# Reflectance Characteristics of Accuflect™ Light Reflecting Ceramic


Accuratus Corporation
35 Howard Street
Phillipsburg, NJ 08865 USA
+1.908.213.7070
http://accuratus.com

## SUMMARY

Accuflect is a ceramic material developed for efficient visible and near infrared light reflection. Two grades are offered with slightly different reflection characteristics. Accuflect B6 has a native ceramic surface with nearly perfect diffuse reflection characteristics. Accuflect G6 has a glazed surface for protection in wet environments and easy cleaning. Typical of ceramics, the material is refractory and corrosion resistant, tolerant of extreme application environments.

## INTRODUCTION

Accuflect light reflecting ceramic is used in demanding diffuse light applications including high temperature infrared process heating, optically pumped laser reflectors and light sources for aesthetic medicine procedures.

Accuflect is a ceramic material with low optical losses in the visible to near infrared light spectrum. Light interacting with the ceramic microstructure results in a high quality diffuse reflector. Significant scattering and minimal penetration of the light into the ceramic body produces an efficient and nearly lambertian reflecting ceramic.

## ACCUFLECT MATERIALS

Accuflect material is manufactured using very carefully controlled processing parameters. The result of the carefully controlled processing is a ceramic body composed of ceramic grains on the order of 10 to 15 microns diameter and 15% porosity. Table 1 lists the typical physical properties of Accuflect.

| ACCUFLECT MATERIAL PROPERTIES | | |
|---|---|---|
| Density | g/cc | 2.3 |
| Porosity | % | 15 |
| Flexural Strength | MPa | 27.5 |
| Compressive Strength | MPa | 62 |
| Maximum Use Temperature | °C | 1200 |
| Thermal Conductivity | W/m°K | 5.8 |
| Thermal Expansion Coefficient | $10^{-6}$/°C | 7.7 |
| Dielectric Strength | kV/mm | 3 |
| Dielectric Constant | - | 5.5 |
| Loss Tangent | - | .003 |

Table 1

Two grades of Accuflect are available. Accuflect B6 is the native ceramic material. It has a nearly perfect diffuse reflectance. It is ideal for use where high temperatures are encountered and the surface is not subject to contamination or liquid ingress.

Accuflect G6 is the same ceramic material as Accuflect B6 but it has an applied glaze layer 150 to 200 microns thick. The glaze provides an easy to clean, protective layer. There is a specular component in addition to the diffuse reflection and a slight decrease in reflectance especially at shorter wavelengths. The maximum use temperature is limited to 700° C due to the lower melting point of the glaze layer.

## ACCUFLECT REFLECTED LIGHT CHARACTERISTICS

Accuflect is a ceramic comprised of mixed oxides selected for their low absorption over visible and NIR wavelengths. The high refractive index of the ceramic grains limits light penetration into the ceramic body and maximizes lambertian behavior with enhanced scattering, reflection and refraction between the ceramic grains and their surroundings. Figure 5 is a series of data plots of % Total Reflectance versus Accuflect thickness. The high efficiency of the Accuflect backscatter is evidenced by the indiscernable differences in % total reflectance at 3 mm and 10 mm thicknesses.

