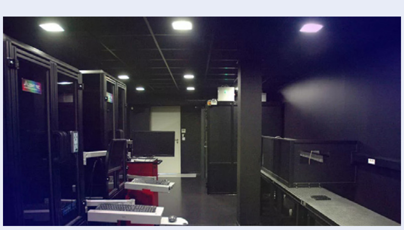
Scattering Measurements Guide

Our Laboratory

Synopsys is proud to introduce its new Photometric Laboratory, complete with:

- Goniophotometer: Synopsys REFLET 180S
- High specular bench (10 meters)
- Video photometer
- Lux meter
- Luminance meter
- Spectrophotometer
- Integrating spheres: 6” (in gold for infrared), 8” and 40”
- Refractometer
- Laboratory class: 10 000 (ISO7) and 100 (ISO5 according ISO 14644-1) cleanrooms

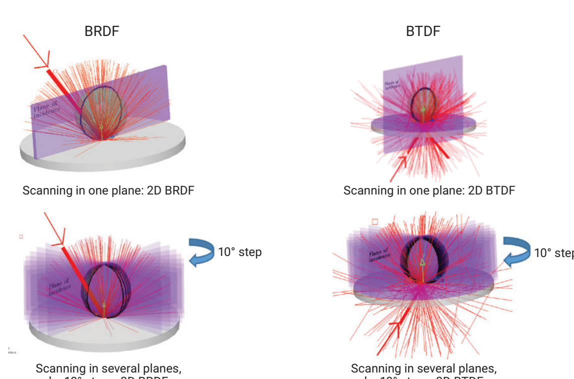
This expertly equipped laboratory strictly regulates temperature and humidity



Product Summary

Instruments	Mini-Diff V2	Mini-Diff Pro	REFLET 180S	High Specular
Type	BRDF/BTDF	BRDF/BTDF	BRDF/ BTDF	BRDF
Dynamic range	10^5	BRDF 10^5 BTDF 10^6	10^9	10^{13}
Wavelength range	630nm, 525nm, 465nm, 850nm, 940nm	630nm, 525nm, 465nm	400nm to 1700nm	280nm to 10,6µ
Incident angles	Fixed: 0°, 20°, 40°, 60°	Tunable: 0° to 60°	Tunable: +90° to -90°	Tunable: +90° to -90°
Angular range	Sphere [0° ; 75°] [0° ; 360°]	Sphere [0° ; 75°] [0° ; 360°]	Full sphere	1 plane from -10° to +90°
Angular accuracy	1°	1°	< 0.1°	< 0.02°
Repeatability	< 2%	< 2%	< 1%	<1%
Weight	2kg	42kg	80kg	200kg
Advantages	• Plug & Play • Easy to use and fast • Portable and compact • Attractive cost	• Dark Box included • Tunable AOI • High repeatability • Attractive cost	• High dynamic range	• Very high dynamic range • Measurement at 0,002° from the specular
			• High precision • High repeatability • Customizable wavelength range	

Scattering Measurement: Scanning Planes



Synopsys.com/optical-solutions

AOI Recommendations

Minimum Incident Angles

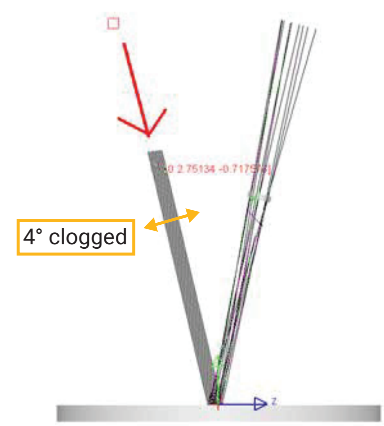
- For BRDF (reflection), when the goniometer is rotating, the detector can obstruct the incident lighting beam
- A 4° blind zone exists because:
  - No light comes back on the normal surface for AOI 0°.
  - There is not enough distributed light, and results are not accurate for AOI < 10°.

