ICSO 2016

International Conference on Space Optics

Biarritz, France

18–21 October 2016

Edited by Bruno Cugny, Nikos Karafolas and Zoran Sodnik

Development of INP immersion grating for the near- to mid-infrared wavelength

Takashi Sukegawa

Yukinobu Okura

Tomonao Nakayasu

esa icso proceedings cnes

International Conference on Space Optics — ICSO 2016, edited by Bruno Cugny, Nikos Karafolas,
Zoran Sodnik, Proc. of SPIE Vol. 10562, 1056206 · © 2016 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2296077

DEVELOPMENT OF INP IMMERSION GRATING FOR THE NEAR- TO MID-INFRARED WAVELENGTH

Takashi. Sukegawa[1], Yukinobu.Okura[1], Tomonao.Nakayasu[1]
[1]Canon Inc, *30-2, Shimomaruko 3-chome, Ohta-ku, Tokyo 146-8501, Japan*

I. INTRODUCTION

An Immersion grating is a powerful optical device for the infrared high-resolution spectroscope. We already fabricated the large CdZnTe(CZT) immersion grating (Sukegawa et al. (2012), Fig.1)[1][2][3] and Germanium(Ge) immersion grating (Sukegawa et al. (2015), Fig.2)[4]. Ge is the best material for a mid-infrared immersion grating because of Ge has very large reflective index (n=4.0). But Germanium can be applied for immersion mode between 2μm to 11μm by the limitation of own transmittance. Recently, since a demand for the high resolution in the near infrared (NIR) also exceeds $\lambda/\Delta\lambda$=100,000 is increasing, a realization of immersion grating of high refractive-index material is desired. Although Si is well known for the practical use immersion element which can be used in the NIR, it is difficult to manufacture with ideal form due to its process. Then, we are developing an immersion grating for the NIR which has the shape of an ideal groove by using a single crystal InP (Indium Phosphide).

An InP is widely used for the optical (LDs and LEDs) and the electronic (HBTs and HEMTs) devices as key materials. Nowadays, the applications of InP are extended for various fields such as infrared imaging sensors and high efficiency solar cells. An InP immersion grating is possible to use around 1 to 8 μm.

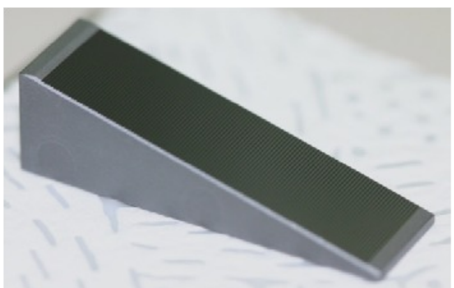


Fig.1 Picture of the CZT immersion grating

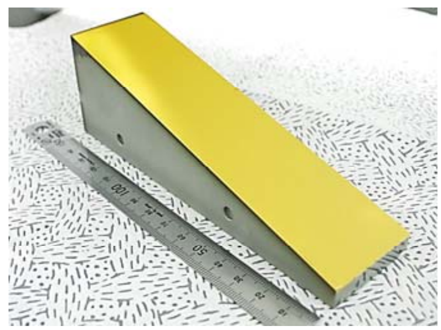


Fig.2 Picture of the Ge immersion grating in 155mm length

II. FABURICATION

Figure 3 shows Canon original free-form processing machine (A-Former) [5]. This machine is the high precision processing machine which Canon developed for an inner product. Canon has a high precision free form cutting machine and ultra-precision cutting process technology. Our high precision free form cutting machine has three liner axes (X-axis, Y-axis, and Z-axis) and two rotations axes (B-axis, C-axis) on a highly rigid frame with air mount to suppress vibration and has a high quality control system which enables positioning resolutions of control axes which is less than 1nm. Moreover, Canon has ultra-precision cutting technology which can control and optimize cutting conditions such as feed speed, cutting depth, and rake angle, etc. and other conditions such as crystal orientation, cutting force, temperature, etc.