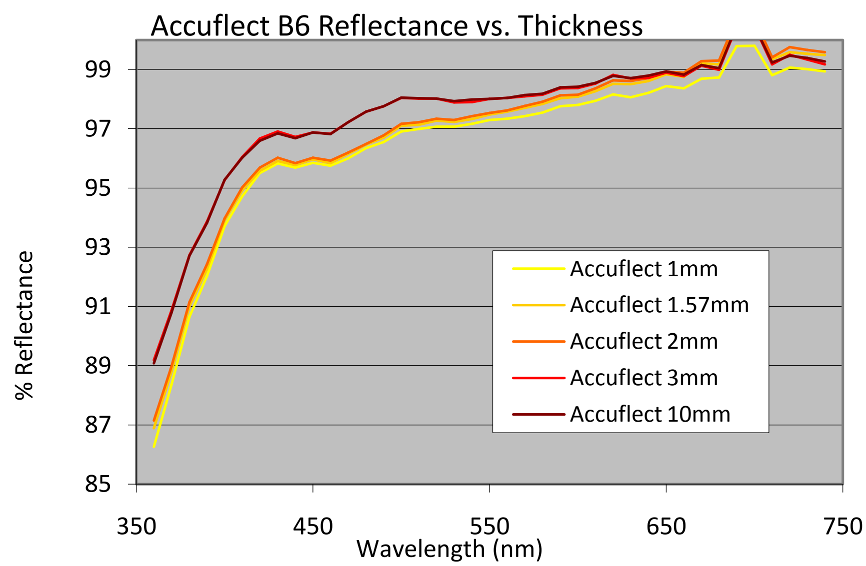


Figure 1

The “% Reflectance” data presented in Figures 5 through 11 is the ratio of the Accuflect reflected flux to that of a perfect diffuse reflector. The common 8 degree hemispherical geometry was used to obtain the data. The Accuflect was illuminated 7 degrees from normal and the reflected flux was collected in an integrating sphere. The result is total reflectance, including both the specular and diffuse reflection components. To extract the specular component a light trap was positioned in the integrating sphere to eliminate the specular reflection leaving only the diffuse flux for measurement. The specular reflectance data are plotted with an expanded scale for both Accuflect B6 and Accuflect G6 for improved resolution of the data.

The BRDF data was collected with a scatterometer constructed with goniometric adjustments in both azimuth and polar axes. The light source was an unpolarized 650 nm laser diode positioned at zero degrees incidence angle. The BRDF data for both Accuflect B6 and Accuflect G6 are plotted with an expanded scale so the small differences between them can be seen.

