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Developments of Practical CdZnTe immersed grating and Machined Germanium/Indium phosphide GRISM for a high-performance Spectrograph in SPACE

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ABSTRACT

Dispersing elements are the key device of the spectrometer. Spectrograph in SPACE has various limitations at size and weight. An immersed grating and GRISM, which is made of high-index material is effective in solution of those problems. First, an absolute efficiency of dispersing element is very important, because the throughput of spectrograph has big relation with the mirror size that is almost equal with a scale of a satellite. When an immersed grating or GRISM made of high-index material with high-throughput is manufacturing, there are many difficulties as the fact known well. Especially it is difficult to obtain the ideal grooved shape and a sufficiently small surface flatness. CANON has already succeeded in the development of a practical Germanium (Ge) and Indium phosphide (InP) immersion echelle grating. On the other hands, about CdZnTe immersed grating, it was only succeeded in processing of grooved shaping on the immersed prism. There was not a back-reflection coating on the grooved surface, which was indispensable in order to obtain a high- efficiency. In this development, a back-reflection coating on the grooved surface for CdZnTe immersed grating has succeeded. Two devices for an actual proof shows very good absolute maximum diffraction efficiency (>75%) and small polarization dependability (< 1%). Since the back-reflection coating is a gold base, it is possible to apply in 10-20μm which range of wavelength is main objective in use of CdZnTe. Moreover, a machined Germanium/Indium phosphide GRISM also has succeeded. This GRISM is a type of transmittance. The grooves on GRISM were machined with a diamond tool. Manufacturing some GRISMs with different resolution, the minimum grooved pitch is about 2.2 μm. These GRISMs have the efficiency and the surface flatness compared with a ZnSe GRISM known before. As the conclusions, these devices are useful to the space application, and becomes indispensable to a high-performance spectrograph.

Keywords: grating, dispersing, immersed grating, GRISM, CdZnTe, Ge, Germanium, InP, Indium phosphide

1. INTRODUCTION

1.1 Machined grating

In the outstanding diffraction grating, since the interval accuracy (RMS) which is less than 1/100 of wavelengths is required, the mechanical diffraction grating has been manufactured by the ruling machine, which specialized in this accuracy conventionally. However, high-precision vibration, temperature, and structural analysis became possible by improvement in simulation technology, and machine tool accuracy improved remarkably. These have the positioning accuracy of Nano-order, and, originally can process a diffraction grating with sufficient accuracy in spite of general-purpose cutting or grinding processing equipment. Since a specular surface is enough obtained only by processing, if high-end cutting in recent years and a grinding processing machine have grid spacing accuracy and enough scale stability, they have the potential of diffraction grating processing. In Canon, the machine for in-company processing has developed according to application. The highly precise surface is especially required of metallic mold processing for optical components, and “A-Former” shown in Fig. 1 is satisfied with these demands.

The diffraction grating, which is kind of an echelle grating, is required for sharp edge and plane, which have the outstanding linearity. Moreover, as for the angle of the edge of two plane, nearly 90 degrees is best in general. Since a shape of tool is transferred as form (shape) by cutting, “cutting” is very suitable the processing method for this geometry demand. Since the single crystal diamond tool has the outstanding linearity and very small edge, it is equipped with the potential, which processes an ideal diffraction grating in Figure 2.

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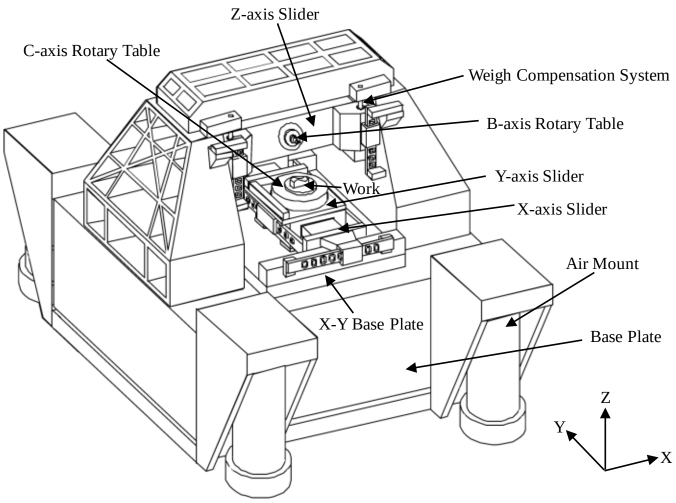


Figure 1. The free-form processing machine (A-Former).

