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Germanium detector with Stirling cryocooler for lunar gamma-ray spectroscopy

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Abstract

The gamma-ray spectrometer (GRS) of Japanese lunar polar orbiter SELENE uses a Ge detector for the first time on a lunar mission. This spectrometer will observe lunar gamma rays for 1 year or more to determine chemical composition over the entire lunar surface. For cooling the Ge detector, we adopted a Stirling cryocooler. The SELENE GRS flight model was completed and an energy resolution of 3.0 keV (FWHM) at 1.33 MeV was achieved. This paper describes the details of the detector-cryogenic system and its performance.

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Keywords: Germanium detector; Stirling cryocooler; Lunar mission; Gamma-ray spectroscopy

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1. Introduction

Gamma-ray spectrometer (GRS) will be on board the Japanese lunar polar orbiter SELENE at 100 km altitude [1]. The spectrometer will observe lunar gamma rays ranging 0.1–12 MeV for 1 year (possibly extended to another year at lower orbit) to obtain spectral information about elemental abundances over the entire lunar surface.

So far, there have been lunar missions leading gamma-ray spectroscopy for chemical abundance on lunar surface. Apollo missions and Lunar Prospector used NaI scintillator [2] and BGO scintillator [3], respectively, which have high detection efficiencies but poor energy resolutions for determination of elemental composition of lunar surface material. SELENE GRS employs a large Ge detector as the main detector. This will be the first lunar mission using Ge detector of which the superior energy resolution can lead to identification of many elements and quantification with high sensitivity [4,5].

To prevent the Ge detector from serious degradation of energy resolution due to radiation damage, we adopted a high purity n-type Ge crystal detector which is able to withstand higher proton/neutron fluence than p-type crystal [6,7]. Ge detector, however, must be cooled down to cryogenic temperature during the operation to reduce the leakage current that can deteriorate the energy resolution. Moreover, cooling of the detector is also necessary to avoid the radiation damage [6,7]. Hence, the cryogenic system of the GRS was designed to cool the Ge detector below 90 K.

In the early missions, Ge detectors were cooled by cryogen [8], and it took heavy payload and could not make a long-term observation. Use of cryogen is not practical in terms of the science payload of SELENE spacecraft which has fourteen instruments sharing the weight budget of about 270 kg for the science payload. Some past missions utilized passive cooler as the cryostat, two-stage passive coolers for interplanetary missions [9,10] and V-groove type radiative coolers for martian missions [11,12] to cool Ge detector. In lunar orbit, however, a heat inflow of daytime lunar infrared radiation to the detector system is more than 10 times as much as that of lunar visible radiation, and consequently more cooling capacity is needed. Moreover, it is difficult for heat radiator to have a sufficient field of view to exhaust the heat into cold space due to the expanse of lunar surface. We have adopted therefore a Stirling cryocooler developed for space use by Sumitomo Heavy Industries, Ltd. The space cryocooler has been fully qualified for long-term use in space environment.

In general, Stirling cryocooler generates mechanical vibration and accordingly the vibration could cause microphonic noise. In the past mission using Stirling cryocooler [13], observations were conducted while the cryocooler was stopped because vibration affected the energy resolution significantly. However, continuous operation is required for longer observation time during limited mission period. The performance of Stirling cryocooler has been improved in respect of power consumption and cooling capacity, and this innovation results in reducing the mechanical vibration. GRSs in recent missions using Ge detectors with Stirling cryocoolers, HESSI spectrometer and INTEGRAL/SPI [14,15], did not show any microphonic effects and have undergone successful observations. They have the performances partly owing to their rigid structures of the instrument in the cryostat, which have nine and nineteen Ge detectors for HESSI spectrometer and INTEGRAL/SPI, respectively. In contrast, SELENE GRS has a light structure of the detector-cryogenic system and it is therefore very likely to be affected by mechanical vibration.

We solved the microphonic problem in the development of SELENE GRS, which was built as shown in Fig. 1 and has been qualified in several environment tests. It shows an energy resolution of 3.0 keV (FWHM) at 1.33 MeV (hereafter energy resolution is expressed in FWHM) in the flight model of the GRS system. This paper describes details of the detector-cryogenic system and its performance.

2. Instrument

2.1. Detector configuration

The GRS consists of three subsystems, Gamma-ray Detector (GRD), Cooler Driving Unit (CDU)