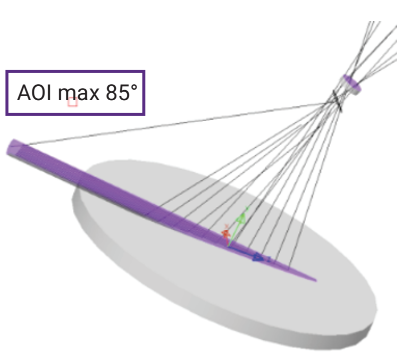
Because of this, we recommend AOI > 10°.

Maximum Incident Angles

- Because of "cosine" consideration, a beam of 3 mm at the level of the sample surface becomes an ellipse. The spot size collected by the receiver must be smaller than 12 mm at the level of the sample. For this reason, we limit the maximum incident angle to 85°.
- BSDF characterization is done for incident angles close to the real-world case and can be transferred to optical simulation software.

We recommend measuring BSDF for 10°, 30°, 50°, 70°.

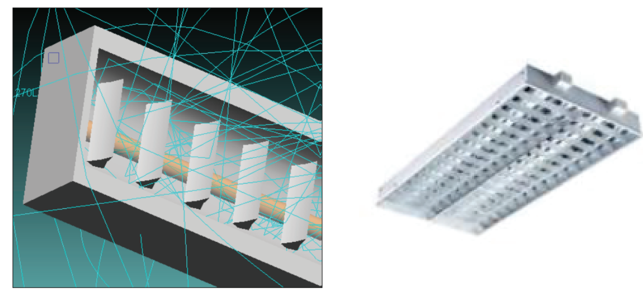




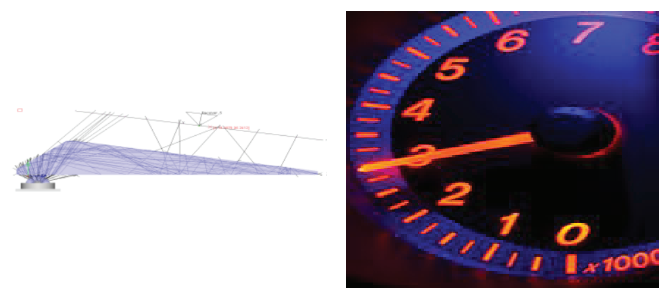
AOI Examples

Example 1: For a louver, most of the rays have incident angles of 0°to 60° on the reflector.

Example 2: For an automotive speedometer needle, most of the TIR incident angles are between 30°and 90°.



Example 1

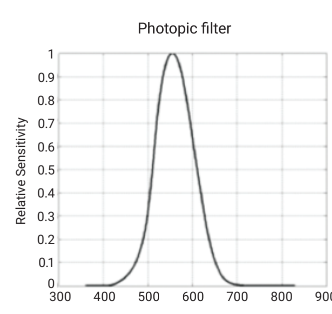


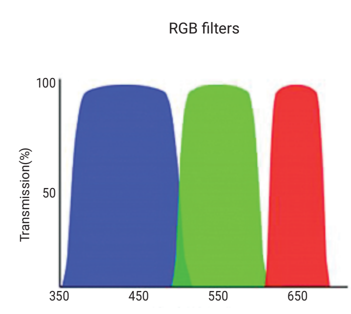
Example 2

Color and Filtered BSDF Measurements

The BRDF values delivered are the "TOTAL BRDF INTEGRATED" over one wavelength range.

Filter use: We can use different filters as photopic filters, RGB filters or many optical filters (from 300nm to 1700nm each 50nm). Using these filters, we are able to provide a filtered BSDF.





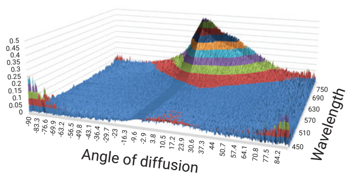
Spectral BSDF

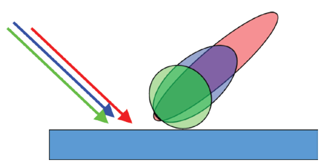
The scattering distribution can change depending on the color (wavelength) for applications such as paints, phosphors, lipsticks, etc.

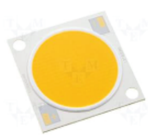
If this is the case, we use a different detector — a spectroradiometer — to measure BRDF or BTDF from 380 nm to 760 nm. The result is one BSDF distribution each 0,6 nm, 1 nm, 5 nm or 10 nm in the wavelength range.

