Light Tec
Scattering measurements guideline
Our Laboratory

Light Tec is equipped with a Photometric Laboratory (a dark room) including:

- Goniophotometers: REFLET 180S.
- High specular bench (10 meters),
- Video photometer
- Lux meter
- Luminancemeter,
- Spectrophotometer,
- Integrating spheres: 6” (in gold for infrared), 8” & 40” inch,
- Refractometer.

The dark room is new and well equipped. Light Tec moved to his new office in 2013. In the laboratory, the temperature and humidity are controlled and regulated for optimal measurement environment.

Laboratory class: 10 000 (ISO7) & 100 (ISO5 according ISO 14644-1) for the clean room.
## Our Products: Summary

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Mini-Diff V2</th>
<th>REFLET 180S</th>
<th>High Specular</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>BRDF/BTDF</td>
<td>BRDF/BTDF</td>
<td>BRDF</td>
</tr>
<tr>
<td><strong>Dynamic range</strong></td>
<td>$10^5$</td>
<td>$10^9$</td>
<td>$10^{13}$</td>
</tr>
<tr>
<td><strong>Wavelength range</strong></td>
<td>465nm+525nm+630nm</td>
<td>400nm to 1700nm</td>
<td>280nm to 10.6µm</td>
</tr>
<tr>
<td><strong>Incident angles</strong></td>
<td>Fixed (R+T): 0°, 20°, 40°, 60°</td>
<td>Tunable: +90° to -90°</td>
<td>Tunable: 0° to +90°</td>
</tr>
<tr>
<td><strong>Angular range</strong></td>
<td>Sphere [0° ; 75°] [0° ; 360°]</td>
<td>Full sphere</td>
<td>1 Plan from -10° to +90°</td>
</tr>
<tr>
<td><strong>Angular accuracy</strong></td>
<td>&lt; 2°</td>
<td>&lt; 0.1°</td>
<td>&lt; 0.02°</td>
</tr>
<tr>
<td><strong>Repeatability</strong></td>
<td>&lt; 5%</td>
<td>&lt; 1%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>2kg</td>
<td>80kg</td>
<td>200Kg</td>
</tr>
</tbody>
</table>

### Advantages

- Plug & Play
- Easy to use & Fast
- Portable & Compact
- Attractive cost
- High dynamic range
- Very high dynamic range
- Measurement at 0,02° from the specular
- High precision
- High repeatability
- Customisable wavelength range
Scattering measurement: scanning planes

**BRDF**
- Scanning in one plane: 2D BRDF
- Scanning in several planes, by 10° steps: 3D BRDF

**BTDF**
- Scanning in one plane: 2D BTDF
- Scanning in several planes, by 10° steps: 3D BTDF
AOI recommendations

**Minimum Incident angles:**
For BRDF (reflection), when the goniometer is rotating, the detector can obstruct the incident lighting beam. We do have a 4° dead zone because of this:

- No light coming back on the normal surface for AOI 0°.
- There is not enough distributed light and results are not accurate for AOI < 10°.

**Therefore, we do 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 sized collected by the receiver has to be smaller than 12 mm at the level of the sample. For this reason we limit the maximum incident angle to 85°.

In case measurements will be implemented into an optical simulation software, the BSDF characterization is done for incident angles close to the real case.

**By default we do recommend to measure 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°.
Colour 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.

Photopic filter

RGB filters
Spectral BSDF

The scattering distribution can change versus the colour (wavelength): applications such as paints, phosphors, lipsticks etc.

In that case we use a different detector – a spectroradiometer. It measures BRDF or BTDF from 380nm to 760nm. The result is one BSDF distribution each 0.6nm, 1nm, 5nm or 10nm in the wavelength range.

This is a large amount of data that has to be handled in an optical simulation software!

We are able to measure 2D or 3D spectral BSDF completely.

However, we do 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
  o Standard: text file (not scripted)
  o On Demand:
    ▪ LightTools, LucidShape and ASTM (text file) format
    ▪ Support to generate other format such as ABg or Gaussian/Lambertian
    ▪ Support to import in other software (ASAP, FRED, TRACEPRO, SPEOS, ZEMAX)
Anisotropy and Isotropy

Isotropy
This is the most general case.
The sample scatters the light uniformly regardless of the light in an angle of incidence.

