# Optical Characterization of Automotive Interior Materials by BSDF

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Future cars with (semi-) autonomous driving enable more use of interior lighting with special visual effects. This deals as well with interior materials, which are illuminated. Thus, we present fully-automated goniophotometer measurements of the cosine corrected BDSF for different automotive interior materials.

## 1 Introduction

The presented work will examine different interior vehicle materials like leather, plastic, wood. All these materials scatter (and reflect) the light differently due to their material characteristics, and thus the visual perception. Therefore, it is necessary to characterize the optical properties with respect to their scattering characteristics.

## 2 Basics of BSDF

The distribution of light due to surface light scattering is commonly described by the bi-directional scattering distribution function, short $\boldsymbol{BSDF}$ [1]. The term bi-directional indicates that the quantity depends on both, the incident light direction and the scattering light direction. In the case of scattering in reflection the BSDF is sometimes called $BRDF$ (bi-directional reflection distribution function). Here, we will use $BSDF$, instead of $BRDF$, because it is more general. The $BSDF$ is defined by the ratio of "scattered surface radiance $L_{scat}$" to "incident surface irradiance $E_{in}$", see Fig. 1:

$$BSDF(\alpha_{in}, \varphi_{in}, \alpha_s, \varphi_s) = \frac{L_{scat}}{E_{in}} = \frac{\frac{d^2P_{scat}}{dA_S \cdot \cos\varphi_S \cdot d\Omega_S}}{\frac{dP_{in}}{dA_S}} = \frac{d^2P_{scat}}{dP_{in} \cdot \cos\varphi_S \cdot d\Omega_S} \qquad (1)$$

where $d^2P_{scat}$ is the (small) amount of scattered light power (in $W$) in the scattering solid angle $d\Omega_s$ (in $sr$), $A_S$ the size (area in $m^2$) of the detector for the scattering power, and $dP_{in}$ the amount of incident light power (in $W$). This area $A_S$ depends on the "detecting scattering angle" $\varphi_s$, since only the cosine part can be "seen" by the detector. The unit of the $BSDF$ is 1/steradian $(1/sr)$.

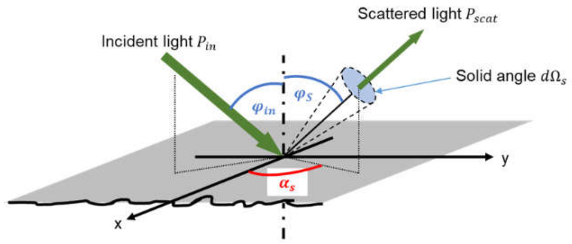


***Fig. 1** . Geometry and terms for light scattering.*

## 3 BSDF measurement method

We measure BSDF using a goniophotometer, see Fig. 2. The distance $d = 500\,mm$ fulfills the photometrical limiting distance [2]: if the distance d is larger than 10 times the largest length of the detector, the measurement uncertainty is below 1 % (our factor is > 380).

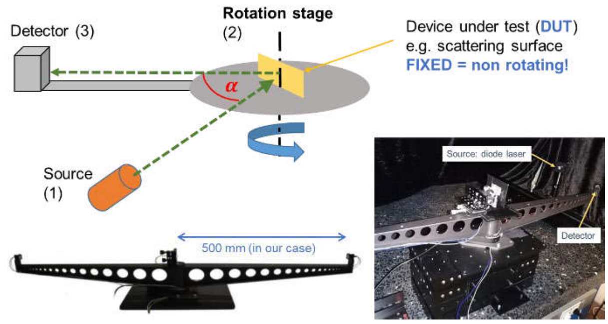


***Fig. 2** Goniophotometer set-up: A source (1) illuminates the DUT mounted on a rotation stage (2) and a detector (3) measures the scattered light. The pictures show the real set-up.*

A green laser diode serves as a source (wavelength: 529 nm, optical power: 4.5 mW CW). The scattering angle $\varphi_s$ ($0° \leq \varphi_s \leq 360°$) is resolved with $\Delta\varphi_s$. The detector is a photodiode S1087-01 from Hamamatsu with 10 pA dark current and 1.3 mm x 1.3 mm photosensitive area resulting in $d\Omega_s = 6.76 \cdot 10^{-6} sr$. The photodiode is used with an operation amp in a transimpedance amplifier configuration using a resistance of 10 kΩ, which yields the measurement result (= optical power) as voltage. At each angle $\varphi_s$ the system measures the light 10 times, calculates the average value and stores it on the computer. This reduces additional noise effects. The whole setup is on an optical granite bench to suppress fluctuations and positioned inside a dark room for stray light suppression. By using LabView the whole set-up is controlled by a computer and fully automated. We tested and verified the whole goniophotometer set-up earlier [3]. Again, the set-up is used to measure BSDF in reflection.

