The Radiation Tolerance of Chalcogenide Glasses

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ABSTRACT

Chalcogenide glasses are compounded from chalcogen elements, such as sulphur, selenium, and tellurium. These glasses are applied to commercial applications, e.g., night vision, because they transmit infrared in the spectral range of 0.8-16μm. Chalcogenide glasses have greater advantages over germanium (Ge), i.e., their wide spectral range of high transmissivity and their small temperature dependence of the refractive index.

We have developed the Compact Infrared Camera (CIRC) with an uncooled infrared array detector (microbolometer) for space applications. The CIRC has been scheduled to launch in 2013 to demonstrate the usability of a microbolometer as a space application. The optics of the CIRC adopts two different kinds of materials for athermal optics. One is germanium, and the other is GASIR1® which is a chalcogenide glass ($Ge_{22}As_{20}Se_{58}$) developed by Umicore. However, the radiation tolerance of GASIR® has not been investigated in the past.

We carried out irradiation tests to investigate the radiation tolerance of GASIR1®. We irradiated GASIR1® with gamma-rays (Co60, 1.17 MeV and 1.33 MeV) up to 3Mrad. We measured the transmissivity and refractive index in the infrared range before and after irradiation. In this paper, we report the results of the irradiation tests of GASIR1®.

Keywords: chalcogenide glass, GASIR, radiation tolerance, irradiation test

1. INTRODUCTION

Chalcogenide glasses are compounded from chalcogen elements (16th group of elements), such as sulphur, selenium, and tellurium. Because they are oxygen-free, chalcogenide glasses are capable of high infrared transmission in the wide spectral range of 0.8-16μm. The most widely distributed glasses, such as silicates, are transparent only in the near infrared up to several micrometers because the vibration frequency of oxygen bonds with any other element approximates these very wavelengths[1].

Today, infrared transparent crystals are usually used in thermal infrared optics such as single crystalline germanium. But chalcogenide glasses have certain advantages over crystalline germanium as the materials for infrared optics. The manufacturing of chalcogenide glass is comparatively easy and more available for mass production. Thus, it enables to be lower cost and manufacture large size production[2][3]. Crystalline germanium, on the other hand, is rare and expensive. In addition, Chalcogenide glasses have small temperature dependence of the refractive index compared to germanium. Therefore, chalcogenide glasses are applied to commercial applications such as night vision.

We have developed the Compact Infrared Camera (CIRC) with an uncooled infrared array detector (microbolometer) for space application[4][5][6]. The optics of the CIRC adopts two different kinds of materials for athermal optics. One is germanium, and the other is GASIR1®, which is a chalcogenide glass ($Ge_{22}As_{20}Se_{58}$) developed by Umicore. However, the radiation tolerance of chalcogenide glasses has not been investigated in the past. So, we examined the radiation tolerance of a chalcogenide glass, GASIR1®.

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2. COMPACT INFRARED CAMERA FOR SPACE APPLICATION

The Compact Infrared Camera (CIRC) is an infrared camera equipped with an uncooled infrared array detector (microbolometer). The main mission of the CIRC is to demonstrate the technology of wildfire detection using a microbolometer. The CIRC is a small, lightweight, and low-cost thermal infrared imager for space applications. We employ athermal optics and shutter-less image correction to reduce the size, weight, and cost of the CIRC.

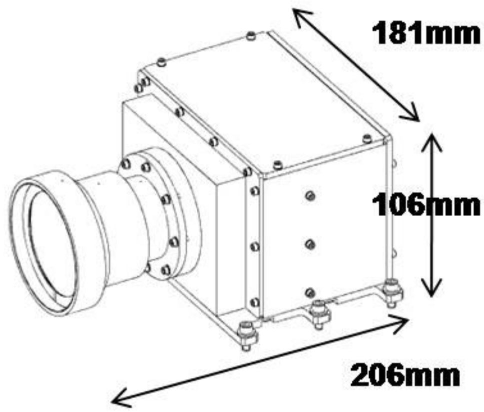

Figure 1. Schematic view of the CIRC.

