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フォトンサイエンス国際卓越大学院プログラム（XPS）
光科学特別実習　報告書

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SPIE Astronomical Telescope + Instrumentation is a biennial international conference on astronomical telescopes and instrumentations. Many astronomers, engineers, and companies present evaluations of their instruments developed so far, the status of instruments under development, and fundamental technologies to fabricate or evaluate their instruments. By participating in this conference, we can obtain the latest information about the instruments and the technologies and apply it to our research and development if it is useful. In addition, it is worth presenting SWIMS-IFU, which we are developing, to make it widely known to the astronomical society. Therefore, I gave a poster presentation on SWIMS-IFU at the conference.

Contents of Presentation

Integral field spectroscopy (IFS) is an observational method in optical and infrared astronomy to obtain spatially resolved spectra over the entire field of view (FoV) with a single exposure by dividing and rearranging the FoV in a line. It allows us to efficiently study spatially extended objects in detail. SWIMS-IFU is an optical unit called integral field unit (IFU) to add the integral field spectroscopy mode to SWIMS (Simultaneous-color Wide-field Infrared Multi-object Spectrograph), which is a near-infrared imager and multi-object spectrograph for TAO 6.5m telescope being constructed at the summit of Cerro Chajnantor (5640m), Chile by Institute of Astronomy, School of Science, the University of Tokyo. In the optics of SWIMS-IFU (Fig.1), the slice-mirror array (S1) consisting of rectangular (18 x 0.52 mm^2) flat mirrors with different angles each other divides the FoV. It has a wider wavelength coverage (0.9 – 2.5 µm) and a larger field of view (16.6 x 12.8 arcsec^2) than existing instruments by optimizing to a seeing limited observation, therefore it can observe spatially extended objects more efficiently.

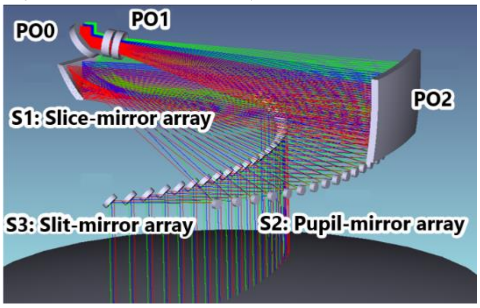

Fig 1 Optical layout of SWIMS-IFU.

Because of the limitation of storage in SWIMS, SWIMS-IFU must be compact (< 170 x 220 x 60 cm^3) and it is too difficult to calibrate positions and angles of 80 small mirrors one by one in the small space. Therefore, we have developed the optical elements utilizing an ultra-precision cutting technique. This is a fabrication method of an optical surface only by cutting, using a machine with nm-order positional accuracy and a high-precision diamond tool. Monolithic fabrication using the ultra-precision cutting technique allows us to make the many mirrors with relative positioning accuracy of µm-order on a single metal material and reduce the positional and angular calibration procedures. With this method we have completed one of the mirror arrays, the slit-mirror array (S3) consisting of 26 small spherical mirrors and carried out test fabrication of the pupil-mirror array (S2) consisting of 12 spherical and 14 elliptical mirrors. I gave a poster presentation on their fabrication processes and performance evaluations. The main results are as follows.

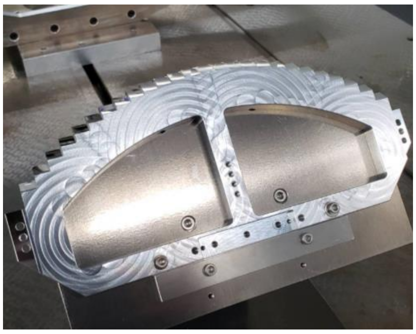
Fig 2 Finished product of the slit-mirror array.

The slit-mirror array (S3) is the final mirror surface of SWIMS-IFU. Rearranged images of an object are focused on this mirror and reflected into SWIMS optics. The 26 spherical mirrors have different radii of curvature (61.6 – 65.1 mm) and angles (42.2 – 43.5 deg). Each mirror has a size of ~ 7 x 5 mm^2. We used a ball end mill with a radius of 0.5 mm to fabricate the mirrors with the different curvatures. To achieve the best surface roughness, we used an aluminum super alloy RSA6061 by RSP technology. The finished product of the slit-mirror array (Fig.2) has surface roughness of R.M.S. = 7.4 nm and a shape error of P-V = 169 nm as an average of the 26 mirrors. These values satisfy the requirements of the surface roughness R.M.S. < 10 nm and the shape error P-V < 300nm. This is the first completion of the optical elements of SWIMS-IFU optics and proves that we can fabricate the complicated mirror arrays using the ultra-precision cutting technique.

The pupil-mirror array is the first mirror after the object image is divided by the slice-mirror array, on which an exit pupil of the slice-mirror array is imaged. Since a shape error of the pupil-mirrors directly affects imaging performance of SWIMS-IFU, we changed a configuration of the fabrication so that the number of simultaneous control axes is 2 instead of 3 as in the fabrication of the slit-mirror array. The 12 spherical mirrors have a radius of curvature of 70 mm and the 14 elliptical mirrors each have two foci at the positions of the corresponding slice-mirror and slit-mirror. We used a ball end mill with a radius of 1mm and a normal aluminum alloy A6061. The finished product has an average shape error of P-V = 142 nm for the 12 spherical mirrors, satisfying the requirement of P-V < 300 nm and improved from the fabrication of the slit-mirror array. Although we could not measure shape errors of the 14 elliptical surfaces with an interferometer, we evaluated their imaging quality with a pinhole imaging test and confirmed that the elliptical mirrors have better imaging quality than the spherical.

Fig 3 Test product of the pupil-mirror array.

As we mentioned above, we completed the slit-mirror array and the test-fabrication of the pupil-mirror array. We are now planning to finish fabrication of all the rest of the optical elements in early 2021, assemble and evaluate them in late 2021. In 2022, we will carry out the first light observation of SWIMS-IFU at Subaru telescope, NAOJ, where SWIMS is now being operated.