Development of Micro-Mirror Slicer Integral Field Unit for Space-borne Solar Spectrographs

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Integral field spectroscopy (IFS) is a two dimensional spectroscopy, providing spectra for each spatial direction of an extended two-dimensional field simultaneously. There are three methods to realize the IFS depending on image slicing devices: micro-lenslet arrays, optical fiber bundles, and narrow rectangular image slicer arrays. Basically, the integral field spectroscopy unit (IFU) acts as a coupler between the telescope and the spectrograph by optically reformatting a two-dimensional rectangular field into a quasi-continuous pseudo-slit located at the entrance focal plane of a spectrograph.

The scientific advantages of IFS for studies of localized and transient solar surface phenomena are obvious. From the viewpoint of high-efficiency spectroscopy, wide wavelength coverage, precision spectro-polarimetry, and space application, the image slicer consisting of all reflective optics is the best option among the three. For space instrumentation, small-sized IFU units are advantageous; they demand that the width of the slicing mirrors should be as narrow as an optimal spectrograph slit width ($< 100\,\mu$m), which is usually difficult to manufacture with glass polishing techniques. In this study, we could successfully applied a Canon's novel technique for high optical performance metallic mirrors of small dimensions.

Keeping in mind a possible application for a future space-borne spectrograph such as SOLAR-C: a next planned Japanese solar space mission, we designed an IFU that utilizes a micro-mirror slicer of 45 arrayed 30-μm-wide metal mirrors and a pseudo-pupil metal mirror array of off-axis conic aspheres re-formatting three pseudo-slits; this design is feasible for optical configuration sharing a spectrograph with a conventional real slit. We manufactured a prototype IFU for evaluation according to the optical design and deposited a protected silver coating on both metal mirrors after its successful space qualification tests.

It demonstrated that the final optical quality of the IFU is sufficiently high for a visible light spectrograph. Each slicer micro-mirror is 1.58 mm long and 30 μm wide with the micro-roughness is less than 1 nm rms and edge sharpness is less than 0.2 μm even after the reflective coating and mirror tilt errors were less than the required accuracies. As to the pseudo-pupil mirrors, the micro-roughness was less than 1.27 nm rms and the surface figure accuracy was less than 59 nm PV. Tilt errors around the x-axis of all surfaces were less than 4.6 arcsec and those around the y-axis of all the surfaces were less than 2.3 arcsec, which are less than the requirement (7.7 arcsec). We confirmed that the pseudo pupils were projected as designed and the re-arranged slicer images were focused by the pseudo-pupil mirrors as three pseudo slits at a distance 200 mm away (see Figure 1).

We also presented a concept of a field lens placed at the slit plane that changes the diverging beam from the pseudo-pupil mirrors to a telecentric beam into a spectrograph. The field lens needs to have a high index larger than 2. Off-the-shelf ZnSe-made cylindrical lenses which are close to the optical design were used and successfully verified the optical performance.

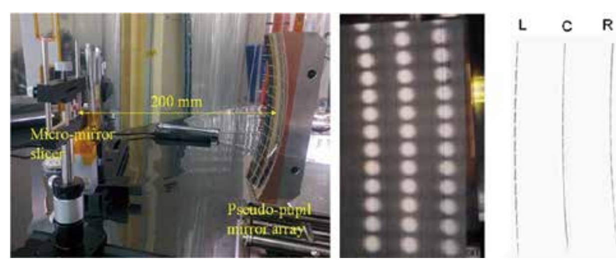

Figure 1: Set up of micro-mirror slicer IFU (left), footprint at pseudo-pupil mirror array of F/24 beams arising from the slicer (middle), and image on a camera of the re-arranged slicers through the ZnSe cylindrical field lens (right), confirming that all the metal mirrors were fabricated as designed.

Reference

[1] Suematsu, Y., et al.: 2017, *CEAS Space J.*, **9**, 421-431.