RESULTS OF THE CRITICAL DESIGN FOR NIRS3: THE NEAR INFRARED SPECTROMETER ON HAYABUSA-2.
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Introduction: NIRS3, the Near Infrared Spectrometer is a candidate scientific instrument for installation on Hayabusa-2 mission. It will observe near infrared spectroscopy at wave lengths of 1.8 to 3.2μm to detect specific molecular absorption bands on the target C-type asteroid. The design of NIRS3 follows the heritage of NIRS that was on Hayabusa and had observed spectroscopy in the 2μm band [1]. To extend the wave length to the 3μm band, we adopted a new type of linear-image sensor, and cooling system for optical and sensor assemblies. This paper reports the results of the critical design for the instruments.

Scientific objectives: The major purpose of NIRS3 is to observe the absorption bands of hydrated minerals in the 3μm band on the candidate target C-type asteroid 1999JU3, which has been reported in ground observations to have an absorption band of hydrated minerals at 0.7μm [2]. C-type asteroids are thought to be mother celestial bodies of carbonaceous chondrites (C-chondrites). C-chondrites have been classified into sub-groups by their composition, organization, and isotope ratio of oxygen [3, 4]. The spectra of C-type asteroids have also been classified into sub-types by their inclination and the existence of absorption bands detected in ground observations [5, 6]. However, the relationship between the sub-groups of C-chondrites and the sub-types of C-type asteroids has not been clarified due to the effects of solar radiation and space weathering. Therefore, we will directly observe the surface of a C-type asteroid without the terrestrial atmospheric absorption in the 3μm band using NIRS3. Detecting younger terrain by global mapping of the asteroid and the ejecta of new crater by the Small Carry-on Impactor (SCI) will also provide the spectra of surface less affected by space weathering. To estimate the quantities of the hydrated minerals with accuracies of 1 to 2 wt%, we designed the NIRS3 system to have a signal-to-noise ratio (SNR) exceeding 50 at 2.6 μm for global mapping. Thus, NIRS3 will shed light on the initial composition, aqueous alternation, thermal metamorphism, and space weathering on the surface of a C-type asteroid.

Instruments: NIRS3 consists of the Spectrometric Unit (NIRS3-S) and the Analog Electric Unit (NIRS3-AE), which are connected with harness cable (NIRS3-HNS). Figure 1 illustrates the conceptual block diagram of NIRS3. NIRS3 has a telemetry and command interface with the Digital Electric instruments (DE), and electric power interface with the Power Supplying Unit (PSU) of bus equipment on Hayabusa-2. A field-programmable gate array (FPGA) in NIRS3-AE controls calibration lamps, a chopper, a heater, and the sensor in NIRS3-S. Near-infrared light obtained by the optical assembly is detected by the sensor, amplified by the pre- and post-amplifiers, converted from analog to digital signals, and down-linked to the ground through DE. Calibration targets with small incandescent lamps supply standard light for intensity and frequency calibration. The electromechanically driven shutter in the slit chops signals at a frequency of 100 Hz to switch light on and off to eliminate dark current noise. A flat transmission grating disperses the light toward the focal plane where the sensor is installed. The passive radiator cools the heat of the sensor and the optical assembly to keep the stage below -80°C (193 K).

Table 1 summarizes the properties of NIRS3 instruments. The spectral sampling and the temperature of the optics and the sensor have been designed to achieve an adequate SNR as described in the next section. The spatial sampling during the global mapping phase at 20km in altitude is about 40m per spectrum, which corresponds to 2m at 1km in altitude in the SCI crater-observation phase.

We adopted a 128-pixel indium arsenide (InAs) photodiode for the linear image sensor of NIRS3 to obtain high sensitivity in the 2 to 3μm band, besides NIRS used a 64-pixel indium gallium arsenide (InGaAs) sensor. The 20 times greater condenser capacity enables establishing high-gain and low-gain modes. FPGA sets the integration time from 10μs to 10ms, and the stacking number from 1 to 1024.

