KASINICS: KASI Near-Infrared Camera System

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ABSTRACT

The Korea Astronomy and Space Science Institute (KASI) is building the KASI Near Infrared Camera System (KASINICS) for the 61-cm telescope at the Sobaeksan Optical Astronomy Observatory (SOAO) in Korea. With KASINICS we will mostly do time monitoring observations, e.g., thermal variations of Jovian planet atmospheres, variable stars, and blazars. We use a 512 x 512 InSb array (Aladdin III Quadrant, Raytheon Co.) for L-band observations as well as J, H, and Ks-bands. The field-of-view of the array is 6 x 6 arcmin with 0.7 arcsec/pixel. Since the SOAO 61-cm telescope was originally designed for visible band observations, we adopt an Offner relay optical system with a Lyot stop to eliminate thermal background emission from the telescope structures. In order to minimize weight and volume, and to overcome thermal contraction problems, we optimize the mechanical design of the camera using the finite-element-method (FEM) analysis. Most of the camera parts including the mirrors are manufactured from the same melt of aluminum alloy to ensure homologous contraction from room temperature to 70 K. We also developed a new control electronics system for the InSb array (see the other paper by Cho et al. in this proceedings). KASINICS is now under the performance test and planned to be in operation at the end of 2006.

Keywords: Infrared, IR camera, IR Instrumentation, Astronomical Instrumentation

1. INTRODUCTION

The Korea Astronomy and Space science Institute (KASI) has been developing the KASI Near Infrared Camera System, KASINICS for observations in near infrared (NIR) wavelengths of J, H, Ks, and L-bands. KASINICS will be mounted on the 61-cm telescope of the Sobaeksan Optical Astronomy Observatory (SOAO) in the Republic of Korea. We plan to use KASINICS for monitoring time-variabilities of Jovian planet atmospheres, variable stars, blazars, etc. The expected limiting magnitudes are 18.1 m_J, 17.2 m_H, 17.5 m_{Ks}, and 12.4 m_L for point sources, with the signal to noise ratio of 10 and the integration time of 100 seconds (Moon et al. 2004).[1]

We have completed manufacturing all the mechanical parts and the electronic controller of KASINICS, and the testing results of the assembled system are successful. In this paper we introduce the design, manufacturing, and testing results of KASINICS.

2. INSTRUMENT OVERVIEW

KASINICS consists of a cooler, an electronic controller, and a cryostat. In the cryostat, a cold box includes optics system, a filter box, detector housing, and two cold heads of the GM cryocooler. Fig. 1 shows the configuration and beam path of KASINICS. The cold box is cooled down to 80 K and the detector box including the IR sensor is maintained at 30 ± 0.2 K by a heater control.

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The optical box contains baffles and an Offner relay system with a Lyot stop which eliminate thermal background emission from the telescope structures. The filter box is designed to be equipped with eight filter modules. The wheel is rotated by a servomotor (SM2315D, Animatics Co.) which is attached to the outer surface of the cryostat. The wheel position sensing is accomplished by three hall-effect sensors and a mechanical switch.

The detector box includes a fan-out board with a 512 × 512 InSb array (Aladdin III Quadrant, Raytheon Co) which has a 6 × 6 arcmin field-of-view (FOV) for the SOAO telescope. We will use J, H, Ks, L-band filters for standard observations and several narrow band filters for emission line observations. The KASINICS controller electronics communicates with the main PC via USB 2.0. More details of the electronic part are described in “Development of the Readout Controller of KASINICS” by Cho et al.[2]

