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Characterization of polarizing filters for the EnVisS camera: procedure and results

Simone Nordera[a,b], Vania Da Deppo[a,b], Paola Zuppella[a,b], Paolo Chioetto[a,b,c]

[a] CNR-Institute for Photonics and Nanotechnologies Padova, Via Trasea 7, 35131 Padova, Italy

[b] INAF-Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, 35122 Padova, Italy

[c] CISAS-Centro di Ateneo di Studi e Attività Spaziali "Giuseppe Colombo", Via Venezia 15, 35131 Padova, Italy

ABSTRACT

In the framework of an ESA space mission, called Comet Interceptor, scheduled for launch in 2029 some polarizers have been tested and characterized. These polarizers are considered for being mounted on the EnVisS (Entire Visible Sky) instrument. EnVisS is a fish-eye camera that will dynamically acquire images of a comet and the surrounding all-sky coma in the visible range exploiting the spacecraft spinning. The spacecraft will perform a fly-by of the comet, venturing very near to its nucleus.

Inside the EnVisS instrument, before reaching the sensor, the acquired light will cross one of the 3 selected scientific filters, i.e. one broadband and two polarizers. The determination of the optical properties of these filters is crucial for the correct prediction of the performance of the camera.

The Padua branch of the CNR-IFN (Italian National Research Council – Institute for Photonics and Nanotechnologies) has a long experience in metrology for space instrumentation and has developed a laboratory system for reflectance and transmittance optical measurements. The set-up is composed of a broadband light source, a rotator stage for allocating the samples, and a spectrometer. According to the purpose of the measurement, the structure of this setup can be arranged by adding other elements along the ray path. This system allows measuring wavelength dependent transmissivity and reflectivity properties for optical components such as mirrors, lenses and filters in the UV, visible and NIR spectral range.

The polarizing filters under selection for the EnVisS instrument are commercially available components based on the wire grid technology. We have measured their optical transmissivity and reflectivity. In this paper, we present the employed instruments, the step-by-step procedure and the results compared to the nominal performance of the polarizers.

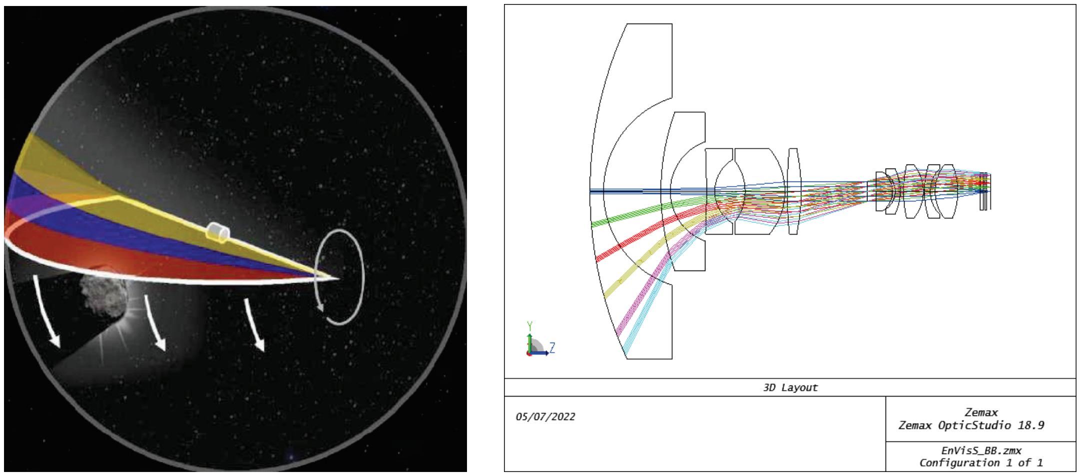
1. INTRODUCTION

Comet Interceptor is the first Fast class ESA mission, which has been conceived to approach and study, by in-situ measurements, a dynamically new comet, or an interstellar object [1]. Unlike Rosetta and Giotto space missions, Comet Interceptor will look at a pristine comet entering the solar system for the first time, with the aim of growing our knowledge on comets. During the foreseen fly-by of the comet, the on-board scientific instruments will study both the "primordial" surface and activity of the nucleus and the structure of the surrounding coma. Before the closest approach, the spacecraft will separate into 3 modules; spacecraft A will keep its distance from the comet, while B1 and B2 will cross the gas and dust coma.