Figure 2. The typical cross section of groove by cutting

1.2 Immersion grating

Although an immersion grating is one of the classic grating[1], it is recently that acquisition generally became possible as an object for infrared region except Si and ZnSe. This is that grooved processing to a brittle material has achieved with improvement in cutting accuracy, and it originates in grooved processing to a semiconducting material with the transmittance characteristic excellent in the infrared region having become easy. In Canon, the immersion grating by the materials, which can cover an infrared region widely and has a large refractive index, has been developed. Now, the materials currently provided is shown in table 1. However, as this paper shows, there is also a still incomplete domain about coating and machined processing required for actual use, and there are many points to be developed continuously.

	InP	**Ge**	**CdZnTe**
Refractive index	3.2	4.0	2.7
Practical Wavelength At Attenuation coefficient（α）＜0.1/cm^{-1}	1.4μm ~ 8μm	2μm ~ 11μm	5μm ~ 20μm
Size availability at the Blaze angle 75 degrees (Maximum diameter of Crystal in 2018)	~100mm (6 inches)	~200mm (16 inches)	~85mm (6 inches)

Table 1. Material characters for the immersion device, which Canon provides in 2018

2. PRACTICAL CdZnTe IMMERSED GRATING

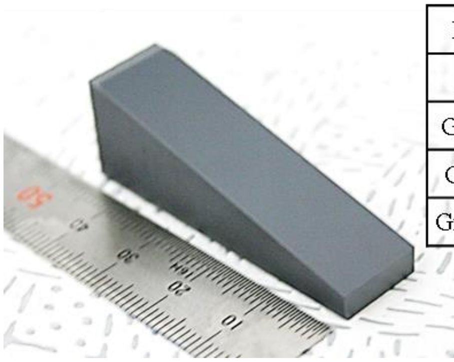
2.1 CdZnTe

It is well known that CdZnTe is the material widely used as a substrate of an infrared detector (HgCdTe imager arrays). Since the character of mechanical machining is good, it is also the first immersion grating, which we shaped by cutting in 2012[2]. Machining examination of grooving, which the size of the device and grooved pitch differ also after this report had advanced, and the large-sized with 80mm in length grating had be succeeded in 2013[3]. However, the stable manufacture processes, such as the reproducibility of machining and coating, had not established yet.

2.2 Machining

In the process of practicality examination, since the process of the grooving by 2013 was unstable, the process was changed radically in 2016. It is necessary to control load in the process of grooving for a brittle material like a CdZnTe to the occurrence of a chip does not produce in the ridgeline. Figure.3 shows the CdZnTe immersion grating by latest machining process with the pitch of 82μm, the parameters of the grating and the picture of grooves by a scanning electron microscope (SEM).

The limit of the surface flatness in the grooved area is the scale stability of processing machine, and originates in the performance of processing machine, such as temperature stability and atmospheric pressure compensation. Since modification by the holding for machining is added in addition to it, a better surface flatness with around 10nmRMS could be expected in the case of a grating with a higher blaze angles(>50 degrees). Figure 4 shows the surface flatness of the CdZnTe immersion grating in Figure 3.



