International Conference on Space Optics—ICSO 2014

La Caleta, Tenerife, Canary Islands

7–10 October 2014

Edited by Zoran Sodnik, Bruno Cugny, and Nikos Karafolas

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International Conference on Space Optics — ICSO 2014, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 10563, 105634S · © 2014 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2304066

DESIGN AND CHARACTERIZATION OF THE BLAZED HOLOGRAPHIC UV GRATINGS FOR TROPOMI

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I. INTRODUCTION

Optical components such as diffraction gratings are widely used in Space-flight satellites to analyse light properties from soft-X rays to Infra-Red. The diffraction gratings are one of the key optical components of space-flight instruments and have to exhibit very high optical performances.

TROPOMI (Tropospheric Monitoring Instrument) is a spectrometer to measure the tropospheric composition for climate and air quality applications. TROPOMI is the payload of the Sentinel-5 Precursor mission which is a collaborative effort of ESA and the Netherlands Space Office (NSO), part of the GMES Space Component Programme.

For TROPOMI, HORIBA Jobin Yvon SAS (France) has designed, produced and characterized, in collaboration with TNO, a set of blazed holographic plane reflexion gratings optimized in the UV spectral range. HORIBA Jobin Yvon SAS (HJY) has been producing such gratings for space experiments since 1968 [1] and has produced some of the most technically-challenging space-flight gratings ever designed, applications ranging from off-plane X-ray gratings to toroidal Variable-Line-Spacing (VLS) gratings for the VUV and transmission deep groove gratings for the IR range [2, 3].

II. TROPOMI UV GRATING DESIGN

UV TROPOMI gratings (Qualification Model, Flight Model and Flight Spare) have been manufactured by HORIBA Jobin Yvon SAS (HJY). HJY has developed a unique expertise in diffraction gratings design and manufacturing processes for holographic, ruled or etched gratings. UV TROPOMI gratings selected technology is replica blazed holographic plane grating optimized in the UV spectral range.
An existing HJY 2400gr/mm blazed holographic grating master was used as a reference and then replicated by a space-qualified grating replication process. Replication process is a cost effective solution for space-flight applications.

The 2400gr/mm holographic grating master used for the project was blazed around ~250nm and to work over a large spectral range from 190 to 650nm. The theoretical diffraction efficiency was computed for TE, TM polarization and unpolarized light given below in Fig. 1.

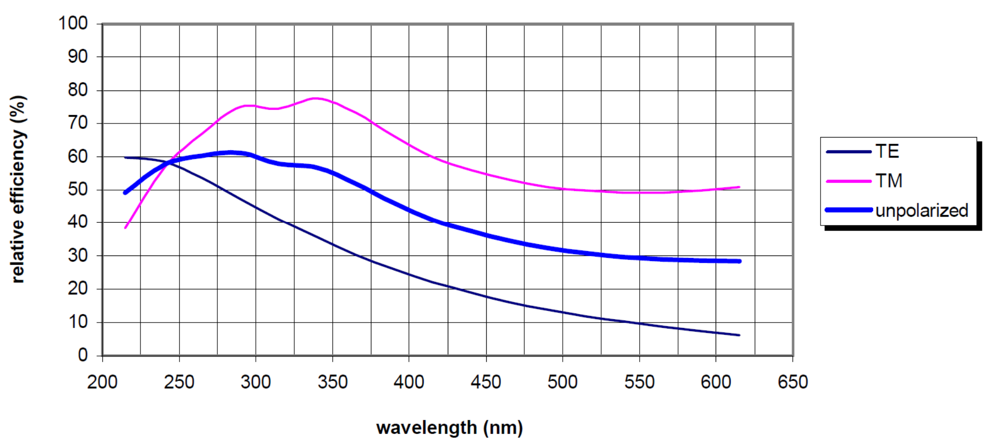

Fig. 1. Theoretical efficiency calculation of the 2400gr/mm blazed holographic plane grating from 210nm to 610nm, for TE, TM polarization and unpolarized light.

The produced replica gratings retain the advantages of the initial master holographic grating :

- Perfect periodicity, plus excellent micro-roughness of the surface eliminates ghosts and enhances stray light rejection ;

- Minimal groove errors provide very high resolution.

In addition, owing to their ion-etched, sawtooth smooth and clean groove profile, UV TROPOMI blazed gratings offer higher peak diffraction efficiency than a standard pure holographic grating. The blaze angle is measured by using Atomic Force Microscope (AFM) to a value of 16.5° (Fig. 2.).

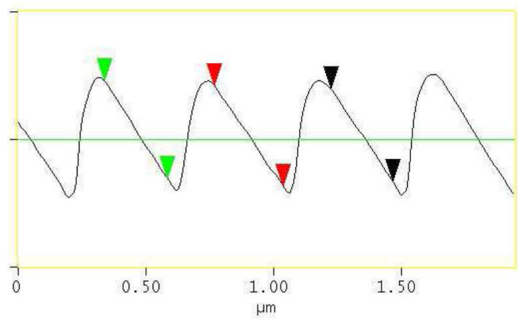

Fig. 2. Blazed holographic plane grating groove profile measurement by AFM

III. TROPOMI UV GRATING CHARACTERIZATION AND OPTICAL PERFORMANCES

A. *Diffraction efficiency measurements*

Thanks to an adapted groove profile and an Aluminium coating, the UV TROPOMI gratings exhibit a high-efficiency over the whole spectral range (from 270nm to 330nm). The measured relative diffraction efficiency of the Flight Model grating is shown by the Figure 3 where efficiency curves in TE, TM polarization and unpolarized light for 1st and 0 orders are presented in Fig. 3. :