EnVisS is one of the instruments of Comet Interceptor and it is placed on the spin stabilized B2 module. This fish-eye camera has a field of view (FOV) of 180° x 45° and it aims to image, in the visible range, the whole coma from its inside [2]; the spinning of the B2 probe provides a scanning motion for the instrument, allowing to image the entire sky with a dynamic FOV of 180x360° (Figure 1a). While the spacecraft rotates, the incoming radiation crosses the optical head, which is constituted by ten lenses, the filter assembly and then it strikes the camera (Figure 1b), a 3D-Plus package with a CMOS sensor of 2k x 2k pixels.

As expected for every space mission, a series of analysis and tests must be performed in ground laboratories to ensure the good performance and success of the instrument and to make it space qualified. These tests are conducted both on single components and on assemblies which become more complex as the design and manufacturing of the instrument proceed.

Currently, the characterization of the EnVisS filters is in progress. The objective of the preliminary activities presented in this paper is to assess the first-order filters optical properties (e.g. transmission and reflectivity) for the final selection of the filters to be used on the instrument flight model. Some samples of the filters are being measured at the CNR-IFN laboratory in Padova (Italy). In the future, a similar characterization will be performed on the real EnVisS filter assembly expected to be realized by the Materion company.



(a) (b)

Figure 1. In (a) schematics of the acquisition of the comet and the full sky through the spinning motion of B2. In (b) ray tracing through the EnVisS optical head performed in Zemax® [3].

2. PROPERTIES OF THE ENVISS FILTERS

As depicted in the ray tracing of EnVisS in Figure 1b, a filter package is placed in front of the detector with the aim of studying the radiance and the polarization properties of the light emitted by the comet's coma. Even if the detailed design of this filter assembly is still in progress, it basically consists of three filter strips placed side by side: the central one is a broadband (BB) filter in the range 550 – 800 nm, while the side ones are linear polarizers. To be able to retrieve from the measurements the intensity, angle and degree of polarization of the incoming radiation, the orientation of the polarizers' axes will differ by 45° from each other [4].

CNR-IFN and Leonardo SpA (Campi Bisenzio-Florence) are in charge for the design of the EnVisS filter assembly, while Materion is one of the candidate suppliers for manufacturing it; Moxtek, or Polarcor, are possible suppliers of the polarizing elements.

The baseline design of the filter assembly foresees the use of 3 different filter pieces, all having the same thickness, but with different optical properties. The filter assembly will be manufactured stitching, via gluing, these 3 components side by side. This manufacturing technique, often called butcher-block [5], has already been used in many other space missions (e.g. the SIMBIO-SYS cameras onboard Bepicolombo [6]).

The EnVisS filter assembly will be composed as follows:

a) a central piece with a "broadband" bandpass in the range 550-800 nm with no polarization selection
b) two side pieces with the same bandpass of the central one but with linear polarization properties

In Figure 2, the schematics of the filter assembly is shown; the three rectangular useful filter strips areas, whose dimensions are 12.5 x 1.1 mm separated by a 0.12 mm gap, are highlighted. The black coated gaps have been inserted with the aim to clearly separate the different filter strip areas, and the corresponding images on the detector, and to reduce the possible straylight issues due to the gluing regions between the glass pieces.

To cope with the space environment, the rad-hard fused silica glass will be expected to be used as the substrate material for all the filter strips.