Blaze Angel	75°
Apex Angle	89.6°
Grooved pitch	82.04μm
Groove width	13mm
Grooved length	47mm

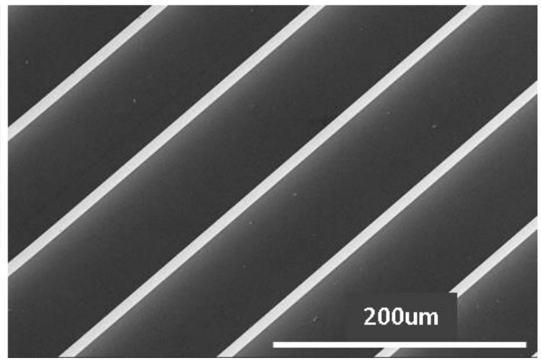
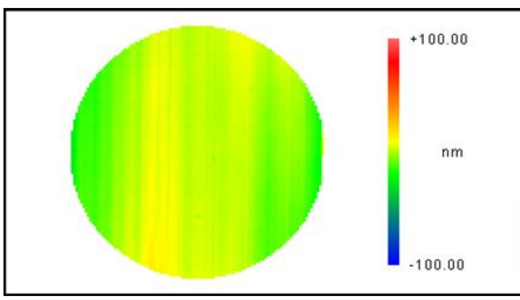


Figure 3. The machined immersion grating (Left), the grating parameters (center), the picture of grooves by SEM (Right)



Surface Flatness in Φ12mm	
PV	42.7nm
RMS	7.0nm

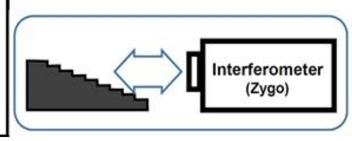


Figure 4. Measured surface flatness of grooved area that measured by interferometer in the Littrow condition

2.3 Reducibility

In order to verify a manufacture difference (reproducibility), two devices was manufactured completely independent timing of each. Table 2 shows each manufactured timing. Figure 5 shows the picture of grating for this evaluation. Comparison of the difference was performed by absolute diffraction efficiency and it was checked that the difference is 1% or less. Figure 6 shows the efficiency characteristic dependence on wavelength in the order of 180th. The outstanding reproducibility has been obtained from the peak wavelength and dependability with both polarizations resembling very closely.

	#1	#2
Shaped of base prism by polishing	August 2016	December 2016
Grooved by cutting	September 2016	July 2017
Coating	July 2017	September 2017

Table 2. The processing date of two CdZnTe immersion grating

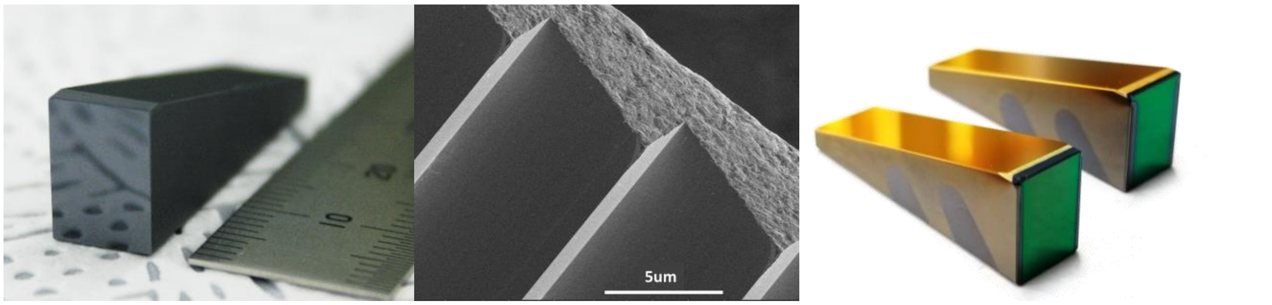
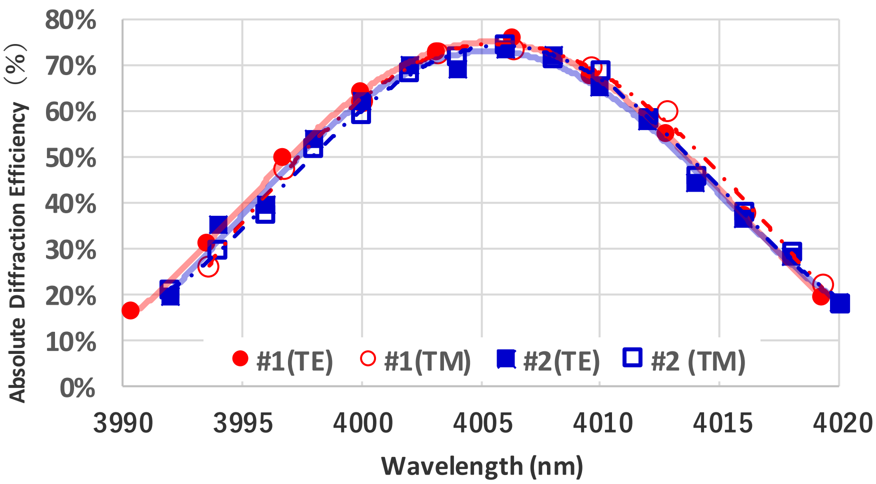