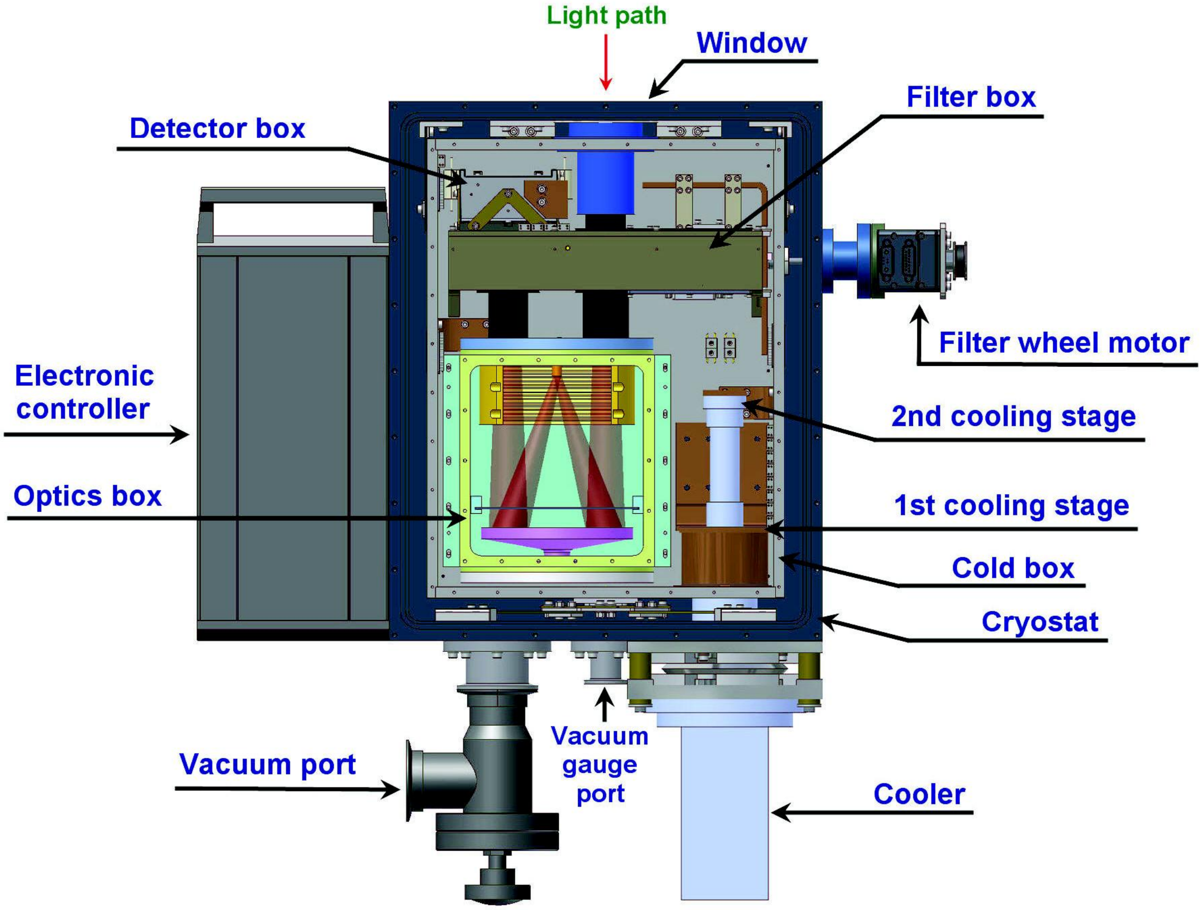

Figure 1. Overview of the KASI Near Infrared Camera System (KASINICS).

Fig. 2 shows the wiring concept of the electronics system which is controlled by the main computer (MS Windows-based PC). To overcome the distance limit of the USB interface, we use an optical fiber extender. The peripherals such as temperature monitor, temperature controller, vacuum monitor, and motor controller communicate with the main computer using the Ethernet to RS-232 converter.

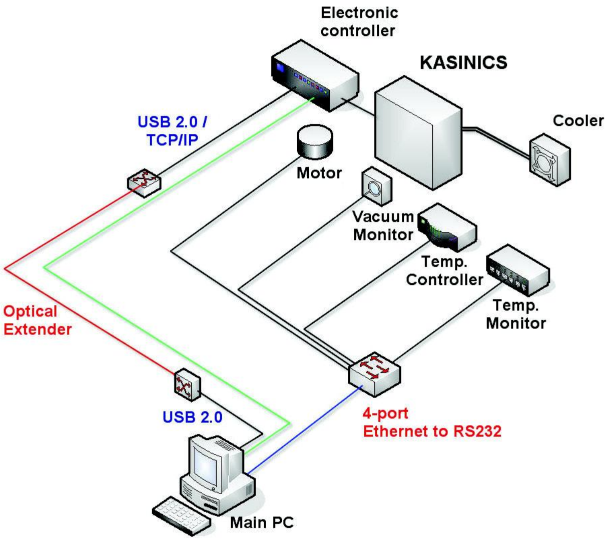

Figure 2. Configuration diagram of electronics system.

3. OPTICAL DESIGN

3.1 Design criteria

Since KASINICS will be installed on the optical telescope, it is necessary to block the thermal radiation from the telescope parts other than the mirrors. A cold Lyot stop, which exists in a re-imaging lens system or Offner system[3], is required to solve this problem. Lens systems are easy to manufacture and align, but have chromatic aberration which degrades image quality significantly. To cover the wide wavelength range (1 ~ 4 μm) in the whole NIR bands, we chose Offner system. On the other hand, the combination of two spherical mirrors in Offner system eliminates spherical aberration.

The median seeing of the SOAO 61-cm telescope is about 2 arcsec in optical wavelengths (Kyeong et al., 1997).[4] Assuming measurements at 0.5 μm and a wavelength dependence of $\lambda^{-6/5}$, we expect 1.7 arcsec and 1.4 arcsec in J-band and L-band, respectively. Then the mean image size of a point source ranges from 54 μm to 67 μm on the focal plane, and it corresponds to 1.9~2.4 pixels with the detector pixel size of 28 μm. Therefore KASINICS needs no conversion lens to change the telescope focal length and this makes the optics simple. Our goal of optical performance is to obtain higher resolutions than the Airy disk size (e.g. 40 μm at J-band) throughout the detector FOV.

