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# Ultra-hydrophobic optical coatings as a means to lower outgassing

Dina Katsir[a], Irene Katsnelson[a], Mila Berezanski*[a]
[a] Acktar, 19 Topaz St., Kiryat-Gat Israel +972-8-6814213

**ABSTRACT**

Space opto-mechanics require materials with low outgassing. With water vapor being a main component of outgassing, when changing the water adhesion of an optical coating, its outgassing potential changes as well. Acktar developed an ultra-hydrophobic light absorbing optical coating, and put it through the qualification process for space applications. The results were compared with other space qualified Acktar coatings, as they constitute the current industry standard. The new coating showed to have the lowest outgassing amongst Acktar's coatings, while retaining all other physical and optical qualities.

**Keywords:** Optical coating, ultra-hydrophobic, outgassing

## 1. INTRODUCTION

All materials intended for the use of the space industry must adhere to strict outgassing standards, with the strictest standard applied for opto-mechanical applications. For many materials, the high content of water vapor in their outgassing qualification tests puts them outside of the standard acceptable outgassing limits. In such cases, the common practice, for both ESA and NASA, is certifying the materials as an exception, provided the packaging, transportation and storage procedures ensure minimal intake of water.

In the last decade, ultra-hydrophobic materials and coatings are increasingly present across many industries, mainly as contamination control in rugged, outdoor environments. This paper will explore the applicability of ultra-hydrophobic optical coatings for the space industry, as a means to reduce water vapor outgassing at its root. The hypothesis presented is: reducing the water adhesion of an optical coating will reduce the amount of water it absorbs, which, in turn, will reduce its outgassing potential as well.

In order to prove its applicability to the space industry, Acktar's newly developed ultra-hydrophobic optical coating was put through an industry standard outgassing test, as well as a full course of other space qualification tests intended for optical coatings. The results were compared to other space-qualified Acktar coatings, previously and currently in use in various space applications, as examples of current industry standard.

## 2. ABBREVIATIONS AND TERMINOLOGY

CVCM – Collected Volatile Condensable Material

NIR – Near Infra-Red (700-1400nm)

RML – Recovered Mass Loss

SWIR – Short Wave Infra-Red (1400-3000nm)

TML – Total Mass Loss

VIS – Visible light (400-700nm)

WVR – Water Vapor Release

## 3. TESTING METHODS

The following tests were performed on samples of 120μm thick aluminum 6061 foil, coated with either the ultra-hydrophobic black coating (UHB), Acktar's Magic Black (MB) or Acktar's Fractal Black (FB). Both MB and FB were previously fully space certified and are in use in several space projects. Thus, comparing the results from UHB to MB and FB amounts to comparison to industry standard.

### 3.1. Hemispherical Reflectance

Each coating's light-absorbing properties were measured in the VIS, NIR and SWIR ranges. Ocean Optics USB4000 spectrometer with a hemispherical integration sphere, calibrated to a black reference, was used for VIS and NIR measurements. Bruker Tensor 27 FT-IR spectrometer, calibrated to a gold reference, was used for SWIR measurements. MB's reflectance was not measured in SWIR range, as it is outside of MB's operational wavelengths.

The hemispherical reflectance is required to be ≤3% in the VIS and NIR ranges, and ≤5% in the SWIR range.

### 3.2. Adhesion Test

For this test, 3M 853 adhesive tape (peel adhesion strength of 440 g/cm) was used. The tape was pressed firmly to the surface of each sample, and then removed with increasing force. Both the sample and the tape were then subjected to visual inspections under a microscope, with notes made of either visible damage to the coating, traces of the coating on the tape, or traces of adhesive on the coating.

### 3.3. Thermal Cycling

Each sample was subjected to 200 cycles under the following conditions:

| | |
|---|---|
| Temperature range: | -70°C to 70°C |
| Rate of change: | 10K/min |
| Holding time: | 5 min |

After the thermal cycling, the samples were inspected under a microscope for damage. They were tested for degradation of performance by the measuring of their hemispherical reflectance (same method as detailed above) and comparison to the results of the initial reflectance measurement.

