LUNAR LASER RANGING EXPERIMENT FOR SELENE-2. H. Noda[1], H. Kunimori[2], H. Araki[1], T. Fuse[2], H. Hanada[1], M. Katayama[3], T. Otsubo[4], S. Sasaki[1], S. Tazawa[1], S. Tsuruta[1], K. Funazaki[5], H. Taniguchi[5], K. Murata[5], [1]National Astronomical Observatory of Japan (2-12 Hoshigaoka, Mizusawa, Oshu, Iwate, Japan. noda@miz.nao.ac.jp), [2]National Institute of Information and Communications Technology (NICT) (Koganei, Tokyo, Japan), [4]National Astronomical Observatory of Japan (Mitaka, Tokyo, Japan), [4]Hitotsubashi University (Kunitachi, Tokyo, Japan), [5]Iwate University (Morioka, Iwate, Japan).

Introduction: We present the development status of the Lunar Laser Ranging experiment proposed to Japanese SELENE-2 lunar landing mission. The Lunar Laser Ranging measures the distance between laser link stations on the Earth and retroreflectors on the Moon, by detecting the time of flight of photons of high-powered laser emitted from the ground station. Since the Earth-Moon distance contains information of lunar orbit, lunar solid tides, and lunar orientation and rotation, we can estimate the inner structure of the Moon through orientation, rotation and tide.

Retroreflector: Retroreflectors put by the Apollo and Luna missions in 1970's (Apollo 11, 14, 15, Lunakhod rover 1 and 2) are arrays of many small Corner Cube Prisms (CCP) (3.8 cm diameter for Apollo). Because of the tilt of these arrays from the Earth direction due to the optical libration, the returned laser pulse is broaden, causing the main range error of more than 1.5 cm ([1]). Therefore retroreflectors with larger single aperture are necessary for more accurate ranging. Meanwhile, the beam width of retroreflector is inversely proportional to the fourth power of aperture. Therefore as the aperture becomes larger, the beam width becomes smaller so that the divergence of the reflected beam cannot cancel the velocity aberration of 3.5 - 7 micro radians ([2]). To cancel the velocity aberration, a large retroreflector needs small amount of offset angle between the reflecting planes (called Dihedral Angle Offset or DAO) to spoil the return beam pattern. The DAO must be optimized to be less than 1 arc second with 0.1 arc seconds accuracy for collect more photons [2,3].

The CCP uses the internal refraction in the prism, therefore the quality of the optical material (fused silica) is important. We concluded that a prism larger than 10 cm in aperture is difficult to develop, because the homogeneity of the fused silica is not sufficient. Therefore, if we want to develop a retroreflector whose aperture is larger than 10 cm, an open (hollow) reflector is necessarily needed.

From the aspect mentioned above, we propose a large single retroreflector of hollow-type with 15 cm aperture. Larger aperture up to 20 cm might be favorable if more mass is permitted for payloads. Assuming the ground station as 1.5 m diameter telescope with relatively high energy laser (about 100 mJ, 10Hz repetition rate), enough photoelectrons can be detected within 10 minutes to achieve less than 1 cm of range uncertainty.

As for the mirror material, some ceramic products (ZPF: zero expansion stiffness ceramics or SiC: silicon carbide) are under consideration. The thermal quality of the material can be evaluated by the coefficient of the thermal expansion (CTE) and the thermal conductivity (TC). The ratio TC/CTE is a good measure of the thermal stability of materials. The TC/CTE ratio for ZPF (~250) is more than five times as large as that of the SiC (~50) or Zerodure (~30), therefore ZPF seems to be the most favorable material for the retroreflector. The method to fasten three planes each other must be developed. Also, realization of such small DAO as 0.1 seconds of arc is challenging with current technology, therefore the development of fabrication method is important.

Ground Station: Currently, McDonald Observatory (Texas, U.S.A.), Observatoire de la Cote d'Azur (France), and the Apache Point Observatory (New Mexico, U.S.A.) range the lunar retroreflectors on a regular basis. The number of total normal point data as of today is more than 17,000 and has been increasing about 300 normal points per year. In the context of preparation for SELENE-2, a ground station in Japan is also needed to range the new retroreflector as well as existing ones. Since there is no Japanese station which can range the Moon, a precursor ranging experiment by using the satellite laser ranging facility in the NICT is ongoing. We use a higher average but lower peak-powered laser with wide pulse width (nanosecond) and high repetition rate (>100Hz) to detect photons from the Moon. The experiment will be done within several years.

References: [1] Murphy T. et al. (2008) *PAPS*, 120, 20-37. [2] Otsubo T. et al. (2010) *Adv. Space Res.*, 45, 733-740. [3] Otsubo T. et al. (2011) *Earth Planet Space*, 63**,** e13-e16.