Fig. 3 shows the optical configuration of KASINICS. The filters and the window are tilted by 5 degrees to prevent the ghost problem (Lee at al., 2005).[5] All optical parts of KASINICS are cooled down to 80 K in order to reduce thermal noises.

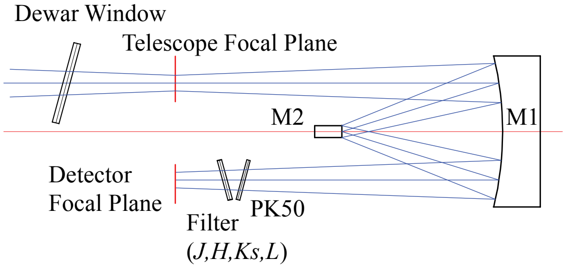

Figure 3. The optical configuration of KASINICS.

3.2 The Offner system

Offner system has a concave primary mirror and a convex secondary. The curvature radius of the secondary is half of that of the primary. The curvature radius of the KASINICS primary is –300 mm and the diameter of the mirror is 140 mm. Table 1 shows parameters of the Offner system. In principle, the distance from the primary to focal plane and the curvature radius of the primary should be equal. The spot sizes, however, increase towards the outer parts of the detector surface due to astigmatism. In order to get a uniform spot size throughout the FOV, we adjust the primary-to-secondary distance from 150 mm to 148.1mm, and the primary-to-focal-plane distance from 300 mm to 303.5mm. Then the resulting spot size is less than 13.2 μm in RMS radius (Yuk et al., 2005).[6]

Table 1. Parameters of the Offner system.

Primary Mirror (M1)	Type	Concave spherical mirror
	Radius of curvature	-300 mm
	Diameter	140 mm
Secondary mirror (M2)	Type	Convex spherical mirror
	Radius of curvature	150 mm
	Outer diameter	9.08 mm
	Inner diameter	4.90 mm
Offset (telescope focus ~ M2)		45 mm
Distance (M1 ~ M2)		148.1 mm
Distance (telescope focus ~ M1)		303.5 mm
Distance (M1 ~ detector)		303.5 mm

All mirrors and mounting parts are made of the same material, i.e., aluminum 6061-T6. When the system is cooled down, this scheme of the same material minimizes the stress of the thermal contraction, increases cooling efficiency, and keeps the optical performance preserved.

The operational temperature of KASINICS is less than 80 K but the optical alignment is performed at room temperature (about 300 K). Since the alignment or the surface curvature of mirrors can be affected by thermal shrinking, any change of optical performance should be investigated within the temperature range. Our finite-element-method (FEM) analysis, given that the system is cooled down from 300 K to 77 K, confirmed that the spot size remains nearly unchanged. Although the curvature radii of the primary and the secondary change between 300 K and 77 K, as shown in Table 2, the contractions of the mirrors and the mounting body with the same ratio compensate it and the surfaces of mirrors keep the spherical shape. Fig. 4 shows spot diagrams at 300 K and 77 K, which have no noticeable difference in the performance.

Table 2. FEM results of cooling the Offner system from 300 K to 77 K.

Temperature	300 K	77 K
Radius of curvature (M1)	300 mm	299.16 mm
Radius of curvature (M2)	150 mm	149.58 mm
Distance (M1 ~ M2)	148.1 mm	147.69 mm
Distance (M1 ~ detector)	301.8 mm	300.96 mm

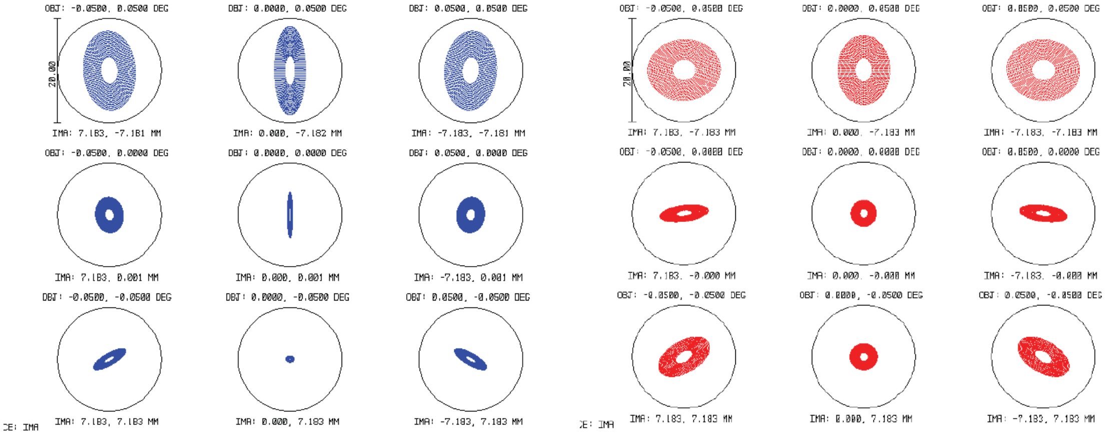

Figure 4. Spot diagrams of the KASINICS Offner system at 300 K (Left) and 77 K(Right). The diameter of each circle is 20 μm.