Figure 5.CdZnTe immersion grating before coating (Left), the edge of grooves by SEM (Center) and after coating (Right)



Absolute Maximum Diffraction Efficiency		
#1	TE	75%
	TM	74%
	Average	75%
#2	TE	73%
	TM	74%
	Average	74%

Figure 6. Measured absolute diffraction efficiencies.at two gratings for both TE and TM waves

3. MACHINED GRISM

3.1 GRISM

GRISM is the dispersion device, which combined a prism and grating in order to be made to go straight for the specific wavelength at desirable order. The change of an image pick-up and spectrum observation is easy, and since the demand of small size (saving the space) and high efficiency are satisfied, it is very useful device as for a dispersing device. Although ZnSe is most popular material for infrared[4], since the refractive index is 2.4, the combination flexibility is restricted. Then, realization of GRISM by germanium and Indium Phosphide with the refractive index of 4 and 3.2 respectively is expected.

3.2 Germanium

In germanium, an immersion grating which has a big pitch already has sold and used in the field[5, 6]. The typical device is called "EGIG" (extreme-high-order echelle Ge grating) and has the pitch of 476μm[7, 8] or 1111μm. However, since GRISM is used at a low order generally, the pitch of groove becomes a similar to an operating wavelength.

In cutting, the difficulties accompanying by the size of a pitch completely differ. With the GRISM for 2μm of a practical use wavelength limit with 1st order, a grooved pitch is closed with 2μm and the step difference of groove is especially set to 500nm or less. According our evaluations, it is very difficult for this small pitch and small step difference to perform stable processing from the acceptable tolerance of a diamond tool setting becoming extremely tight. Of course, since in machining which processes one groove at each path, the increase in a number of grooves is directly related with increase of machining time, and serves as restrictions of equipment exclusive time. Although this restriction is equivalent to the ability not to enlarge incidence beam size as an optical element, we made the GRISM with the pitch of 2.2μm for the effective beam diameter of 32mm as a proof of the practical device. The grating parameters is shown in Table 3. This GEISM for the center wavelength of 2.2μm has the design of the spectrum resolution (λ/Δλ) with 4500 at the diameter of 32mm. Figure 7 shows the pictures of Ge GRISM and the grooves. Although processing conditions are severe, in suitable processing conditions, good grooves are obtained. Figure 8 shows measured surface flatness of flat and grooved both surface. It has become lambda/100 or less to design wavelength 2.2μm by RMS. It is the level without consideration about the influence of wavefront error.

