Scattering measurements

Guidelines for measurements service
Content

• Introduction
  – Light Tec Presentation
  – Instruments available.

• Scattering measurements
  – Reflectors
  – Diffusers
  – Colors issues

• Volume Scattering measurements
• High Specular Measurements
• Prices
Light Tec: Locations

Light Tec Sarl, Hyères, France
- Main office: 500 m², 10 employees
- Training room
- R&D for REFLET/Mini
- Photometric laboratory

Light Tec GmbH
Munich, Germany
- 150 m², 4 employees
- Training room

Aix en Provence, France
REFLET assembling
- 3 employees
Light Tec Activities

- Scattering measurements
  - Measurements service
  - Instruments
- Simulation Software
  - Code V: optical design
  - LightTools: illumination design
  - Rsoft: nano optics
  - TFCalc: thin film design
- Engineering
  - Lighting
  - Displays
  - Optical design
Instruments available for Scattering measurement

BRDF= Bidirectional Reflected Distributed Function, BTDF= Bidirectional Transmission Distributed Function

<table>
<thead>
<tr>
<th></th>
<th>REFLET</th>
<th>High Specular</th>
<th>MINI-DIFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>BRDF/BTDF</td>
<td>BRDF</td>
<td>BRDF/BTDF</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>10 e 9</td>
<td>10 e 13</td>
<td>10 e 4</td>
</tr>
<tr>
<td>Wavelength range</td>
<td>400 1700 nm</td>
<td>300nm 1700 nm</td>
<td>620 nm</td>
</tr>
<tr>
<td>Incident Angles</td>
<td>Tunable +90° to -90°</td>
<td>Tunable +90° to 0°</td>
<td>Fixed 0°, 20°, 40°, 60°</td>
</tr>
<tr>
<td>Angular Accuracy</td>
<td>&lt;0.5°</td>
<td>&lt;0.02°</td>
<td>&lt;2°</td>
</tr>
<tr>
<td>Repeatability</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Weight</td>
<td>80 Kg</td>
<td>200 Kg</td>
<td>2 Kg</td>
</tr>
</tbody>
</table>
Instruments available for TIS measurements
TIS = Total Integrated Scattered Light

• We do have 2 integrating spheres at LightTec
  – One is 10 inches diameter. It is used for TIS measurements
  – One is 40 inches. It is used for large samples.
Scattering measurements: definition of the scanning planes

- When we use our goniophotometer REFLET, we are scanning the light distribution in one plane (one slice).
- This plane can be the incident plane or any other plane rotated around the normal to the sample.
- For a 3D BSDF measurement, we do recommend 10 different scanning planes (0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°).

Scanning in the one plane: 2D BRDF

Scanning in the several planes: 3D BRDF

This image is animated if you use the diaporama model
Case of reflectors

- If the material is a « reflector » then the light is diffused in a small angle.

- If the divergence of the diffused beam is < 20° and > 5°, then we increase the accuracy of the measurement doing 2 bundle of measurements:
  - The one describer on the previous slide with a step of 10° between the slices
    AND
  - A second measurement that we call “Near Specular” where we actually add more scan around the specular beam with a step of 1° between slices.

- If the divergence of the diffused beam (< 5 degree), please go the slide presenting the measurement of « High Specular Measurement »
Miscellaneous

- **Flatness of the sample**
  The sample has to be flat, if not the divergent beam is generated at the same time by the scattering and the curvature and so it is not possible to separate both effects.

- **Anisotropy**
  In case the surfaces have anisotropic structure, we can rotate the incident plan by 90°.

Two 3D BRDF measurements are normally enough:
- one 3D BRDF for an incident plane parallel to the microlines,
- and one 3D BRDF for an incident plane perpendicular to the microlines.
• **Size of the beam**

The beam diameter (spot size on the sample) can be tuned from 0.5 mm to 12 mm.

So in case we want to measure an “hammer” surface, it is possible if the period of the “hemmer” structure is in the range of 3 mm max, like this it is average in the case we do use the large beam.

• **Minimum Incident angles**

For BRDF (reflection), when the goniometer is rotating, the detector is obstructing the incident lighting beam. We do have a dead zone of 4°. Because of this, we normally do not measure for 0° incident angle, because then we have no light coming back on the normal to the surface.

We do recommend a minimum incident angle of 10°, like this we do have a nice distributed light toward the normal to the surface.

• **Maximum Incident angles**

Because of “cosine” consideration, if we use a beam of 3 mm at the level of the sample, it becomes an ellipse at the level of the surface. The beam collected by the receiver as to be smaller than 12 mm at the level of the sample. For this reason we limit the max incident angle to 85°.
Recommended incident angles

As far as these measurements are done to be injected in simulation software, we do the BSDF characterization for incident angles close to the real case.

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

Example 2
For the automotive pointer, most to the TIR incident angle are between 30° and 90°.

