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STRAY LIGHT SOLUTION FOR GHGSAT NANOSATELLITE

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ABSTRACT

GHGSat is world's first nanosatellite dedicated for monitoring greenhouse gas (GHG) and air quality gas (AQG) emissions from any industrial site in the world. The satellite was designed and constructed by MPB Communications to monitor carbon dioxide (CO2) and methane (CH4) from a low earth orbit (about 500 km).

To reach the designated resolution of less than 50 meters and high precision of greenhouse gases monitoring, the nanosatellite has large aperture in order to collect enough optical signal. The aperture of about 10cm causes significant stray light issues with limited solution options without adding too much weight to the light weight satellite.

As the stray light was the main concern in this project, many precautions was taken. As a solution for blocking unwanted light, baffle with many vanes was used. However, having the vanes is not optimal solution without high absorbing coating applied on it. The coating requirements was low reflectance, no outgassing in space environment and long life stability, being a satellite inaccessible for maintenance.

The chosen coating for stray light elimination was Acktar Vacuum Black^{TM}. Hemispherical reflectance and BRDF data was examined before making the choice.

The satellite was launched in June 2016 and the images was analyzed to ensure the aimed resolution and precision of the optical system. After almost two years of activity, no visible changes was discovered in image quality nor stray light issues detected.

Keywords: GHGSat, GHG, AQG, stray light, unwanted light, baffle, vanes, black coating

1. INTRODUCTION

GHGSat built the world's first nanosatellite capable of monitoring greenhouse gas (GHG) and air quality gas (AQG) emissions from any industrial site in the world. The instrument which is designed, integrated and tested by MPB Communications will be used to monitor carbon dioxide (CO2) and methane (CH4) from a low earth orbit of about 500 km. The instrument was designed to be very small (about 20x20x20 cm), very light (<10 kg) and consume very little power (< 20 W) in order to fit in the limited size, weight and power budgets of a nanosatellite. Figure 1 shows an illustration of the GHGSat instrument. In that illustration, we can see the front baffle and the vanes that help greatly with the stray light performance.

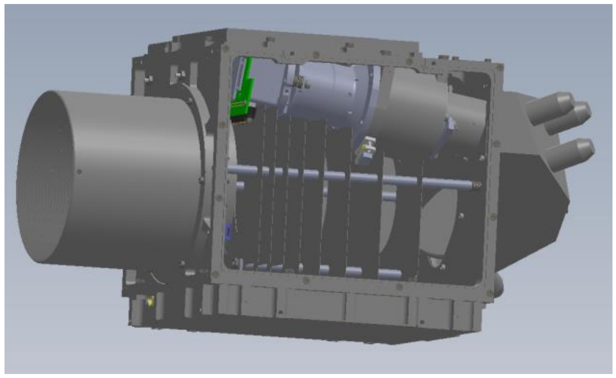

Figure 1. GHGSat instrument 3D illustration.

The instrument will monitor greenhouse gases with a precision in parts per million / billion, and a resolution of < 50 meters. The high resolution and the sensitivity require a large front aperture in order to collect enough optical signal, however, this large front aperture (on order of 10 cm diameter) with the size of the instrument imply a considerable stray light risk. The signal from the field of view of the instrument is very small compared to the total light that can enter the instrument; according to our models, it is about 5.9×103 times greater. The size of the instrument also prevented from using a pupil at an intermediary image plane in the system, technique that is often used to block stray light for remote sensing missions, since there is no such plane in it.

Stray light was a major concern during the GHGSat instrument design phase and many precautions had to be taken. The instrument is equipped with a baffle and many vanes in order to cut the unwanted light from outside the required field of view. To avoid unwanted reflections from these components, all the surfaces near the optical path should be black coated. After examining few possible solution for black coatings, Acktar Vacuum Black^{TM} coating was chosen to enhance the stray light performance.

Figures 2-5 show components of the GHGSat instrument that were coated with the Vacuum Black^{TM} coating. The front baffle, which is the first step in blocking the unwanted light and the front lens of the instrument are displayed in figures 2 and 3, respectively.