3.3 The Lyot Stop and Baffles

A cold Lyot stop, which is provided by the Offner secondary, is basically used to remove unwanted radiation from the telescope. Fig. 5 shows pupil images of the telescope primary which is projected onto the Offner secondary. We can see that, in our design, the positions of images are slightly different with viewing angles. The left panel of Fig. 5 corresponds to a projection map of the outer boundary of the telescope primary. The maximum size of the Offner secondary is determined by the innermost circle of the map since thermal radiation from outer parts of the telescope primary should be removed. The right panel of Fig. 5 is a projection map of the Cassegrain hole. The central part of the Offner secondary should be drilled out to block the thermal radiation from the hole. The inner size of the Offner secondary is then designed to be the same as the outermost circle in the projection map. Although this design reduces the amount of incident light, it eliminates all thermal radiation from the telescope parts other than the primary and secondary mirrors.

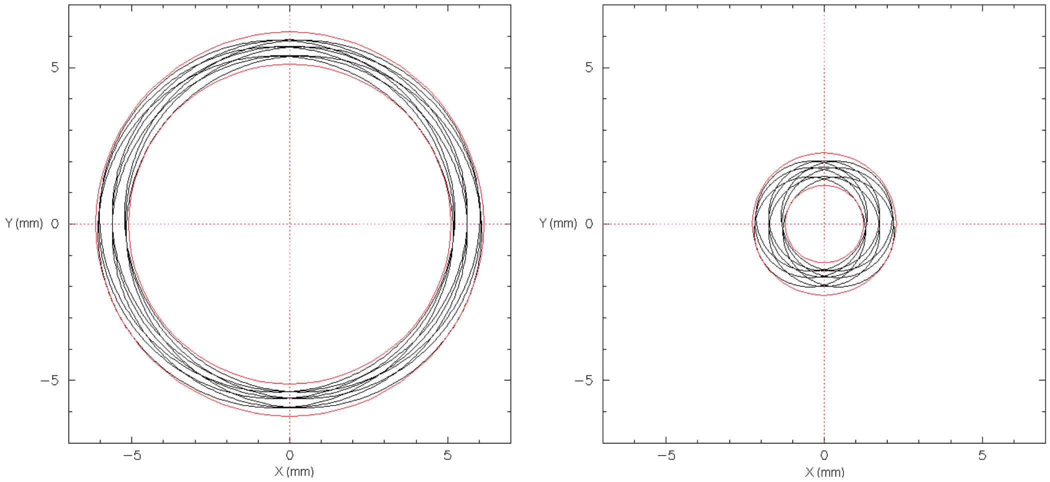

Figure 5. Projection map of the outer boundary (Left) and the central hole (Right) of the telescope primary onto the secondary of the KASINCIS Offner system.

Cylindrical baffles are installed on the filter box and the optical box, to avoid stray light. There are seven baffles of thin plates in the optical box. These baffles can stop stray light into the cold Lyot stop and detector and scattered light inside the optical system. Fig. 6 shows the design of six baffles which are assembled with the secondary module. Fig. 7 shows the 3-dimensional (3D) model and manufactured parts of the optical system.

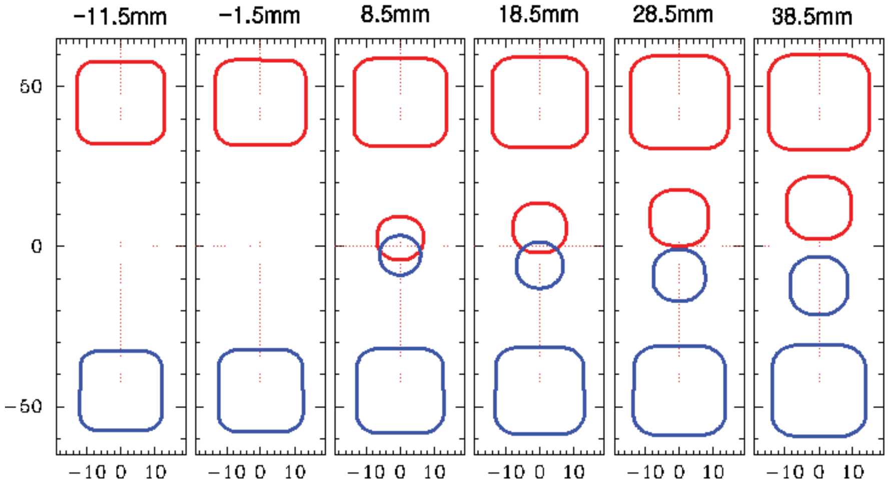

Figure 6. Baffles assembled with the secondary module. The numbers on top are the relative distances to the secondary. The upper holes are the paths from the telescope to the secondary.

