A Design and Trial Production of the Image Slicer Unit for the Mid-Infrared Spectrograph

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ABSTRACT

An image slicer is highly in demand for an integral field unit (IFU) spectrograph of the next generation infrared telescopes. This paper reports the results of the trial production of three key optical elements for a small format (number of slice; n=5) image slicer, i.e. monolithic slice mirrors, monolithic pupil mirrors and monolithic pseudo slit mirrors. We have demonstrated that sufficiently high processing accuracy and mirror surface accuracy for infrared observations are achieved for each optical element based on our super precision cutting techniques.

Keywords: Integral Field Unit (IFU), image slicer, SPICA Mid-Infrared Camera and Spectrometers, spectroscopy

1. DESIGN OF THE IMAGE SLICER FOR SPICA MCS/MRS-S

The integral field spectroscopic function plays an extremely important role in the next generation infrared instruments in, for example, understanding the dust condensation processes around massive stars with active mass loss, unveiling the complicated structures of circumstellar medium around late-type red giants, and characterizing the properties of proto-planetary disks and envelopes. In particular, an image slicer is highly in demand for an integral field unit (IFU) spectrograph of the next generation infrared instruments such as Thirty Meter Telescope (TMT) Mid-Infrared Camera High-disperser & IFU Spectrograph (MICHI; Packham et al. 2012, Okamoto et al. 2010) and SPICA (Space Infrared Telescope for Cosmology and Astrophysics; Nakagawa et al. 2012) Mid-Infrared Camera and Spectrometer (MCS; Kataza et al. 2012). For example, the optical layout of the image slicer for SPICA MCS Medium Resolution Spectrometer (MRS; Sakon et al. 2012) short channel (MRS-S) is shown in Figure. 1. Based on the result of the current optical design, the refocused image with a field-of-view size of 6 arcsec by 12 arcsec is divided into 5 slitlets with the slice mirrors, and then the image of each slitlet refocused by the spherical pupil mirror is aligned to each pseudo slit mirror and, finally, a pseudo slit image is obtained.

An image slicer for mid-infrared instrument had previously been examined and developed for MIRSIS (Okamoto et al. 2008). However, the slice mirrors adopted for the image slicer of MRSIS are produced by piling up several pieces of independent thin aluminum plates of 300μm thickness and, for this reason, careful and complicated optical alignment is

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needed to obtain pseudo slit images aligned in a straight line. The production of monolithic slice mirrors with thinner mirror width should, therefore, be the key for the success in achieving stable pseudo slit image for SPICA/MCS/MRS-S. So far, Sakon et al. (2012) have reported the success of the trial production of a monolithic slice mirrors piece with 174μm slit width by means of the ultra-precision cutting with ULG-300 with single crystal diamond bits at the Advanced Technology Center (ATC) National Astronomical Observatory of Japan (NAOJ). This paper repots the results of our further trial production of the key optical elements including the monolithic small format slice mirror (with 5 slices), the monolithic pupil mirror, and the monolithic pseudo slit mirror.

