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Antireflection and Absorbing coatings for TROPOMI SWIR immersed grating

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Abstract— **CILAS is involved in a scientific project for SRON Netherlands Institute for Space Research, on the development of multilayer coatings for the silicon immersed grating prism, which is a key component of the short-wave-infrared (SWIR) channel of the TROPOMI imaging spectrometer.**

For the project, two specific coatings have been implemented and qualified by CILAS: first, an antireflection coating deposited on the entrance and exit facets of the immersed grating prism, which reaches a very low value of reflectivity in the infrared [2305nm; 2385nm] spectral range and for a wide angular range [0° to 47°] of incidence of the transmitted light, and second, a metal-dielectric absorbing coating for the third facet of the prism to eliminate parasitic light inside the silicon prism.

Index Terms— **antireflection coating, absorbing coating, immersed grating, dual ion beam sputtering, optical monitoring**

I. Introduction

The TROPOMI (TROPOspheric Monitoring Instrument) instrument is intended to be launched as a precursor mission for the ESA Sentinel-5 program, the so called Sentinel-5 Precursor satellite [1]. This instrument is dedicated to the monitoring of Earth atmosphere composition: pollutant gas carbon monoxide (CO), greenhouse gas methane (CH4) and water (H2O) will be measured in the SWIR spectral range, down to the earth surface thus providing major information about atmospheric carbon and the hydrological cycle.

For several years, CILAS has developed an expertise in the field of optical thin films deposition and in-situ visible and infrared optical monitoring techniques that enable us today to successfully answer increasing requests of space systems for Earth observation and monitoring. In particular, Dual Ion Beam Sputtering technology (DIBS) allows us to guarantee the production of coatings which are nearly insensitive to temperature and atmospheric conditions.

Such dense technology has been used and dedicated samples and prototype models have been developed to guarantee the spectral response of the coatings deposited on the immersed grating prism. We present here the spectral measurements and numerous experimental results of qualification tests in temperature down to 90 K and humidity that show the reliability of these multidielectric and metal-dielectric functions for space environment.

II. Coatings Development and Manufacturing

A. Coatings specification and design

The immersed grating, provided by SRON, is a single crystal of silicon with a grating surface etched onto one face [2]. To avoid losses on the entrance facet of the prism, an antireflection coating with very low value of reflectivity in the infrared [2305nm; 2385nm] spectral range and a wide angular range [0° to 47°] of incidence is specified. Furthermore, to eliminate the parasitic light inside the silicon prism, the passive facet needs an absorbing coating (Fig. 1). Each area to be coated is approximately 50 x 50 mm^2.

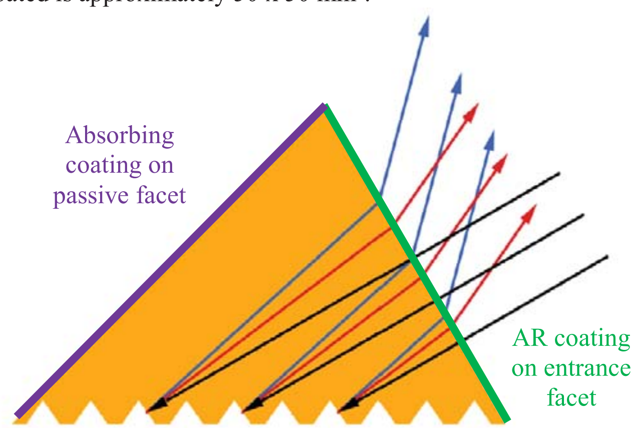

Fig. 1. Schematic Immersed grating with V-grooves. Incoming rays in black, dispersed light in red and blue. AR coating in green and Absorbing coating in purple.