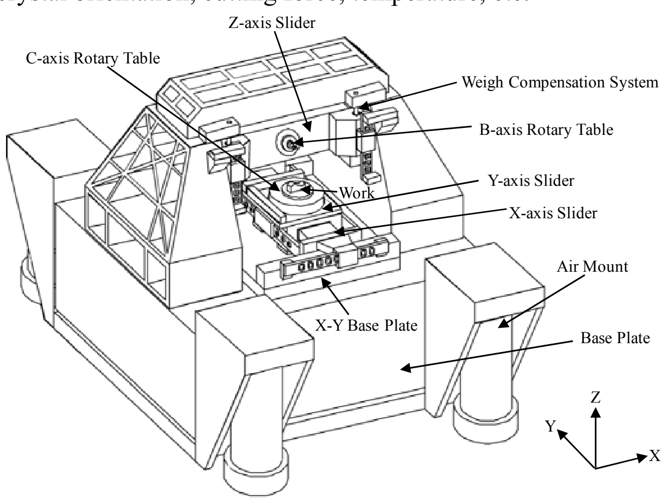


Fig.3 Canon original free-form processing machine (A-Former)

Figure 4 shows drawing of the first InP immersion grating. And Table 1 shows grating parameters. This grating has 990 grooves on the diffraction surface with the groove width of 18.9mm and grooved length of 46.8mm. As the results, the total processing length was up to 18.7m within fabricating of 990 grooves. The cutting tool is a single crystal diamond tool. The crystal orientation of blaze facet is (100) orientation faces of the single crystal InP which is made by JX Nippon Mining & Metals Corporation.

Figure 5 shows picture of the test InP prism for the first completed immersion grating. Figure 6 shows scanning electron microscope (SEM) image of the first InP immersion grating. There is no defect like a chipping in the cutting plane.

Figure 7 shows result of having measured the surface roughness of the test InP immersion grating by the Zygo NewView. We evaluated the surface roughness of the groove using a ZygoNewView3D Optical Surface Profiler. In order to evaluate change of surface roughness depending on processing in advance, measurement was performed in the start of processing, and the end of processing at each □30μm area of a counter facet. There was slight degradation from 2.21nm (rms) to 2.73nm (rms) in this grating. And the end of processing at 8x30μm area of a blaze facet was 1.78nm (rms).

Figure 8 shows the measurement setup of the surface irregularity in the air. The surface irregularity was measured with a Zygo interferometer. To measure only the surface irregularity of fabricated grooves, we measured the surface irregularity of the m=142 reflected light from the diffraction surface at 632.8 nm under the Littrow condition in the air.

Figure 9 shows a result of having measured an irregularity of the test InP immersion grating. The measured irregularity in an area 14.7 mm (V) × 18.9 mm (H) is 53.5 nm (PV) or 12.1 nm (rms).

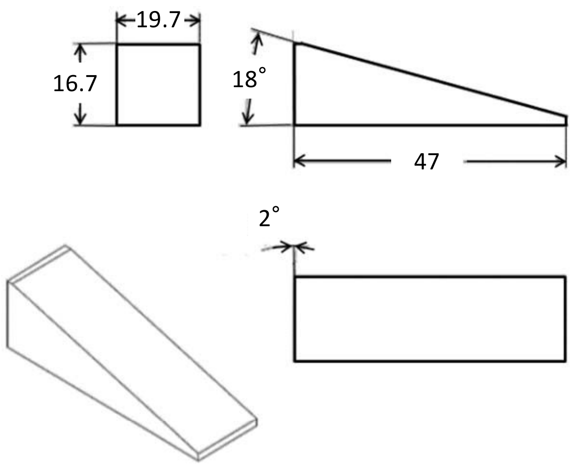


Fig.4 The drawing of the InP prism

Groove Pitch	47.3μm
Blaze angle	72°
Apex angle	86°
Groove size	17.76μm × 45.09μm
Groove area	18.9mm(Width) 46.8mm(Length)