2.1 Hardware Design

Figure 1 shows a schematic view of the CIRC. The CIRC is based on a commercial infrared camera developed by Mitsubishi Electric Corporation (MELCO). However, to utilize it for space applications, we added some modifications to the hardware design.

The specifications of the CIRC are shown in Table 1. We set the baseline specifications to meet requirements for wildfire detection [4][5]. The detector uses a large format (640×480) to obtain a wide field of view. The spatial resolution is an important factor for wildfire detection. The baseline specification of the spatial resolution is 200 m from the altitude of 600 km. The Noise Equivalent Differential Temperature (NEDT) is related to the contrast between a background area and a burning area. If the NEDT is smaller, detectability of the wildfire increases. Considering the detector performance and the optical design, we set the NEDT is 0.2K at 300K background.

To reduce the size, weight, and cost, we minimized the functions of the CIRC. The optics unit of the CIRC uses f/1.2 optics. We employ athermal optics to maintain optical performance in a wide range of temperatures. This will be an advantage of the CIRC for small satellites, because we do not need an active thermal control or a focus mechanism for the optics.

We use a 640×480 pixel SOI diode uncooled IR FPA of which pixel size is 25 μm^2. The NEDT is 40 mK with f/1 optics. Drive and readout circuits are almost the same as those of a commercial infrared camera. For space applications, we are planning to perform a radiation damage test, and a screening of commercial devices.

Table 1. Main specification of the CIRC

Item	Characteristics
Detector	Uncooled infrared detector (SOI diode)
Number of pixels	640 × 480
Wavelength	8 - 12 μm
Size	20×18×10cm
Mass	2.6kg
Power Consumption	20W
Spatial Resolution	200m observed from 600km (0.33 rad)
Field of View	12° × 9°(128km×96km)
Exposure	33ms
Dynamics Range	180K - 400K
NEDT	0.2K @ 300K

2.2 Athermal Optics

The optics of the CIRC is f/1.2 refractive optics. The focal length of the optics is 78 mm.

The temperature of the CIRC is changed on orbit. The temperature change of the optics will cause a defocus because refractive indices of lens materials are highly dependent on temperature. To compensate for this defocus, we have to employ a focus mechanism or a heater to keep the optics temperature constant. However, such mechanisms increase sensor resources. Athermal optics can compensate for the defocus due to temperature change without such mechanisms.

Figure 2 shows the optical design of the CIRC. The athermal optics of the CIRC compensate for the defocus by utilizing a combination of different lens materials and diffractive lenses. The optics of the CIRC uses germanium and chalcogenide glass (GASIR®1). Figure 3 shows the calculated MTF of the CIRC optics versus the ambient temperature from -15°C to 50°C. The MTF is constant over the wide range of temperatures.