### 3.4. Outgassing Test

All samples were baked prior to the test at 180°C for 12 hours, and then an outgassing test was performed in accordance with ASTM E-595 standard[1]:

First, 24 hours of conditioning, when samples were kept in 23°C and 50% relative humidity, and then weighted ($m_0$). Next, the samples were placed in a vacuum chamber (pressure of $\leq 10^{-3}$Pa) at 125°C for 24 hours. During this period, some of the mass released by the samples is condensed by collector plates maintained at 25°C. At the end of the vacuum cycle, the chamber is repressurized with dry, inert gas, and the samples are weighted ($m_1$). Additionally, the collection plates are weighted, and their initial weight is subtracted to determine the weight of the collected particles ($m_c$). Lastly, the samples go through another 24-hour conditioning period (23°C and 50% relative humidity), and weighted ($m_2$) once more.

The relevant parameters are calculated:

$$TML(\%) = \frac{m_0 - m_1}{m_0} \cdot 100$$

$$RML(\%) = \frac{m_0 - m_2}{m_0} \cdot 100$$

$$WVR(\%) = TML - RML$$

$$CVCM(\%) = \frac{m_c}{m_0} \cdot 100$$

In order to qualify, both TML and RML should be <1%, and CVCM <0.1%. Cases in which TML >1%, but RML is <1%, are also acceptable.

# 4. RESULTS

## 4.1. Hemispherical Reflectance

Fig. 1 shows the composite results for hemispherical reflectance measurement in the wavelength range of 400-3000nm. The results show slightly elevated reflectance in the NIR range, though still well under the allowed maximum of 3%. There is no significant difference in VIS and SWIR ranges.

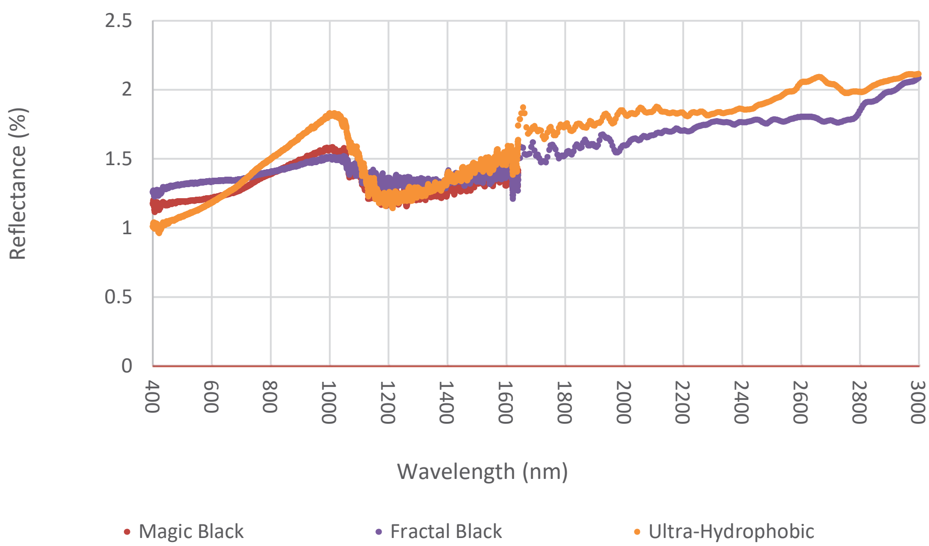


Fig. 1: Hemispherical reflectance: Magic Black, Fractal Black and Ultra-Hydrophobic Black.

## 4.2. Adhesion Test

The tape adhered strongly to the coating, but was removed cleanly under sufficient force. The microscope analysis of all samples and removed strips of tape showed no degradation of the coating, no traces of adhesive on the coating, and no traces of coating on the tape.

## 4.3. Thermal Cycling

The microscope inspection of all three samples showed no degradation of coating.

The comparison of measured reflectance pre- and post- thermal cycling, likewise, shows no degradation in coting performance (Fig. 2-4).

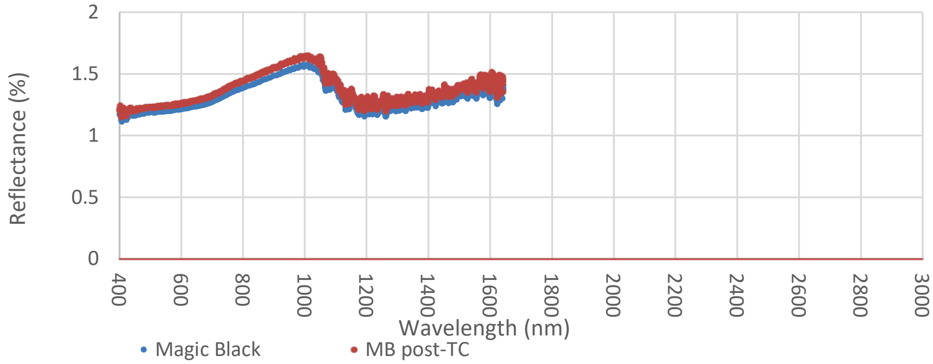


Fig. 2: Magic Black: hemispherical reflectance, before and after thermal cycling.