Table.1 The grating parameters of the first InP immersion grating

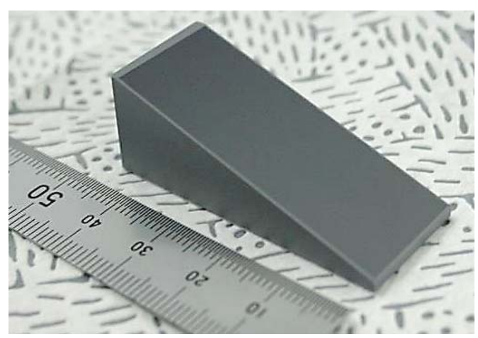


Fig.5 Picture of the first InP immersion grating

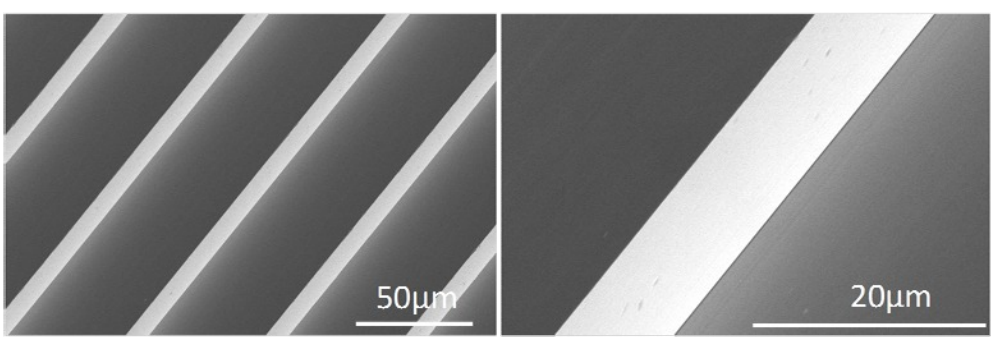


Fig.6 SEM image of the test InP immersion grating. : x 1,000(left), x 5,000(right)

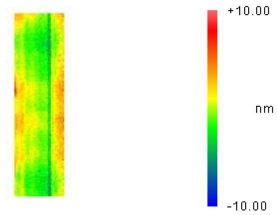
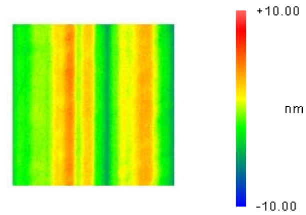
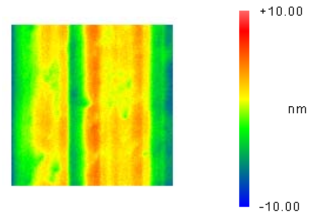
Placement	Start of Processing	End of Processing
Blaze facet Evaluation Area:8µm × 30µm	Limitation by physical intervention	
Surface roughness(rms)		1.76nm
Counter facet Evaluation Area:30µm × 30µm		
Surface roughness(rms)	2.21nm	2.73nm

Fig.7 The surface roughness of the InP immersion grating by the Zygo NewView 3D optical surface profiler

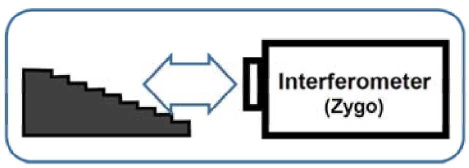


Fig.8 The measurement setup of the surface irregularity

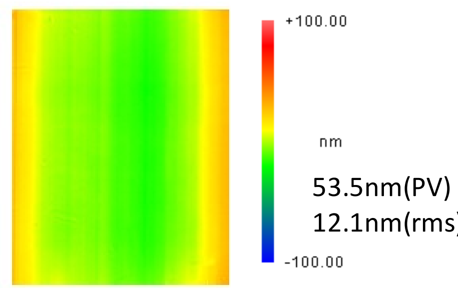


Fig.9 The surface irregularity of the first InP immersion grating (The grooves run vertically)

The back-reflective coating is indispensable for a practical immersion grating and the diffraction efficiency performance with a back-reflective coating is very important at the practical performance evaluation. On the other hands, in order to avoid the influence of performance of anti-reflection coating at the entrance of the immersion grating, the reflective coating was coated only at the diffraction (grooved) surface. (Fig.10) The main reflective layer of the back-reflective coating is gold. Since the device after processing is very precious, it forms a coating by holding to the custom holder (Fig.11) which served as fall prevention at the time of coating process. Since an entrance/exit surface of an immersion grating is usually a flat plane, an anti-reflection coating which is optimized by the desired wavelength range can be applied by extension of general coating technology for the NIR.