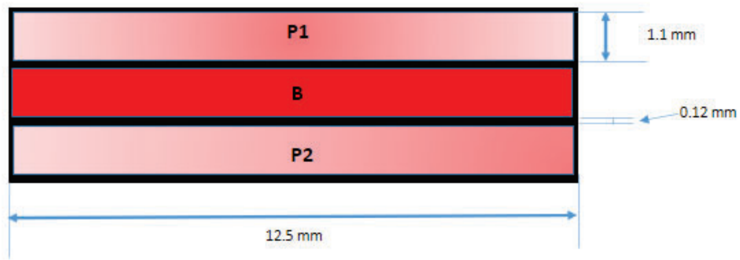


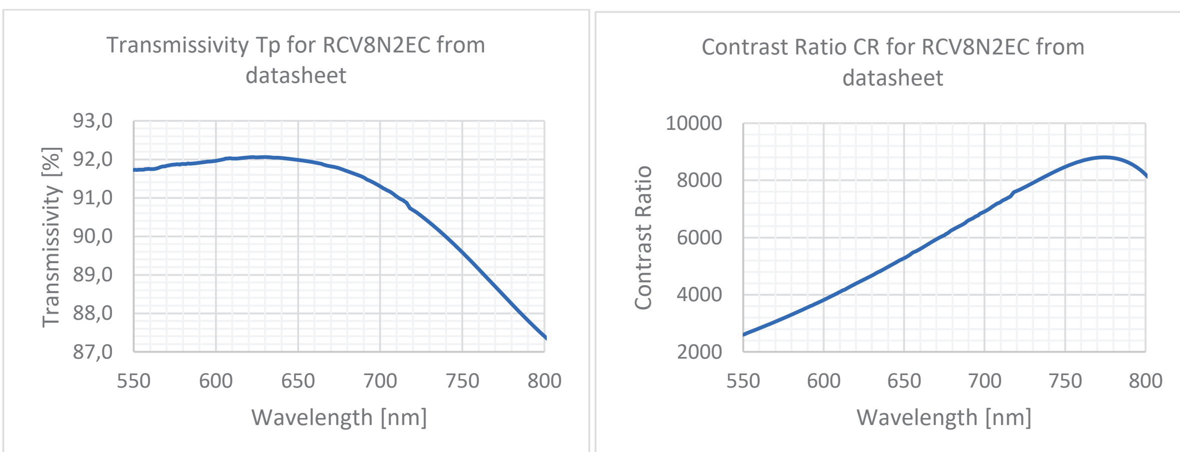
Figure 2. Schematic design of the filter assembly: a central broadband (B) filter and two linear polarizers (P1 and P2) at the sides. The useful filter areas dimensions are highlighted, the remaining of the filter assembly will be black coated.

2.1 Items under test

The high transmissivity and high contrast of polarizer RCV8N2EC by Moxtek are the main reasons for choosing this item. Its polarizing properties are known and listed by the supplier from 300 nm to 3300 nm. It is produced by means of a Nanowire® technology, it has a nominal thickness of 1 mm and a diameter 25 mm.

Datasheets of this polarizer show its properties of transmissivity T_p and T_s and its Contrast Ratio (CR) [7]; T_p is the transmissivity when the incident radiation is fully polarized with a polarization direction parallel to the polarizer axis, T_s is the transmissivity when the incident radiation is totally polarized with a polarization direction perpendicular to the polarizer axis, and CR is the ratio between T_p and T_s. These datasheets report T_p higher than 87% and CR higher than 6000 in the range 550 – 800 nm (Figure 3).

The visual inspection of these items shows no significant difference between the two optical surfaces. The polarizer is enclosed inside a black ring. Two aligned white lines show the direction of the polarization axis, while two black grooves are present on the back side (Figure 4).



(a) (b)

Figure 3. Properties of transmissivity T_p and Contrast Ratio CR of polarizer RCV8N2EC from its datasheet.