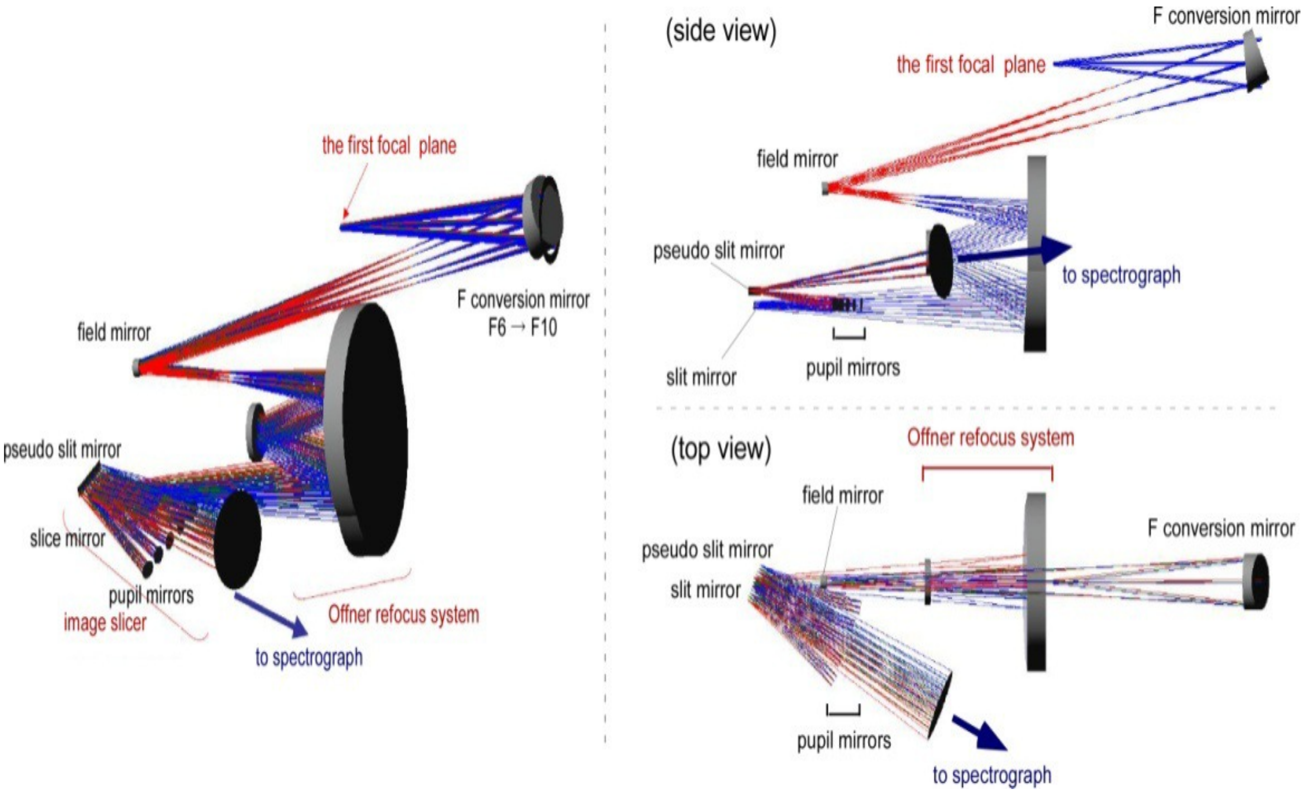

Figure 1. The schematic view of the optical layout of the image slicer designed for SPICA MCS/MRS-S (Sakon et al. 2012)

2. TRIAL PRODUCTION OF MONOLITHIC SLICE MIRRORS, MONOLITHIC PSEUDO SLIT MIRRORS, ANDMONOLUTHIC PUPIL MIRRORS FOR SPICA/MCS/MRS-S

2.1 A test piece of monolithic slice mirrors and monolithic pseudo slit mirrors for SPICA/MCS/MRS-S

In order to simplify the optical adjustment of the IFU unit, the monolithic slice mirrors and the monolithic pesudo slit mirrors are made from a single RSA6061 T6 aluminum block. The slice mirrors for MRS-S were produced using nano-center N2C-53U-S5N5 ultra high-precision machine with a single crystal diamond bite at NAGASE INTEGREX Co., Ltd. The width of each slice mirror is designed to be 184μm and the thickness of the single crystal diamond bite was 187μm. Based on the measurements of surface roughness (Ra) with Zygo NewView Optical Profilers, Ra<50nm is achieved at any position of the slice mirrors. On the other hand, the pseudo slit mirrors for MRS-S are produced with N2C-53U-S5N5 using an R-bite of R=0.08mm. Based on the measurements of surface roughness (Ra) with Zygo NewView Optical Profilers, Ra<20nm is achieved at any position of the pseudo slit mirrors.