Table 1. Properties of NIRS3 instruments

item	properties
optical assembly	
spectral range	1.8-3.2µm
spectral sampling	18nm/pixel
field of view	0.1°
spatial sampling	~40m/spectrum (*)
aperture diameter	32mm
optical elements	Si, Ge
spectrometer	grating
temperature	< 193 K (*)
shutter	
driver	electro-mechanical
frequency	100Hz
sensor	
photo diode	InAs
pixel number	128ch (linear)
pixel pitch	50µm
pixel height	100µm
temperature	<193 K (*)
analogue electronics	
quantum bit	16 bit
digital electronics	
integration time	10 µs - 10 ms
stacking number	2^0-2^{10} (1-1024)

*) at 20 km in altitude.

Results of critical design: The critical design of NIRS3 started in August, 2011. We performed ground properties tests and environmental tests using the engineering model of NIRS3-S and NIRS3-AE including the newly developed InAs sensor and the shutter.

We performed a trade-off of the sensor cooling mechanism for the sensor using the results of thermal tests. We enlarged the radiator rather than the Peltier thermoelectric device at the sensor because the device did not have enough performance at 193K stage. Thermal analysis after the radiator modification demonstrated that we will attain down to 177 K at 20km in altitude.

Results of SNR property tests implied that the rapid increase of the dark current in the InAs sensor degrades the SNR when the integration time exceeds 200µs at 193K. Therefore, we improved the SNR by (1) cooling the sensor to below 187K to reduce the dark current low sufficiently for 400µs integration, (2) sampling three-times of 400µs integration in one shutter-open period, and (3) spectral binning of two channels. The adjusted SNR remains above 50 at 2.6µs during a sufficient period for global mapping.

These results of the critical design show that NIRS3 performs well enough for scientific applications.

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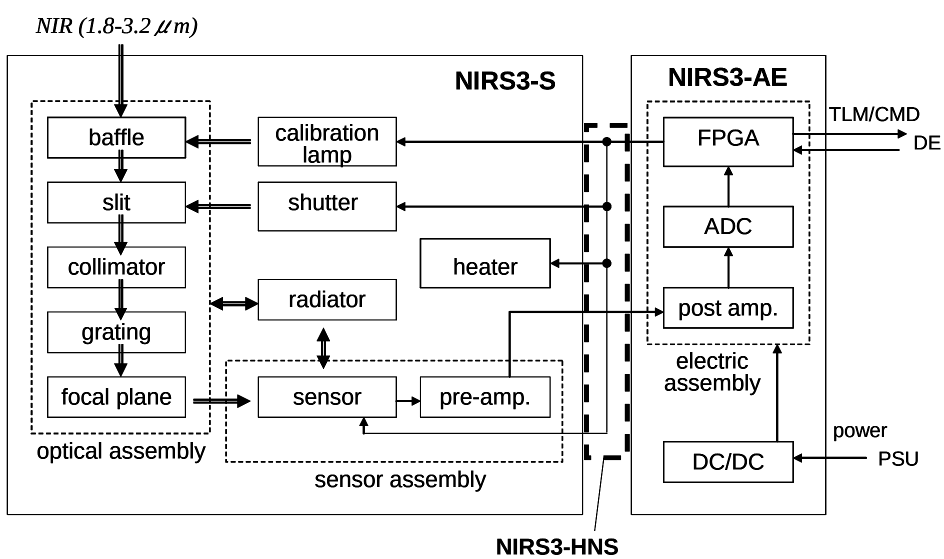

Figure 1. Conceptual block diagram of NIRS3, the Near Infrared Spectrometer on Hayabusa-2. NIRS3 consists of the Spectrometric Unit (NIRS3-S) and the Analog Electric Unit (NIRS3-AE), which are connected with harness cable (NIRS3-HNS).