DGaO-Proceedings 2020– http://www.dgao-proceedings.de – ISSN: 1614-8436 – urn:nbn:de:0287-2020-P011-5

submitted: 17.Jun.2020 published: 13.Jul.2020

## 4 Measurement results

The determination of $BSDF$ according Eq. (1) requires a calibration of the optical power vs. measured voltage. We measured the laser power focused with an uncoated N-BK7 f = 100 mm lens using a calibrated integrating sphere. Afterwards, we focused the laser beam on the photodiode with the same lens (thus illuminating only the photosensitive area of the photodiode). A voltage of $U = 8.45\,V$ measured with the photodiode and operation amp corresponds to $P = 3.6\,mW$ (measured) optical power using the N-BK7 lens. Thus, the incident power from the laser diode without lens is $P_{in} = 3.92\,mW$. With an in-plane measurement the BSDF is measured (in reflection), see Fig. 3.

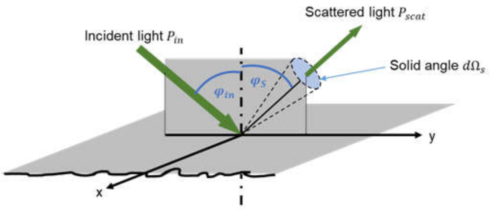


***Fig. 3*** *Geometry of an in-plane BSDF measurement.*

The laser has an incident angle of $\varphi_{in} = -20°$ (to the surface perpendicular) for all measurements. Here, the cosine corrected BSDF (also called angle-resolved scattering, $ARS$) is plotted:

$$ARS(\varphi_S) = BSDF \cdot \cos\varphi_s = \frac{d^2 P_{scat}}{dP_{in} \cdot d\Omega_s} \qquad (2)$$

This avoids singularities at around $\pm 90°$ due to the cosine factor and enables a fair comparison.

The measured materials shows Fig. 4


***Fig. 4*** *Picture of the 3 measured materials.*

The first measurement is on a smooth transparent plastic surface. Here we make a "proof of principle". Plastic has about 4% reflection losses and a strong peak at the specular reflection should be detected, i. e. at +20° (corresponding to the law of reflection). We measured roughly 4% of reflected power which justifies the measurement set-up. Also, a strong peak at +20° in the cosine-corrected BSDF is observed, see Fig. 5 indicating the correctness of the measurement of a smooth transparent plastic surface.

The next two measurements are on white leather and wood, see Fig. 6, with rough and/or structured surfaces.

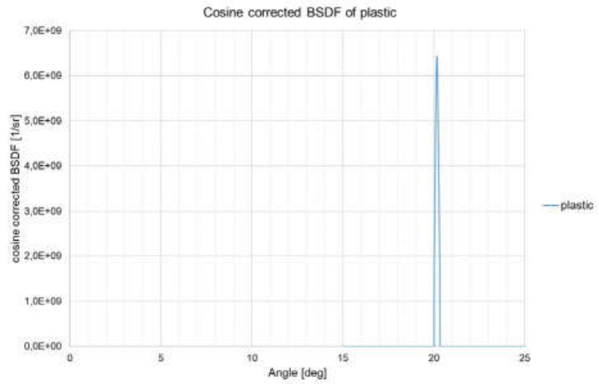


***Fig. 5*** *Cosine corrected BSDF (ARS) measurement of transparent plastic (resolved with $\Delta\varphi_s = 0.007°$).*

For white leather, a more forward scattering at the specular angle +20° is observed. A noise analysis of the measurement results indicates that the fluctuations stem mainly from the operation amp [4].

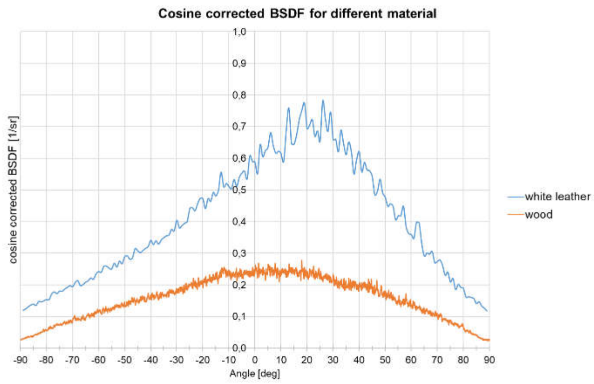


***Fig. 6*** *. Cosine corrected BSDF (ARS) measurement of white leather and wood as possible automotive interior materials.*

## 5 Summary

We characterized three different automotive materials by cosine corrected BSDF that can be used for modelling and designing future automotive light scenarios. In future, more materials will be characterized and the operation amp amp will be optimized for lower noise.

## References

[1] John Stover, *Optical Scattering Measurement and Analysis*, (SPIE Press, Bellingham 2012)

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[4] J. Laukert, M. Schürholz, P. Thai: „*Rauschoptimierung einer OPV-Schaltung zur Messung optischer Lichtleistung*", student project work at Pforzheim University, Feb. 2020.