Table 1 gives the specification of reflectivity according to the angle of incidence of the transmitted light. The theoretical spectral response of the designed antireflection coating on Si substrate for different angles of incidence is given in Fig. 2

Angles of incidence	R%
0°-> 5°	5.10^{-3} in the range [2280-2410nm]
14°	2.10^{-3} at 2431 nm
25°	2.10^{-3} at 2385nm
47°	5.10^{-3} at 2305nm

Table 1. Antireflection coating specifications

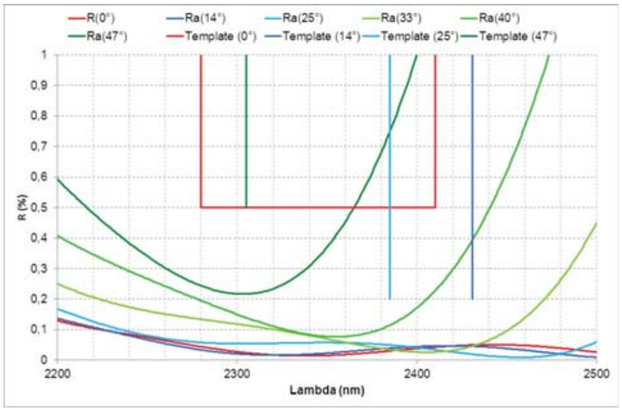

Fig. 2. Theoretical spectral response of the designed antireflection coating on Si substrate for different angles of incidence

On the passive facet of the immersed grating prism, a metal-dielectric absorbing coating has been designed to eliminate stray light inside the silicon prism. For this coating the requirement is R<1.5% for 2280nm to 2410nm at 0° to 30° AoI in the silicon prism medium. Fig. 3 presents the theoretical spectral response of the designed absorbing coating on Si substrate for different angles of incidence.

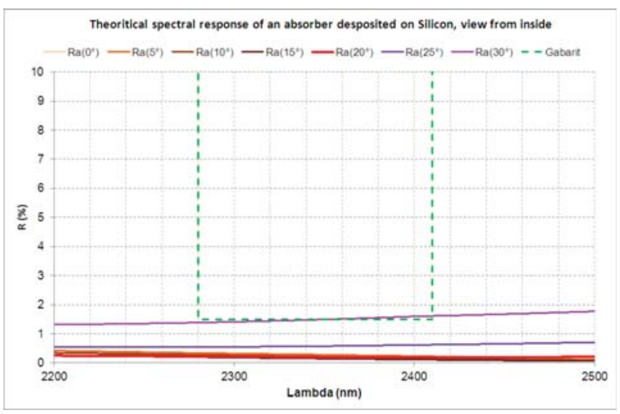

Fig. 3. Theoretical spectral response of the designed absorbing coating on Si substrate for different angles of incidence, in the silicon medium

Both coatings shall be used in space environment and show no defect larger than 0.16 mm according to NF ISO 10110-7 norm 5/C 4x0.16.

B. Antireflection and Absorbing Coatings manufacturing

The technology used for manufacturing these two coatings is Dual Ion Beam Sputtering (D.I.B.S.). It uses one ion beam gun for sputtering a target and a second one to improve the density of the sputtered material (Fig. 4). This technology leads to very dense layers and high quality coatings and is intensively used for manufacturing very narrow band filters for the optical telecommunication market. The density of the deposed layer is very close to the bulk material and enables the filter to be nearly insensitive to environmental parameters.

It enables to have very smooth interfaces too, that lead to very low scattering levels. This is a privileged technology for space applications as there is no measurable spectral shift between air and vacuum and versus temperature variations, and as coatings show very low ageing effects. The second ion beam is also used for cleaning the substrate before coating and leads to very good adhesion.

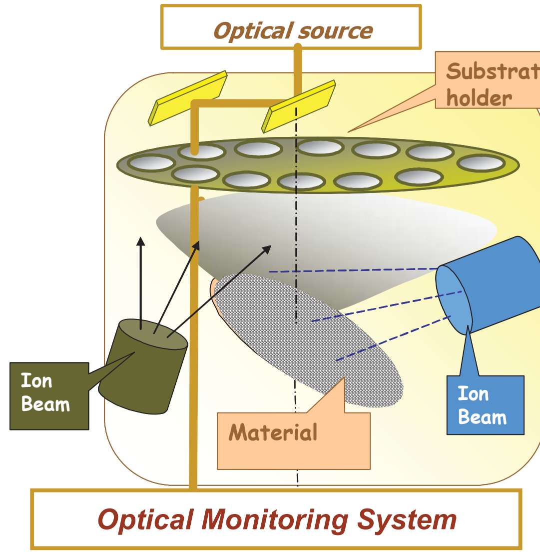

Fig. 4. Dual Ion Beam Sputtering principle

An infrared optical monitoring system [3] has been used in order to control wavelengths in the useful spectral range. Moreover a dedicated substrates holder has been designed in order to maintain without damage the silicon prism.