Anisotropy
The scattering distribution depends on plane of the incident light. Generally, those samples appear to have stripes on their surfaces.
In this case, 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 has to be flat. Otherwise, a divergent beam is generated at the same time by the scattering and the curvature.

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.
Case of reflectors : Diffused reflector and Near Specular (NS) reflector

If the diffused beam is $> 20^\circ$, we measure one 3D BRDF in each incident plane every $10^\circ$.

If the diffused beam is between $5^\circ$ and $20^\circ$, we do two bundles of measurements:
• One measurement 3D BRDF with plane every $10^\circ$,
• One measurement near specular with plane every $1^\circ$
Measurement that we call “Near Specular” have a diffused beam of $< 5^\circ$.
We scan around the specular beam with a step of $1^\circ$ between each slice.

The Near Specular measurement is done with High Specular Bench. If the divergence of the diffused beam is smaller than $5^\circ$, please see the slide explaining the method of “High Specular Measurement”.
Case of transmissive diffusers

Cases

- Transmissive Diffusers used in transmission only
- Transmissive Diffusers used in transmission and reflection from one side
- Transmissive Diffusers used in transmission and reflection used from both sides
- Guided diffuser (TIR)
- Volume diffusers

Measurements

- BTDF
- BRDF & BTDF : Front or Back
- BRDF & BTDF : Front and Back
- TIR BRDF (optional TIR BTDF)
- Volume diffusers: MIE scattering & Gegenbaueur
Case of diffusers: Definition Back & Front, BRDF & BTDF

If BRDF and BTDF is used and the diffuser is only on one side, (the other side is polished), then there are 2 cases:

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

In case the measurement has to be used into an optical simulation software, the surface property has to be applied on the surface (left or right one), BUT

The diffuser HAS to be set up with a refractive index of 1 as the ambient air. If the refractive index is not 1 (e.g. 1.5 as the refractive index of the plastic material for example), the software will propagate the light in the diffuser and will apply Fresnel reflection on the diffused light resulting in additional scattering that is not currently existing.
Total Internal Reflectance (TIR) light measurements

In this case our focus is in the light diffused “inside” the light pipe. A special measurement where the top surface (Fresnel losses) has no influence is required.

The way to do this is to get the light injected with an hemispherical lens (24mm diameter) towards the surface diffusing back the light.

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. So ideally we want to get an hemisphere with the diffuser on the plane surface.

If this special hemisphere cannot be supplied, we use one of our hemisphere (PC) with an “index matching liquid” between the hemisphere and the sample.
Total Integrated Scattered light measurements (TIS)

Definition of TIS: it is the ratio of the total power generated by all contributions of scattered radiation into the forward or the 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!

1. A goniophotometer scans a limited number of planes, so it does not collect all the scattered light.
2. 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.

By a given BSDF measurement (BRDF or BTDF), we can calculate the TIS with an accuracy:
• Around few % for one diffused sample,
• Around 5 % to ....100 % for one specular sample,

Due to such enormous potential errors, we do recommend a high accurate TIS measurement using an integrating sphere.
Total Integrated Scattered light measurements (TIS)

For space programs for example, it is important to evaluate the evolution of the TIS (Total Integrated Scatter light) during the manufacturing cycle. Different parameters can affect the actual TIS of the surface. Measuring bundle of samples following different treatments can help a lot on the knowledge of the most efficient technique:

- Aging
- Cleaning
- Manufacturing

These TIS measurement can be done with
- White light (from 400 to 1700nm),
- With laser emitting at 532, 638, 808 and 850nm
- With IR laser at 1,55, 3,39 and 10,6μm,
- Repeatability +/- 0.03%

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

Example of several measured AOI

Acktar type materials
Volume Scattering measurement

For volume scattering, we first measure the 2D BTDF of the same sample in 4 different thicknesses.

Using these 4 BTDF measurements, we have developed a special routine allowing to find the parameter needed to simulate this material with:

- **Gegenbaueur model**: mean free path, Alpha and g parameters.
- **Mie Scattering model**: radius, density and refractive index of particles. (Upon demand)

Afterwards we double check if the calculated data provide the same simulation results as the measurements.
Volume Scattering: examples

Picture of a measured sample

Grey colour

Spectral colour

Flash

Headlights
High Resolution BRDF

We can measure as close as 0.02° from the specular:
• 2D BRDF, very high dynamic: $10^{13}$,
• Laser sources at 280, 375, 445, 532, 638 and 850nm and IR lasers at 1,55, 3,39 and 10,6μm.