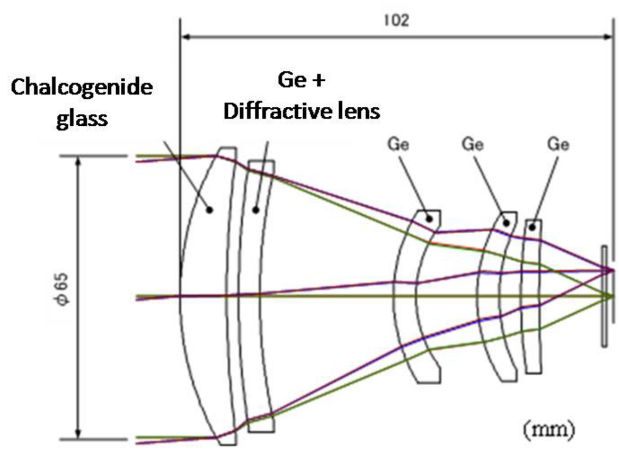

Figure 2. Schematic view the athermal optics of the CIRC

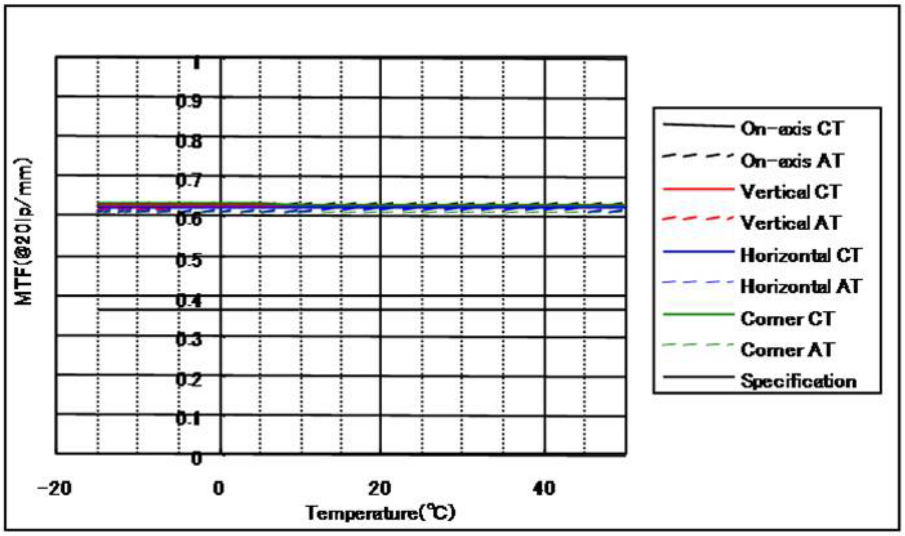

Figure 3. Calculated MTF of the CIRC optics in the ambient temperature from -15°C to 50 °C.

3. IRRADIATION TEST WITH GAMMA-RAYS

As shown in section 2.2, the GASIR1® is a key material for the CIRC optics. However, the radiation tolerance of GASIR1® has not been investigated in the past. So, we examined the radiation tolerance of GASIR1®.

We carried out irradiation tests at Tokyo Metropolitan Industrial Technology Research Institute. In order to compare the radiation tolerance of GASIR1® with that of other infrared lens materials, Ge and ZnSe are added to samples. We irradiated the samples with gamma-ray (Co60, 1.17 MeV and 1.33 MeV) up to 3 Mrad.

We carried out the irradiation test twice. The first irradiation test was performed on March 5, 2009, and the second test was performed on October 13, 2009. The irradiance level in first test was up to 100krad, and its level in second test was up to 3Mrad.

3.1 Irradiance Level

Figure 4 shows the depth-dose curve in a sun-synchronous orbit at an attitude of 600km from January 1, 2010 to December 31, 2010. The horizontal axis represents an aluminum shield depth in millimeters. The vertical axis represents the total dose radiation in rad. The absorption material is GaAs. Although the radiation environment of the CIRC is still unknown, we can estimate the irradiation level of GASIR1® lens on orbit from this depth-dose curve. If the aluminum shield depth is 1mm, the total dose level is about 10krad per year. However, if the aluminum shield depth is 0.1mm (almost no shield), the total dose level increase up to 180krad per year. The GASIR1® lens of the CIRC is exposed to space. It means that we cannot expect the shield effect by a lens holder or other lenses. The 3Mrad irradiation corresponds to the total dose radiation of about 17 years, which is enough longer than a typical satellite lifetime in a low earth orbit.

We first performed the irradiance test up to 100krad to confirm the radiation tolerance in a low dose level. After confirming the radiation tolerance up to 100krad, we performed a further irradiation test up to 3Mrad.

