X-RAY GENERATOR FOR ACTIVE X-RAY FLUORESCENCE SPECTROMETER ON-BOARD LANDING ROVER FOR FUTURE PLANETARY MISSIONS.

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Introduction: Remote sensing data obtained by global observations include the geological, geochemical, mineralogical, and petrological information about global areas of the Moon, Mars, and asteroids. The global investigations of remote sensing data promote our knowledge and understanding of the origin and evolution of those planets [e.g., 1]. The first Japanese large-scaled lunar orbiting explorer, Kaguya (SELenological and ENgineering Explorer, SELENE) launched at September 2007, has made a global observation of the Moon [1]. The global observation by Kaguya has provided new scientific results which are interesting for future lunar explorations.

After the successful remote observations of the Moon, Mars, asteroids, etc., the landing and/or sample-returned missions will be followed, in order to investigate their geology in more details. We have been developing the Active X-ray Spectrometer (AXS) for the embarkation to future landing missions, as elemental analyzing device to obtain the geochemical data of planetary rock samples on site. In this paper, the outline of space-borne X-ray generator for the AXS for future planetary missions, and the present status of development are presented and discussed.

Outline of AXS: The Active X-ray Spectrometer (AXS) is composed of an active X-ray generator and a silicon drift detector (SDD). Basic instrumental concept of the AXS was presented and discussed in Kim et al. [2]. The AXS aims to determine the elemental abundance of rock samples by X-Ray Fluorescence spectroscopy (XRF). The AXS can detect X-rays from major elements of silicates (Mg, Al, Si, K, Ca, Ti, Fe, etc.). These elements provide very important information to understand geochemical characteristics of rocks, and categorize rock samples [e.g., 3]. The basic studies for the development of AXS have been performed for future landing missions [e.g., 4,5].

Silicon Drift Detctor (SDD). An SDD is used as main X-ray detector in AXS. The SDD is small in size and light in weight. Furthermore, the excellent energy resolution (<3 % @6.4keV Fe) of thermoelectrically-cooled SDD provides a powerful method in identifying fluorescent X-rays of light major elements as Mg, Al, etc. [e.g., 4,5].

Active X-ray Generator. Radioactive sources have been often used in space for active excitation source, for example, alpha particle X-ray generator in Mars landing missions [e.g., 6], and radioactive sources as ^{55}Fe and ^{109}Cd in lunar landing mission by China [7]. Our active X-ray generator is designed to induce fluorescence X-rays from rock samples without those radioactive sources, because it is difficult to mount the radioactive source on spacecraft in Japan. In this work, two types of active X-ray generator are studied and under development. The first is with a pyroelectric crystal [2,5], and the second is with carbon nanotube (CNT).

1) Pyroelectric crystals such as $LiTaO_3$ and $LiNbO_3$ are used for X-ray generator to make a basic test [5]. Such pyroelectric crystals produce a high voltage at the crystal surface by changing the temperature of crystals. Electrons generated by pyroelectric crystals encounter metallic target (e.g., Ag), and then X-rays are emitted from the target. The X-ray emission intensity depends heavily on several operation parameters as size of crystal, kinds of inner gas, and pressure, which are being investigated now [5].
2) X-ray tubes using CNT field-emission electron sources have been studied for the usage in medical field [e.g., 8]. We study the application of X-ray tube using CNT to geological field. Figure 1 shows the photo of CNT made by XinRay Systems Inc., which is used for the development of X-ray tube in this work. It is expected to obtain the greater intensity of X-rays from CNT sources than that from pyroelectric crystal.

In comparison with both methods, we aim to reveal each advantage and disadvantage, and study their capability to apply them for future planetary missions. These generators are superior to the generators with radioactive sources in reducing the risk of exposure at laboratory experiments, because we can switch the X-ray emission as appropriate. The advantage will expand the application field of these X-ray generators.

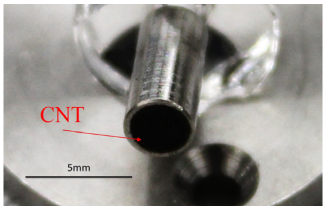

Figure 1. The photo of CNT. Scale bar is 5 mm in size. This CNT was made by XinRay Systems Inc. (7020 Kit Creek Road, Suite 210, Research Triangle Park NC27709).

Simulation study: Here, we present an example of observation target of AXS. Global observation by Kaguya mission provides interesting targets for future science missions of lunar exploration. Among them, Kaguya data observed the global presence of PAN (purest anorthosite) [9]. A massive PAN layer could constrain the formation processes of the earliest anorthosite crystallized from the lunar magma ocean. Nagaoka et al. [10] found several pure anorthosite clasts in the lunar meteorites and pointed the Mg# variations among them. If such samples could be analyzed on site, we may select specific samples to return to the earth for precise investigations. Here, X-ray emission with the mineral data of pure anorthosite (PA1) observed in Dhofar 489 [10], is simulated and discussed.

Simulation setting. A simulation tool used for this work was PENELOPE (version 2008) [11]. X-rays of Ag L (2.98 keV, 3.15 keV) and bremsstrahlung were used as excitation source. A detector were set in parallel to a sample emitting fluorescent X-rays (Figure 2). We took the detector energy resolution (183 eV in FWHM at 6.40 keV (Fe K_{α})) into consideration in deriving the energy spectrum.

Simulation Results. Figure 3 shows several energy spectra of X-rays from samples consisting of plagioclase (Plg) and olivine (Ol) on several mixing patterns : 80vol.% Plg + 20% Ol ; 90% Plg + 10% Ol ; 95% Plg + 5% Ol ; 98% Plg + 2% Ol. The most remarkable differences between these spectra are the intensities of Fe K lines (Figure 3). Only on the Fe/Si ratios (Si is almost constant), we could determine whether the sample is pure anorthosite or not. On the bulk compositions as shown in the simulation, the AXS could characterize the rock sample on site, thus the AXS is a powerful tool as an initial analysis equipment on site to select the planetary rock samples to being back.

Summary: We are forwarding the development of X-ray generator for active X-ray fluorescence spectrometer on-board planetary landing mission on the basis of both of laboratory experiment and simulation study. Our study would provide beneficial and safe observational instrument to future planetary explorations.

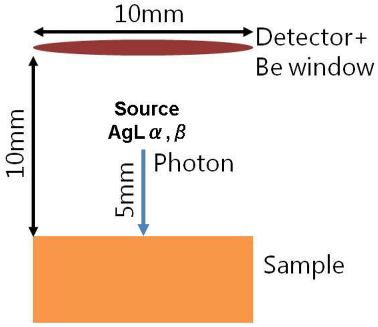

Figure 2. Setting in simulation of X-ray emission in this work.

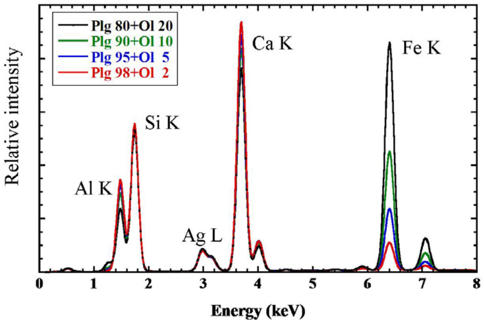

Figure 3. Energy spectra obtained by the simulation for the samples mixing of plagioclase (Plg) and olivine (Ol).

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