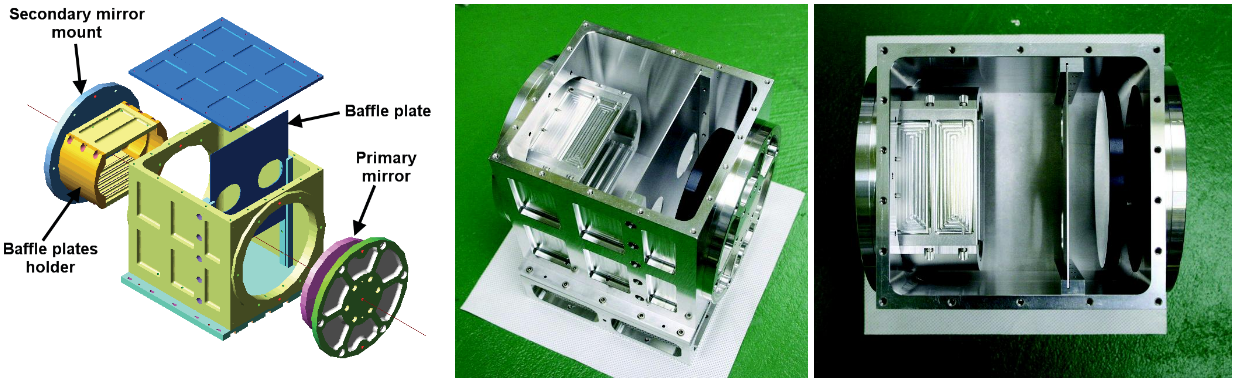

Figure 7. Schematic diagram and photos of the optical system.

4. MECHANICAL DESIGN

The total weight of KASINICS is about 80kg and the dimension is 39 × 40 × 50 cm^3. Most of the parts including the mirror were manufactured from the same melt of aluminum 6061-T6 alloy to ensure homologous contraction from room temperature to 80 K as other IR instruments. The base panel of a cold box plays a role of optical bench to align the optical axes.

4.1 Cryostat design

The rectangular shaped cryostat is keeping the vacuum and preventing thermal inputs from room environments (see Fig. 8). It has a few electric feed through and motion feed through for the filter wheel. The G10 fiberglass truss supports cold box and insulates thermally from the cryostat. The outer surface of cold box was polished to minimize the emissivity.