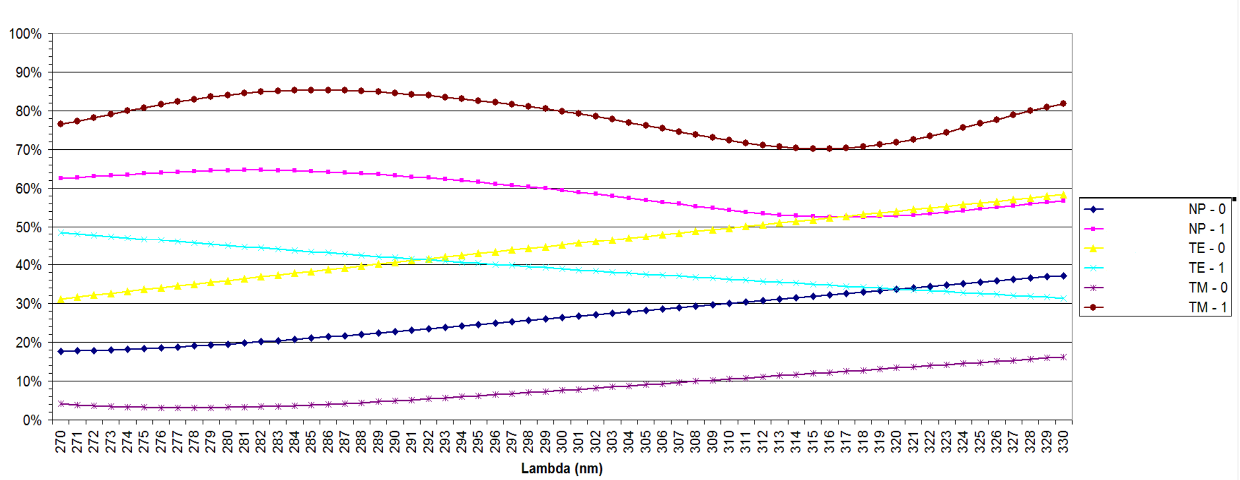

Fig. 3. Measurement of relative diffraction efficiency of the Flight Model (FM) grating for -1st order, at 15° deviation angle, with TE polarization (cyan colour), TM polarization (brown colour), Unpolarized light (pink colour) and 0 order with TE polarization (yellow colour), TM polarization (purple colour), Unpolarized light (blue colour).

The relative diffraction efficiencies for unpolarized light are measured and give 63.7% at 275nm and 59.4% at 300nm, which is in good accordance with the theory.

The QM grating has been used for performing environmental tests (temperature cycling from -50°C to +45°C and humidity from 25 to 60%) according to the TROPOMI space-flight mission requirements. The tests have been performed and passed successfully. HJY replica gratings had been already initially space-flight qualified during the Long Duration Exposure Facility (LDEF) NASA's mission in the 80's [4].

B. Stray light measurement

The stray light of the grating is of paramount importance for the performance on the TROPOMI instrument. Without adequate stray light performance, light from high-radiance clouds can completely dazzle nearly low-radiance areas. As the stray light performance of the spectrometer is likely dominated by the grating, the stray light performance of each grating is accurately measured at TNO.

The measurements have been performance by illuminating the grating with a laser with a 532 nm wavelength and detecting the scattered light as function of scatter angle. In the describe stray light test setup, all the gratings are measured at the same 532 nm wavelength, which allows us to make good comparisons between gratings. However, it should be noted that the quoted values are only true for the given wavelength. The stray light level at UV wavelength will be significantly higher.

The detector proves a signal proportional to the amount of light that is collected within a small, well-defined field-of-view. The detector can also be rotated directly into the incidence beam to provide a reference measurement. The ratio of grating and reference measurements is normalised with the order efficiency to get the value for the bi-directional scatter distribution function (BSDF).
The incidence angle is set to 50° as compromise to make both incidence and diffraction angles as similar as possible to the instrument configuration. Note that it is not possible to exactly match both angles, due to the difference between measurement and instrument wavelength.

Figure 4 shows a representative measurement for the grating stray light. At zero detection angle, a strong peak is visible, which is due to the -1 grating order. The width of this peak is 1.2°, consistent with the field-of-view of the detector. The black line is for a perfectly flat silicon wafer, and indicates the stray light level of the setup. This shows that the setup can distinguish extremely low stray light levels down to 10^{-4} /sr at 5° degrees from specular reflection.
The green line represents a well-polished mirror. Even good gratings are expected to give more stray light than such a mirror, which is the reason why the grating dominates the stray light level of the instrument.

Gratings with a good stray light performance, typically have a stray light levels of $2*10^{-2}$ to $5*10^{-2}$ /sr at 5° from the grating order. The measured value for the TROPOMI UV grating is $2.2*10^{-2}$ /sr, which is nicely within the best effort specification of : < $2.8*10^{-2}$ /sr at 5° from the grating order.

IV. CONCLUSION

We have described in this paper the detailed design and optical performances characterization of the TROPOMI UV 2400gr/mm blazed holographic replica gratings produced by HJY. A peak efficiency of about 64% for unpolarized light has been measured. A very good performance in stray light was also noticed. The produced gratings were then environmentally tested in temperature and humidity cycling and passed successfully these tests.
All the results pave the way for future space-flight projects such as the ESA SENTINEL-5 project.

V. ACKNOWLEDGMENT

This document has been produced with the financial assistance of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union and/or ESA. The Sentinel 5 Precursor mission, a collaborative effort of ESA and the Netherlands Space Office (NSO), is part of the GMES Space Component Programme.

ESA and the Netherland Space Office share the procurement of the TROPOMI. The consortium composing the mission comprises Astrium Ltd (Stevenage - UK), as Mission Prime, and an integrated team of Dutch Space (Leiden - NL) and TNO (Delft - NL) is responsible for the Payload.

VI. REFERENCES

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