The overall process is very stable and enables, together with an in-situ optical monitoring carried out directly on one of the witness samples, to reach the required performance on all the components.

C. Spectral measurements

Specific witness samples have been used to measure the spectral performances of each coating. For the antireflection coating, spectral measurement in reflectance has been done on silicon prismatic windows at all angles of incidence (from 8° to 47°) to avoid effect of the uncoated rear face.

Performances of absorbing coating shall be measured up to 30° of incidence inside the silicon, through the front face. Due to the substrate high index of refraction, front face of samples has been coated with an antireflection coating. The absorbing coating is then deposited on the rear face of the witness samples. For the measurement of the reflectance at 30° of incidence inside the silicon substrate, the following procedure has been used:

- manufacturing of specific test prims with facets at 30° of incidence

- antireflection coating on entrance and exit facets of this prism
- absorbing coating on the base plate of the prism to be characterized

Fig. 5 illustrates the measurement at 30° that has been performed with a Perkin-Elmer Lambda 950 spectrometer at TNO, equipped with an Absolute Reflectance/Transmittance Analyzer (ARTA) based on a goniometer and an integrating sphere. The incident light at normal incidence of the facet is not deviated and reaches the absorbing coating with 30° of incidence.

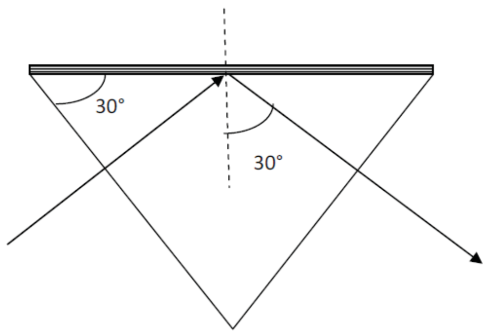

Fig. 5. Schematic view of specific prism for spectral measurement

III. Results

The production of the Immersed Grating involves a lot of steps and different manufacturers. The coatings to be deposited by CILAS are the final steps. Thus the coating of the Flight models shall be completely secured to avoid any risks.

Three project phases have been led. First a development phase, including the development of antireflection and absorbing coatings on witness samples, development of the substrates holder, definition of the coating procedures and then realization of the coatings on a breadboard model (BBM).

Qualification phase allowed the realization of the coatings on qualification model (EQM) and environmental tests.

Finally, after validation of the procedures and success of the qualification tests, the flight model and the flight spare model have been successfully coated.

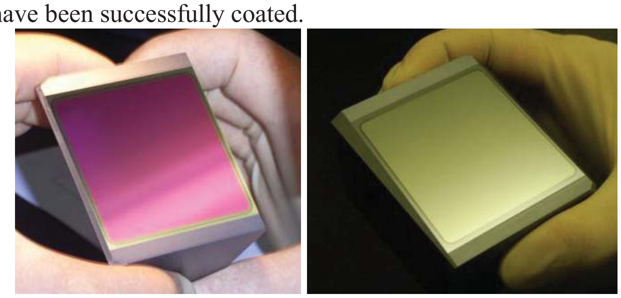

Fig. 6. Flight Model with its AR-coating (left) and absorbing coating (right)

A. Spectral performances

Spectral responses of the coatings, measured on witness sample, at ambient temperature are given Fig. 7 for different angles of incidence.