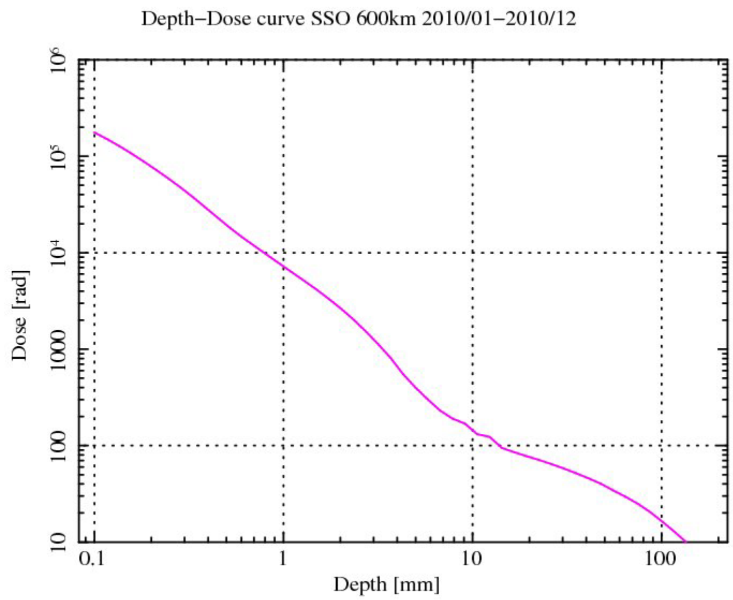

Figure 4. Depth-dose curve in a sun-synchronous orbit at an attitude of 600km from January 1, 2010 to December 31, 2010. The horizontal axis represents an aluminum shield depth in millimeters. The vertical axis represents the total dose radiation in rad.

3.2 Samples

We prepared samples for irradiation test, anti-reflective (AR) coated GASIR1®, uncoated GASIR1®, germanium(Ge), and ZnSe. Table 2 shows the specifications of each sample. We prepared five samples for each material. Their identification labels are from A to E. Table 3 shows the irradiance level of each sample. We carried out the irradiation test twice. In the first irradiation test, the irradiation level was from 5krad to 100krad. In the second irradiation test, the irradiation level was from 300krad to 3Mrad. Figure 5 shows the picture of the samples used in the irradiation test: GASIR1®, uncoated GASIR1®, Ge, and ZnSe attached to lens holders.

Table 2. The list of samples for gamma-ray irradiation test

Samples	**AR coat**	**Diameter**	**Thickness**
GASIR1®	Nothing	20mm	3mm
GASIR1®	Both Faces	20mm	2mm
Ge	Both Faces	20mm	1mm
ZeSe	Both Faces	20mm	3mm

Table 3. The irradiance level of five test samples in the first and the second irradiation test.

	A	**B**	**C**	**D**	**E**
1st test (krad)	100	50	10	5	0
2nd test (krad)	3000	1000	0	300	0

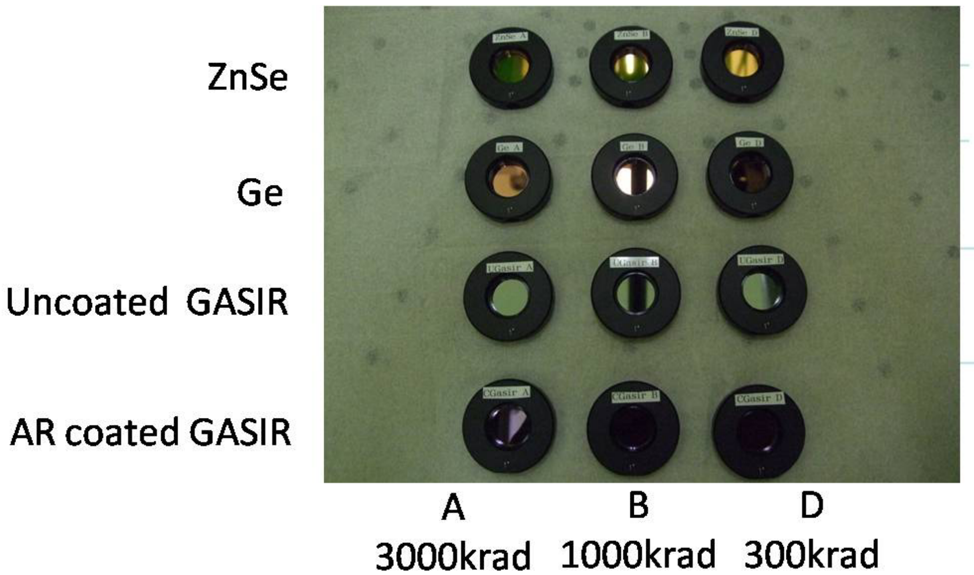

Figure 5. The samples used in the second irradiation test: ZnSe, Ge, Uncoated GASIR, and AR coated GASIR1®.