Grating Parameter	
Blaze Angel (Prism Angle)	19.19°
Apex Angle	89.6°
Grooved pitch	2.17μm
Groove width	34mm
Grooved length	39.7mm

Table 3. The grating parameters

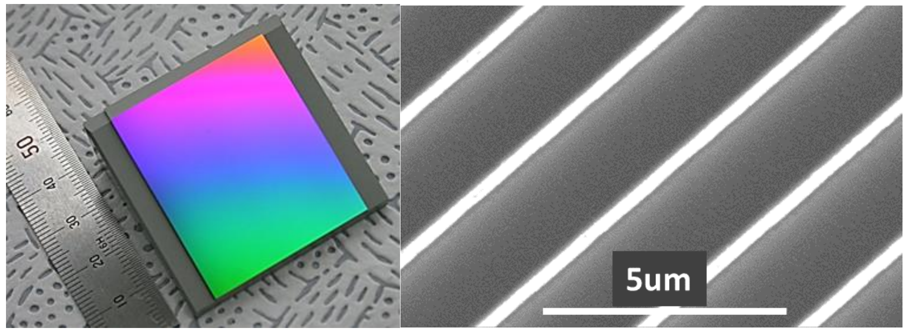
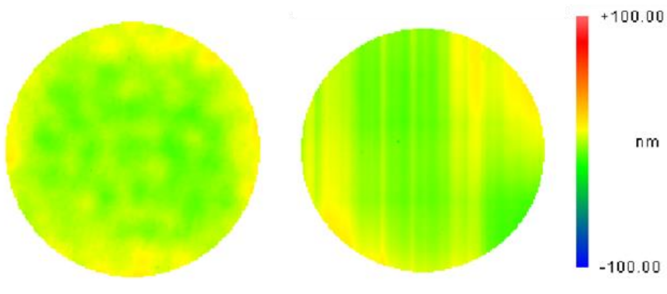


Figure 7. The picture of Ge GRISM (Left), the picture of grooves by SEM (Right)



Surface	Flatness in Φ32mm
Plane	**28.5nm(PV) 5.4nm(RMS)**
Grooved (1st order)	**35.7nm(PV) 6.3nm(RMS)**

Figure 8. Measured surface flatness of entrance surface and grooved surface

Since Ge is high index material, the antireflection coating is indispensable in order to achieve high efficiency. Figure 9 shows the picture of Ge GRISM after AR coting on both side, with the protected cover for the effective area of both surface and the transport package, respectively. Although the detailed evaluation of diffraction efficiency has not finished yet, it is enough to expect over 90% to the theoretical efficiency or over 60% of absolute efficiency by presumption from measured surface roughness and a number of defects.

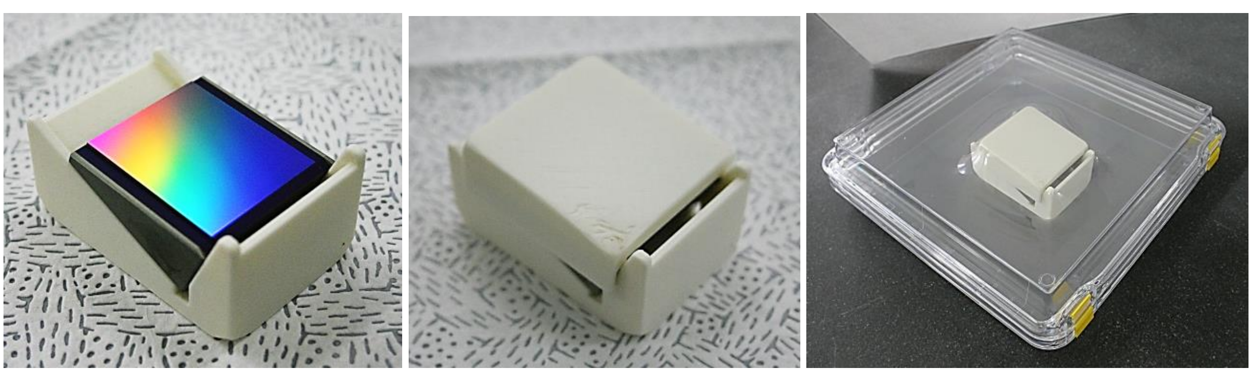


Figure 9. Ge GRISM after AR coating (Left), with protected cover (center) and in the package for transportation (Right)

3.3 Indium Phosphide (InP)

In Indium Phosphide, an immersion grating which has a big pitch already fabricated by machining[9]. Fundamental recognitions of machining are completely the same as germanium for machined GRISM. In our initial investigation, the InP of restrictions is severer. Moreover, since the cover wavelength is shorter than germanium, the detailed investigation of process conditions for InP are required.

