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DEVELOPMENT OF A CRYOGENIC TESTING SYSTEM FOR MID-INFRARED DETECTORS ON SPICA

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ABSTRACT

For future space IR missions, such as SPICA, it is crucial to establish an experimental method for evaluating the performance of mid-IR detectors. In particular, the wavelength dependence of the sensitivity is important but difficult to be measured properly. We are now preparing a testing system for mid-IR Si:As/Si:Sb detectors on SPICA. We have designed a cryogenic optical system in which IR signal light from a pinhole is collimated, passed through an optical filter, and focused onto a detector. With this system, we can measure the photoresponse of the detector for various IR light using optical filters with different wavelength properties. We have fabricated aluminum mirrors which are adopted to minimize thermal distortion effects and evaluated the surface figure errors. The total wavefront error of the optical system is 1.3 μm RMS, which is small enough for the target wavelengths (20–37 μm) of SPICA. The point spread function measured at a room temperature is consistent with that predicted by the simulation. We report the optical performance of the system at cryogenic temperatures.

Key words: instrumentation:detectors ; instrumentation:optical system

1. INTRODUCTION

We plan to evaluate the wavelength dependence of the sensitivity of mid-IR array detectors (Si:As and Si:Sb) which are candidate detectors for SPICA. In the previous work (Mori, 2012), experiments were performed under high background environments with low S/N ratios. The photo-response of the detector in a cryostat was measured with the incident monochromatic light generated by a monochromator at a room temperature. To make measurements with higher S/N ratios under low background environments, we need to place all the test system in a cryostat.

@Our cryogenic optical system (Figure 1) requires the following features for the detector experiments.

- Quasi-monochromatic light is produced by a light source and a narrow-band optical filter. Several kinds of optical filters can be selected to produce various monochromatic light.
- Aluminum mirrors are used to minimize optical misalignment at low temperatures due to thermal contraction. The mirror should have surface accuracy high enough for the target wavelengths (20–37 μm).
- Quasi-monochromatic light makes a spot image smaller than the detector size (8 mm × 8 mm) for evaluation of the photo-response.

In this paper, we report the evaluation results of the optical system.

2. METHOD

2.1. *Surface figure errors of mirrors*

We evaluate the surface figure errors of the manufactured aluminum mirrors by using a Fizeau interferom-

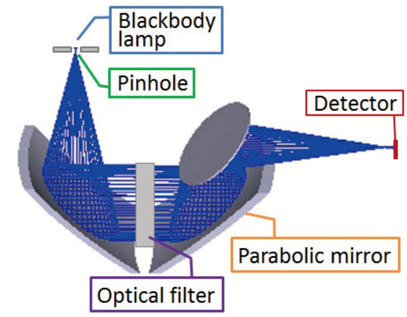

Figure 1. Illustration of the cryogenic optical system. An IR light from a pinhole is collimated, passed through an optical filter, and focused onto the detector.

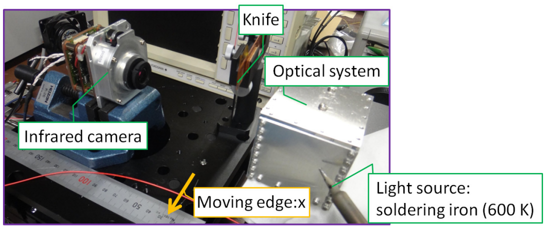

Figure 2. Configuration of the knife edge test at a room temperature. An IR light is produced by a soldering iron and a pinhole. The focus image is taken with the IR camera which has a sensitivity for a wavelength range of 8–13 μm.

eter and cross-check them by using a laser probe 3D measuring instrument (NH-6). The total wavefront error (WFE) of the system is estimated from the surface figure errors of each mirror assuming that the alignment error of the optical elements is negligible. Then, we check whether the total WFE is sufficiently small for the target wavelengths or not.