This is a large amount of data for optical simulation software to handle. We are able to measure 2D or 3D spectral BSDF completely.

However, we recommend 2D, which is already quite complex.







BSDF Delivery

- 2D BRDF: In the incident plane, BRDF value each 0.1°, for each incident angle
- 2D BTDF: In the incident plane, BTDF value each 0.1°, for each incident angle
- 3D BRDF: 19 different planes every 10°, BRDF value each 0.1°, for each incident angle
- 3D BTDF: 19 different planes every 10°, BTDF value each 0.1°, for each incident angle
- Files delivered
  - – Standard: Text file (not scripted)
  - – On demand:
    - – LightTools, LucidShape, or ASTM (text file) format
    - – Other formats such as ABg or Gaussian/ Lambertian
    - – Other software formats, including ASAP, FRED, TracePro, SPEOS, and Zemax

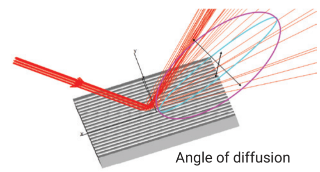
Anisotropy and Isotropy

Isotropy

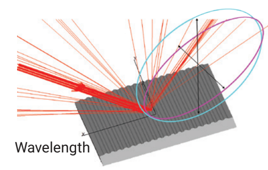
This is the most common case. The sample scatters light uniformly, regardless of incidence angle.

Anisotropy

The scattering distribution depends on plane of the incident light. Generally, these samples appear to have stripes on their surfaces. In these cases, we can rotate the incident plane by 90°. In many cases, two 3D BRDF measurements are enough.



One 3D BRDF for an incident plane parallel to the micro lines

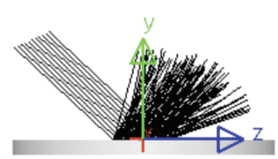


One 3D BRDF for an incident plane perpendicular to the micro lines

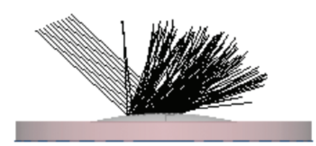
Recommendations

Flatness of the Sample

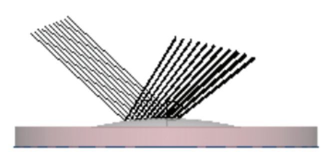
The sample must be flat; otherwise, a divergent beam is generated at the same time by the scattering and the curvature.



Scattering only



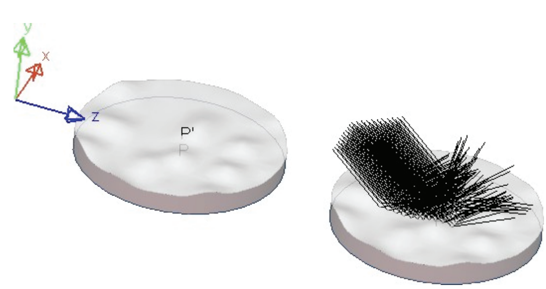
Curved, reflecting and scattering



Curved and reflecting only

Beam Size

The beam diameter (spot size on the sample) can be tuned from 1mm to 12mm. In the case of measuring a “hammer” surface, the period of the “hammer “ structure should not exceed a value of 3mm.

