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Top: Light scattering measurement system MLS5 for hemispherical scattering analysis from UV to VIS and NIR

Cover: Alignment of a free-form mirror for light scattering measurement in a laboratory light scattering instrument

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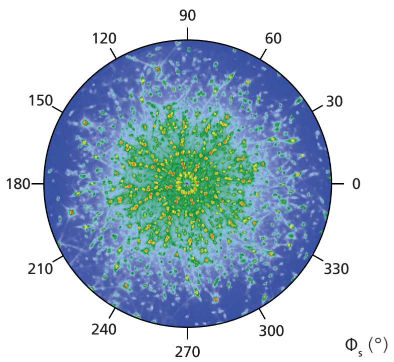
Light Scattering

Measurement & Analysis



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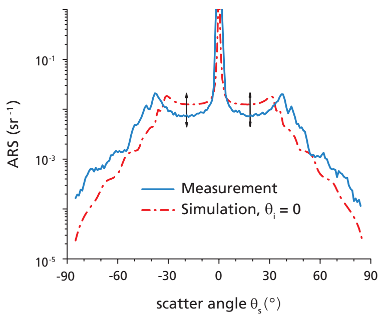

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1: 3D hemispherical scattering distribution of a gemstone (diamond) measured at 532 nm

2: Scattering distribution of a highly reflective interference coating for DUV lithography - measurement at 193 nm and modeling

3: Customized instrument for angle resolved scatter measurements in the IR

Light Scattering

Background

Light scattering caused by imperfections of optical components can critically affect the performance of optical systems. Even high-quality optical components exhibit some level of light scattering leading to optical losses, image degradation, and straylight. Detailed knowledge of the scattering properties through angle resolved and total light scattering measurements is therefore essential for quality control and performance predictions.

The causes for light scattering range from simple residual surface roughness to surface or subsurface defects, contaminations, interference effects, bulk effects, and grating inhomogeneities. While Total Scattering (TS) provides a simple number for the scatter loss of an optical component, Angle Resolved Scattering (ARS/BRDF) provides more detailed information on the angular distribution of the scattered light. Therefore, it is a powerful tool for the characterization of the scattering origins with applications for various optical components from polished and coated surfaces to diffraction gratings and black surfaces.

Depending on the final application and the characteristics of the sample to be analyzed, measuring light scattering can be a challenging task and requires careful considerations and planning. We have a 30 year long history of performing high-quality scatter measurements in various scenarios.

Service

- Analyze your problem and develop measurement plans tailored to your specific needs
- Perform high-quality light scattering measurements
- Develop customized instruments for light scattering measurements
- Link light scattering properties to surface imperfections (roughness, defects), fabrication processes, optical design, and functional properties
- Model light scattering of surfaces, coatings, and optical materials supported by roughness analysis

Parameters

- ARS or BRDF according to ISO 19986 or SEMI/ASTM1392
- TS according to ISO 13696
- Reflectance, Transmittance, diffraction efficiency
- Wavelengths from EUV (13.5 nm) to IR (10.6 µm)
- High sensitivities / lowest noise levels (noise equivalent BRDF $<10^{-8}$ sr^{-1} for VIS/NIR)
- Highest angular resolution / smallest near angle limits (down to 0.1°)
- Angular scans (in-plane, out-of-plane, 3D) and sample mappings
- Export of scatter data to straylight simulation codes (FRED, ASAP, ZEMAX, and others)
- Laboratory instruments, table top scatterometers, and compact scatter sensors

Data sheet | Light Scattering

Measurement & Analysis Examples

Supersmooth surfaces with roughness levels down to 0.1 nm rms require measurements with highest sensitivities and lowest background noise close to or even below the Rayleigh scatter level of the surrounding medium.

Even though scatter measurements **on rough surface** are not challenging regarding sensitivity, speckle effects have to be taken into consideration.

Diffraction gratings have to be measured with a well collimated/defined and monochromatic incident beam. In addition to parasitic light scattering within the diffraction plane, pronounced out-of-plane scattering often occurs (see Fig. 4).

For **imaging applications**, the scattering distribution often has to be accurately measured also at very small angles such as 0.1° with respect to the specular direction. This requires a well-designed illumination system and exact knowledge of the near angular system signature.

Interference coatings (Fig. 2) sometimes show a tremendous spectral variation of the scattering properties leading to a need for measurements not only at the central wavelength but also at other wavelengths within the active band and at the band edges.

Studying **optical materials** often leads to the challenge of separating bulk from surface effects.

Black coatings (Fig. 5) used as straylight absorbers in optical systems show a strong dependence of scattering from the angle of incidence as well as pronounced anisotropic scattering. Moreover, the scattering characteristics in the VIS, UV, and IR spectral ranges can vary from perfectly diffuse to strongly specular.

Curved elements such as concave or convex mirrors, lenses, and other optical components require well-controlled incident beam characteristics to maintain high angular resolution.

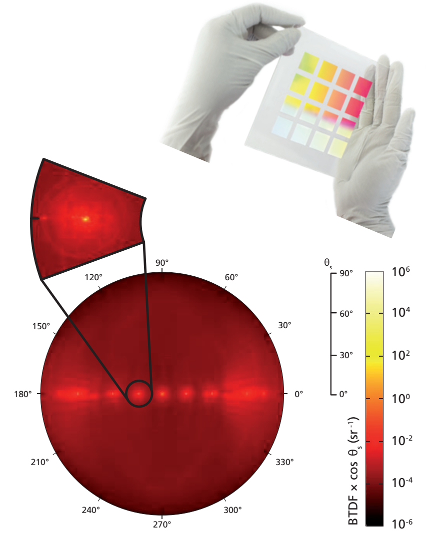
Measurements on **small samples** such as microlenses require reduction of the illumination spot on the sample from typically 1 mm to 100 µm.

For **large components**, areal scatter mappings of the surface can provide useful information about sources of inhomogeneity and the distribution of isolated defects (Fig. 6).

Summary

Fraunhofer IOF is specialized in analyzing various optical problems, finding the right measurement strategy to balance gain of information and effort, performing high-quality light scattering measurements, and interpreting the results to support your development.

In addition to measurements using our in-house laboratory systems, we offer customized (table-top) instruments and compact sensors to be used close to or even in fabrication processes.



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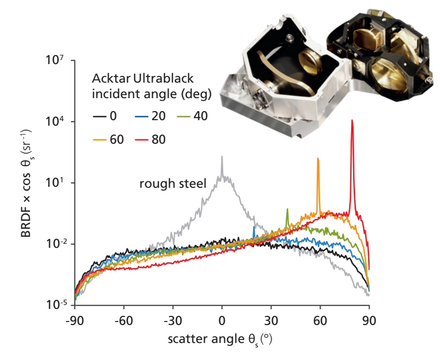

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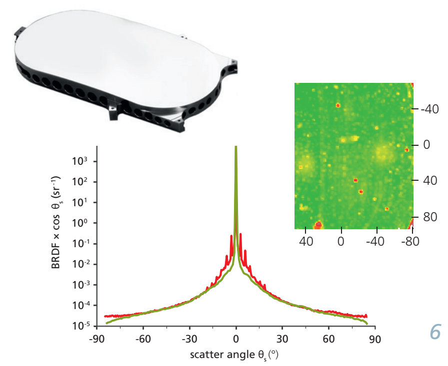

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4: 3D hemispherical scattering distribution of a diffraction grating measured at 325 nm

5: Scattering distribution of a black coating at different angles of incidence measured at 4.63 µm

6: Spatially resolved scattering mapping and Scattering distribution of a free-form mirror measured at 532 nm