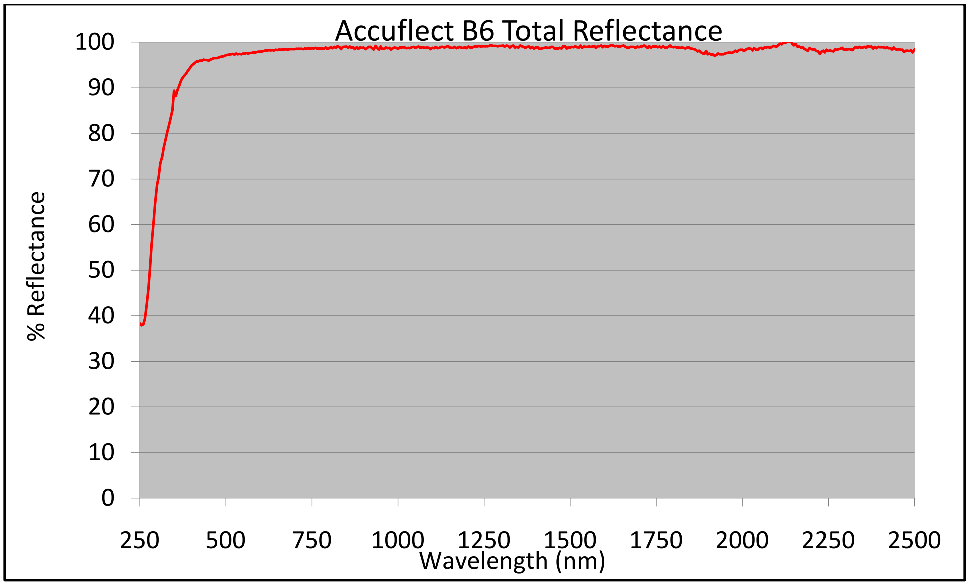


Figure 2

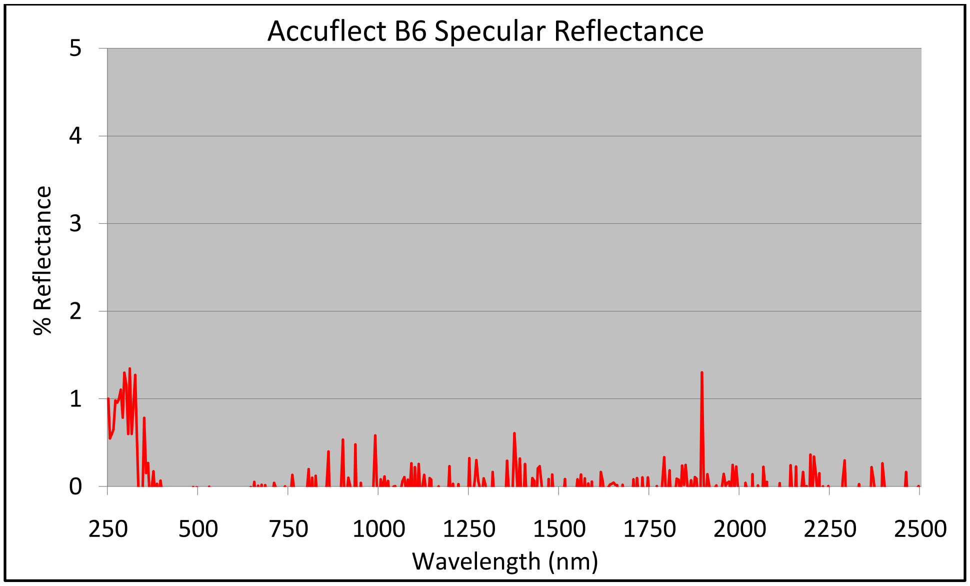


Figure 3

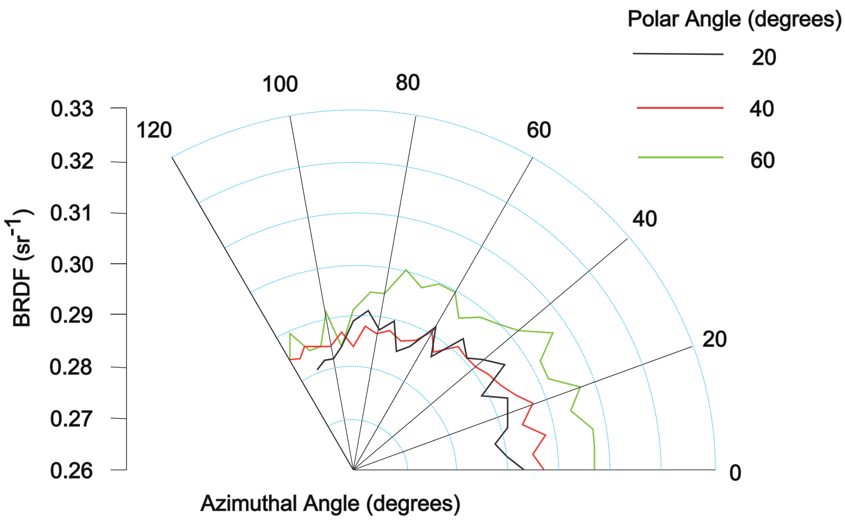


Figure 4 Accuflect B6 BRDF

Accuflect B6 has a native ceramic surface with high reflectance and nearly perfect lambertian behavior. This can be seen in the total reflectance and BRDF data presented in Figures 6 and 8. The uniformity of the BRDF data and nearly zero specular reflectance in Figure 7 show the essentially non-existent specular reflectance of Accuflect B6.

Accuflect G6 has a glazed surface comprised of a transparent borosilicate glass composition. Light reflection from the material is a mix of diffuse light from the native ceramic and roughly 4% specular reflection from the glazed surface. Figures 9 and 10 show the reflectance from the Accuflect glazed material. Figure 11 is the BRDF plot. The small specular reflection from the glaze surface is evident at a polar angle of approximately 60 degrees.