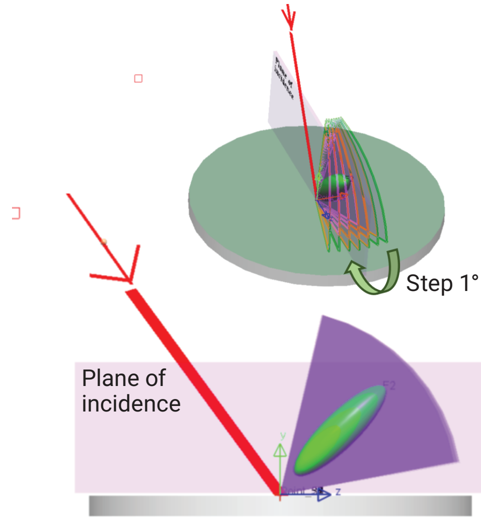


Near Specular (NS) Reflector

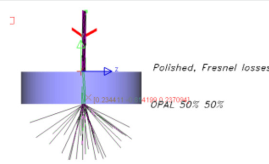
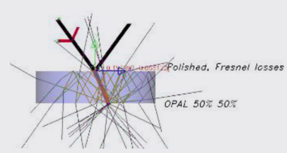
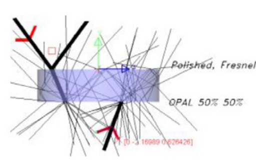
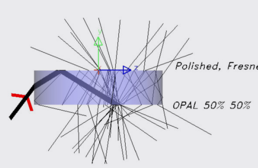
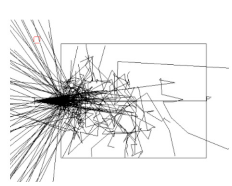
If the diffused beam is greater than 20°, we measure one 3D BRDF in each incident plane every 10°. If the diffused beam is between 5° and 20°, we do two sets of measurements:

- One measurement 3D BRDF in each incident plane every 10°
- One measurement near specular in each incident plane every 1°

Measurements that we call "near specular" have a diffused beam of less than 5°. We scan around the specular beam with a step of 1° between each slice. The near specular is done with the High Specular Bench. If the divergence of the diffused beam is smaller than 5°, see "High Resolution BRDF" on page 7.



Transmissive Diffusers

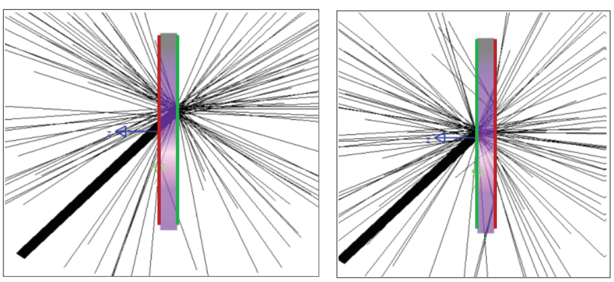
Cases		Measurements
Transmissive diffusers used in transmission only		BTDF
Transmissive diffusers used in transmission and reflection from one side		BRDF and BTD: Front or Back
Transmissive diffusers used in transmission and reflection used from both sides		BRDF and BTD: Front and Back
Guided diffuser (TIR)		TIR BRDF (optional TIR BTDF)
Volume diffusers		Volume diffusers: MIE scattering and Gegenbauer

Diffusers: Defining Back, Front, BRDF and BTDF

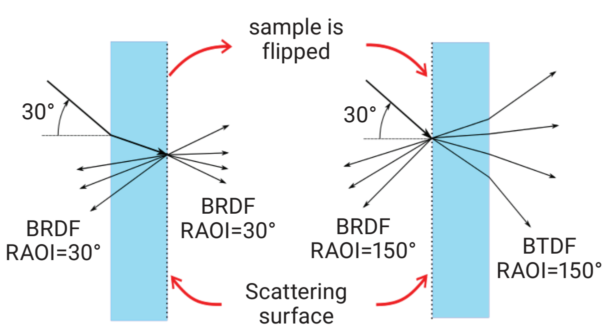
If BRDF and BTDF are used and the diffuser is only on one side (the other side is polished), then there are two cases:

- The light hits the polished surface = FRONT first
- The light hits the diffused surface = BACK first

The surface property must be applied on the surface (left or right) if the measurement is to be used in optical simulation software. The diffuser must be set up with a refractive index of 1 for the ambient air. If the refractive index is not 1 (e.g., 1.5 for the refractive index of the plastic material, for example), the software will propagate light in the diffuser and apply Fresnel reflection on the diffused light, resulting in additional scattering that does not exist.

