Light scattering measurements on optical components at 157 nm and 193 nm

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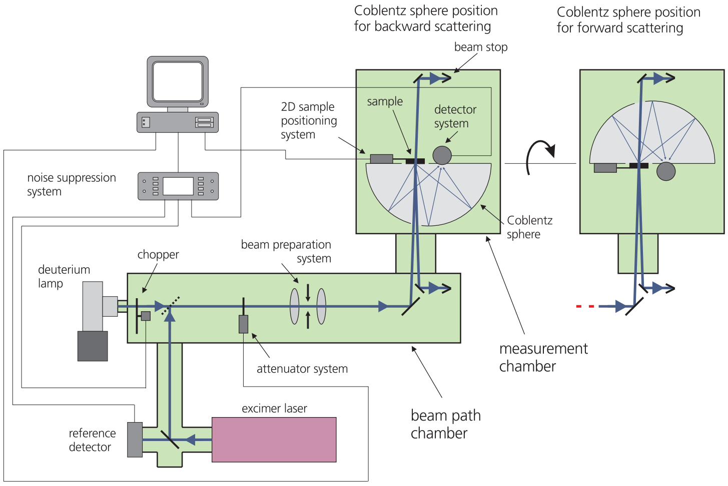

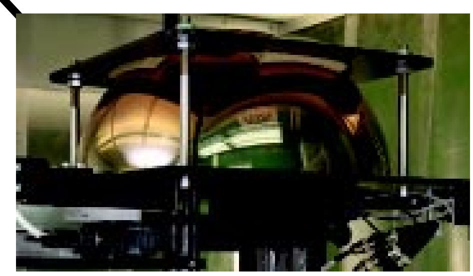

Fig. 1:
VUV measurement system, 157 / 193 nm. Photograph of the vacuum chambers (left), schematic diagram of the instrument (top right), and Coblentz sphere - position for total forward scatter measurement (bottom right).

The quality of optical thin film components is critically influenced by surface and interface roughness. With the ongoing trend of today's optical lithography towards ever decreasing wavelengths, the requirements for low-scatter optics in the DUV and VUV spectral regions and, in the long-term, at EUV wavelengths, are significantly increasing.
We report on an optimized instrumentation for total backscattering (TS-R) and forward scattering (TS-T) measurements of optical components at 157 nm and 193 nm. The design and construction of this instrumentation were driven by the industrial demands as mentioned above.
The TS-system, schematically shown in Fig. 1 (top right) and described in detail in /1/, is based on a Coblentz sphere (Fig. 1, bottom right). The Coblentz sphere images the light scattered into the backward or forward hemisphere within an angular range from 2° to 85° onto the detector according to ISO/DIS 13696 /2/.

High quality steel chambers (Fig. 1, left) for the collecting element and beam path can be operated in both vacuum and nitrogen atmosphere.
A specific technical arrangement allows for easy change from backscatter to forward scatter measurement, maintaining identical sample position and beam parameters.
The system was in particular optimized with respect to high resolution (low background scatter), fast and robust operation, and suitable purging/pumping regime. Although the system can be operated with an excimer laser as well as with a deuterium lamp, we mainly use the excimer laser, because this configuration enables the best performance.
The extremely low background scatter levels achieved for operation at 157 nm are depicted in Fig. 2. These signals represent detection limits of about 1×10^{-6} (1 ppm) in both the forward and backward directions at 157 nm and 193 nm for measurement in vacuum. If the system is purged with pure nitrogen, Rayleigh scattering by gas molecules increases the background level by about two orders of magnitude.
Measurements under vacuum conditions, however, can cause hydro carbon contamination of the sample surfaces and optical elements.
By suitably combining operation in vacuum and purge gas, Rayleigh

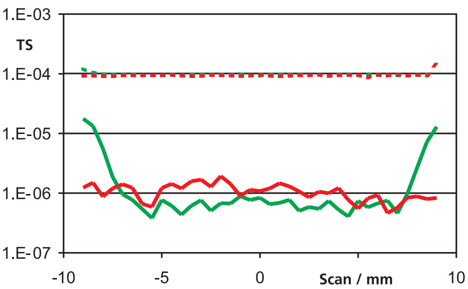

Fig. 2:
Background scatter levels of the VUV TS set-up at 157 nm in the forward (red) and backward (green) directions. The measurements were performed in purge gas (dotted line) and vacuum (full line).

scattering at gas molecules and hydro carbon contaminations can be minimized.

For high performance optics it is essential to assure a constant quality over the whole sample area. A small diameter of the illuminating beam enables two-dimensional mappings of the total scattering with a spatial resolution better than one millimeter. This provides excellent information on the homogeneity of optical components. Fig. 3 shows a two-dimensional TS-mapping (λ = 157 nm) over the entire optically used area of a dielectric high reflective multilayer coating on CaF_2. The structures in this TS-diagram originate from inhomogeneities in the coating or particles and scratches on the substrate.