Instrument: bench of 10 meters long.
Clean room: class 100 – ISO 5
Application: high polished mirror, quasi specular and a lot more.

De-convolution of the measurement

Laser signatures
High Resolution BRDF examples

For some space programs for example, it is important to measure the Scattering data of material:
- with a very narrow diffusion for mirrors
- for baffles (edge scattering)
- or structure

MIRRORS

Baffle

Structure
Refractive index measurements: Description

Need to know the refractive index of PMMA
- At different wavelengths because of the dispersion
- Refractive index of PMMA depends on manufacture process
- It is not common to measure the refractive index of samples made in PMMA

Usually:
PMMA plates are lighted up in transmission

More and more usual:
Edge lighting
-> internal reflections
Refractive index measurements: Measurements

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

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Theoretical refractive index</th>
<th>Measured refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>638nm</td>
<td>1.5149</td>
<td>1.515 ± 0.001</td>
</tr>
<tr>
<td>532nm</td>
<td>1.5195</td>
<td>1.520 ± 0.001</td>
</tr>
<tr>
<td>445nm</td>
<td>1.5258</td>
<td>1.526 ± 0.001</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Measured refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>638nm</td>
<td>1.481 ± 0.001</td>
</tr>
<tr>
<td>532nm</td>
<td>1.484 ± 0.001</td>
</tr>
<tr>
<td>445nm</td>
<td>1.490 ± 0.001</td>
</tr>
</tbody>
</table>
Refractive index measurements: Applications

- Automotive: head & rear lamps
Refractive index measurements: Refractometer

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Refractometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Refractive index</td>
</tr>
<tr>
<td>Wavelength</td>
<td>445 nm, 532 nm, 638 nm and 1550 nm</td>
</tr>
<tr>
<td>Accuracy</td>
<td>+/- 0.001</td>
</tr>
<tr>
<td>Repeatability</td>
<td>&lt;0.5%</td>
</tr>
<tr>
<td>Weight</td>
<td>100 Kg</td>
</tr>
</tbody>
</table>
| Advantages | • High precision  
             • High repeatability |
## Measurement

<table>
<thead>
<tr>
<th>Standard Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D BRDF or BTDF (Front or Back) for <strong>one incident angle</strong></td>
</tr>
<tr>
<td>3D BRDF or BTDF (Front or Back) for <strong>one incident angle in 18 planes</strong></td>
</tr>
<tr>
<td>TIS Measurements</td>
</tr>
<tr>
<td>2D BRDF or BTDF Spectral / AOI</td>
</tr>
<tr>
<td>(3D BRDF or BTDF Spectral / AOI / Plan)</td>
</tr>
<tr>
<td>Volume scattering: Gegenbaueur models</td>
</tr>
<tr>
<td>High Specular Measurements: BRDF or BTDF (Front or Back) in the visible light or IR</td>
</tr>
<tr>
<td>TIS measurement includes</td>
</tr>
<tr>
<td>Refractive index: 1 wavelength (445 nm, 532 nm, 638 nm and 1550 nm) + Spectral transmission.</td>
</tr>
</tbody>
</table>

## Measurement Package

<table>
<thead>
<tr>
<th>For reflecting diffusers</th>
<th>3D BRDF or BTDF measurement for 10°/30°/50°/70° and TIS measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>For Mirrors</td>
<td>3D BRDF or BTDF measurement for 10°/30°/50°/70° with near specular and TIS measurements</td>
</tr>
<tr>
<td>For light guide diffuser with TIR effect</td>
<td>2D TIR BRDF or BTDF measurements for 10°/30°/50°/70° and TIS measurements</td>
</tr>
<tr>
<td>For diffusers used from single side</td>
<td>2D BRDF and BTDF for 10°/30°/50°/70° and TIS measurements</td>
</tr>
<tr>
<td>For diffusers used from both sides (Front and Back)</td>
<td>2D BRDF and BTDF for 10°/30°/50°/70° and TIS measurements</td>
</tr>
<tr>
<td>For diffusers used from single side</td>
<td>3D BRDF and BTDF for 10°/30°/50°/70° and TIS measurements</td>
</tr>
<tr>
<td>For diffusers used from both sides (Front and Back)</td>
<td>3D BRDF and 3D BTDF for 10°/30°/50°/70° and TIS measurements</td>
</tr>
</tbody>
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CONTACT

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