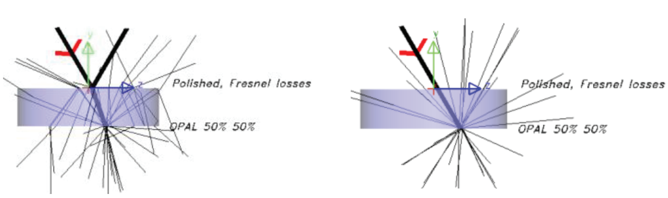


Front Back



Incident light from “inside” the sample is the FRONT $0° \leq$ AIO/RA OI $\leq 90°$

Incident light from “outside” the sample is the BACK $90° \leq$ AIO/RA OI $\leq 180°$



n Wrong n Correct

Total Internal Reflectance (TIR) Light Measurements

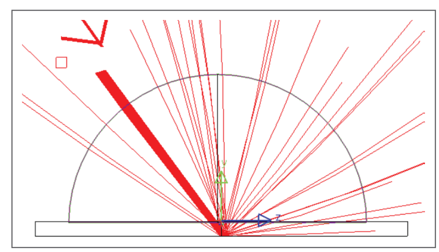
For TIR cases, our focus is on the light diffused “inside” the light pipe. This requires a special measurement where the top surface (Fresnel losses) has no influence.

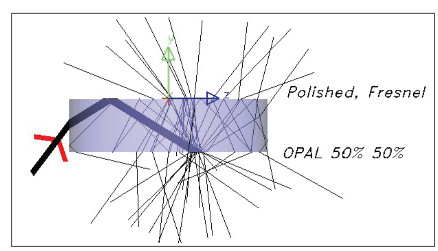
Our method is to introduce the light with a hemispherical lens (24mm diameter) aimed towards the surface, to diffuse the light back.

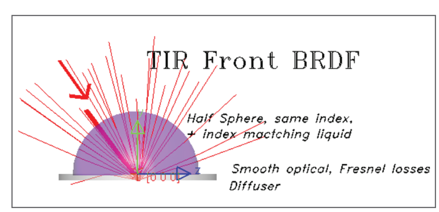
The light is then measured as a normal BRDF or BTDF.

The best sample to measure is a sample where the hemisphere has exactly the same index as the sample. Ideally, we want to get a hemisphere with the diffuser on the plane surface.

If this special hemisphere cannot be supplied, we use a polycarbonate hemispheres (PC) with an “index-matching-liquid” between the hemisphere and the sample.







Total Integrated Scattered Light Measurements

Total Integrated Scatter (TIS) is the ratio of the total power generated by all contributions of scattered radiation into the forward or backward half-space (or both), to the power of the incident radiation.

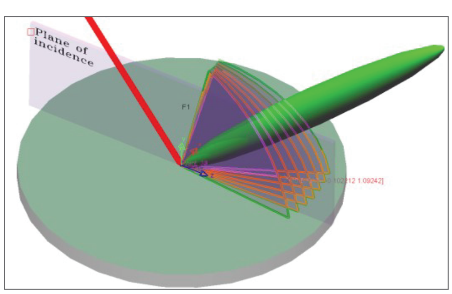
It is not possible to get the TIS from a BSDF measurement only. A goniophotometer scans a limited number of planes, so it does not collect all the scattered light.

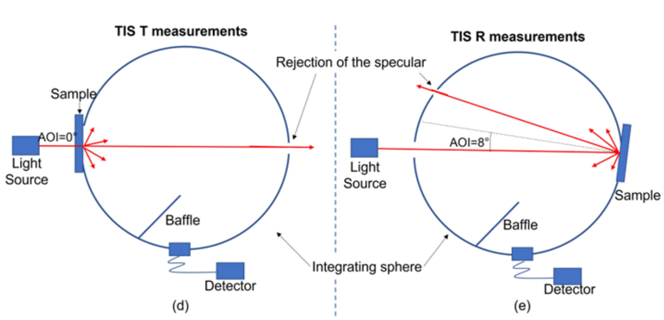
In the case of a scatter distribution, with a peak around the specular direction, the sensor may not have the right dynamic to measure the exact maximum values.

Using a given BSDF measurement (BRDF or BTDF), we can calculate the TIS with an accuracy of:

- Less than 5% for one diffused sample
- From 5% to 100% for one specular sample

Because of the wide range of potential errors, we recommend a highly accurate TIS measurement using an integrating sphere.