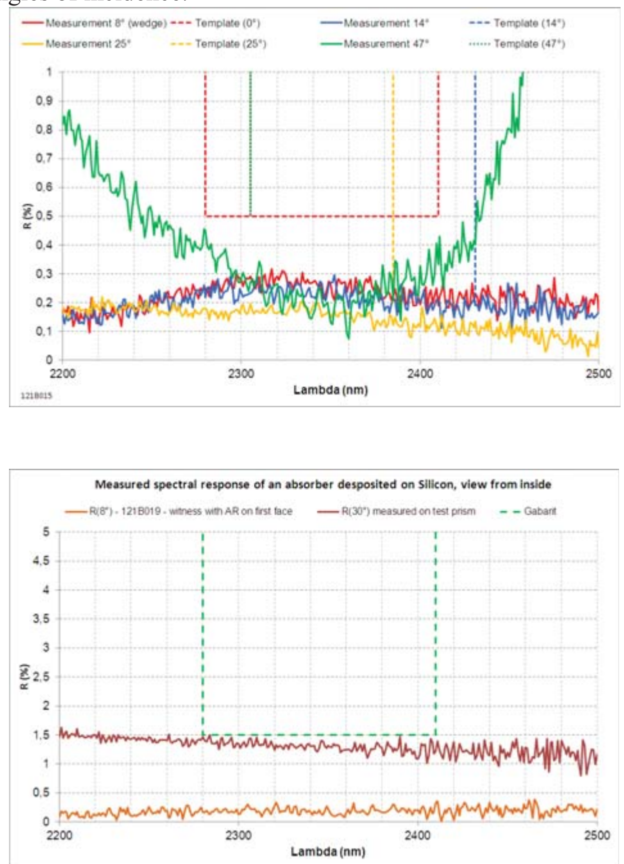

Fig. 7. Measured spectral response of the antireflection coating (top) and absorbing coating (bottom)

During development phase, a theoretical analysis, based on a bibliographic study [4, 5], has been conducted to estimate the behaviour of the antireflection coating under low temperature. In particular, the thermal shift from 20°C to -83°C has been calculated. It can be considered that for dense coatings, for which refractive indices are similar to bulk materials, a variation of temperature will induce 3 major independent effects : variation of refractive indices (dn/dT) of the substrate, the high index material and the low index material constituting the antireflection coating, mechanical dilatation of the substrate and mechanical dilatation of the layers.

The major effect that has been calculated is a spectral shift of about -5nm and an increase of reflectance less than 0.02%, the major contributor being thermal dependence of refractive indices (dn/dT).

B. Environmental performances

Environmental and durability qualification tests and acceptance tests have been conducted respectively on the EQM model then on Flight witness samples.

The tests described in Table 2 have been performed with successful results performing no degradation as well for spectral measurements as for cosmetic performances.

Test	Test description
Thermal cycling	20 cycles -80 / +50 °C with 2°/min slope and 1 hour min/max stage at ambient pressure and under nitrogen atmosphere
Humidity	48 hours exposure to 40°C and 95% humidity
Adhesion	test 02, level 02 according to ISO 9211-3
Abrasion	test 01, level 01 according to ISO 9211-3

Table 2. Test plan

These results show that Dual Ion Beam Sputtering technique used for the realisation of multi-dielectric AR and metal-dielectric absorber functions is particularly well adapted for space applications.

Moreover previous pre-development space project for ESA conducted on similar coatings at CILAS has demonstrated high stability of spectral performances under radiations (Gamma with 60 krads total radiation dose and Protons with energy up to 40 MeV and a flux of 2×10^{10} protons/cm^2).

IV. CONCLUSIONS

Two specific coatings, with low reflectivity, have been designed, manufactured and tested for the immersed diffraction gratings for the TROPOMI SWIR spectrometer. The optical performance is compliant with the requirements. Thermal cycling and humidity conditions have not modified the spectral responses and the quality of the coatings.

This work led in close connexion with SRON has permitted the successful realization of the coatings of the Immersed Grating Flight model which will be launched in 2015.

Moreover, in the frame of studies in the other SWIR wavelength bands of interest for trace gas monitoring: 1.6 µm and 2.0 µm, preliminary designs of antireflection and absorbing coatings have been evaluated showing that similar spectral performances can be reached with our DIBS technology.

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