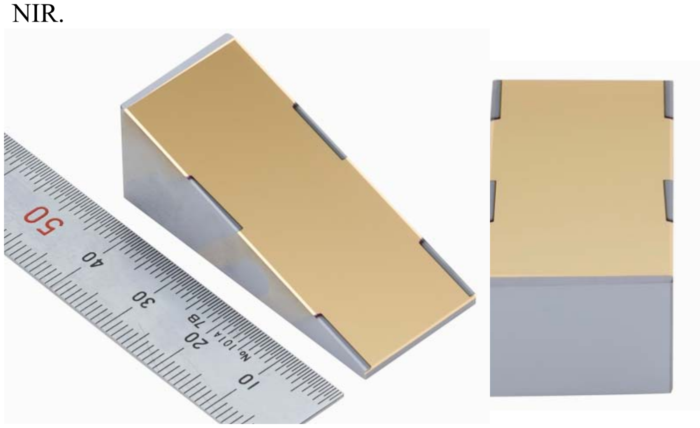


Fig.10 Picture of the InP immersion grating with back-reflective coating (Without an anti-reflection coating at the entrance/exit surface)

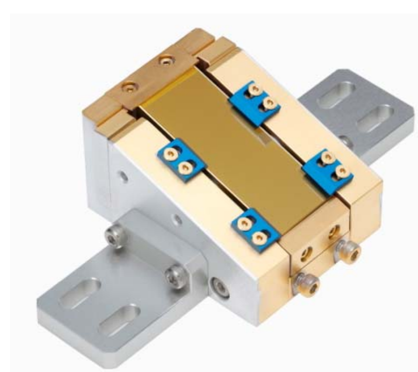


Fig.11 Picture of the coating holder which is holding the grating

Moreover, this coating holder can be used as a transportation holder and the additional covers which protect an entrance / exit surface at the front of an immersion grating and a diffracting (grooved) surface can be attached. (Fig.12)

Fig.12 Picture of the coating holder at transportation use

III. OPTICAL PERFORMNCE

We obtained the diffraction lights by He-Ne laser of green at 543.5nm under the Littrow condition in the air. (Fig.13) Fig14 shows the measured diffraction pattern image on CCD. Fig15 shows the derived spectrum which was normalized by the peak intensity of the strongest diffraction order (m=164,165,166). There is no distinct ghost pattern which was observed even around the strongest order and between orders.

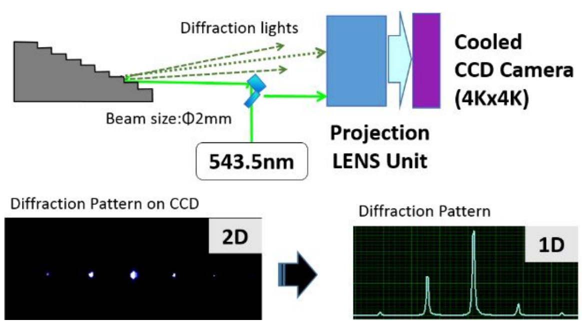


Fig .13 Optical configuration for measuring the diffraction lights by green laser under the Littrow condition in the air.