3.3 Irradiation Facility

Irradiation tests were carried out at Tokyo Metropolitan Industrial Technology Research Institute. Table 4 shows a brief overview of the irradiation test room. Figure 6 shows a picture of the Irradiation Room 1.

Table 4. Irradiation test facility at Tokyo Metropolitan Industrial Technology Research Institute

	Irradiation Room 1	Irradiation Room2
Date of Irradiation Test	October 13,2009	March 5,2009
Radiation Source	^{60}Co (1.17MeV, 1.33MeV)	
Radiation Capacity	185TBq	129.5TBq
Weight of Radiation Source Container	About 630kg with Pb shield	About 760kg with 4 ton of Pb Shield
Irradiation Room	about 8m^3	about 60m^3
Safety System	Automatic display and interlock by dosemeter	
Control System	Hand operation	
Drive System	Floor-standing slow hoist with motor	

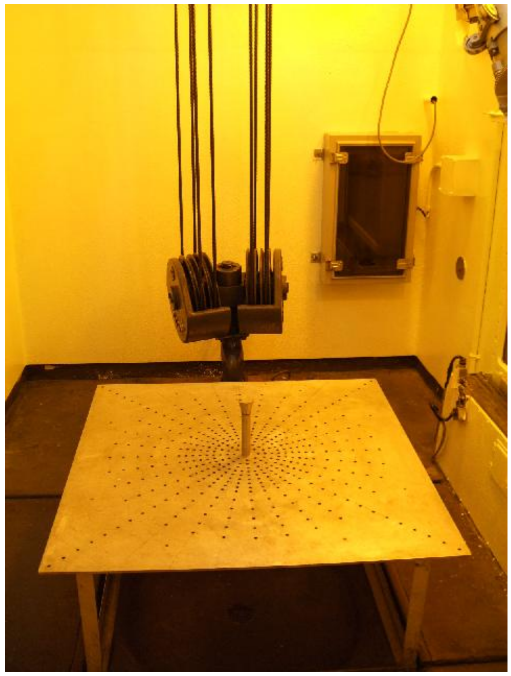

Figure 6. Tokyo Metropolitan Industrial Technology Research Institute irradiation room 1.

3.4 Configuration of the Irradiation Test

Figure 7 and Figure 8 show the pictures of the configuration of the irradiation test. Figure 7 is a picture of the first irradiation test. Figure 8 is a picture of the second irradiation test. We controlled the irradiation level by changing the distance from the radiation source Co60 to the test samples. The test samples were attached to lens holder and settled at the location calculated by the absorbed dose rate.

Figure 7. The configuration of the first irradiation test.

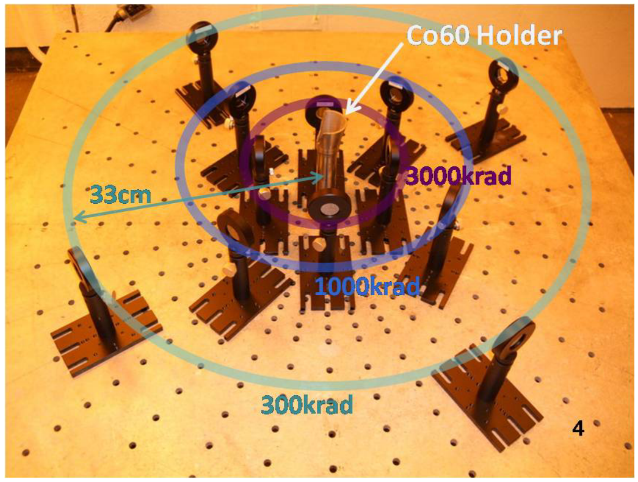

Figure 8. The configuration of the second irradiation test.

