Laboratory Experiments of an Infrared Detector and Metal Mirrors for the SCI Development

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ABSTRACT

We present our recent activities on laboratory experiments of an infrared detector and metal mirrors for the *SPICA*/SCI. We plan to adopt a Si:As detector array for the SCI to cover the wavelength region from 4 to 28 μm. We have evaluated a bias dependence of the cutoff wavelength of the Si:As detector. Our results suggest a possible extension of the cutoff wavelength through efficient increase in the sensitivity at longer wavelengths. We have also measured the wavelength dependence of reflectance on the detector surface to verify that the detector receives the light of wavelengths longer than the designed cutoff wavelength. We also fabricated prototype metal mirrors and evaluated their surface roughness and surface figure errors. The roughness satisfies the SCI requirement, while the figure errors do not. We have identified a problem in each of the fabrication and evaluation processes, which will lead to the improvements of the surface figure errors and the measurement accuracies.

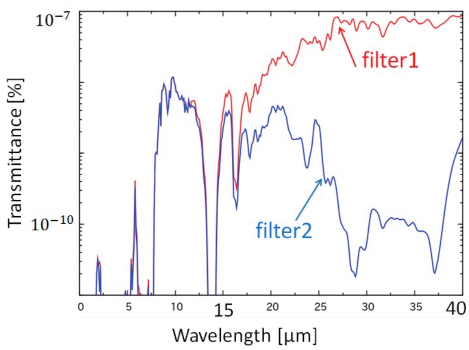
1. INTRODUCTION

The SCI (SPICA Coronagraph Instrument) is one of the focal-plane instruments proposed for *SPICA*. At wavelengths from 4 to 28 μm, the SCI will observe objects close to bright sources such as exoplanetary systems, debris disks and galactic nuclei (Enya et al. 2011). To achieve the coronagraphic capability of the wide wavelength coverage, a Si:As array detector and high-accuracy optics are needed. We report our recent activities on laboratory experiments of the detector and metal mirrors.

2. LABORATORY TESTS OF A SI:AS INFRARED DETECTOR FOR DEVELOPMENT OF THE SCI

The extension of the cutoff wavelength of a Si:As detector beyond ~28 μm is desirable, because molecular hydrogen gas emits the pure rotational fundamental line at a wavelength of ~28 μm. Therefore, we have investigated the bias dependence of the cutoff wavelength. We have also measured the reflectance on the detector surface. For these investigations we utilized a Si:As detector, a backup detector for the *AKARI*/IRC (Wada et al. 2008).

We have evaluated the photo-response of the Si:As detector with two broadband filters. Figure 1 Left shows the spectral transmission curves of the filters. For both filter bands, the relative photo-response increases with bias voltages. This increase is larger for filter1 than for filter2. The result suggests an elongation of the cutoff wavelength of the detector sensitivity with higher bias voltage (Mori et al. 2012).



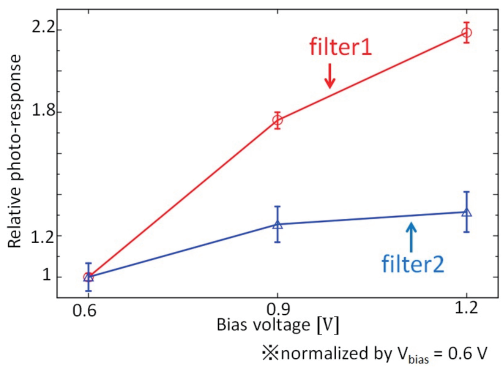


Figure 1. *Left*: Transmission curves of filters 1 and 2. *Right*: Bias dependence of the relative photo-response of the detector with filters 1 and 2. The responses at a bias voltage 0.6 V are normalized to a unity.

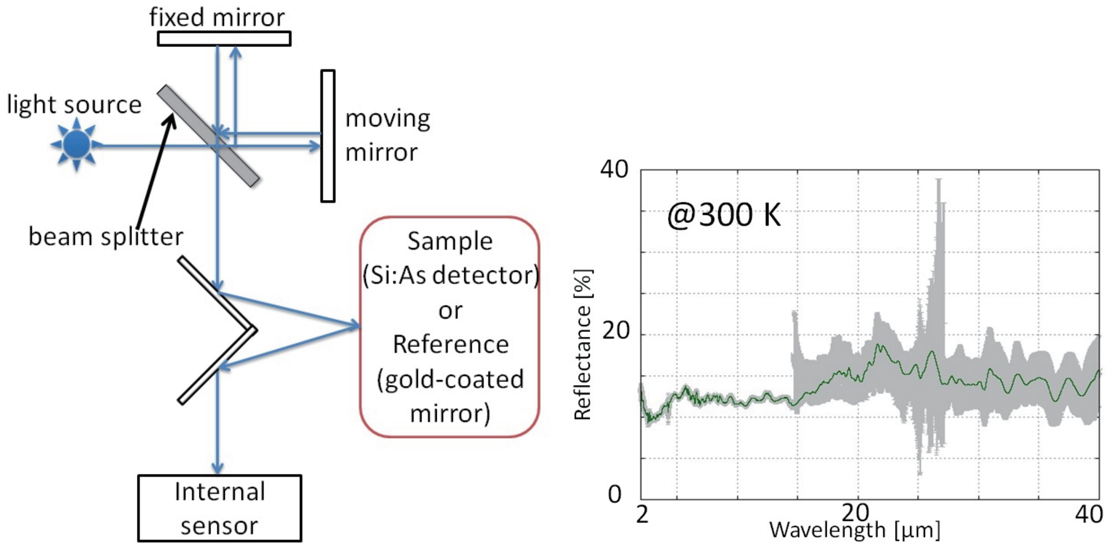


Figure 2. *Left*: Configuration for the surface reflectance measurement. *Right*: The surface reflectance of the detector at 300 K. The gray hatch indicates errors. We have used two different internal sensors covering the two wavelength regions: 2–15 μm and 15–40 μm.