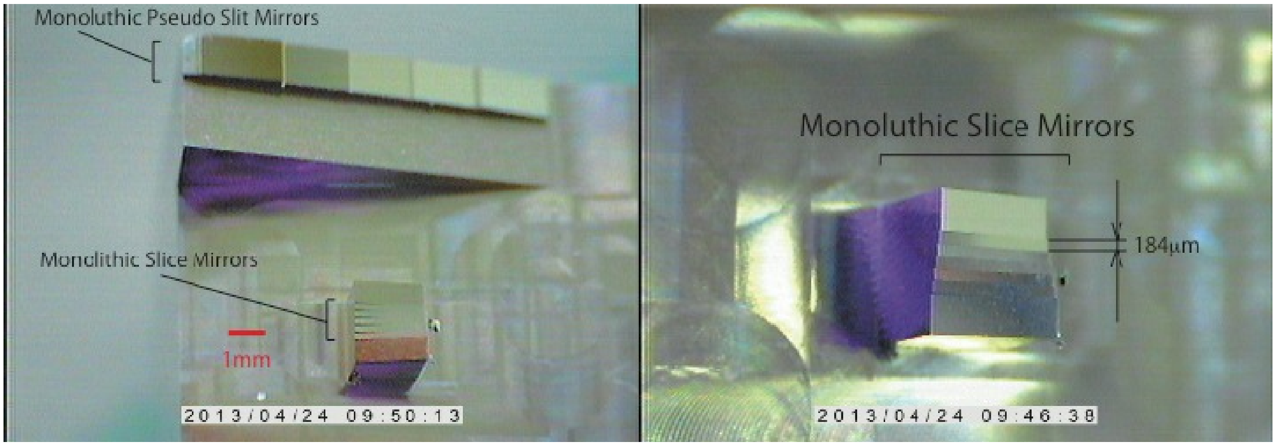

Figure 2. Test pieces of monolithic slice mirrors and pseudo slit mirrors of MC/ MRS-S produced using Nano-center N2C-53U-S5N5 with a single crystal diamond bite at NAGASE INTEGREX Co., Ltd.

2.2 The effective length of each pseudo slit mirror for SPICA MCS/MRS-S

The R-bite of R=0.08mm was used to produce the pseudo slit mirrors. In this case, unprocessed part remains at the boundary area of each mirror due to the processing using R-bite of R=0.08mm. As a result, the effective length of each pseudo slit mirrors shortens slightly than the design level. The left panels in Figure 3 show the design drawings of the pseudo slit mirrors, where values are given in the units of mm. The right panel in Figure 3 and the panels in Figure 4 show the sectional drawings along the C-C cut provided as a result of the non-contact three-dimensional shape measurements with NH-3N (Mitaka Kohki Co., Ltd) performed at the University of Tokyo together with the design level.

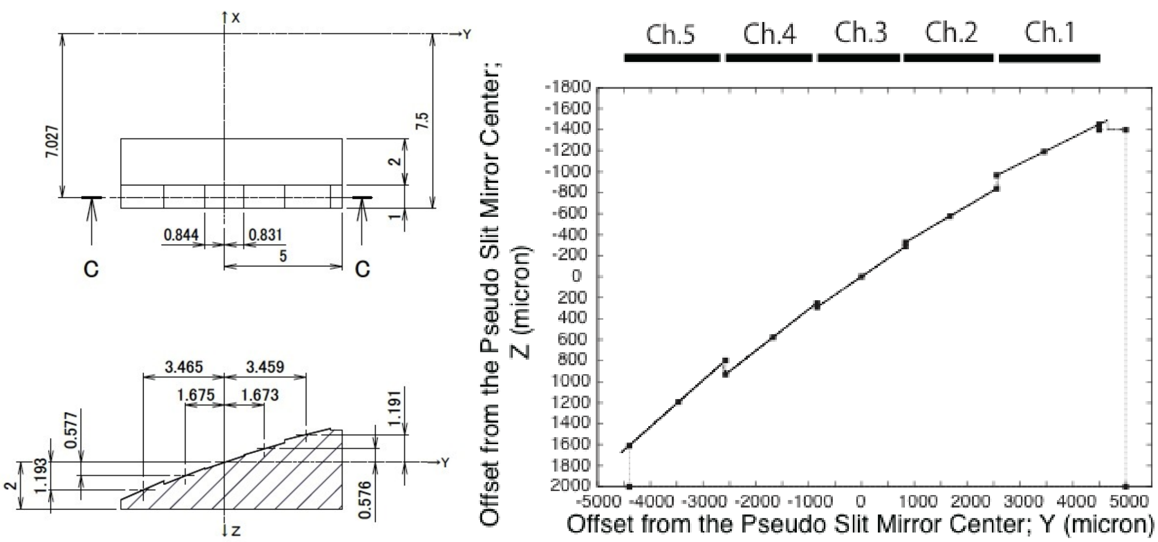

Figure 3. – The left panels show the design drawing of the pseudo slit mirrors. Values are given in the units of mm. The right panel shows the sectional drawings along the C-C cut provided as a result of the 3-D shape measurement with NH-3N (shown with red solid line). The design level is shown by a dotted line with solid squares indicating the endpoints and the center of each pseudo slit mirror.