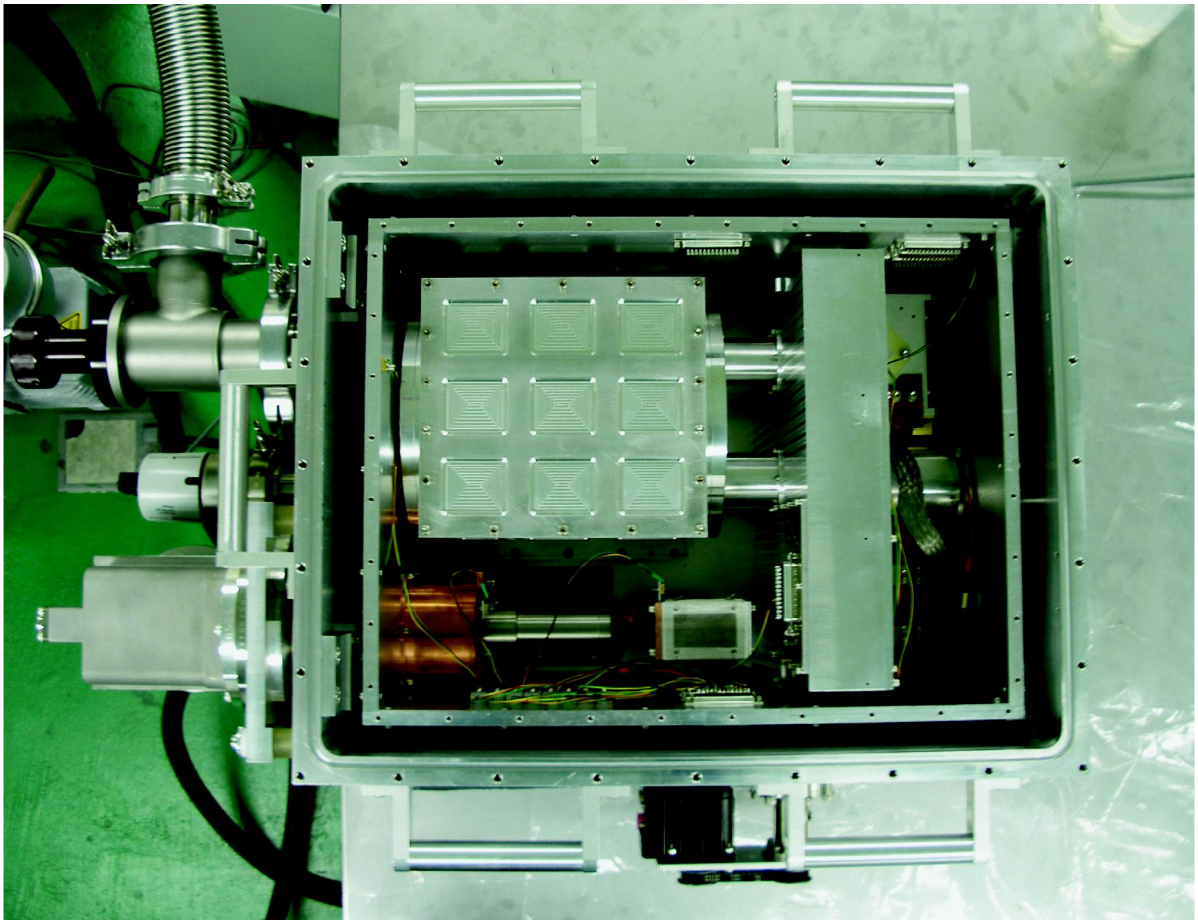

Figure 8. KASINICS cryostat.

We use a low vibration GM cryocooler (RF50D, Suzuki Shokan Co.). Even though its vibration is low, we installed a shock absorber which is assembled from Urethane and bellows between a cryostat and a cooler. For cooling the inner optical box, the copper straps connect the cold box to the first stage of cooler. The second stage is linked to the detector box with a copper bar and copper straps. The thermal path of an optical box and a filter box is going through surface contact with cold box.

4.2 Filter and detector box

Filter box has a wheel, worm gear, and monitoring sensor module. A filter wheel contains eight filter modules which can hold two filters such as blocking and band-pass filters. Each filter is installed with 5 degrees tilt angle to remove the ghost effects[3]. The structure of the filter module is shown in Fig. 9 and Fig. 10. Using this filter module, we can easily exchange and maintain the filter sets. To protect filter damage against thermal shrink of filter-holder, we put a spring which is made of same aluminum material and has a feature of few grooves on a cylinder to be flexible. Fig. 9 shows the filter box and a filter module. The assembled feature of the filter module and the sensor module is shown in Fig. 10.

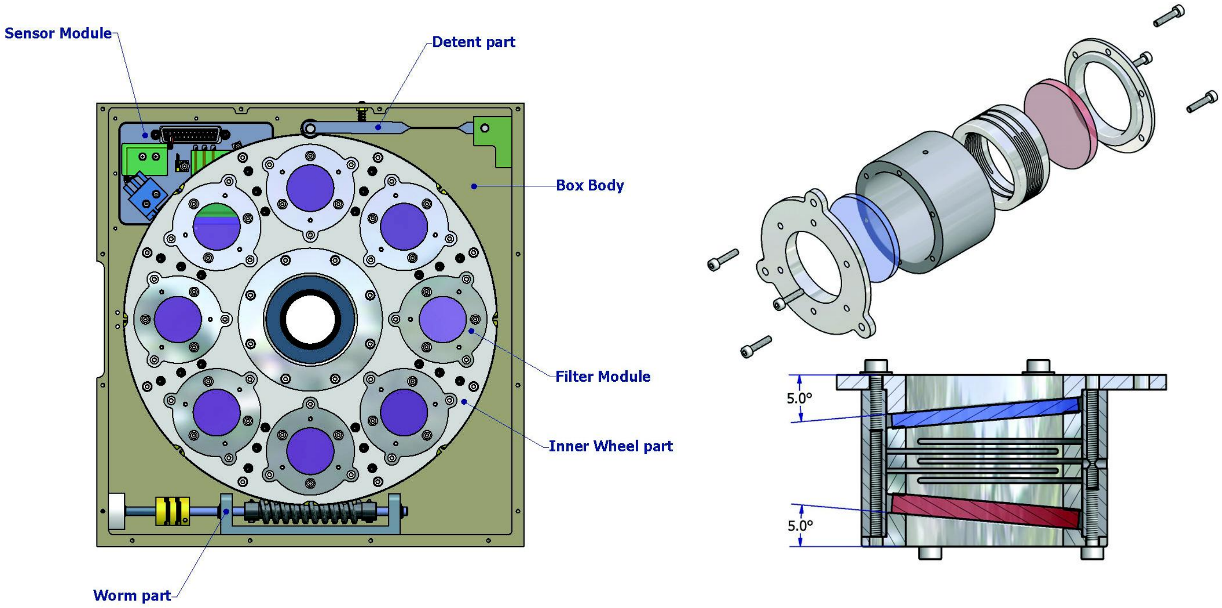

Figure 9. Design of the filter box (left) and filter module (right).

Figure 10. A spring unit (left), a filter module assembly (middle) and a sensor module (right).

The position of each filter is monitored by three hall-effect sensors and one mechanical switch. All sensors of the filter box are assembled in the small panel, and these also can be accessible and disassembled easily from the filter box. We can set up three magnets at each filter position in the wheel if user wants to know the absolute positions of filters. These mechanical and electrical parts are working well under the 80K.