As a result of its transmission range extending to wavelengths as short as 120 nm, CaF_2 is gaining crucial importance in UV-optical applications. It has become the material of choice for many optical components of KrF (248 nm) and ArF (193 nm) excimer laser waver steppers, and is the main material for use at 157 nm. Fig. 4 displays a forward scatter mapping (λ = 157 nm) of a superpolished CaF_2 substrate. As a result of the high resolution of the measurement system even slight variations of the polishing quality across the surface can be clearly detected through the corresponding scatter level variations.

Beside the difficulties in high quality polishing of CaF_2, volume scattering from the CaF_2 bulk can also considerably limit the performances at 157 nm and 193 nm. To investigate volume scattering of CaF_2 substrates, we measured TS-T and TS-R at 193 nm on two identically polished CaF_2 substrates (Fig. 5). One sample (B) reveals drastically increased forward scatter losses indicating volume scattering in the bulk material of the sample since the surface finish was identical for both samples.

A two-dimensional mapping of the sample that exhibited volume scattering is also given in Fig. 5. The inhomogeneous scatter losses are caused by volume imperfections in the substrate material.

The extension of the system to angle resolved scatter (ARS), transmittance and reflectance (T, R) measurements has been constructed and is currently being implemented.

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References

/1/ Jörg Steinert, Stefan Gliech, Angela Duparré: “Light scattering measurements on optical thin film components at 157 nm and 193 nm,” Applied Optics (2002), in print

/2/ ISO/FDIS 13696, “Laser and laser related equipment. Test method for radiation scattered by optical components”, International Organization for Standardization, Geneva, 1999.

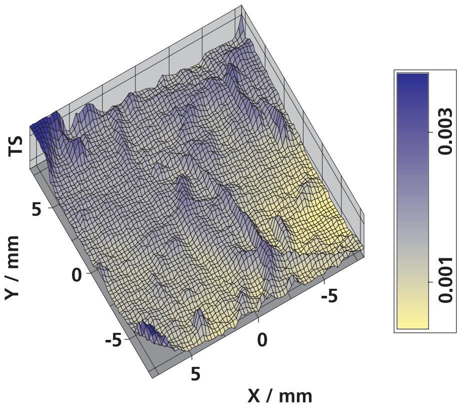

Fig. 3:
Two-dimensional backscatter mapping at 157 nm of a fluoride multiplayer HR system on CaF_2.

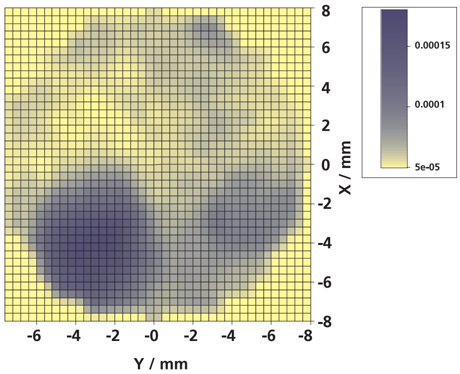

Fig. 4:
Forward scatter mapping at 157 nm of a superpolished CaF_2 substrate.

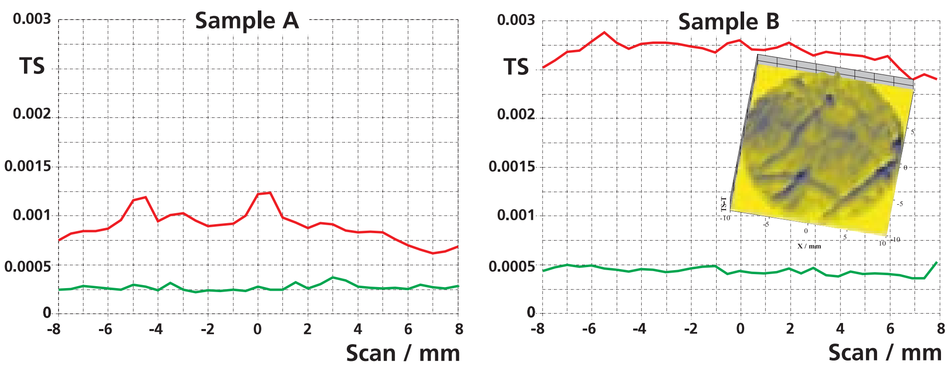

Fig. 5:
Forward scatter (red) and backscatter (green) scans at 193 nm of two identically polished CaF_2 substrates (A, B). One sample (B) shows noticeably increased TS-T – values indicating volume scattering from the bulk of the substrate.