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The Effects of Surface Roughness on Diffuse Optical Reflection and Photoyields on Spacecraft Materials

Amberly Evans Jensen
Utah State University

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Amberly Evans
J.R. Dennison, Mentor
Jennifer Roth, Undergraduate Mentor
Physics Department, Utah State University
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Abstract:

The goal of this project was to measure the change in the absorbance of spacecraft materials due to changes in the surface of the material. The absorbance was obtained by measuring reflectance and transmittance. We found that modifying the surface of a material did affect the material's specular reflectance. However, the change may not have been entirely due to an increase in absorbance, but may also imply an increase in the diffuse reflection. To understand the affect on absorbance, diffuse reflectance and transmission will need to be measured. This will lead to a prediction of how surface modification affects the charging of spacecraft.

Introduction:

Understanding the optical properties of materials provides information about how they accumulate charge, an important aspect in predicting the lifetime of spacecraft. These properties include reflection, transmission, and absorption. Absorbed photons can contribute to charge accumulation in materials through photoemission, whereas reflected and transmitted photons can not. However, reflection (R) and transmission (T) are more easily measured and can then be related to absorbance (A) through a simple conservation law as R+T+A=1. Small changes in absorption have been shown to lead to drastic changes in spacecraft potential [1]. Surface modification of a material can lead to changes in absorbance, thus affecting the charging. In the harsh space environment, damage to spacecraft is expected and must be taken into account when constructing spacecraft. Damage, or surface modification, may include changes in the uniformity of a surface in the form of scratches or other blemishes. It can also entail the deposition of foreign substances onto the surface of the spacecraft. Both scenarios affect how electrons and photons both enter and leave the material and thus, affect the accumulation of charge. It is expected that the more roughened or contaminated a material, the more absorbent it will become. Studying these effects in a controlled environment provides better understanding for determining which materials are most appropriate to use in spacecraft construction.

Methods:

This project was performed using Kapton HN, a common polymer used in spacecraft. Each sample was mounted to a copper substrate for data collection. However, Kapton is a very transparent material, so in order to obtain reflectivity measurements for Kapton, Aerodag, a carbon substance, was applied to the bottom side of each sample. By doing so, the light transmitted through the Kapton is absorbed by the Aerodag, preventing that light from reflecting off the copper substrate, back through the Kapton and being collected by the spectrometer. Roughening compounds were used to create the roughened/scratched samples. These compounds are composed of alumina particles of specified uniform size so they make uniform scratches in the material. By using a variety of sizes of compounds from 0.05 µm to 50 µm, we could see how much the reflection/transmission/absorption changed with respect to the size of scratches.

In order to obtain reflectivity measurements, the set-up shown in Figure 1 was used. A fiber optic probe channeled light from a UV/VIS/NIR deuterium source onto the sample. Reflected light was collected by the probe and channeled to a diffraction grating spectrometer interfaced to a computer.

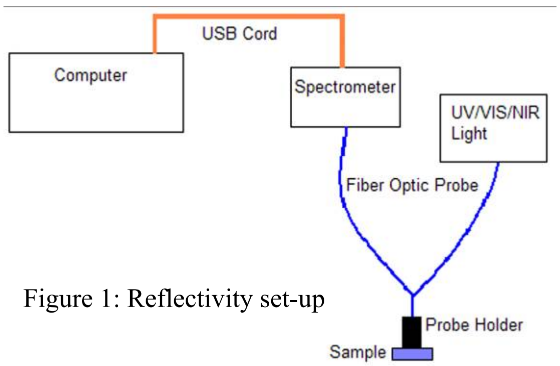

Figure 1: Reflectivity set-up

Results and Conclusions:

Roughening Kapton HN had a general effect of decreasing the reflectance (Figure 2a). However, it is apparent that the reflectance is dependant on the position of the reflectance collection probe. This is evident from some of the data which show that the reflectance changed very little (Figure 2b).

(a)

(b)