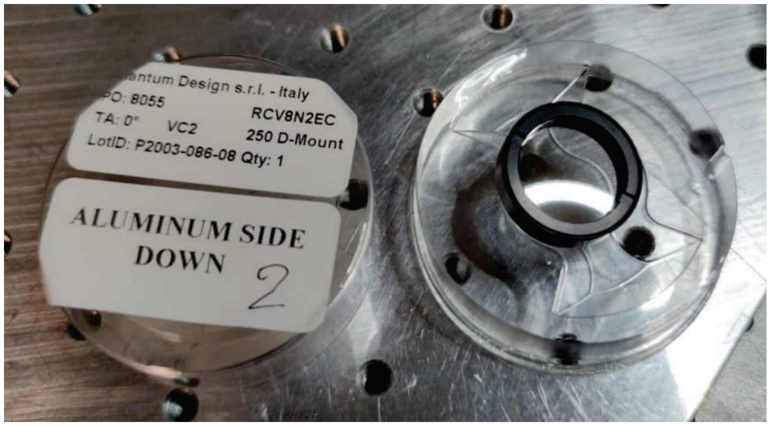


Figure 4. Filters RCV8N2EC by Moxtek.

3. THE LABORATORY SETUP

The characterization of the filters has been carried out in a laboratory of CNR-IFN in Padua (IT). Tests have been performed at ambient temperature and pressure with lights switched off and by the same operator.

3.1 The setup of the reflectometer

The equipment used for testing the filters can be employed for measurements of both reflectivity and transmissivity, for polarizing and non-polarizing optical elements [8]. It allows covering a wide spectral range, from 360 nm to 2600 nm, and it can be edited to several angles of incident, in a θ-2θ configuration. The basic setup is composed of a broadband light source, a rotator stage for the samples, a cosine corrector and a spectrometer (Figure 5). The rotator stage encloses the sample and it is placed in front of the light source at the desired incidence angle (8°-80°). The specimen holder can be equipped by a rotating mounting as in case of polarizers' characterization (Figure 6). The light, reflected or transmitted by the sample, is then collected by the cosine corrector and detected by the sensor of the spectrometer. The use of a laser source assists the alignment phases (Figure 7).

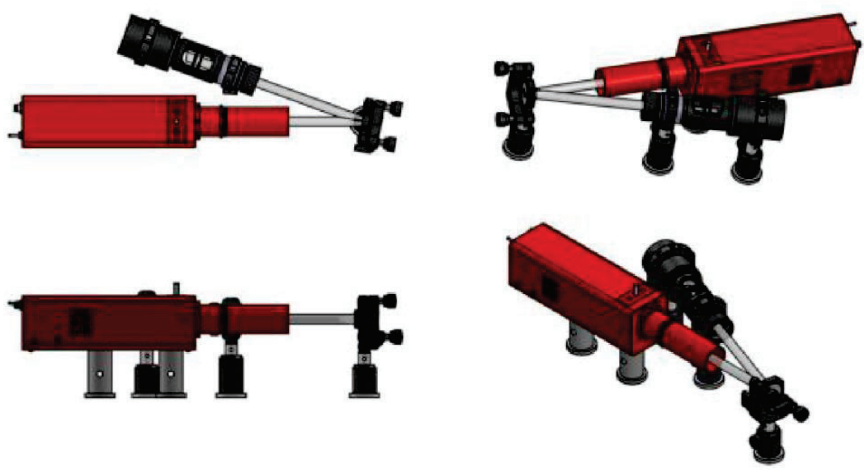


Figure 5. Design of the reflectometer's equipment for the measurements of reflective properties.

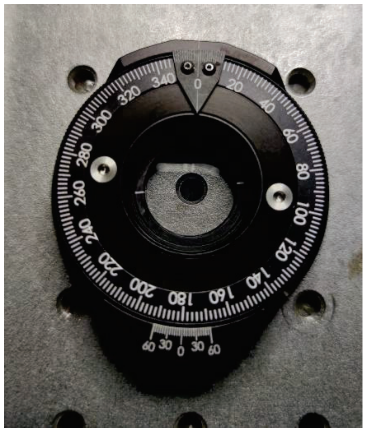


Figure 6. Rotator stage with the polarizer inside.