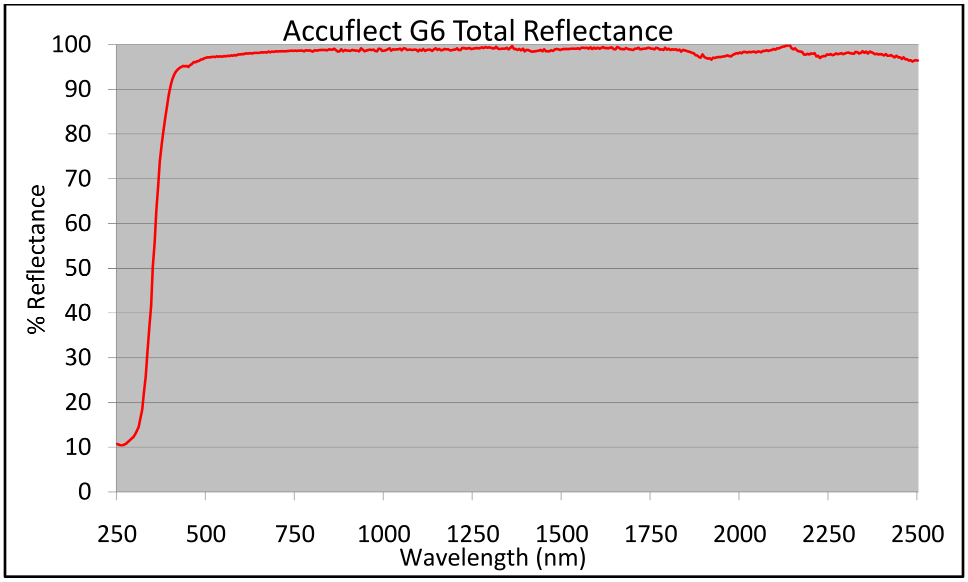


**Figure 5**

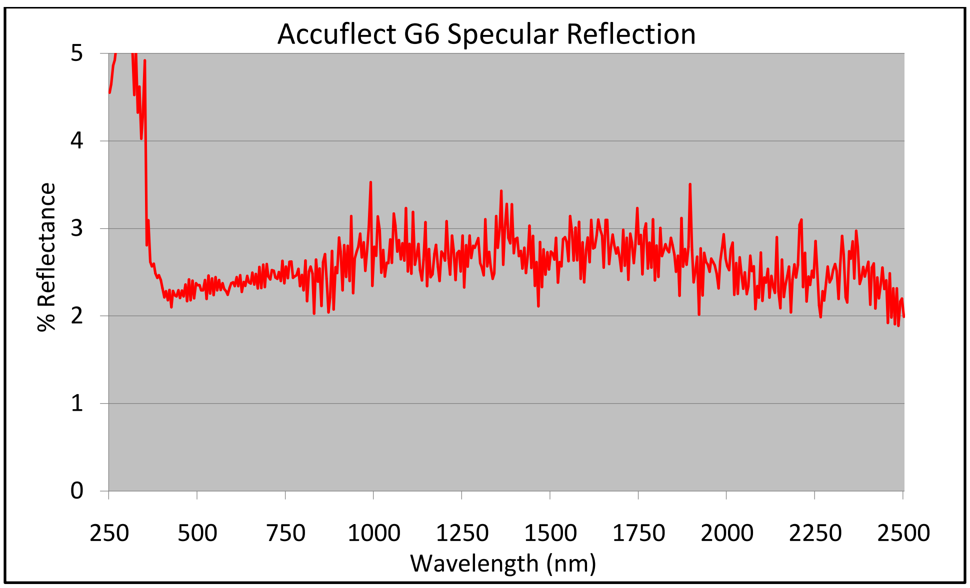


**Figure 6**

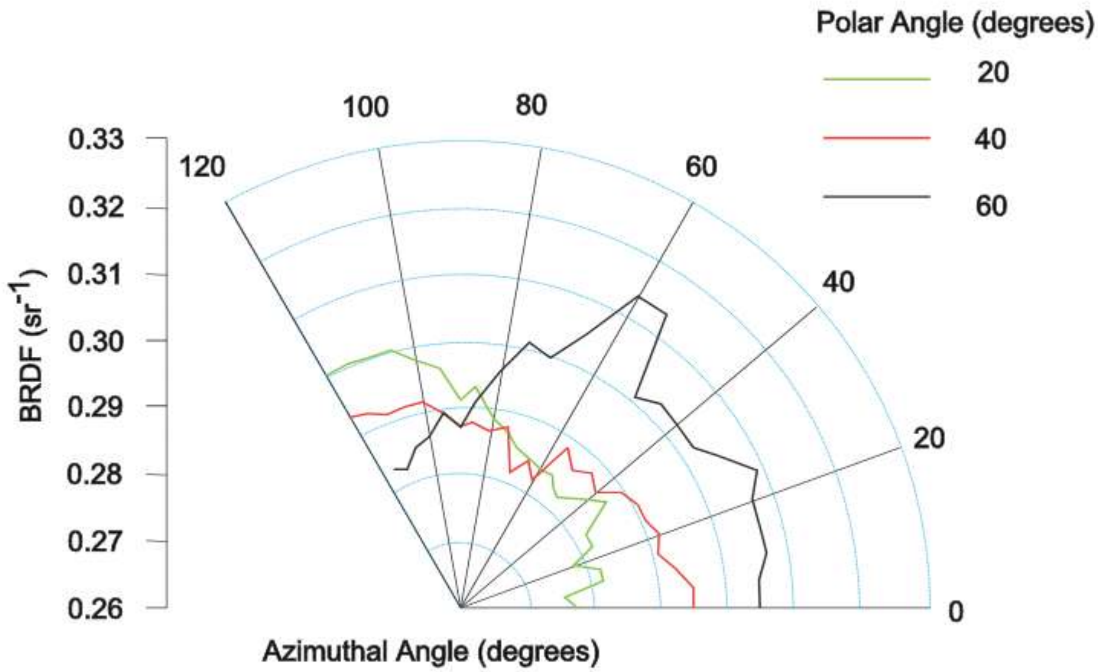


Figure 7 Accuflect G6 BRDF

# APPENDIX

SALIENT LIGHT REFLECTION CONCEPTS

Specular reflection is a mirror-like reflection wherein the incident light ray is reflected at a polar angle equal to the incident ray polar angle and at the opposite azimuthal angle (θ) with respect to the surface normal. (See figure 1)