We have measured the reflectance of the detector surface using a Fourier transform infrared spectrometer (FT-IR). The Si:As array detector is installed in the optical path of the FT-IR (Figure 2 *Left*) and the gold-coated mirror is used as a reference. We find that the surface reflectance of the detector is less than 20 % for a wavelength range of 2–40 μm at a room temperature (Figure 2 *Right*). Thus we confirm that the detector receives infrared light at wavelengths longer than the designed cutoff wavelength of the Si:As detector.

3. FABRICATION AND EVALUATION OF METAL MIRRORS

To achieve high coronagraphic performance, the SCI requires high precision optics. To minimize thermal deformation of optical elements and misalignment of the optics at cryogenic temperatures, all the mirrors and support structures are made of aluminum alloy, the same material with the whole structure of the SCI assembly. The fabrication of the mirrors needs ultra-precision machining to meet the SCI requirements.

We fabricated four prototypes of aluminum alloy mirrors with different parameters of the machining. Two mirrors are flat and the two others are off-axis paraboloidal. The aperture sizes of the flat mirrors and the off-axis paraboloidal mirrors are 20 mm and 50 mm, respectively. Figure 3 shows photos of our sample mirrors. Table 1 summarizes the machining parameters. We have evaluated the surface figure errors and the surface roughness of the sample mirrors by a Fizeau interferometer. A He-Ne laser is used as a light source. For the measured surface figure errors of the mirrors, we calculated the power spectral densities (PSDs), which are plotted in Figure 4.

From the measurement of all the mirrors, we find that the surface roughness is <10 nm (RMS) which satisfies the SCI requirement. However, the surface figure errors do not satisfy the requirements as can be seen in Figure 4; we find that the surface figure errors are dominated by low-frequency components, which is probably attributed to thermal deformation of the machining table. For the off-axis paraboloidal mirrors, the measurement of the surface figure errors is likely to be affected by misalignment of the optics during tests. In order to mitigate the deformation of the machining table, we will control the temperature of the table more precisely. In order to improve the optical alignment, we prepare the Shack-Hartmann sensor optics, which is used simultaneously in measuring the mirrors by the Fizeau interferometer.

Table 1. Machining parameters for mirror fabrication.

Sample ID	A1	A2	B1	B2
Mirror type	flat		paraboloidal	
Num. of screw holes for fixation	3	3	3	3
Table rotation speed [rpm]	100	100	500	900
Radius of bite edge [mm]	0.4	0.4	1.0	0.5
Feed per revolution [μm/rev]	5.0	3.0	4.0	1.6

Detector and Mirrors for the SCI

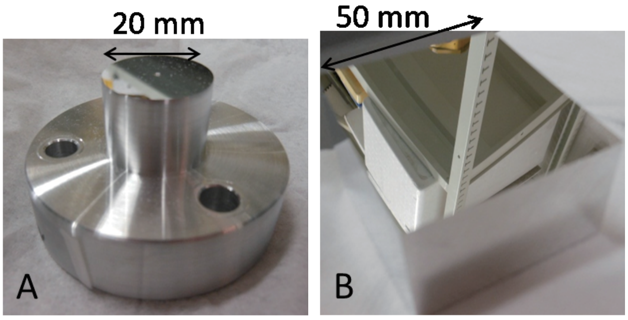


Figure 3. *Left:* Flat mirror. *Right:* Off-axis paraboloidal mirror.

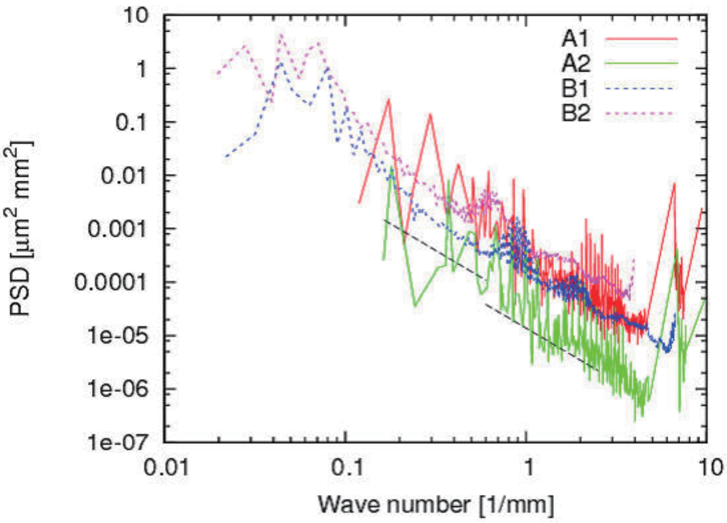


Figure 4. PSDs of our mirror samples. The red and green solid lines correspond to the PSDs measured for the flat mirrors A1 and A2, respectively. The blue and magenta dotted lines are PSDs for the off-axis paraboloidal B1 and B2, respectively. The gray dashed lines indicate the requirements for the SCI.

4. SUMMARY

We have evaluated a bias dependence of the cutoff wavelength of the Si:As detector. Our results suggest an elongation of the cutoff wavelength of the detector sensitivity with higher bias voltage. The surface reflectance of the detector is measured to be lower than 20 % at 2–40 μm. Thus we confirm that the detector receives infrared light at wavelengths longer than 28 μm. We have also fabricated and evaluated the prototype metal mirrors for the SCI. The surface roughness of <10 nm (RMS) satisfies the SCI requirement, while the surface figure errors do not. As for the latter, we have two issues to be addressed; one is temperature control during the machining, and the other is optical alignment during the measurement.

REFERENCES

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