DEVELOPMENT OF HAYABUSA-2 LIDAR. N. Namiki[1], T. Mizuno[2], M. Mita[2], K Kawahara[2], H. Kunimori[3], H. Senshu[1], R. Yamada[4], H. Noda[4], M. Shizugami[4], N. Hirata[5], H. Ikeda[6], S. Abe[7], K. Matsumoto[4], S. Oshigami[4], F. Yoshida[4], N. Hirata[8], H. Miyamoto[8], S. Sasaki[9], H. Araki[4], S. Tazawa[4], Y. Ishihara[2], M. Kobayashi[1], K. Wada[1], H. Demura[5], J. Kimura[10], M. Hayakawa[2], and N. Kobayashi[2], [1]PERC/Chitech (2-17-1 Tsudanuma, Narashino, Chiba, JAPAN 275-0016; nori.namiki@perc.it-chiba.ac.jp), [2]ISAS/JAXA (Sagamihara, Kanagawa, JAPAN 252-5210), [3]NICT (Koganei, Tokyo, JAPAN 184-8795), [4]NAOJ (Mizusawa, Oshu, Iwate, JAPAN 023-0861), [5]Univ. Aizu (Aizu-Wakamatsu, Fukushima, JAPAN 965-8580), [6]ARD/JAXA (Tsukuba, Ibaraki, JAPAN 305-8505), [7]Nihon University (Funabashi, Chiba, JAPAN 274-8501), [8]Univ. Tokyo (Tokyo, JAPAN 113-0032), [9]Osaka University (Toyonaka, Osaka, JAPAN 565-0043), [10]Tokyo Institute of Technology (Tokyo, JAPAN 152-8550).

Introduction: The Japanese first asteroid mission, Hayabusa, visited at the small asteroid 25143 Itokawa in September, 2005. Images taken by Hayabusa are combined with other remote sensing observations revealing that this asteroid as small as 500 m in the longest axis is the first rubble-pile body identified in our solar system [1]. Despite that several engineering problems occurred on the spacecraft before and after the rendezvous with Itokawa, Hayabusa successfully retrieved samples from the surface of 25143 Itokawa to the Earth in 2010 to reveal unpredicted nature of a very small asteroid [1-5].

JAXA and collaborating scientists are now developing the second asteroid mission named "Hayabusa-2". Hayabusa-2 is based on a heritage of the first Hayabusa. At the same time, Hayabusa-2 is improving engineering and scientific achievements of the first Hayabusa, and also challenging new technologies. Furthermore, target asteroid is different from that of the first Hayabusa. The asteroid 25143 Itokawa explored by Hayabusa is silicate-rich S-type. On the other hand, Hayabusa-2 is visiting a C-type asteroid, (162173) 1999 JU3.

An architecture of the Hayabusa-2 spacecraft is developed on the basis of the first Hayabusa, with some improvements and new challenges from the original design. For example, four ion engines of Hayabusa-2 are reinforced 25 % from old ones in order to travel farther distance than the orbit of 25143 Itokawa.

The launch windows to reach 1999 JU3 are limited. Hayabusa-2 needs to depart from the Earth in 2014 in either early December 2014, or July 2015. After Earth swing-by in December 2015, Hayabusa-2 will arrive at the asteroid in June 2018. During rendezvous phase of about one and half year, the asteroid will be observed carefully to reveal the shape and the surface properties by Multiband Imager (ONC-T), Near Infrared Spectrometer (NIRS3), Thermal Infrared Imager (TIR), and Laser Altimeter (LIDAR).

LIDAR measures altitudes of the spacecraft from a surface of the asteroid by taking a time of flight of laser pulse. As a part of Attitude and Orbit Control System (AOCS), the LIDAR data are used for navigation of the spacecraft. The data are particularly important during touchdown operation. Besides, the LIDAR data are served for scientific analysis of the shape, mass, and surface properties of the asteroid in order to elucidate physical evolution of minor bodies such as impact fragmentation and coagulation. We also wish to expand outcomes of Itokawa exploration by examining uniformity and variation of porosity within rubble-pile body and detecting dusts levitating above the surface of asteroid. The remote sensing observations of Hayabusa-2 will be carried out from Home Position (HP), middle altitude, and low altitude whose distances from the asteroid surface are nominally 20 km, 5 km, and 1 km, respectively.

Design of Hayabusa-2 LIDAR is based on that of the first Hayabusa (Table 1) [6, 7]. The size and weight are 240 x 240 x 230 mm (Figure 1) and 3.7 kg, respectively. Laser pulses of 10 mJ at 1064 nm wavelength are emitted from a passive Q switched Nd:YAG laser at 1 Hz at fastest. The 1-mrad divergent beam corresponds to surface footprint diameter of 20 m at HP. A Cassegrain type telescope of 127 mm in diameter is used as a primary receiver to measure distance longer than 1 km. In addition, another receiver optics is implemented for range measurement shorter than 1 km and longer than 30 m. Light reflected from the surface is refocused onto a silicon avalanche photodiode through a narrow band-pass interference filter. All optics are aligned on optical bench. Detector and elec-

Table 1. Specification of Hayabusa-2 LIDAR.