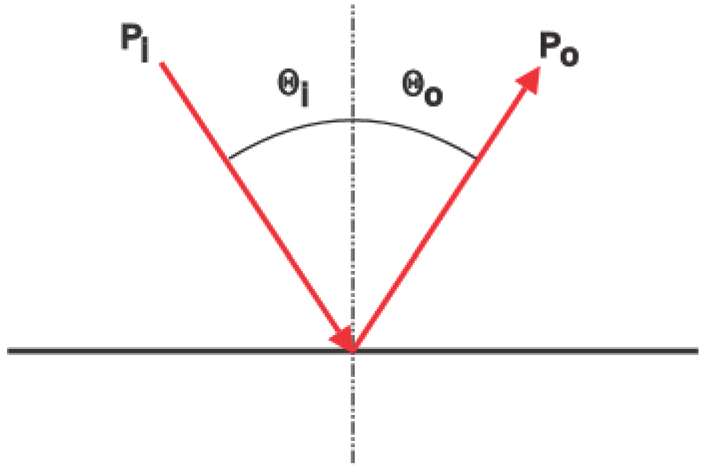


Figure 8 Specular Reflection

This reflection is typical of polished electrically conductive surfaces (metals) at all angles of incidence and smooth dielectric surfaces at oblique angles of incidence less than Brewster's Angle. The case for dielectrics is complicated by Fresnel reflection at angles of incidence greater than Brewster's Angle. When an incident light ray intersects the smooth boundary between materials with different refractive indices a percentage of the light is specularly reflected with the balance refracted. At near normal incidence, an unpolarized light ray will reflect according to the following relationship:

$$R = \frac{1}{2}\left[\frac{\sin(\omega - \emptyset)}{\sin(\omega + \emptyset)}\right]^2 + \frac{1}{2}\left[\frac{\tan(\omega - \emptyset)}{\tan(\omega + \emptyset)}\right]^2$$

Equation 1

Where: R=reflectance

$\omega$ = refracted ray angle with respect to the surface normal

$\emptyset$ = incident ray angle with respet to the surface normal

Figure 2 shows the reflection and refraction at the interface between two dielectric media where refractive index $\eta_2 > \eta_1$.

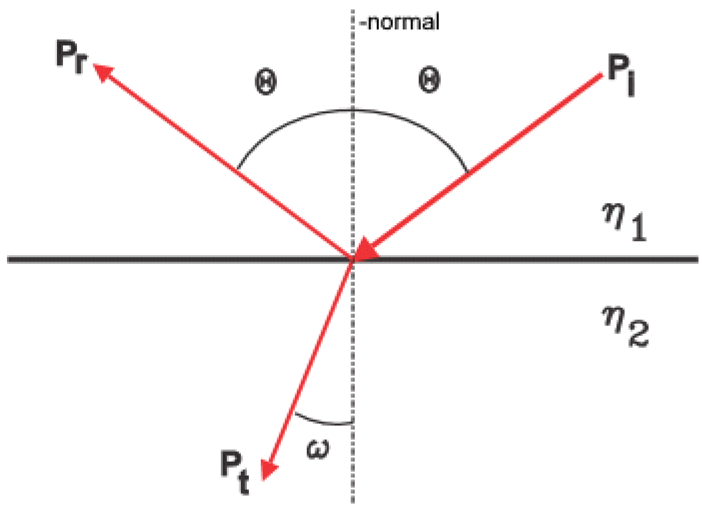


Figure 9 Fresnel Reflection

Lambert's Cosine Law for a perfectly diffuse emitter or reflector states the emitted light flux from the surface is proportional to the cosine of the angle between the surface normal and the viewing angle. (Figure 3) A perfect diffuse reflector exhibits equal brightness regardless of the viewing angle. As the viewing angle lowers, the apparent viewing area increases. The net result is equal albedo regardless of viewing angle.