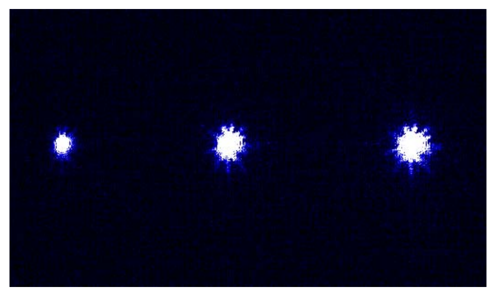


Fig .14 Measured diffraction pattern image on CCD

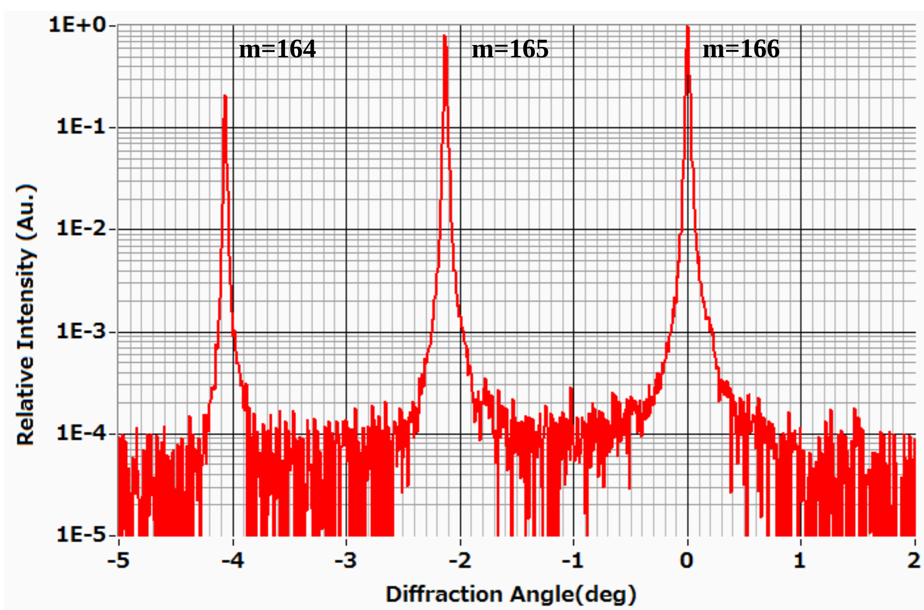


Fig.15 The measured diffraction pattern at 543.5nm (m=164,165,166) (Angle “0” at the peak of m=166)

We also obtained the diffraction efficiency curve at approximately 1.55μm under the immersion configuration (Fig.16). This IR laser could be tuned a wavelength from 1.52 to 1.57μm. The bandwidth was $\Delta\lambda/\lambda=1\times10^{-9}$, which was narrower than the theoretical spectral resolution of the fabricated immersion grating.

Fig17 shows the measured absolute diffraction efficiency of m=180 under immersion configuration for both TM (triangles) and TE waves (circles) at the center of the grooved area. The maximum efficiencies of the TM and TE waves obtained 40% and 45%, respectively. Considering this result is obtained without Anti-reflection coating at the entrance/exit surface, 70% or more of the maximum efficiency is expected at the both polarization in giving suitable anti-reflection coating on the entrance/exit surface.

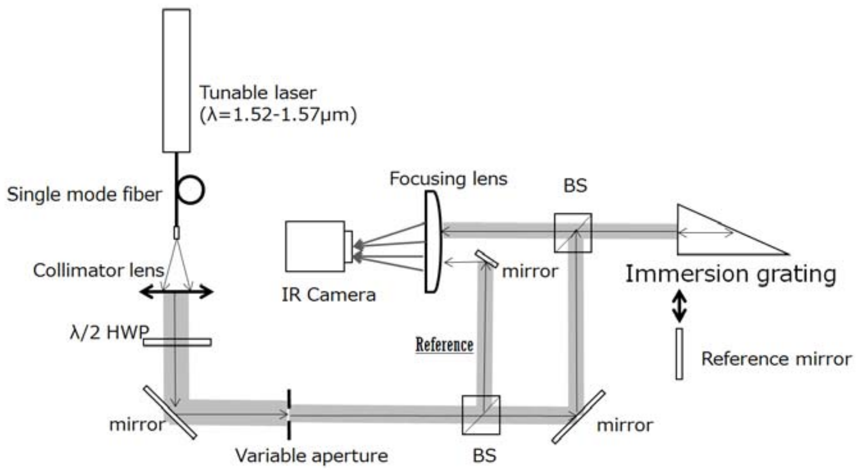


Fig.16 Optical configuration for measuring the diffraction efficiency in the IR region under the immersion configuration.