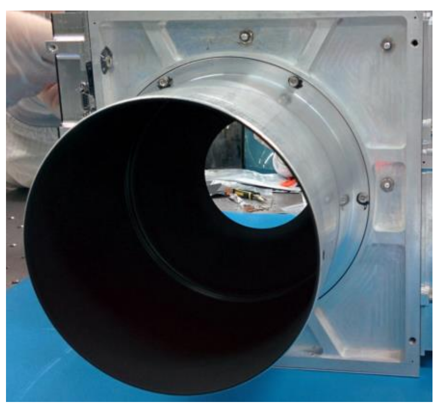

Figure 2. GHGSat instrument baffle coated with Vacuum Black^{TM} and front lens.

The eight principal vanes of the instrument with two different angles of view are exhibited in figures 3-4. Those vanes were strategically positioned in order to prevent the blocked light to be reflected back to the optical path.

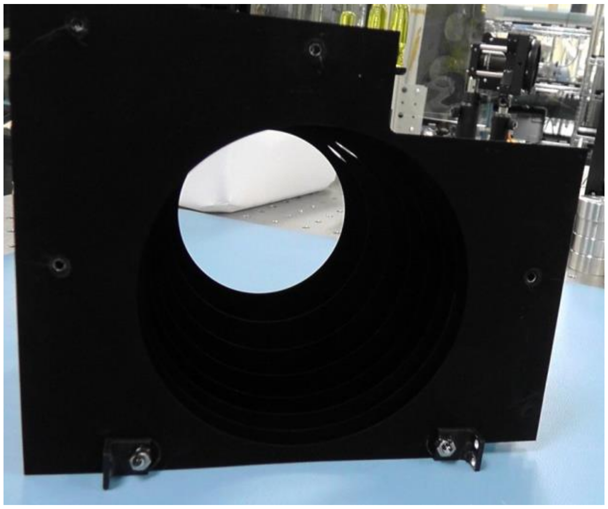

Figure 3. GHGSat instrument vanes coated with Vacuum Black^{TM} (front view).

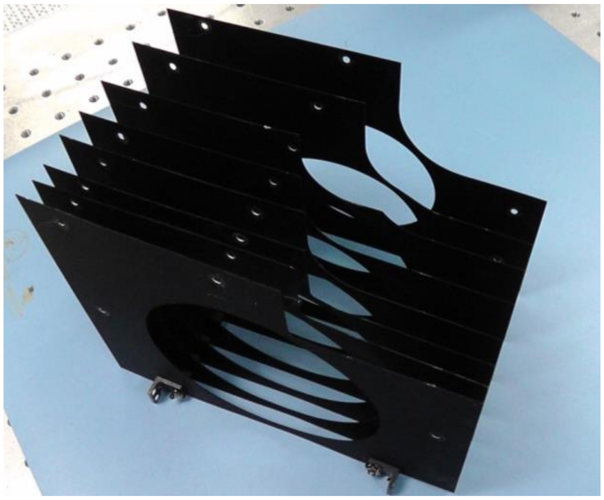

Figure 4. GHGSat instrument vanes coated with Vacuum Black^{TM} (top view).

Figure 5 shows a lens barrel that was also coated using Acktar's Vacuum Black^{TM}. Every item that is near the optical path of the instrument has been coated that way in order to reduce the scattered light in the system.

Figure 5. GHGSat Acktar Vacuum Black™ coated lens barrel.

2. COATING PERFORMANCE AND STRAYLIGHT

In this section the stray light performance of the GHGSat instrument will be discussed. Optical performance of Acktar Vacuum™ in the required spectral range is presented.

2.1. BRDF and TIS of Acktar coatings

Total integrated scattering (TIS) and bidirectional reflectance distribution function (BRDF) measurements of the Acktar Vacuum Black™ were taken in the wavelength of interest - 1600 nm, to verify its performance. The results are displayed in figures 6 and 7.