By default we do recommend to measure BSDF for 10° 30° 50° 70°
Case of transmissive diffusers

Several 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 to be done

- BTDF
- FRONT BRDF and BTDF OR BACK BRDF and BTDF
- FRONT BRDF and BTDF AND BACK BRDF and BTDF
- TIR BRDF optional TIR BTDF
- Volume scattering MIE characterization
BTDF measurements

- When we use our goniophotometer REFLET 180, we are scanning the light distribution in one plane (one slice).
- This plane can be the incident plane or any other plane rotated around the normal to the sample.
- For a 3D BSDF measurement, we do recommend 10 different scanning planes (0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°).

Scanning in the one plane: 2D BTDF  
Scanning in the several planes: 3D BTDF

Step 10°
In case the interest is for BRDF and BTDF, and if the diffuser is on one side only, (the other side is polished), then there are 2 cases:
The light hits first the polished surface = FRONT
The light hits first the diffused surface = BACK

When the measurement is done and has to be set up in the 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 set up as 1 (1.5 as the refractive index of the plastic for example), then the software will propagate the light in the diffuser and will apply Fresnel reflection on the diffused light, and will add extra scattering not existing.
TIR measurements

- In case the interest is for the light diffused “inside” the light pipe, we need to do a special measurement where the top surface (Fresnel losses) has no influence.
- The way to do this is to get the light injected with and hemispherical lens (24 mm 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 to be measured.
- It is not perfect, but better than normal BACK BRDF measurement.
TIS measurements
TIS = Total Integrated Scattered Light

- It is not possible to get the TIS from a BSDF measurement

- 1st: a goniophotometer is scanning in a limited number of planes, so it is not collecting all the scatter light.

- 2nd: in case of a scatter distribution having a pic around the specular, the sensor may have not the right dynamic to measure the exact pic value.

- From a 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

- Because of these big potential errors, we do recommend that we also measure the TIS, using an integrating sphere.
Wavelength Issues

- What is described in the previous slides is measured with sensors which can work in to wavelength range:
  - 400 - 900 nm and 900 - 1700 nm
- The BRDF values delivered are the “TOTAL BRDF integrated” over one wavelength range.

- Filter use: We can use different filters
  - Photopic Filter
  - Red Filter
  - Green Filter
  - Blue Filter
  - Infrared Filter (800 nm)
  - Other filters on demands

- Using these filters we do provide a filtered BSDF.

- Spectral BSDF: We can also measure the BSDF values of wavelength from 380 nm to 760 nm.
  Please find more info in next slide.
Spectral BSDF

The scattering distribution can change versus the color (wavelength):
Applications: paints, phosphor, lipstick

In that case we can use another detector: a spectroradiometer.

It can measure BRDF or BTDF from 380 to 760 nm. The result is one BSDF distribution each 4 nm on that range.
This is a lot of data to handle in one simulation software.
But we can measure it.

We can do 2D or 3D spectral BSDF. 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: 10 different planes (0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°), BTDF value each 0.1 °, for each incident angle
- 3D BTDF: 10 different planes (0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°), BTDF value each 0.1 °, for each incident angle

- Files delivered
  Standard: text file (not scripted)
  On Demand:
  LightTools format, ASTM format,
  Support to generate other format Abg, Gaussian/Lambertian
  Support to import in other software (ASAP, FRED, TRACEPRO, SPEOS, ZEMAX)
Volume Scattering measurement

- For this case, we are first measuring the 2D BTDF of the same sample delivered 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:
  - Mie Scattering model
  - Gegenbaueur model
- We then double check that the data calculated are giving the same simulations results as the measurements
- We are delivering 3 parameters for Mie Model
  - Radius of the particles, Density of particles, Refractive index of particles
- We are delivering 3 parameters for Gegenbaueur Model
  - Mean free path, Alpha and g parameters
High Resolution BDRF

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
High Resolution BDRF

- We can measure as close as 0.02° from the specular.
- 1 D BRDF, very high dynamic 10e13
- Sources: Laser 375 nm, 455 nm, 532 nm, 633 nm, 638 nm, 808 nm, 830 nm.

Detectors: the REFLET one + a set of PMTs + ADS

Bench set up: 2 meters long

Sample + Source holder set on double goniometer
High Resolution BDRF

- We can measure as close as 0.02° from the specular.
- 1 D BRDF, very high dynamic 10e 13

- Sources: Laser 375 nm, 455 nm, 532 nm, 633 nm, 638, nm, 808 nm, 830 nm.

- Application: High polished mirror, quasi specular

De-convolution of the measurement

Laser signatures
TIS measurements

- 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 bundles of samples following different treatments can help a lot on the knowledge of the most efficient technique.
  - Aging
  - Cleaning
  - Manufacturing

- These TIS measurements can be done with
  - White light (400 – 1700 nm)
  - With laser emitting at 532 nm, 633 nm, 808 nm
  - Repeatability +/- 0.03 %

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

- Future developments:
  - Installation of a 20 m² clean room in our office
  - Cleanliness Class: Class 100 (ISO 5), Class 1,000 (ISO 6), Class 10,000 (ISO 7), Class 100,000 (ISO 8)
  - 3-5 micron range and 10 micron range
And please, come to visit us!

Our office and laboratory location