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Light Scattering of optical Components and their Imperfections: Measurement, Modelling, and System Analysis

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Abstract. Light scattering in optical systems is caused by various imperfections such as surface roughness, bulk inhomogeneity, contamination, and ghost light beam paths. Control of these scattering sources is crucial, particularly for high-precision optical components, and involves both measurement and modelling from the design phase through fabrication to system integration. Recent developments at Fraunhofer IOF have led to advanced instruments for characterization of both optical components and system. Moreover Light scattering measurements provide not only analysis capabilities but also critical data for optimizing fabrication processes by identifying scattering contributors. Results and applications of these techniques and tools will be presented, highlighting their impact on optimizing optical system fabrication.

1 Introduction

Light scattering of optical components and in optical systems is caused by numerous types of imperfections such as interface or surface roughness, bulk inhomogeneity, particles and other contamination, as well as ghost light paths [1-6]. Thus, light scattering control based on measurement and modelling is required in particular for high precision optical components and systems. This control of light scattering sources is required over the entire fabrication process of optical systems beginning in the design phase over the fabrication of components and system integration.

Moreover, the variety of scattering origins and complexity of scattering mechanisms for different types of optical components requires the combination of experimental light scattering measurement and modelling as base of a thorough stray light analysis on system level.

At the same time light scattering measurement not only enables the scattering to be analysed or provides input for system level stray light analysis. It also provides numerous information on the scattering contributors [2-6] and thus enables optimization of the corresponding fabrication processes.

Consequently, instruments for at wavelength characterization of optical components and even of optical systems have been developed over recent years at Fraunhofer IOF [3-6] for measurement of the angle resolved scattering (ARS) or bidirectional scattering distribution function (BSDF). Exemplary results and application of corresponding analysis techniques and tools will be presented and discussed.

2 Scattering analysis - examples

2.1 Imperfections (Defects, MOC, PAC)

Even with highest care in the fabrication of precision optical components, defects and contamination might not be avoidable. Therefore, a central question is which levels of imperfections of a specific kind can be tolerated without violating the scattering requirements determined in the design process of an optical system.

Moreover, the scattering of single features distributed over extended surface areas has to be assessed to provide useful scattering data. This can be achieved using a combination of area covering scattering mappings, ARS/BSDF measurement and averaging.

The following figure shows such averaging results for a silicon wafer and a commercially available protected Al mirror which have both a PAC level of approximately 150 ppm.

Even this moderate contamination level increases the scattering of the supersmooth Si wafer by more than a factor of 100. On the other hand, the increase is less than a factor of 10 for the protected Al mirror since the initial scattering of the clean mirror is already significantly higher by the interface roughness of the mirror.

In the talk further results for contamination induced scattering will be presented including the analysis and modelling of scattering induced by molecular contamination (MOC).

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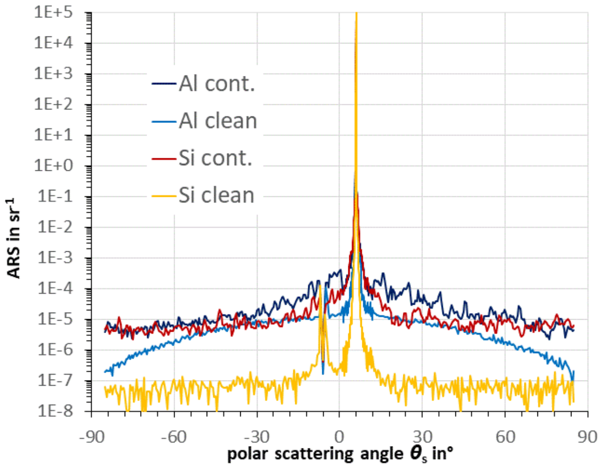

Fig. 1. Average angle resolved scattering of a protected Al mirror and a Si wafer at an illumination wavelength of 532 nm for the uncontaminated surfaces and contaminated with a PAC level of appr. 150 ppm.

2.2 Scattering footprints of imperfections and fabrication technologies

Angle resolved scattering distributions carry valuable information on the scattering origins. Consequently, scattering measurement and analysis can be exploited to investigate the scattering origins and to optimize the corresponding processes. Typical examples are:

- scattering by Turning marks on diamond turned optics
- scattering from surface roughness by different polishing techniques
- Ghost light of grating (e.g. by holography or e-beam lithography)
- Scattering by interface roughness evolution in optical thin film coatings.

The hemispherical scattering distributions of two low loss multilayer mirrors obtained at an illumination wavelength of 633 nm on the following figure reveals for example information on:

- substrate roughness given by the anisotropic star like scattering pattern (top) caused by anisotropic scratch like features on the substrate
- interface roughness and coating design given by the ring like pattern caused by interference of roughness induced light scattering
- presence of a coating defect or a particle represented by the oscillation in the scattering distribution (bottom).

From these scattering distributions hemispherical scattering losses of only 1.8 ppm and 2.1 ppm were determined demonstrating the high sensitivity achieved using scattering analysis and providing an essential part of the energy balance of low loss components.

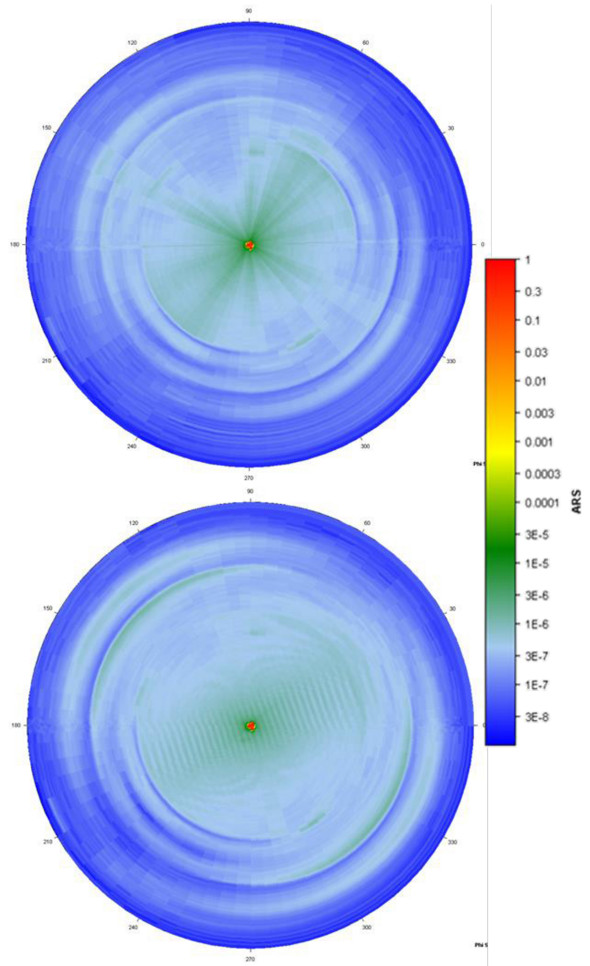

Fig. 2. Hemispherical scattering distribution of two low-loss multilayer mirrors at an illumination wavelength of 633 nm. (backward hemisphere, normal incidence, hemispherical scattering loss of 1.8 ppm (top) 2.1 ppm (bottom).

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