The total scattered light is very low for low angles of incidence (near normal) and increases when getting closer to grazing angles.

For BRDF, three different angles are examined: The incidence angle of the input light, the scattering angle and the angle from the reflection plane. In the results shown below, the measurements were taken in the plane of reflection (where the scattering can reach its maximum value).

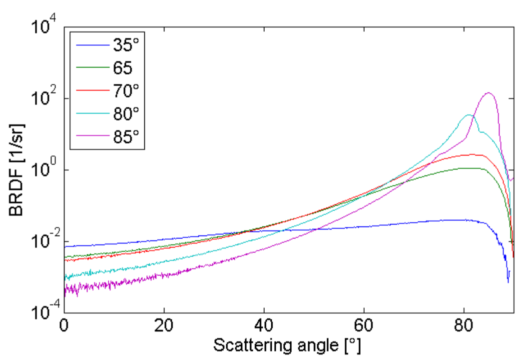

Figure 6. BRDF at various incidence angles of Vacuum Black™ at 1600 nm.

TIS measurements were also taken as shown in figure 8. According to that data, the total scattering from Vacuum Black™ for high incidence angles reveals very good results.

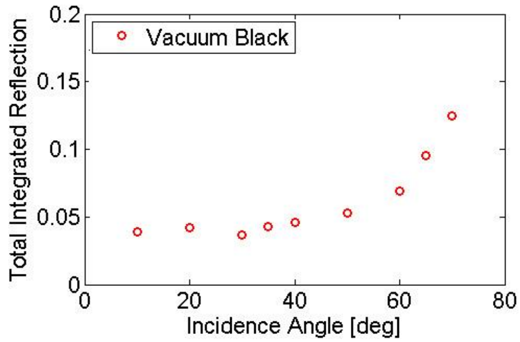

Figure 7. Total integrated scattering of Vacuum and coating at various incidence angles.

The Vacuum Black™ coating from Acktar was selected for its reflectance properties in our wavelength range of interest (around 1600 nm), but also for its good properties for use in the space environment. An important feature is that Acktar coatings are thin and conform perfectly to sharp vanes edges. This allows minimum specular reflection from the slopping edges of the vanes. In addition Acktar coatings have essentially no outgassing. The coatings have a wide range thermal stability and are resistant to ATOX and space radiation [1].

2.2. Stray light performance of the instrument

The stray light requirement suggests a ratio of signals from two distinct FOV regions: the Science FOV (SFOV) and the out of field signal (OFOV). The requirement can then be modeled directly as

$$Stray\ Light\ Performance = OFOV/SFOV < 0.05\%$$

Setting up the model to apply this ratio accurately requires an estimate of the irradiance at the sensor due to the two fields of view. Those FOVs can then be set up as sources for direct simulation.

Using the BRDF data, simulation were done using LightTools illumination design software to evaluate the stray light performance of the GHGSat instrument. According to this model, our stray light performance limits the SNR of our system to about a value of 2000 (neglecting all the other sources of noise).

With the Baffle, incorporating about 16 vanes in total, and most of the near optical path components coated with the Vacuum Black™ coating the annular source transmittance of the instrument looks like figure 8.

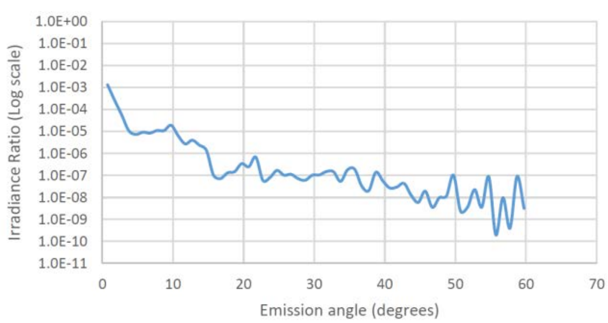

Figure 8. Annular source transmittance of the GHGSAT instrument.

