CHARACTERIZATION OF BIDIRECTIONAL TRANSMISSIVE AND REFLECTIVE PROPERTIES OF BLACK SILICON

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This paper describes the initial work of characterizing the transmissive and reflective properties of Black Silicon (Si) diffusers. The diffusers are 100mm diameter black silicon samples fabricated at Goddard Space Flight Center (GSFC). The 8° Directional Hemispherical Reflectance (DHR) from 250nm to 20 microns and the Bidirectional Reflectance Distribution Function (BRDF) and Bidirectional Transmissive Distribution Function (BTDF) of a Black Si sample were measured at 632.8nm, 1064nm, and 1550nm using the GSFC Code 618 Radiometric Calibration Laboratory's (RCL)'s optical scatterometer. The diffuser exhibits extremely low specular reflection up to ~1100nm. There is no evidence of retroscatter. The measurements are traceable to those made at the National Institute of Standards and Technology (NIST).

INTRODUCTION

This work was performed at Goddard Space Flight Center's (GSFC) Code 618 Radiometric Calibration Laboratory, a secondary calibration facility with radiometric calibration measurements traceable to those made at the National Institute of Standards and Technology (NIST). The facility's optical scatterometer, [1], was used for BRDF and BTDF measurements at 632.8nm, 1064nm, and 1550nm whereas a Perkin-Elmer Lambda 1050 spectrometer with 150 mm PTFE coated integrating sphere was used for the Directional Hemispherical Reflectance and Transmittance measurements from 250nm to 2500nm. A Bruker 125HR Fourier Transform Infrared (FTIR) spectrometer with 75mm diameter gold coated integrating sphere was used in the range of 2.5microns to 20microns.

EXPERIMENTAL

The Black Si sample was created on a silicon wafer by cryogenic etching [1, 2]. The sample was then mounted in a custom prepared holder used for BRDF, BTDF and directional reflectance and transmittance hemispherical measurements.

RESULTS AND DISCUSSION

The diffuser 8° DHR from 250nm to 2500nm is shown in Fig.1. The Black Si diffuser hemispherical reflectance in UV-VIS-NIR-SWIR can be divided in three distinctive areas. The first is from 250nm to 1micron. In this wavelength range, the reflectance is ~0.5%. The second area is from 1micron to 1.2microns, in which the reflectance grows rapidly from 0.5% to 50%. The third area is from 1.2microns to 2.5microns characterized by reflectance of ~50% to ~52%. The 8° DHR data demonstrate the extreme blackness of the Black Si sample from 250nm up to about 1000nm quantified by the total amount of light that is isotropically reflected. It is worth noting that Black Si possesses the lowest hemispherical reflectance among most often used black materials from 250nm to 1000nm. The 0° Directional Hemispherical Transmittance (DHT) from 250nm to 2.5microns is shown in Fig.2. The directional hemispherical reflectance from 2.5 microns to 20microns is shown in Fig.3.

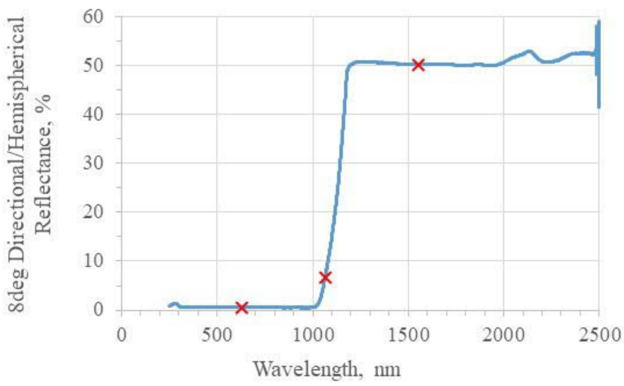

Figure 1. Directional hemispherical reflectance from 250nm to 2.5microns, with 632.8nm, 1064nm, and 1550nm marked

While the directional hemispherical reflectance quantifies the total amount of light that is reflected over all angles, it does not provide sufficient directional information required to characterize diffuse materials. The BRDF and BTDF describes the reflectance and transmittance of a target in a specific direction as a function of illumination and viewing geometries. BRDF and BTDF were measured on the RCL scatterometer. The BRDF was measured at 1550nm at angles of incidence 0°, 45° and 60° and viewing angles from -60° to 60° in steps of 5° as shown in Fig.4.

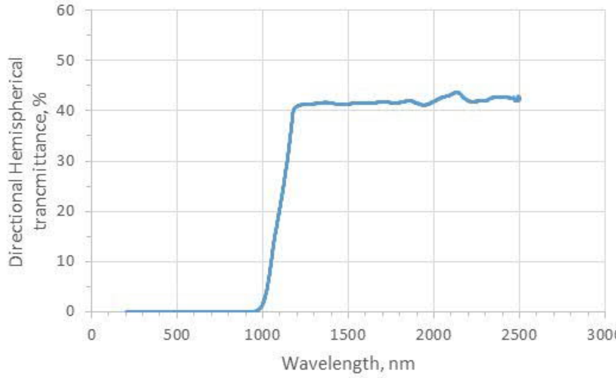

Figure 2. Directional hemispherical transmittance from 250nm to 2.5microns.