In order to rotate the filter wheel, a radial ceramic ball bearing is used. Since the material of the bearing part is different from the filter wheel, we also adopt spring hold structure around the bearing mount surface area as shown in Fig. 11. Bearing mount of a worm axis was also applied similar scheme as the previous method.

A detector box is shown Fig. 12 and temperature sensor is in the center of this box. Two heat resistors are mounted for temperature control. We use, however, use only one resistor which is close by copper strap, because of sufficient heat power.

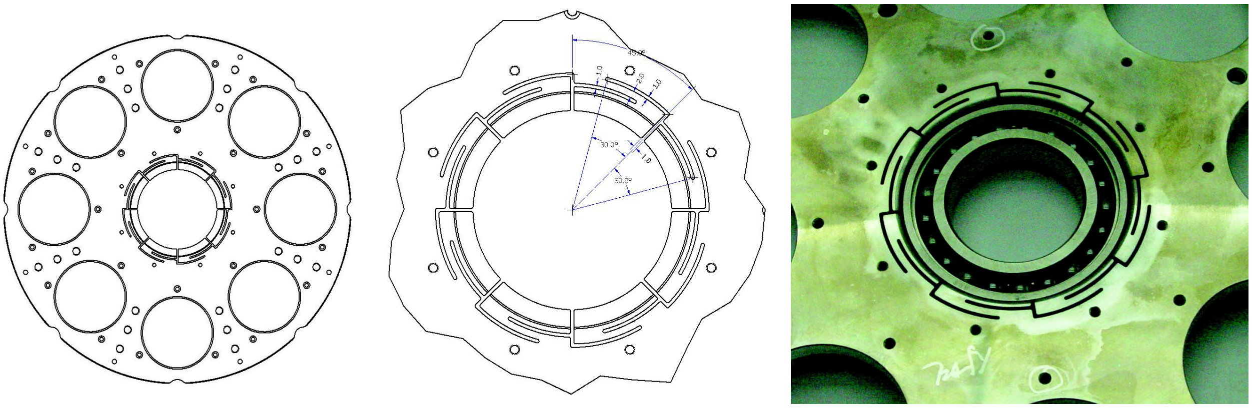

Figure 11. Bearing mount of the filter wheel.

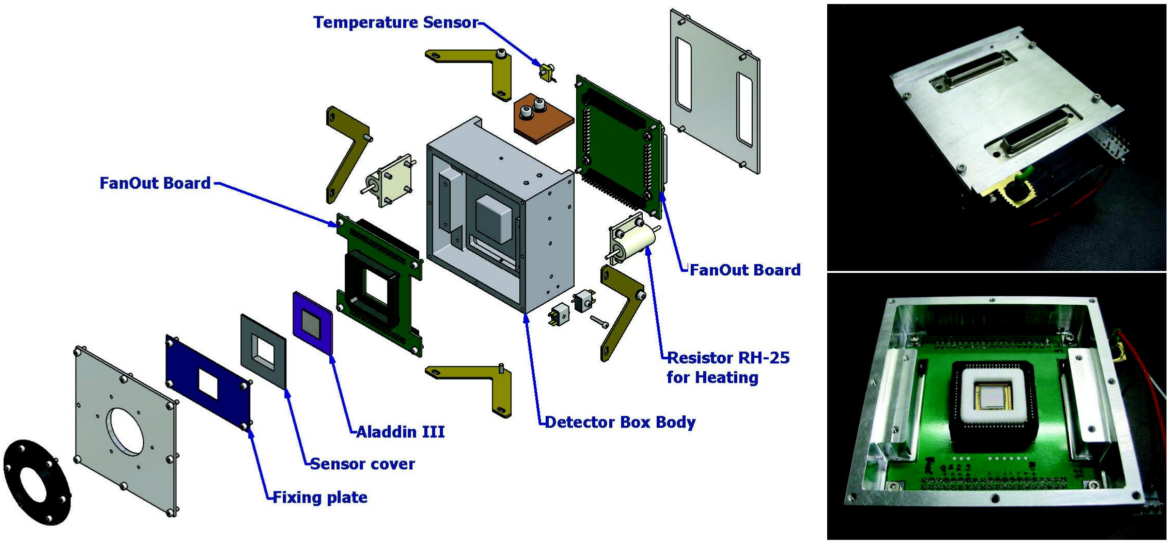

Figure 12. Schematic diagram of the detector box (left) and assembly feature (right).

5. INSTRUMENT TESTS

5.1 Optical Test

We investigated the surface profiles of the primary and secondary mirrors using WYKO interferometer to measure the manufacturing accuracy. For the primary mirror, the PV (Peak to Valley) value is about $\lambda/9$ and the RMS value is $\lambda/56$ at 1 μm. The secondary has PV of $\lambda/26$ and RMS of $\lambda/161$. Consequently the surface accuracy of the Offner mirrors is high enough to be used in NIR.