According to this graph, most of the noise comes from the angles very near our science field of view.

3. ACKTAR COATING PROPERTIES

This section describes Acktar coatings for a general use in space, not directly related to the choice that was made for the GHGSat instrument.

3.1. Coating properties

All Acktar Black coatings are completely inorganic and are composed exclusively of non-ferrous metals and non-ferrous metal oxides. The coatings do not incorporate any organic materials.

Acktar™ coatings produce extremely high absorptance over a wide range of wavelengths (~1.5% from 193nm to 10.6µm). The coating thickness is only a few micrometers thick and its density is typically ~1.8 g/cm3. The coating performance is stable in a wide range of temperatures -269°C to +380°C.

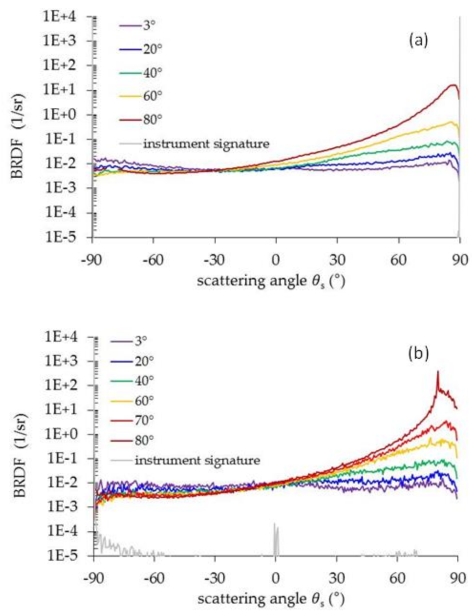

Figure 9. BRDF at various incidence angles of Vacuum Black™ (a) at 532 nm (b) at 1064 nm.

3.2. Vacuum Black™

Vacuum Black™ is chosen where very low reflectance / high emissivity is required in the FUV – UV and VIS to SWIR regions - typically for stray-light suppression.

The BRDF and hemispherical reflectance of Vacuum Black™ are displayed in figure 9 for 532 nm and 1064 nm input light, respectively. Figure 10 shows the hemispherical reflectance for Vacuum Black™ and Magic Black™. For a visible spectrum application, Magic Black™ would be the best choice. For the GHGSat project's Vacuum Black™ was more suitable, as wavelength of 1600 nm was of interest.

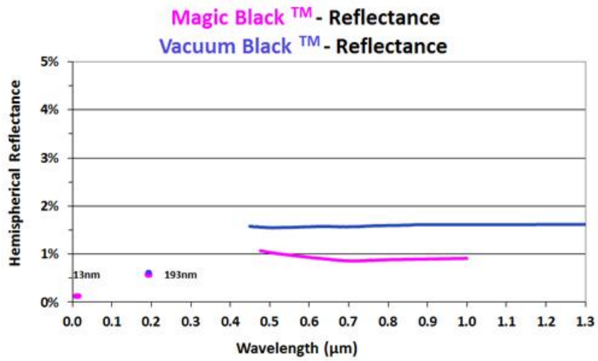

Figure 10. Hemispherical reflectance of Vacuum and Magic Black™ coatings.

In addition to its superior optical performance Vacuum Black™ (and other Acktar Black coatings) delivers many other attributes important in space applications:

- essentially zero CVCM,
- vacuum and thermal-vacuum cycling compatible,
- operating temperatures from (-)269C to (+) 380C,
- no particulation - compatible with class 1 clean-rooms,
- only a few microns thick (typically 3-5 µm),
- compatible with virtually all substrate materials,
- resistant to ATOX.

Vacuum Black™ has been extensively tested and qualified for space.

4. CONCLUSION

Vacuum Black™ coating from Acktar was chosen for the GHGSat instrument based on its optimal optical properties for the wavelength of interest -1600nm, and its overall space properties.

With all the precautions in place and the Acktar coating on the surfaces near the optical path, the stray light concern has been mitigated and the launch of this nanosatellite was approved.

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