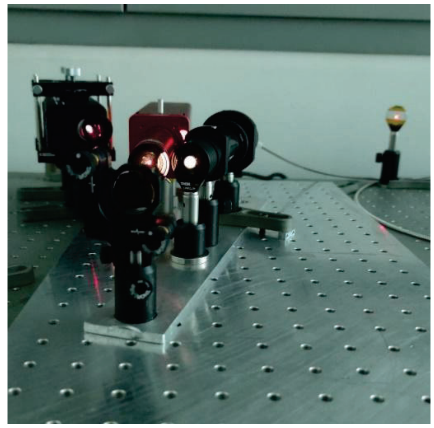


Figure 7. Picture of the lab setup with the laser input switched on (left), the target of the laser (right) and a stage in front of the sensor.

3.2 Software for data acquisition

In order to read the data received by the spectrometer, Admesy Iliad® software must be installed on the user's computer. It shows the spectrum of the irradiance that strikes the detector (Figure 8) in real time, allowing the export of plots or data files.

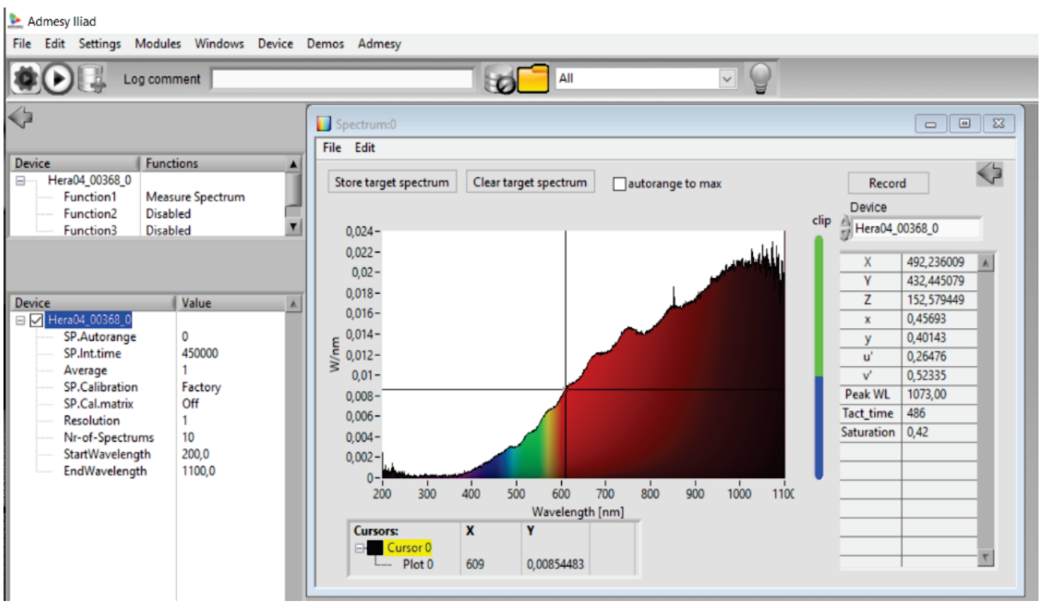


Figure 8. Spectrum of the irradiance read by the spectrometer using Admesy Iliad® software.

4. MEASUREMENTS AND RESULTS

The optical properties tested in the lab are transmissivities T_p and T_s and reflectivities R_p and R_s. In this analysis, 5 measurements have been carried out for each configuration in order to preliminarily estimate the measurements repeatability.

In case of unpolarized input light, the reflectivity is obtained by comparing the power reflected by the filter with the power of the direct beam, the last one retrieved by measuring the throughput of a reference mirror with well-known optical properties. The design setup is the same as the one shown in Figure 5, with both the mirror and the filter placed into the rotator stage, one by one. The reflectivity is obtained as:

$$r_{filter} = \frac{P_{f-r}}{P_{ref}} r_{mir} \tag{1}$$

where $P_{f\text{-}r}$ is the power reflected by the filter, P_{ref} is the power reflected by the reference mirror and r_{mir} is the nominal reflectivity of the reference mirror (Figure 9).