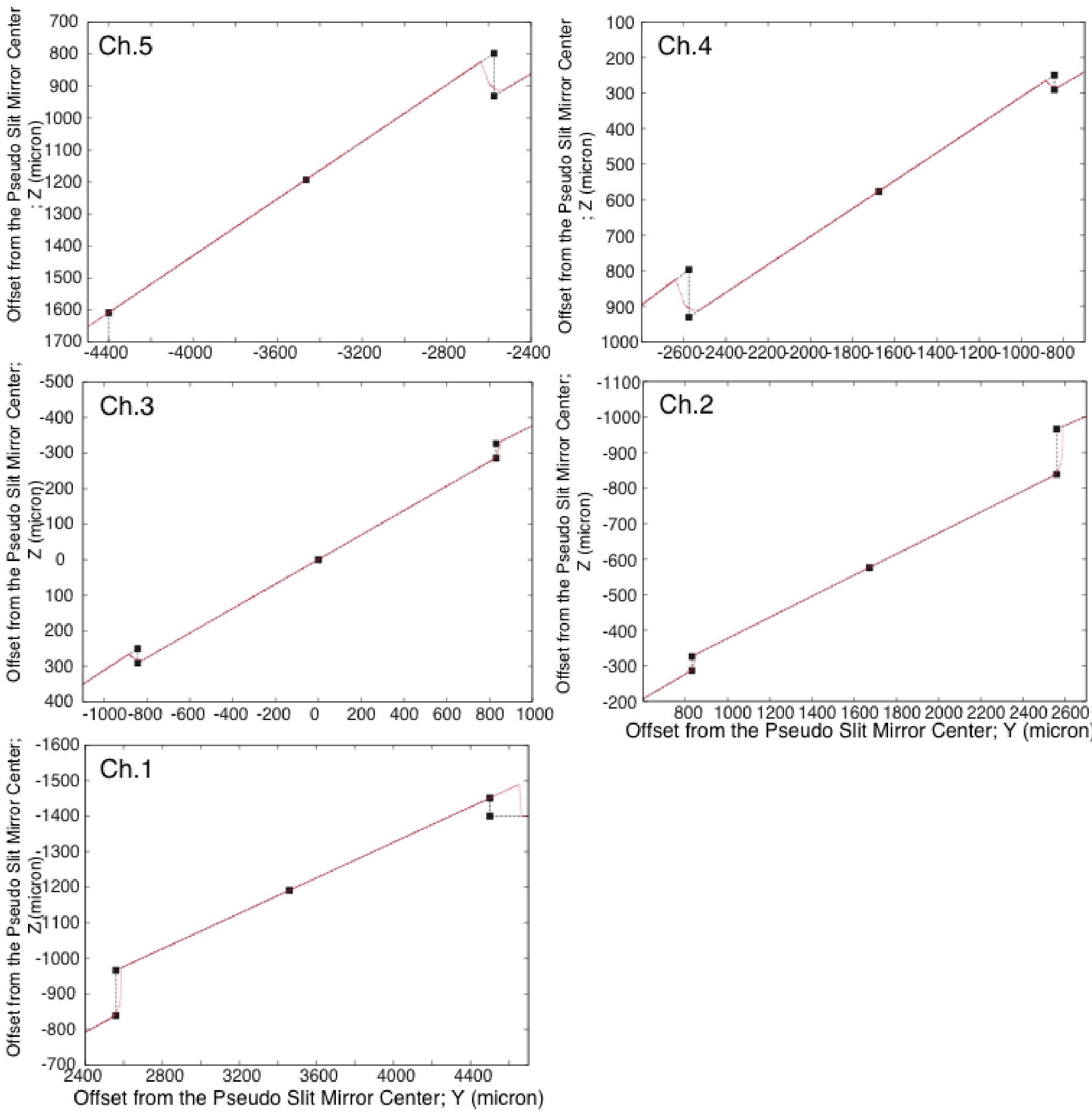

Figure 4. – The sectional drawings for each pseudo slit mirror (Ch. 5—Ch.1) along the C-C cut provided as a result of the 3-D shape measurement with NH-3N (shown with red solid line). The design level is shown by a dotted line with solid squares indicating the endpoints and the center of each pseudo slit mirror. (The same as right panel of Figure. 3)

The measurements show that the effective pseudo slit mirror length, where the sufficient flatness and the mirror surface precision for the infrared wavelength are ensured, shortens by 30-70μm per one side in comparison with the design level. Figure 4 shows the field-of-view region covered by the effective area of the pseudo slit mirrors.