Parameter	Value
Altitude range	30 m ~ 25 km or longer
Range resolution	0.5 m
Range accuracy (1σ)	± 1 m or less (at 30-m altitude) ± 5.5 m or less (at 25-km altitude)
Pulse repetition rate	1 Hz
Receiver telescope	Cassegrain type
Telescope diameter	127 mm
Pulse energy	10 mJ or more
Pulse width	10 nsec or less
Pulse divergence	1 mrad
Field of view	1.5 mrad
Receiver detector	Si-APD
Power consumption	18.5 W (w/o survival heater)

tronics are implemented in a chassis. Telemetry and command are transferred between LIDAR and the ground station via AOCS. The range data passed to AOCS are used to keep the spacecraft in a safe distance from the asteroid or control touchdown approach.

Hayabusa-2 LIDAR will provide a time resolution of less than 3.33 ns corresponding to 0.5-m range resolution (Table 1). LIDAR is expected to measure the distance from 30 m to 25 km above the surface of the asteroid. During mission phases, topographic data will be acquired constantly to cover entire surface of the asteroid. The experiment will provide the integrated intensity of the transmitted and returned pulses allowing an assessment of surface albedo including shadowed areas. Overall, Hayabusa-2 LIDAR is sufficient for spacecraft navigation, but is not as high-performance as the most recent instrument onboard OSIRIS-Rex [8, 9]. To compensate for the performance of the instrument, we need to take most advantage of experiences of the first Hayabusa in operational planning.

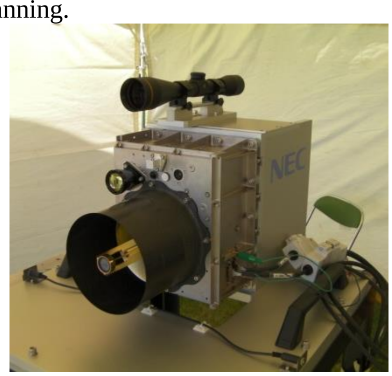

Fig. 1. Field test model of Hayabusa-2 LIDAR.

Dust Count Mode: Hayabusa-2 LIDAR is equipped with a new function called "dust count mode". The new function is aimed to detect a very weak scattering light from a dust cloud around the asteroid, if ever exists. The dust count mode works similarly to aerosol lidar which is a popular method to measure the abundance of aerosol in the terrestrial atmosphere within a distance bin along a line-of-sight. The difference of aerosol lidar and the dust count mode of Hayabusa-2 LIDAR is that the dust count mode is not capable of measuring the abundances of dust particles, but detect a return pulse higher than a given threshold level.

A range of 1 km is divided into 50 bins, thus a spatial resolution of the dust count mode is 20 m (Fig. 2). Wait time shown in Fig. 2 is a parameter to start 1-km range and is variable from 0 to 19 km. In the dust count mode, LIDAR detects an existence of dusts in each bin. The threshold level is also variable in four levels allowing to distinguish the abundance of dust particle in step-wise manner.

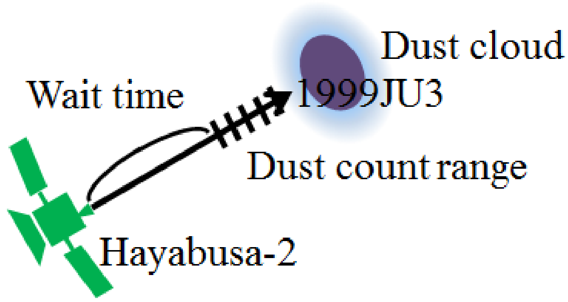

Fig. 2. Schematic figure of the dust count mode.

Optical Transponder System: Hayabusa-2 LIDAR is also equipped with a function for laser link experiment. "Optical transponder" system enables LIDAR to receive the laser pulse from a ground SLR station and to send back a return pulse to the same ground station. The laser link experiment will be carried out at a time of Earth swing-by which is scheduled a year after the launch.

Laser link experiment will be the first full-operation of LIDAR. In addition, the experiment will provide an opportunity of in-flight measurement of the alignment of LIDAR bore-sight after the launch. The SLR telescope of 1.5m aperture in NICT Koganei will be used as a ground station. A 1-micron laser with power of 1.2J and repetition rate of 10Hz will be installed for this experiment. The spacecraft scans the Earth at a certain rate so that footprint of LIDAR overlaps each other. Taking into account the attitude determination error of 0.5 mrad, the bore-sight of LIDAR to the spacecraft body will be determined within an accuracy of 1.5 mrad.

Status Of Manufacturing LIDAR: In 2013, an engineering model of LIDAR was developed and has been tested to verify every function of the instrument. The first of these tests was the field test held between May 26 and June 1 on runway at Taiki-cho in Hokkaido. The second was a thermal vacuum test which was held during July 9 to 22 using a thermal vacuum chamber of Nippon Electric Company (NEC). Manufacturing of flight model has begun in December 2014.

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