For space program applications, it is important to evaluate the evolution of the TIS during the manufacturing cycle. Various parameters can affect the actual TIS of the surface. Measuring a bundle of samples following different treatments can help with the knowledge of the most efficient technique:

- Aging
- Cleaning
- Manufacturing

These TIS measurement can be done with:

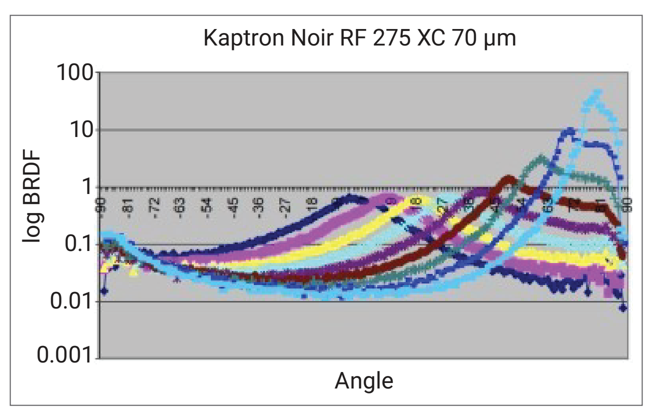
- White light (from 400 to 1700nm)
- With a laser emitting at 532, 638, 808 and 850nm
- With an IR laser at 1,55, 3,39 and 10,6µm
- Repeatability +/- 0.03%

Three different integrating spheres are available for samples from 10 to 100mm.

Total Integrated Scattered Light with Specular Rejection

Synopsys offers TIS Measurements with specular component rejection.

This configuration (close to a haze measurements) can be very useful for comparing low scattering light samples such as mirrors for the space industry or glass coatings. It enables the quantification of the resulting diffuse light without taking into consideration the non-deviated part from specular component.



Credit : Acktar deep black coatings

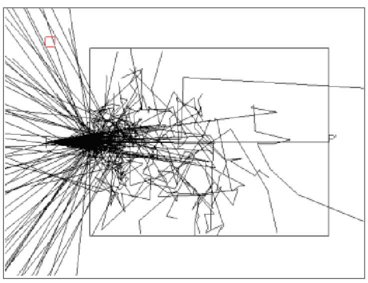
Volume Scattering Measurements

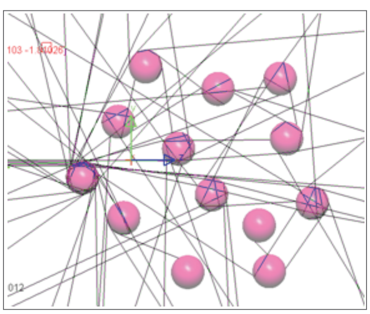
For volume scattering, we first measure the 2D BTDF of the sample in four different thicknesses.

Using these four BTDF measurements, we use a special method we developed to find the parameter needed to simulate this material:

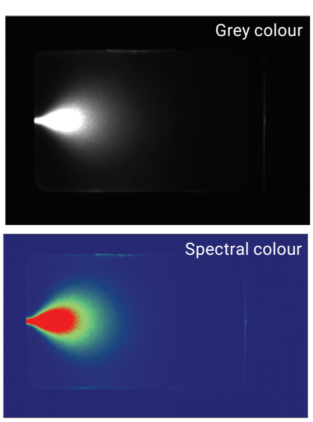
- Gegenbauer model: mean free path, Alpha, and g parameters
- Mie Scattering model (available on request): radius, density and refractive index of particles.

We then verify that the calculated data provides the same simulation results as the measurements.