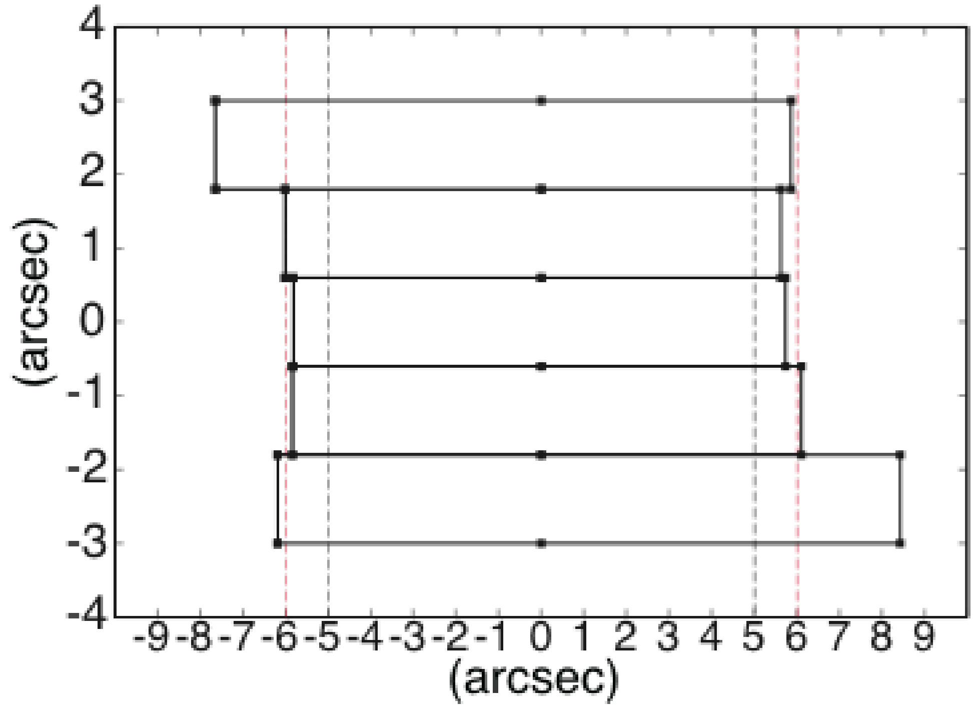

Figure 5. – The field-of-view region covered by pseudo slit mirrors excluding the unprocessed areas of each mirror.

2.3 A test piece of monolithic pupil mirrors for SPICA MCS/MRS-S

A test piece of the pupil mirrors for MRS-S was produced from a RSA6061 T6 aluminum block using Nanoform 250 at Crystal Optics Ltd. (see Figure 6). Based on the shape precision measurement of each spherical pupil mirror with Ultrahigh Accurate 3-D Profilometer (UA3P), r.m.s.<0.034 μm and P-V<0.19μm were achieved for each pupil mirror. From the measurements with Zygo NewView Optical Profilters, nice surface roughness Ra<20nm is achieved at any position of the pupil mirrors.

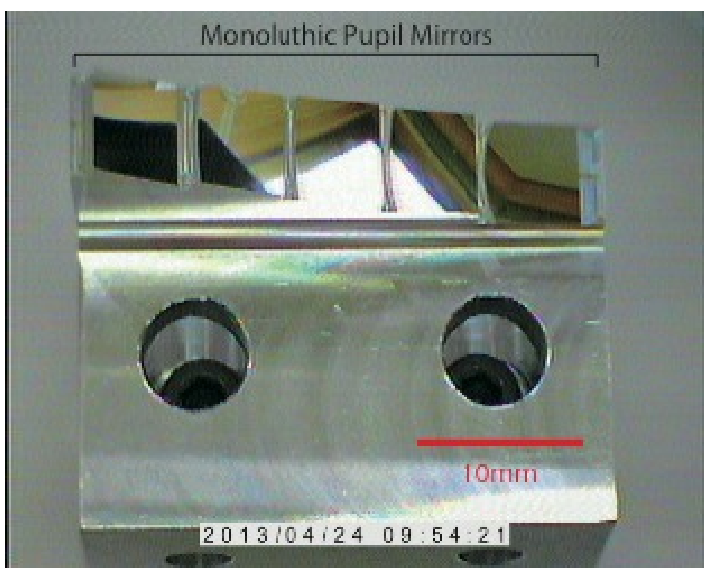

Figure 6. – The test piece of monolithic pupil mirrors for MRS-S produced using Nanoform 250 at Crystal Optics Ltd.