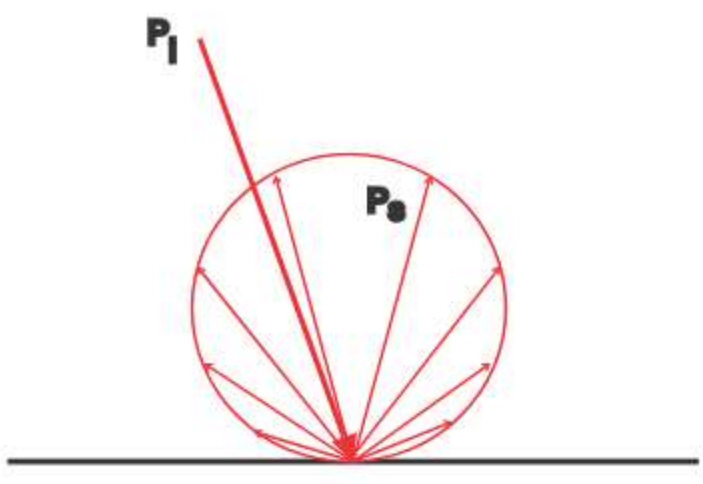


Figure 10 Diffuse Reflection

Diffuse reflectance is often measured with the bidirectional reflectance distribution function or BRDF. It describes the distribution of reflected light at a surface and approximates the BSSRDF, bi-directional sub-surface scattering reflectance distribution function. It is the ratio of the surface radiance emitted into specific azimuth and polar angles to the incident irradiance at specified polar and azimuth angles. The radiance is the light scattered through solid angle Ω per illuminated surface area A per unit projected solid angle.

$$BRDF = \frac{dP_s / d\Omega_s}{P_i cos\Theta_s}$$

Equation 2

A perfect lambertian surface with reflection coefficient R diffuses the incident power, $P_i$, uniformly through a hemisphere of 2∏ steradians.

The reflection coefficient is the aggregate of the scattered and specular power emitted into the hemispherical space above the reflector and can be expressed as the integrated reflected power divided by the incident power.

$$R = \frac{1}{P_i} \int_0^{\frac{\Pi}{2}} \int_0^{2\Pi} (dP_s / d\Omega_s) sin\Theta_s d\Theta_s d\Phi_s$$

Equation 3

Substituting from equation 2 above:

$$R = \int_0^{\frac{\Pi}{2}} \int_0^{2\Pi} (BRDF) cos\Theta_s \, sin\Theta_s d\Theta_s d\Phi_s$$

Equation 4

When integrated, a perfect lambertian reflector (reflection coefficient of 1) yields

$$BRDF_{lambertian} = \frac{1}{\Pi} \; sr^{-1}$$

A perfect specular reflector will yield a non-zero BRDF only for a pair of mirror reflected directions.

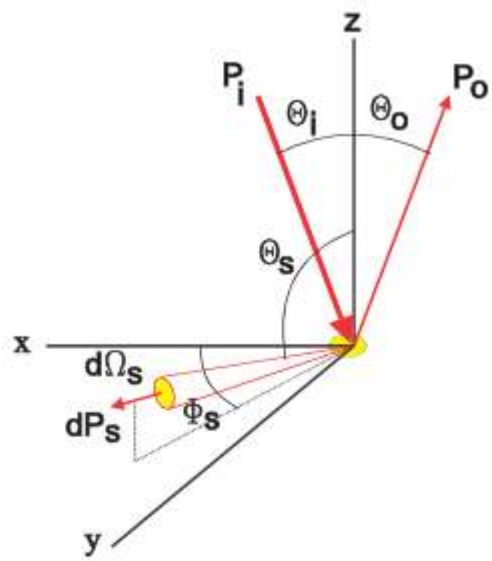


Figure 11 BRDF

BIBLIOGRAPHY

A GUIDE TO REFLECTANCE COATINGS AND MATERIALS. Labsphere.

Fejer, M.M., A. Alexandrovski and R.K. Route. "Absorption Studies in Sapphire." LIGO-G010152-00-Z. E.L. Ginzton Laboratory. Stanford University.

Zhang, Hao and Kenneth Voss. "Bidirectional Reflectance of Dry and Submerged Spectralon Plaque". Optical Society of America. 2006.

Nayar, Shree K., Katsushi Ikeuchi and Takeo Kanade. "Surface Reflection: Physical and Geometrical Perspectives". CMU-RI-TR-89-7. Carnegie Mellon University. 1989.

Cohen, Michael R. and Louis J. Small III. "Tech Note 3: Diffuse Reflectance Measurement of Standard Diffusers". www.4physics.com/tn3/lambertian.htm. 2005.

Stover, John C. "Optical Scattering Measurement and Analysis". 2nd ed. SPIE. 1995.