2.2. *Optical alignment at a room temperature*

We align the optical elements and assemble the optical system. The focus adjustment is made through a knife edge test (e.g., Kim et al., 2003) with IR light at a room temperature. The knife edge test is a method to evaluate the imaging performance of the optical system by the intensity profile (the edge transfer function; ETF) of a source crossing a sharp edge of a mask put on a focus plane. Figure 2 shows the configuration of the test. The imaging performance is evaluated by the FWHM of the point spread function (PSF) estimated from the measured ETF.

2.3. *Imaging perfomance at 6 K*

We evaluate the imaging performance of the cryogenic optical system at 6 K. The whole system is set in a cryostat including the optical system and the detector module. An IR light source is made from a blackbody

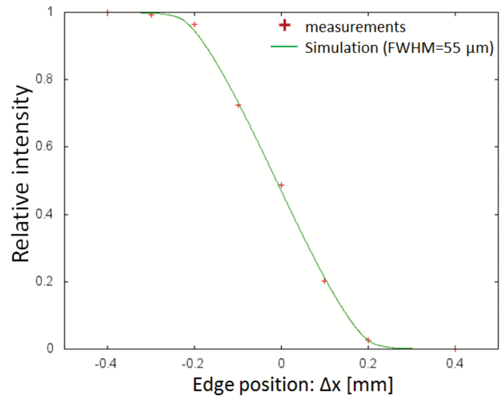

Figure 3. ETF of a pinhole (Φ500 μm) image at a room temperature. The data points indicate the result of the measurement, while the curve indicates that of the simulation assuming that the FWHM of the PSF is 55 μm, and that the magnification of the optics is $\times$1.3.

lamp (1200 K) and a pinhole (Φ500 μm). The light through the optics is focused on the Si:As array detector of 256 $\times$ 256 pixels with the size of 8 mm $\times$ 8 mm. The PSF and the intensity of the spot image are evaluated.

3. RESULT AND DISCUSSION

3.1. *Surface figure error of the mirror*

The surface figure error of the flat mirror is measured to be 310 μm RMS by a Fizeau interferometer, which is confirmed by measurement with NH-6. The values are consistent between these measurements. Assuming that all the mirrors have similar surface figure errors, because they are manufactured in the same method, the total WFE of the optical system is estimated as 1.3 μm RMS without optical alignment errors. This is smaller than $\lambda/14$ where λ is the target wavelengths (20–37 μm), thus satisfying the requirements.

3.2. *Imaging performance at a room temperature*

Figure 3 shows the ETF evaluated at a room temperature after the focus adjustment. The FWHM of the PSF estimated from the ETF is 55 μm, which is consistent with the designed value. The magnification of the optical system is also confirmed to be consistent with the designed value of $\times$1.3. We use 8–13 μm IR light for the focusing and the evaluation of the imaging performance. At a room temperature, the optical system has imaging performance as designed.

3.3. *Imaging performance at 6 K*

Figure 4 shows a pinhole (Φ500 μm) image taken with the Si:As array detector at 6 K. The spot size is smaller

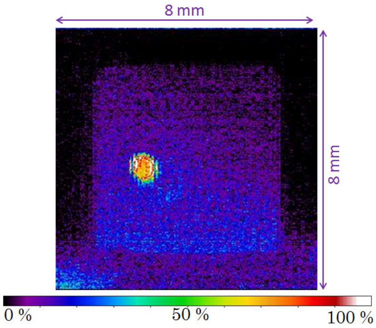

Figure 4. Pinhole (Φ500 μm) image taken with the Si:As array detector at 6 K. The color bar indicates the intensity normalized at the peak.

than 810 μm and the S/N ratio is higher than 100. We successfully obtain a spot image small enough to measure the total flux with one frame image.

4. SUMMARY

For evaluation of the wavelength dependence of sensitivity of mid-IR array detectors (Si:As and Si:Sb) for SPICA as a function of wavelength, we have established a cryogenic optical testing system. We measured the surface figure errors of the manufactured mirrors. The total imaging performance of the optical system is evaluated at a room temperature and at 6 K. Our cryogenic optical system can provide a spot image of a quasi-monochromatic light on a detector in a wavelength range of 20–37 μm, the size and S/N ratios of which satisfy the requirements for the detector experiments. We are ready for detector experiments for SPICA.

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