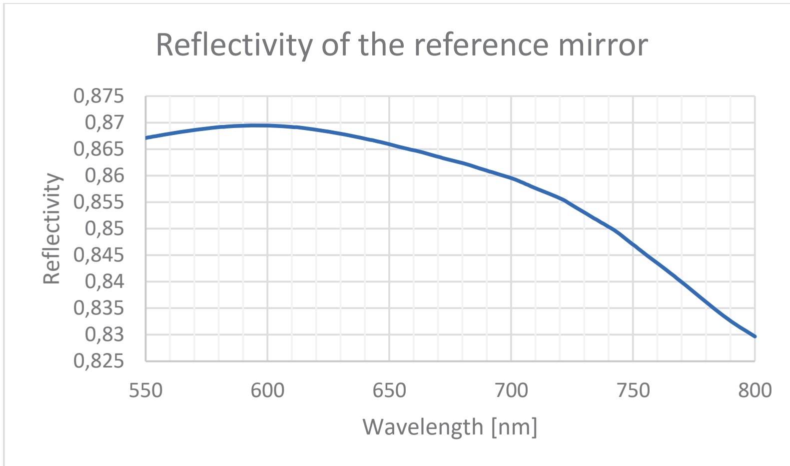


Figure 9. Reflectivity of the reference mirror.

The transmissivity is tested with the reference mirror in the rotator stage and the filter in a dedicated stage placed between the reference mirror and the cosine corrector. It is evaluated by means of the following relationship:

$$t_{filter} = \frac{P_{f-t}}{P_{ref}} \tag{2}$$

where $P_{f\text{-}t}$ is the power received by the spectrometer after the beam is being reflected by the mirror and transmitted by the filter.

The properties R_p, R_s, T_p and T_s were computed by adding a polarizer in front of the light source, with its polarization axis oriented parallel or perpendicular to the sample's axis. These properties are evaluated by means of Eq. (1) and Eq. (2) and results are shown in Figure 10; these plots show the optical throughputs averaged over 5 sampling (black lines), these curves shifted by +/-sigma, and the nominal trends provided by the provider.

