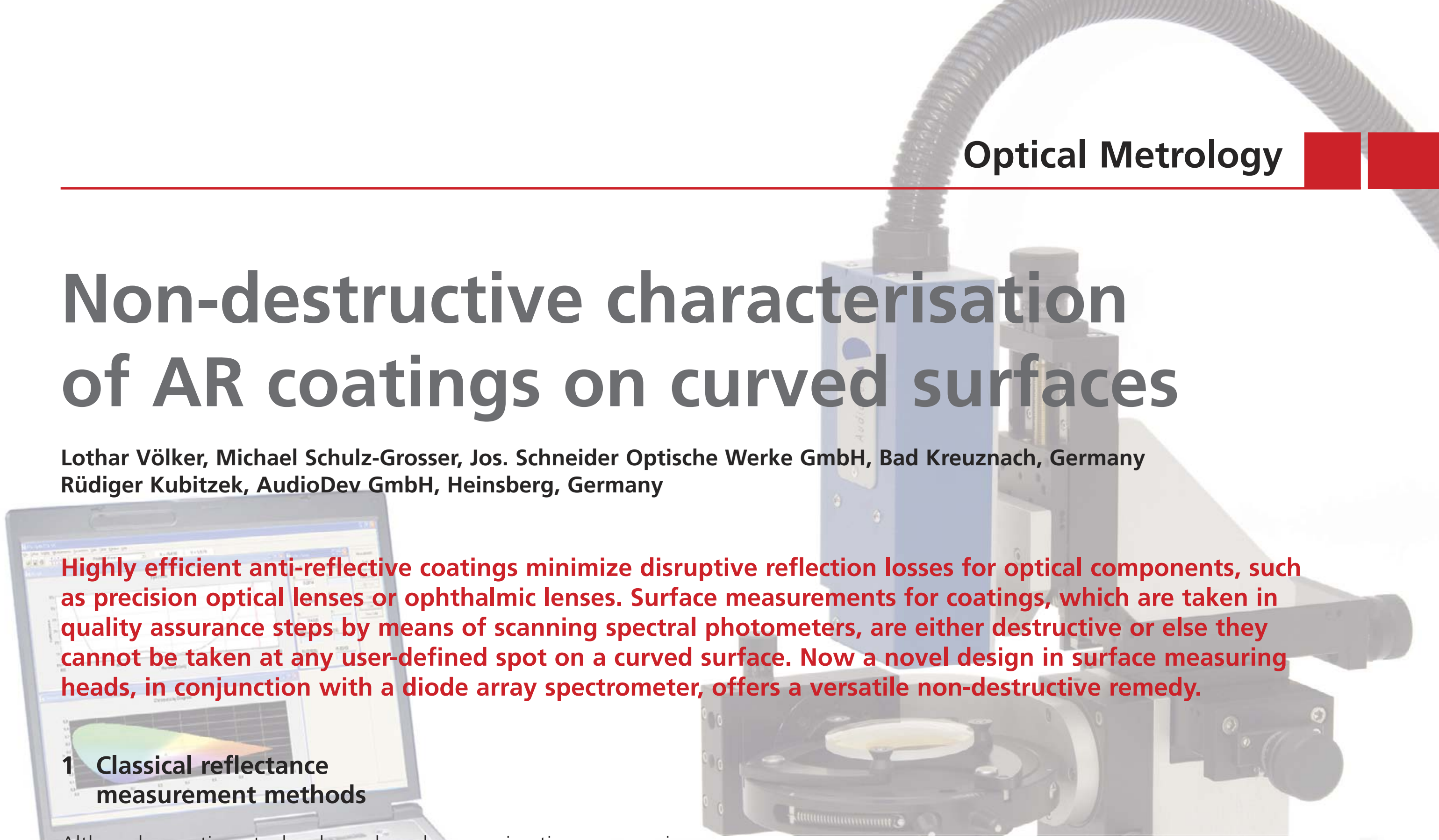


Non-destructive characterisation of AR coatings on curved surfaces

Lothar Völker, Michael Schulz-Grosser, Jos. Schneider Optische Werke GmbH, Bad Kreuznach, Germany
Rüdiger Kubitzek, AudioDev GmbH, Heinsberg, Germany

Highly efficient anti-reflective coatings minimize disruptive reflection losses for optical components, such as precision optical lenses or ophthalmic lenses. Surface measurements for coatings, which are taken in quality assurance steps by means of scanning spectral photometers, are either destructive or else they cannot be taken at any user-defined spot on a curved surface. Now a novel design in surface measuring heads, in conjunction with a diode array spectrometer, offers a versatile non-destructive remedy.