2.4 Assembly of slice mirrors, pupil mirrors and pseudo slit mirrors

The test piece of unified monolithic slice mirrors and monolithic pseudo slit mirrors and the test piece of monolithic pupil mirrors are assembled and mounted on the surface plate made of Al (see Figure 7). The 3-D relative positions of these test pieces are adjusted with an accuracy of a few μm by determining the datum surface on the Al surface plate by taking account of the machining error intrinsic to each test piece. The assembled unit is used for the infrared imaging quality test of the pseudo slit image.

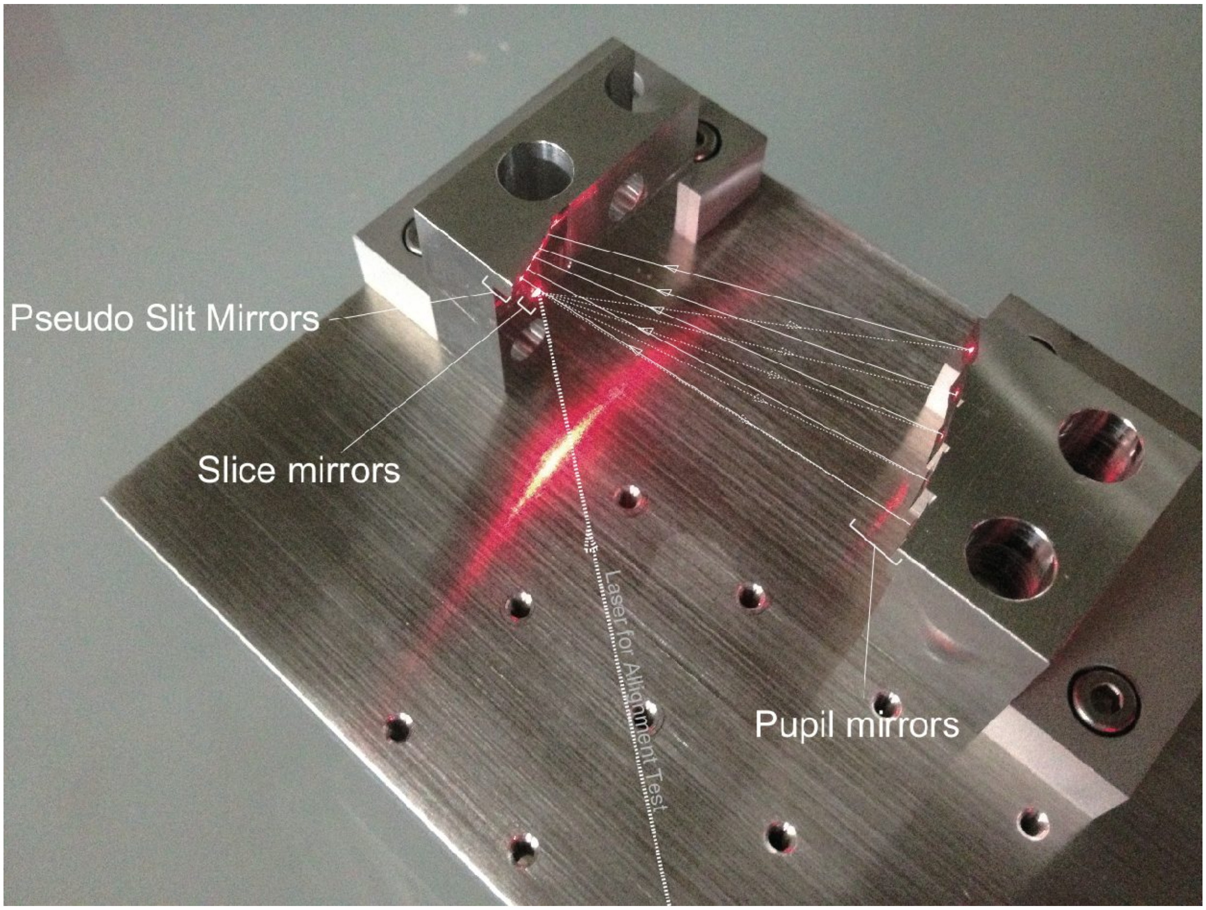

Figure 7. The results of the Assembly of the produced test piece of the monolithic slice mirrors and pseudo slit mirrors and the produced test piece of the monolithic pupil mirrors on the Al surface plate.

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