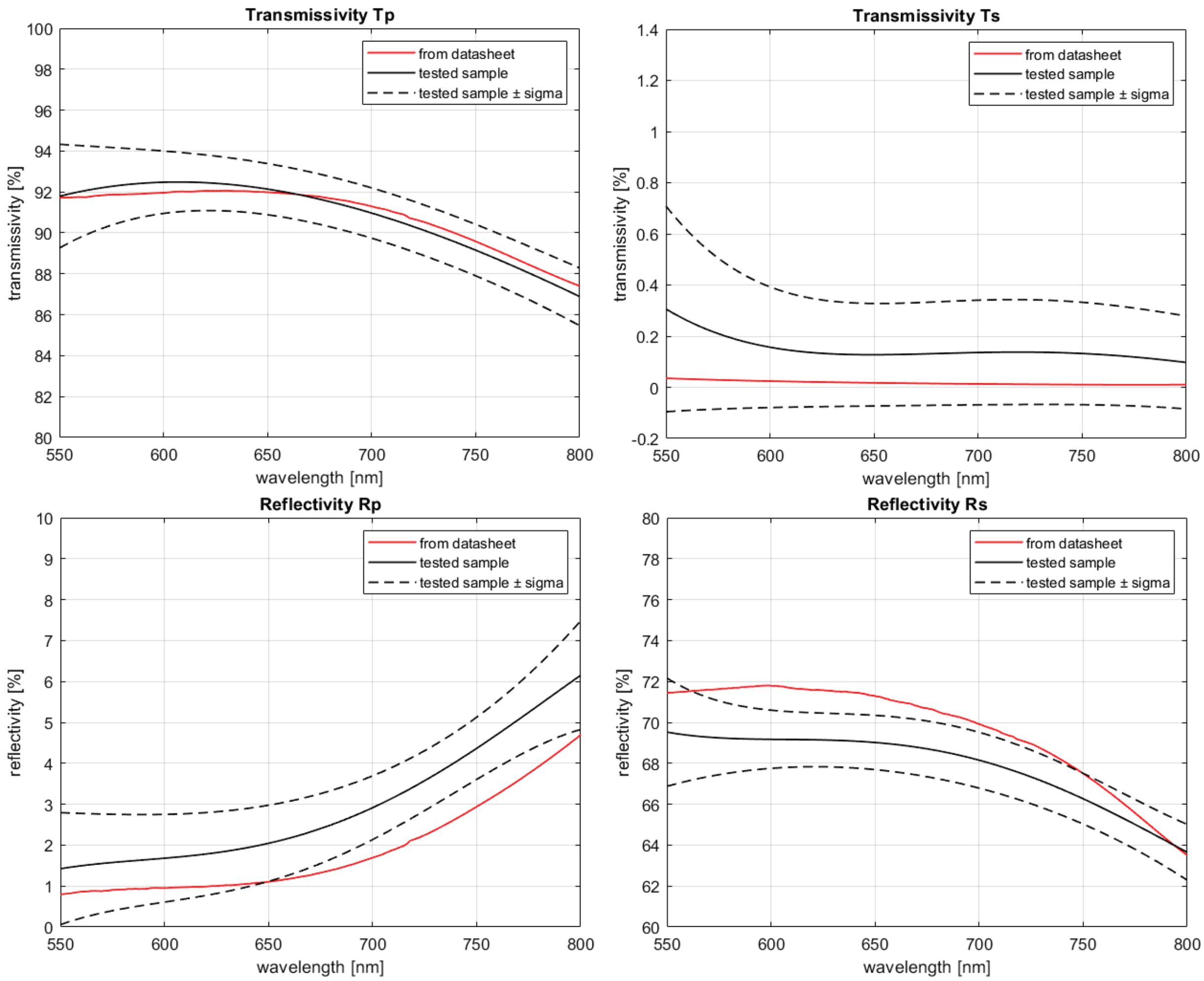


Figure 10. Results of lab tests for the characterization of the polarizer and comparison with data from the supplier; the optical parameters shown are transmissivity T_p and T_s and reflectivity R_p and R_s.

The transmissivity T_p is the optical property that best fits nominal Moxtek data, definitely inside the error range, while the transmissivity T_s overestimates provided data by more than one order of magnitude; reasons for this discrepancy on results might be:

1. not sufficient precision on the alignment of the polarizers axes.
   It will be improved in the next measurements with dedicated sample holders and optimized alignment procedure.
2. very low signal of the Ts, hence a very low SNR.
   We are working in order to optimize the experimental setup and to reduce the noise in the measurements
3. that the incident light beam towards the tested filter is not fully polarized.
   The use of a train of polarizers can be evaluated according to the signal values.

Results of reflectivities approach the comparison data, with a maximum deviation < 3 %.

5. CONCLUSIONS

EnVisS is a space camera that will fly aboard the Comet Interceptor mission and aims to dynamically image, in the visible range, the coma of a long period comet yet to be discovered. Before reaching the detector, the light from the comet coma entering the EnVisS instrument will cross a filter strip assembly composed of 3 pieces: a broadband filter and two linear polarizers. At present, for linear polarizers the RCV8N2EC by Moxtek is considered as a possible candidate. The optical properties of these polarizers have been tested in the laboratory of CNR-IFN in Padova (Italy) and compared to data from the supplier.

The setup built for the tests consists of a broadband light source, a rotator stage, a cosine corrector and a spectrometer, controlled by an ad-hoc computer software. Filters have been placed on different stages according to the optical property under test: transmissivities T_p and T_s and reflectivities R_p and R_s. While the transmissivity T_p fits well the comparison data, the transmissivities T_s and the reflectivities highlight a polarizing function worse than expected. Plausible reasons for discrepancies between test and datasheet, such as the alignment of the filter's axis, low SNR and polarization residual of the beam, have been identified. Possible corrections are in evaluation in order to improve the next experimental measurements.

6. ACKNOWLEDGEMENTS

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