Volume Scattering Examples



Picture of a measured sample

Flash

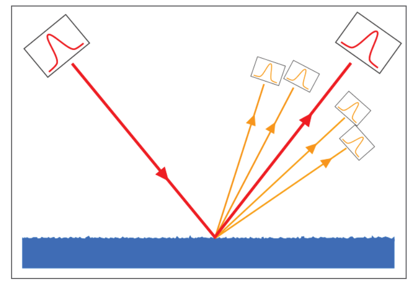
Headlights

High-Resolution BRDF

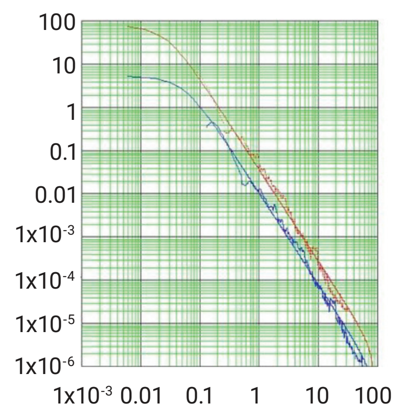
We can measure as close as 0.02° from the specular:

- 2D BRDF, very high dynamic: 1013
- Laser sources at 280, 375, 445, 532, 638 and 850nm and IR lasers at 1,55, 3,39 and 10,6µm

Instrument: 10-meter bench
Clean room: class 100 – ISO 5
Applications: high polished mirror, quasi-specular, and many more.



De-convolution of the measurement



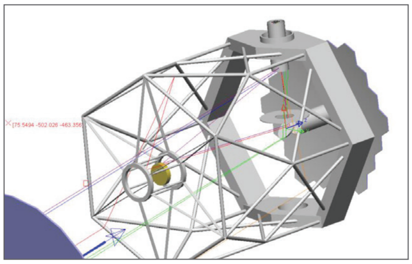
Laser signatures

High-Resolution BRDF Examples

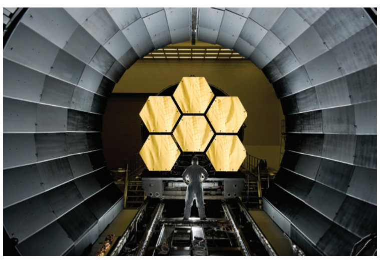
For some space programs, it is important to measure the scattering data of material:

- With very narrow diffusion for mirrors
- For baffles (edge scattering)
- For structure

Baffle



Structure



Mirrors

- Standard: N-BK7 flat window Φ1"
- Thickness 1mm

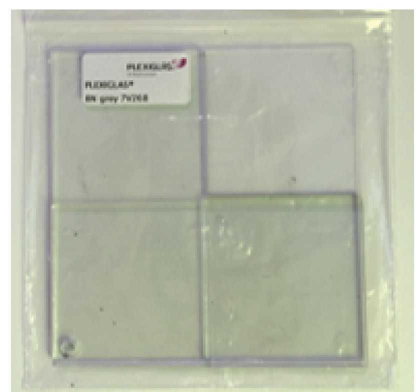
Wavelength	Theoretical refractive index	Measured refractive index
638nm	1.5149	1.515 ± 0.001
532nm	1.5195	1.520 ± 0.001
445nm	1.5258	1.526 ± 0.001

Refractive Index Description Measurements

Refractive Index is a critical characteristic of a material for optical design and simulation. It can vary from theoretical values for specific material, depending on the molding process.

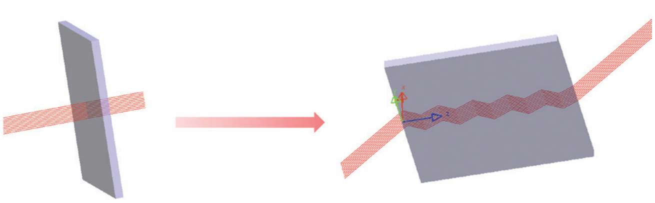
We measure refractive index at different wavelengths for your sample.

Example for PMMA material :



- PMMA
- Thickness 1mm, 2mm, 3mm & 4mm

Wavelength	Theoretical refractive index
638nm	1.481 ± 0.001
532nm	1.484 ± 0.001
445nm	1.490 ± 0.001



Usually:
PMMA plates are lighted up in transmission

More and more usual:
Edge lighting => internal reflections

Refractive Index: Applications

Automotive: head and rear lamps

Refractometer

Instrument	Refractometer
Type	Refractive index
Wavelength	445 nm, 532 nm, 638 nm and 1550 nm
Accuracy	+/- 0.001
Repeatability	<0.5%
Weight	100 Kg
Advantages	• High precision • High repeatability

For more information contact:

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