We made the GRISM for the center wavelength of 2.2μm with the pitch of 16.9μm for the effective beam diameter of 32mm as a proof of the practical device at this time. The grating parameters is shown in Table 4. Figure 10 shows the pictures of InP GRISM after AR coating on both surface and the grooves. In such large pitch, good grooves are obtained. Figure 11 shows measured surface flatness of flat and grooved both surface. Figure 12 shows the picture of the grooved surface after AR coting on both side and the transport package.

Grating Parameter	
Blaze Angel (Prism Angle)	3.48°
Apex Angle	90°
Grooved pitch	16.949μm
Groove width	34mm
Grooved length	39.7mm

Table 4. The grating parameters

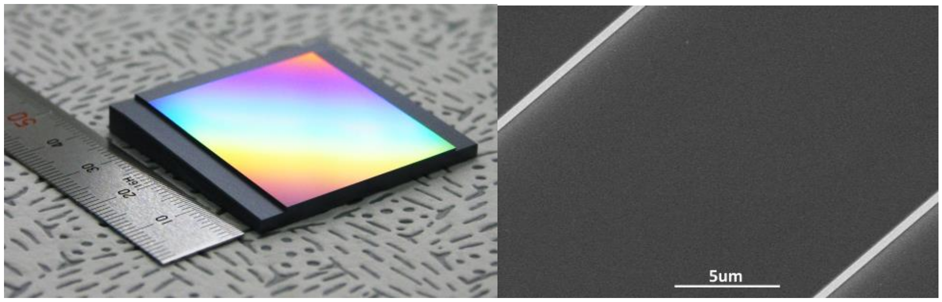
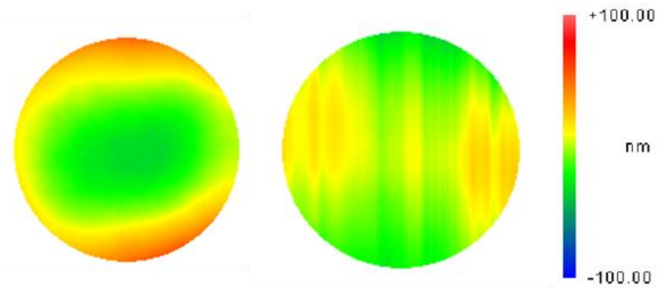


Figure 10. The picture of Ge GRISM (Left), the picture of grooves by SEM (Right)



Surface	Flatness in Φ32mm
Plane	90.6nm(PV) 20.2nm(RMS)
Grooved (1st order)	58.9nm(PV) 11.3nm(RMS)

Figure 11. Measured surface flatness of entrance surface and grooved surface

Figure 12.The grooved surface with AR (Left), the flat surface with AR (center) and in the case for transportation (Right)

4. SUMMARY

In this paper, the prospect of practical device in CdZnTe was obtained by realized coating. It was able to confirm about the reproducibility that the performance of the device manufactured independently had be mostly in agreement.

Moreover, the GRISM made of Ge and InP is able to fabricate by machining (cutting). However, machined process for a small pitch (<5μm) needs examination and improving more detailed.

It is possible to use as a cross-disperser or a low-order immersion grating by giving a high reflective coating to the grooved plane instead of AR coating. The mechanical diffraction device is widely use for a high dispersion spectroscope to a low dispersion spectrum by this examination. Furthermore, a compact and highly efficient spectroscope could be designed by combining these devices.

Since there is always demand of a compactness with high resolution in infrared spectroscopy, it is clear that these mechanical grating becomes one of the solution for this demand. We think in space that spectroscope with an immersion grating is used standardly as an alternative spectroscope of FT-IR which especially has a movable unit.

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