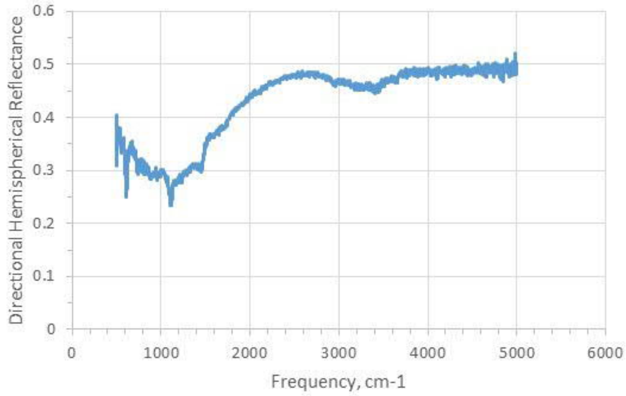

Figure 3. Directional hemispherical reflectance from 500 to 5000cm-1

The BTDF was measured at 1550nm and at the same angles of incidence as the BRDF measurements, 0°, 45° and 60°, and at viewing angles, from -50° to 50° in steps of 5° as measured from the negative normal to the sample surface. These data are shown in Fig.5. The Black Si diffuser exhibits virtually no forward or backward scatter and retroscatter. However, the Black Si sample does not show appreciable reflectance or transmittance peaks with the exception of the specular direction. The FWHM of the specular scatter was 1.5nm when measured in steps of 0.5deg. The specular reflectance largely originates from the top surface of the sample, characteristic of a one-bounce surface scattering process. In contrast, the Black Si performs as a very good volume diffuser with multiple reflections within the coating. Interestingly, there is no evidence of retroscatter in the Black Si sample. Retroscatter, if present, would originate from reflectance off the illuminated interior sides of the coating's structure. The lack of retroscatter indicates that light illuminating the inside of the coating structure is undergoing multiple internal reflections [3].

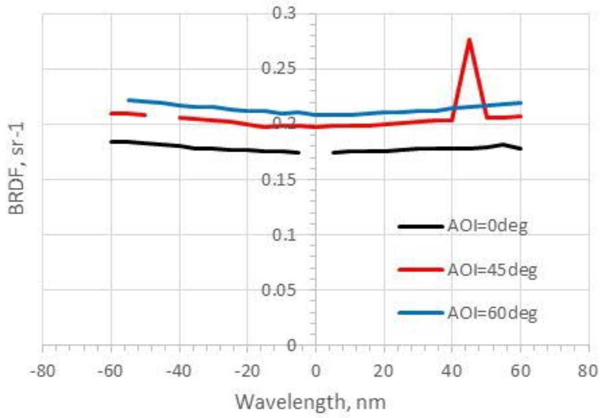

Figure 4. BRDF at 1550nm

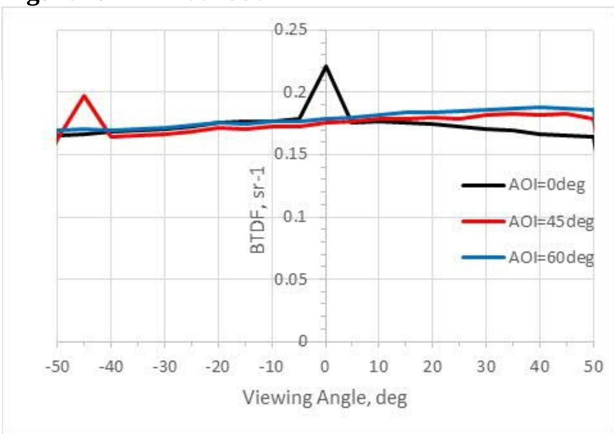

Figure 5. BTDF at 1550nm

The goal of this research was to characterize the diffuse scattering properties of Black Si. It exhibits close to isotropic scattering both in reflectance and transmittance as evident from Figures 4 and 5 and the hemispherical reflectance and transmittance as shown in Figures 1 to 3. The work presented in this paper constitutes only the initial steps in examining the potential of using Black Si as a calibration target for space instruments. Additional engineering and testing is required to ultimately optimize and qualify Black Si formulations for space use. Elements of this environmental validation effort are currently underway.

REFERENCES

[1] Georgi Georgiev, et al, "The Bidirectional Reflectance of Black Silicon Used in Space and Earth Remote Sensing Applications", Proc. SPIE, Vol. 11151, Edited by Steven Neeck, September 2019.

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