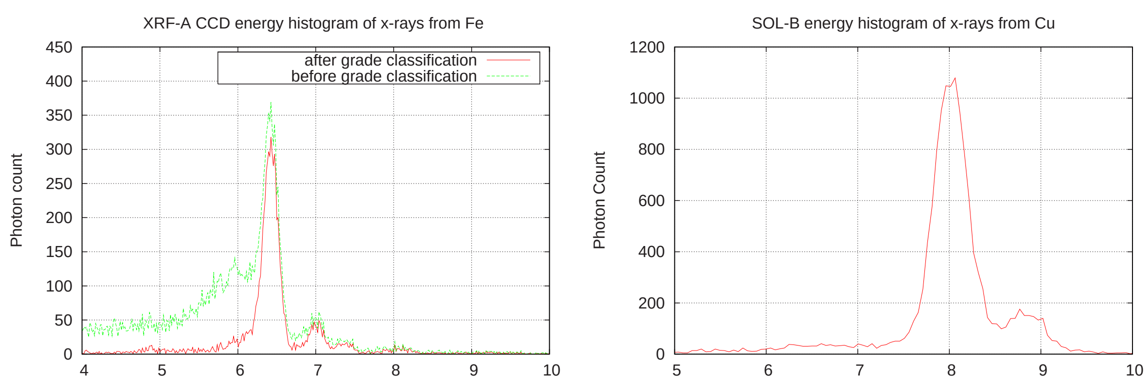

Figure 2: Energy Histogram by XRF-A and SOL-BC. Left: Histogram of *event* mode data from one of CCDs on XRF-A. Fluorescent x-rays of Fe was inputted. Kα and Kβ peaks were differentiated clearly even on the spectrum before grade classification. Right: Histogram by SOL-B solar monitor. Fluorescent x-rays of Cu was inputted.