3.5 Measurement

Before and after irradiation, we measured transmission of each sample by Fourier Transform Infrared Spectroscopy. We used Spectrum One manufactured by Perkin Elmer. The wavenumber range of measurement, is 7800~350 cm^{-1} This corresponds to 2.5 ~ 22.5 μm in wavelength. The wavenumber resolution is 4 cm^{-1}.

In addition, we measured the refractive index of uncoated GASIR1® at 1.55 μm before and after irradiation at Umicore's facility.

4. RESULTS

4.1 Transmission

The measurement results are shown in Figure 9 and Figure 10. Figure 9 shows the transmissions of AR coated GASIR1®, uncoated GASIR1®, Ge and ZnSe before and after irradiation. Left figures show the transmissions before irradiation test. Right ones show those of after irradiation test. These figures show the transmission of AR coated GASIR1®, uncoated GASIR1®, Ge, ZnSe starting from the top.

Figure 10 shows the ratio of transmission after irradiation divided by those of before irradiation in order to investigate the effect of radiation.

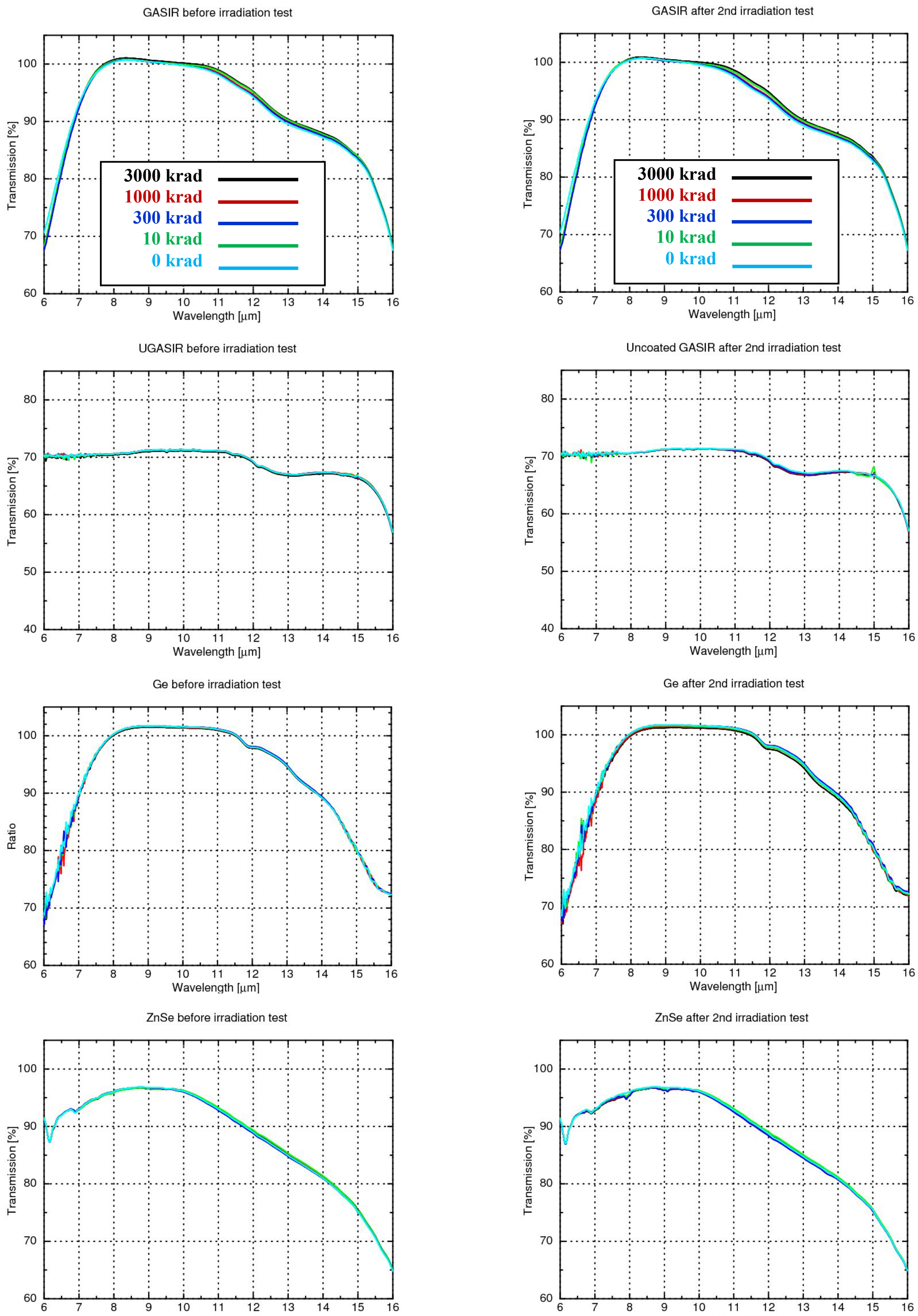

Figure 9. Left figures show the transmissions before irradiation test. Right one show those of after irradiation test. The horizontal axis represents wavelength, and the vertical axis represents transmission in percent. These figures show the transmission of AR coated GASIR1®, uncoated GASIR1®, Ge, ZnSe starting from the top.

We can see there is a slight change (less than 1%) of transmission after irradiation in Figure 10. The change can be seen especially at the wavelength of more than 11μm. However, a clear relationship between the degradation of transmission and the irradiance level can not be seen. Therefore, we confirmed that GASIR1® has a high radiation tolerance like other infrared optics materials such as Ge and ZnSe. In addition, there is not much difference in radiation tolerance of the transmission between AR coated GASIR1® and uncoated GASIR1®.

We can see some features like absorption lines around 7μm, 8μm, 9μm, and 15μm in ZnSe transmission. These features are not related with the irradiation level. We consider these are influenced by absorption of air at the time of measurements or contamination of the samples