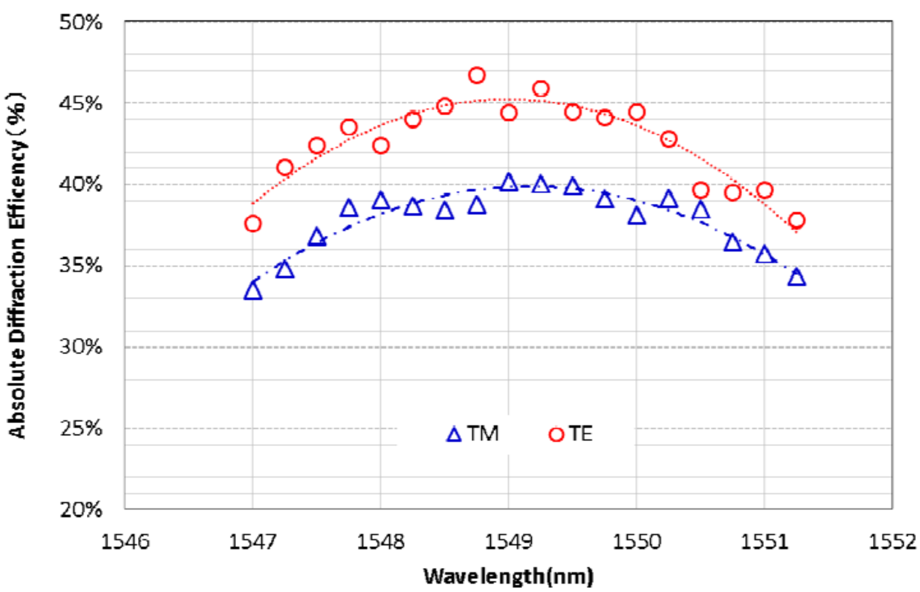


Fig.17 Measured absolute diffraction efficiencies m=180 under immersion configuration for both TM (triangles) and TE waves (circles).

IV. SUMMARY

We have succeeded in fabricating the high performance machined-InP immersion grating. Although the size of a device still limited by a material size of InP ingot, an immersion grating with about 80mm in length can be fabricated at the blaze angle of 72 degrees. The theoretical spectral resolution of InP immersion grating in this length at 1.55um is estimated to be $\lambda/\Delta\lambda$=300,000. Even if there is 2% of loss on each side at the entrance / exit surface, the estimated maximum diffraction efficiency of the TE waves reached over 80% in particular. Since our InP immersion grating is able to realize very high wavelength resolution with compactness, the practical use is expected not only for a high resolution spectrometer in the NIR but also for a device of laser communications like a DWEM (Dense Wavelength Division Multiplexing) especially in the space.

By this development, the immersed echelle grating by cutting which has ideal form mostly became possible to applying in the wider range infrared region which is about 1-20μm by using CdZnTe, Ge and InP.

V. REFERENCES

[1] T. Sukegawa, S. Sugiyama, T. Kitamura, Y. Okura, and M. Koyama, "High-performance astronomical gratings by Canon," Proc. SPIE8450, 84502V (2012).

[2] Ikeda, Y., Kobayashi, N., Sarugaku, Y., Sukegawa, T., Sugiyama, S., Kaji, S., Nakanishi, K., Kondo, S., Yasui, C., Kataza, H., Nakagawa, T, and Kawakita, H., "Machined immersion grating with theoretically predicted diffraction efficiency" Vol. 54, No. 16 / June 1 2015 / Applied Optics 5193

[3] Naoto Kobayashi , Yuji Ikeda , Hideyo Kawakita, Keigo Enya, Takao Nakagawa, Hirokazu Kataza , Hideo Matsuhara , Yasuhiro Hirahara, and Hitoshi Tokoro, "Mid-infrared high-resolution spectrograph for SPICA", in [Space Telescopes and Instrumentation 2008: Optical, Infrared, and Millimeter . Edited by Jacobus M. Oschmann, Jr.; Mattheus W. M. de Graauw; Howard A. Mac Ewen, Proceedings of the SPIE, Volume 7010, pp.701032 (2008)], (2008)

[4] T. Sukegawa, T. Suzuki, T. Kitamura, "Astronomical large Ge immersion grating by CANON" Proc. *SPIE* 9912, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation II, 99122V (July 22, 2016)

[5] Yokomatsu, T., Takizawa, N., Deguchi, A., Saito, T., Kumai, K., "Development of High Precision Free Form Cutting Machine", Proc.JSPE, (1999), (in Japanese).