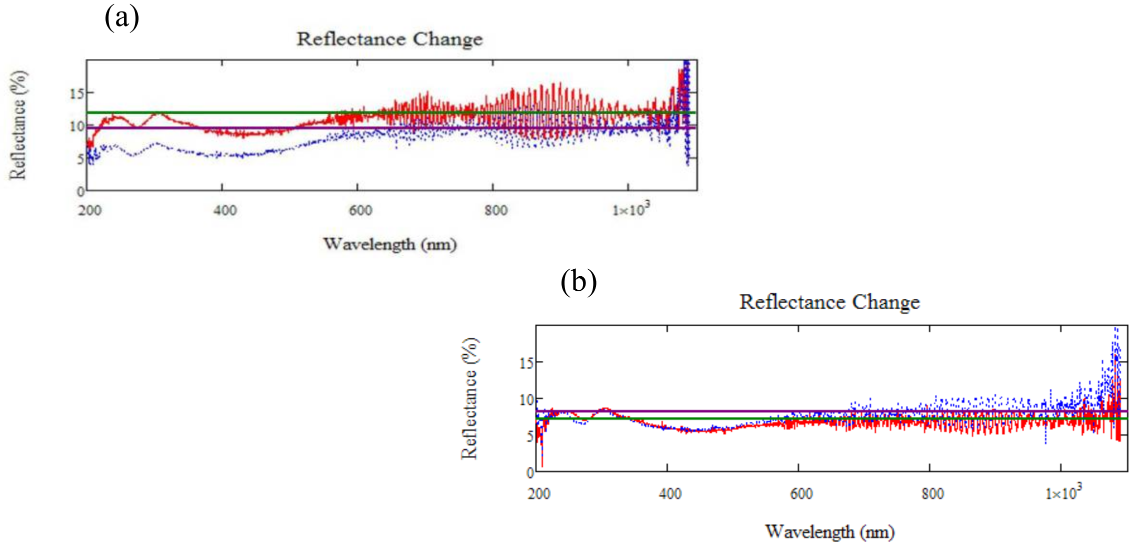

Figure 2: Reflectance of Kapton HN. The red data show the reflectance of unroughened Kapton, the green line indicating the average reflectance. The blue data show the reflectance of Kapton HN roughened with 9.5µm Aluminum Oxide roughening comound, the purple line indicating the average reflectance. Figure (a) shows the reflectance measured over ~0.8 mm^2 of the sample while figure (b) is taken over a different area of the same size.

Kapton HN samples were used, ~25 μm thick with index of refraction n≈1.70. Although the reflectance varied somewhat with wavelength, the mean value (~12%, green line) was somewhat smaller than the value predicted from Fresnel's Equations of 13.4%. The discrepancy suggests an absorption coefficient for Kapton HN of $\alpha \approx 2.2$ mm^{-1}. The Kapton spectrum exhibits thin film interference at higher wavelengths, the oscillations seen in the spectra. From the oscillation spacings, n≈1.71. Based on the maximum spread of the interference oscillations for Kapton HN, $\alpha \approx 1.9$ mm^{-1}.

The average reflectivity is reduced to ~9.5% (purple line), consistent with ~30% being either diffuse reflectance or enhanced absorbance. As seen in the spectra, the thin film interference of Kapton HN is not greatly affected by roughening.

As mentioned earlier, the overall decrease in reflectance suggests two possible scenarios. One, the absorbance of Kapton HN increases due to roughening. This would be consistent with our predictions and would also predict an increase in charge accumulation. The other is an increase in diffuse reflection. Most likely, a combination of the two occurs. When the diffuse reflection and the transmission are measured, then the change in the absorbance can be more completely assessed.

This project provided a way for me to learn how to do research and how to present the results of that research. I had the opportunity to present a poster at the 4 Corners Section meeting of the American Physical Society [2]. I also plan on presenting a more extensive report of my findings at the USU Student Showcase in spring of 2010.

I will also extend this research to transmission measurements of Kapton HN and reflectance measurements on gold, as well as studying the affects of contamination on the surfaces [3]. The project has also provided the means to prepare to work with samples that have been exposed to the space environment. The Material Physics Group took part in the Materials International Space Station Experiment (MISSE) and had the opportunity to send samples to the ISS for approximately 18 months to be exposed to space [4]. I had the opportunity to go to NASA's Langley Research Center in October 2009 to retrieve these samples and I will be able to extend my research from this project to the MISSE samples, many of which have roughened or contaminated surfaces due to their exposure to the space environment.

References:

1. JR Dennison, R.C. Hoffmann, and J. Abbott, "Triggering Threshold Spacecraft Charging with Changes in Electron Emission from Materials," Paper AIAA-2007-1098, *Proceedings of the 45th American Institute of Aeronautics and Astronomics Meeting on Aerospace Sciences*, 16 pages, Reno, NV, January, 10, 2007.

2.Evans, Amberly, JR Dennison. *The Effects of Surface Contamination and Roughening on Optical Properties and Photoyields on Spacecraft Materials.* Oct. 23, 2009.

3. Evans, Amberly, JR Dennison. *The Effects of Surface Contamination on Diffuse Optical Reflection and Photoyields on Spacecraft Materials*. Eccles Undergraduate Research Fellowship. March 20, 2009

4. J.R. Dennison, Joshua L. Hodges, J. Duce, and Amberly Evans, "Flight Experiments on the Effects of Contamination on Electron Emission of Materials," Paper Number,: AIAA-2009-, *Proceedings of the 1st AIAA Atmospheric and Space Environments Conference*, 2009.

Table 1. URCO Expenses

Item	Vendor	Date	Account Charged	Amount
Vacuum Supplies	MDC Vacuum Products	9-11-09	380.03	380.03
Sample Prep Supplies	USU Chem Stores	6-30-09	47.12	47.12
Materials	Lowe's	3-7-09	14.98	14.98
	Lowe's	4-24-09	42.22	42.22
Parts	McMaster-Carr	3-16-09	130.15	130.15
	Standard Plumbing Supply	5-12-09	36.22	36.22
	Harbor Freight	3-27-09	116.25	116.25
	McMaster-Carr	5-29-09	16.65	16.65
	McMaster-Carr	6-10-09	15.13	15.13
	Kurt J. Lesker Company	3-27-09	203.33	201.25
Total			1002.08	1000