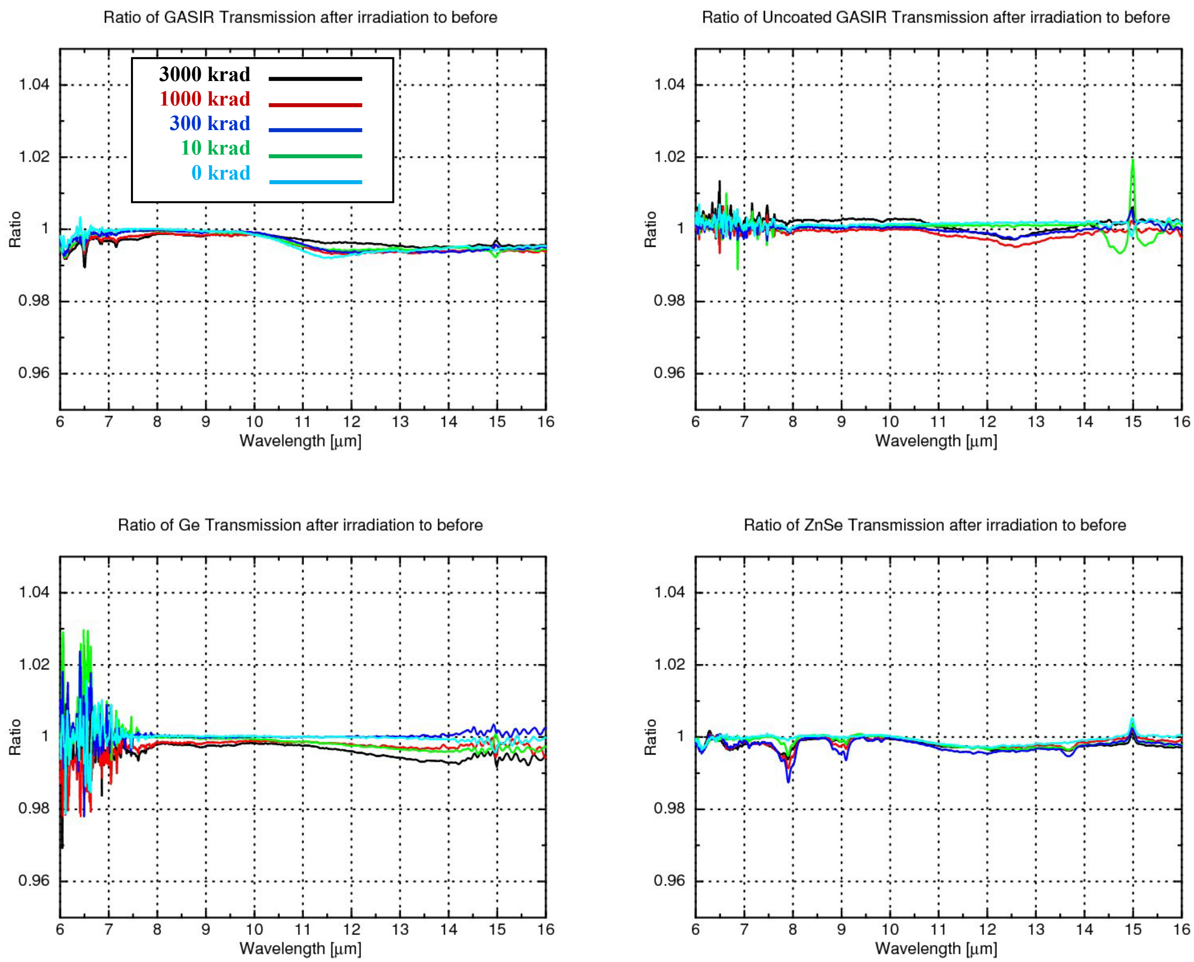

Figure 10. The ratio of transmission after irradiation divided by those of before irradiation. The horizontal axis is Wavelength. The upper left is the transmission of ARcoated GASIR1®, the upper right is that of uncoated GASIR, the lower left is that of Ge, and the lower right is that of ZnSe.

4.2 Refractive index

We measured the refractive index of uncoated GASIR1® at 1.55 µm before and after irradiation at Umicore's facility. We measured three points at each sample and three times at each measurement point. Table 5 shows the result of the measurement of uncoated GASIR1®. The values of the refractive index are averages of nine measurements, (three measurements at each of the three points). The tolerance on this measurement is +/- 0.0005. So, a difference of 0.0001 is negligible. Therefore, we can conclude that there is no influence of the gamma-ray irradiation on GASIR1®'s refractive index.

Table 5. Measurement results of refractive index of uncoated GASIR1®

	GASIR1 A	GASIR1 B	GASIR1 C	GASIR1 D	GASIR1 E
Irradiance Level of 1st test [krad]	100	50	10	5	0
After 1st Irradiation Test	2.5424	2.5422	2.5424	2.5422	2.5422
Irradiance Level of 2nd test [krad]	3000	1000	0	300	0
After 2nd Irradiation Test	2.5424	2.5422	2.5424	2.5423	2.5423

5. SUMMARY

We carried out the irradiation tests in order to investigate the radiation tolerance of GASIR1®. We irradiated GASIR1® with gamma-rays (Co60, 1.17MeV and 1.33MeV) up to 3Mrad. We measured the transmission and refractive index in the infrared range before and after irradiation.

There is a slight change (less than 1%) of the transmission of GASIR1® after irradiation. We also confirmed there is no change of refractive index of GASIR1® at 1.55 µm. Therefore, the GASIR1® turned out to be tolerant of high irradiation up to 3Mrad. We confirmed that GASIR1® is an infrared optics material able to be utilized for space applications.

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