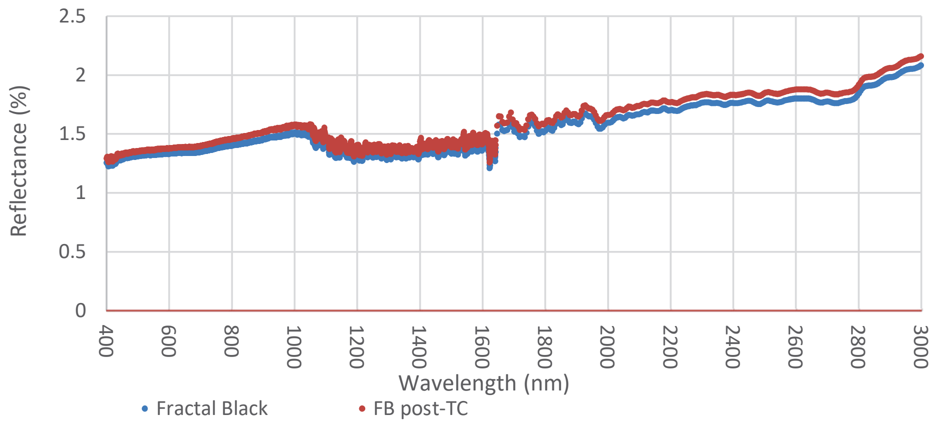


Fig. 3: Fractal Black: hemispherical reflectance, before and after thermal cycling.

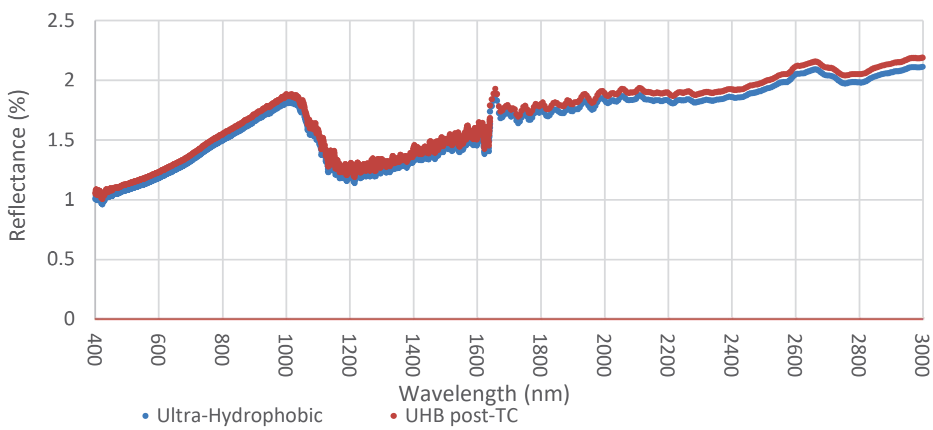


Fig. 4: Ultra-Hydrophobic Black: hemispherical reflectance, before and after thermal cycling.

### 4.4. Outgassing Test

The ultra-hydrophobic coating showed drastically lower TML and RML percentages, while also keeping to near 0 CVCM.

Table 1: Outgassing test results

| **Coating type** | **Ultra-Hydrophobic Black** | **Magic Black** | **Fractal Black** | **Required** |
|---|---|---|---|---|
| TML (%) | 0.23 | 1.67 | 1.53 | <1 |
| RML (%) | 0.05 | 0.34 | 0.31 | <1 |
| WVR (%) | 0.18 | 1.33 | 1.22 | |
| CVCM (%) | 0.00* | <0.01 | 0.00* | <0.1 |

*CVCM too low to measure with standard instruments.

## 5. CONCLUSION

The tests performed show the ultra-hydrophobic black coating to be compatible with the requirements of the space industry standard, while outperforming existing coatings in the outgassing test. Incorporating hydrophobic qualities in optical coatings intended for use in space applications, will allow for less stringent requirements for packaging and storage, since the coating's water absorption is miniscule, even in highly humid environments.

In order to fully understand the impact of ultra-hydrophobic optical coatings in this context, a long-term outgassing kinetics study should be performed.

## REFERENCES

[1] ASTM-E-595-93, Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment, Vol 15.03, pp. 586-592: ASMT International, 2002.