We also tested the optical performance of the Offner system. We measured the resolution and check any distortion using standard optical targets. Fig. 13 shows the testing images. At the center of the FOV, the testing image for resolution can be resolved down to element 5 in group 5 of the USAF target, which corresponds to 20 μm. The resolution remains as high as 40 μm within a 18 × 18 mm FOV and this satisfies the requirement of better than 40 μm within the detector FOV of 14.4 × 14.4 mm. As for the distortion, we did not find any significant displacement of reference points larger than the optical resolution. Therefore we conclude that the distortion effect is negligible for the Offner system.

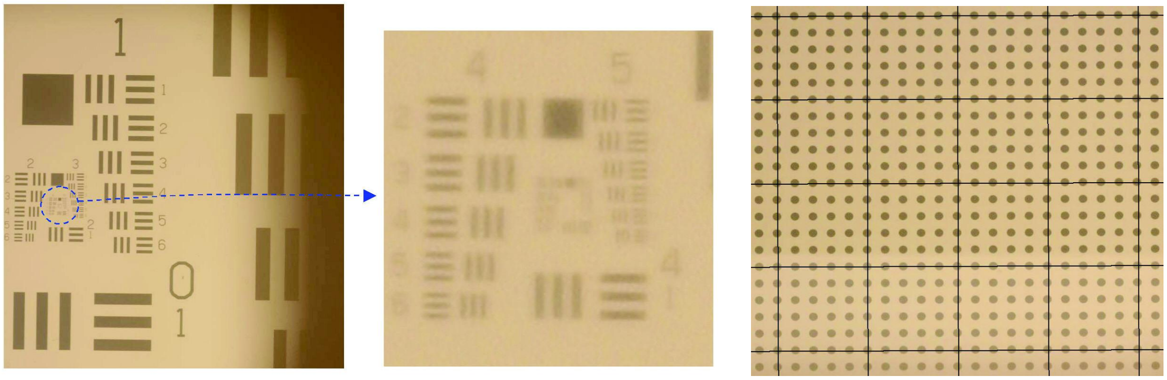

Figure 13. Testing images for resolution (left) and distortion (right).

5.2 Cooling Test

Kang et al.[7] estimated that the total thermal inputs power of KASINICS is 14 W and Cooling time is about 50 hours at the worst case. The cooling powers of our cryocooler are 18 W at the first stage and 4.8 W at the second stage respectively.

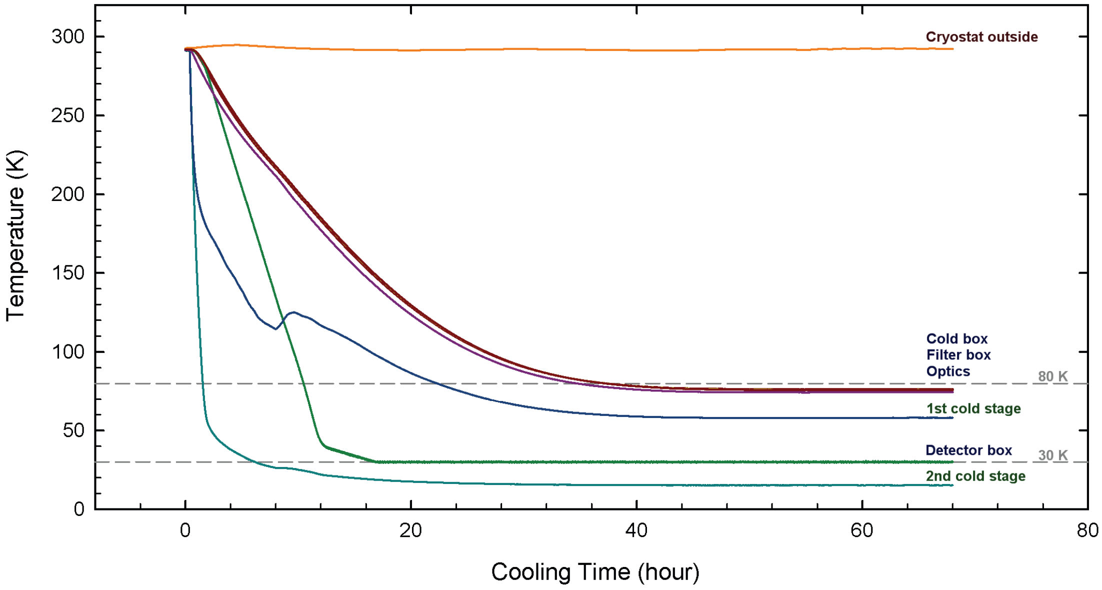

Figure 14. Temperature curve of cooling test

For cooling test, eight temperature sensors were attached on each part of KASINICS, such as the filter box, the detector box, the cold box, and cold heads. The test result is represented at Fig.14. As our result, Cold box temperatures reached down to the 80K after 40 hours running, and then kept the 76K. The detector box came to 30 K after 20 hours and it was successfully controlled within ±0.1 K by a temperature controller.

ACKNOWLEDGMENTS

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