1 Classical reflectance measurement methods

Although coating technology has been enhanced consistently in recent years, and quality assurance has gained significance at the same time, spectral reflectance measurement methods for coated optical elements have remained almost unchanged. Conventional reflection techniques demonstrate serious problems with some optical reflection measurements, because the classical process can not distinguish between rear-side reflections and front-side reflections of the component that is to be measured. Some witness samples are still included in every batch of lenses to be coated. And after coatings are completed, in time-consuming procedures, these witness samples must be roughened and blackened on the reverse side prior to measurements in order to eliminate bothersome rear-side reflections[1]. The witness samples are then measured with a regular spectrophotometer, with the assumption that the measured reflectance values are representative for the entire batch of coated optical elements.

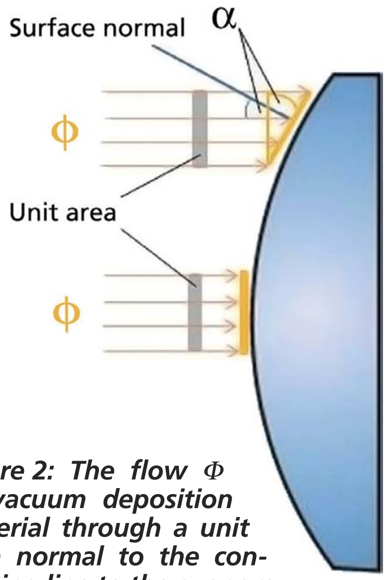


Figure 2: The flow Φ of vacuum deposition material through a unit area normal to the connecting line to the evaporation source is constant. However, for geometrical reasons a given quantity of vacuum deposition material will be distributed over a larger surface area in the lens periphery as opposed to the lens centre

Unfortunately, 100% control of component quality cannot be accomplished via this classical measurement process. Real production lenses cannot be tested due to the destructive nature of this process. The extent of the difficulties of reflection measurement problems is evident when a customer raises issues or complaints; until recently there have been no measurement data taken directly on the optics.

Some reflectance measurements can be misleading, because even high-performance spectrophotometers only measure spectral reflectance averaged over a relatively large area in the centre of the component. More often, spectral reflectance characteristics at the centre differ considerably from actual off-axis characteristics (**figure 1**).

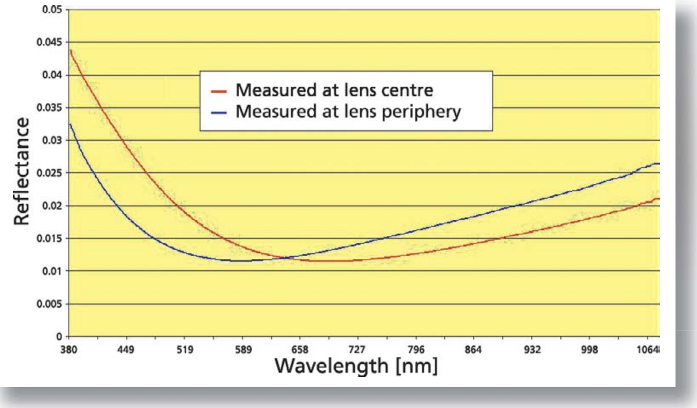


Figure 1: Spectral reflectance characteristics for a single layer MgF_2 coating on a standard plano-convex lens (50 mm diameter, ~50 mm radius of curvature) measured in the centre (red curve) and in the periphery (blue curve) of the lens. The spectrum measured in the periphery clearly reveals a blue shift

Whenever convex lenses with small radii of curvature have been coated in a vacuum chamber with conventional calotte systems instead of a planetary system, significant differences in reflectance characteristics can be present. For example, the distances between the height at the lens periphery and the lens centre to the evaporation source are significantly different. This is because there are more flat angles under which light is impinging on the lens periphery. This also causes thinner layers of coating material to be deposited there as opposed to the lens centre (**figure 2**). That azimuthal layer thickness distribution, which is in first approximation

---

[1] The necessity to roughen and blacken the test specimen on the reverse side does not come from the curved surface, but from the measurement geometry (normal incidence) that does not allow a spatial separation of front and rear side reflections as a matter of principle. There are further reasons why witness samples are still used, e.g. the need to carry out scratch resistance tests or adhesive tape tests to estimate coating adhesion.

Originally published in German in Photonik 1/2010

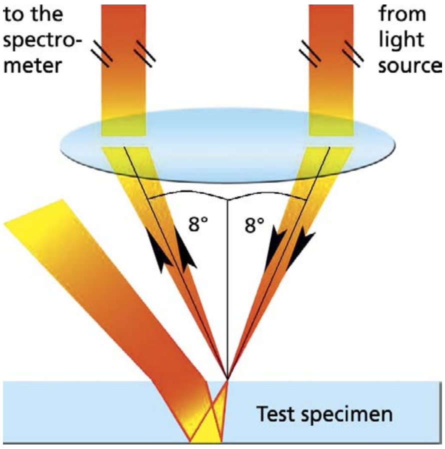


Figure 3: Schematic diagram of the measuring head, which omits the focus and tilt sensors, as well as the transmitted beam, for the sake of simplicity

proportional to the cosine of the angle α between the surface normal and the evaporation direction, leads to a blue shift of the spectral reflectance characteristics of the AR coating [1].

In camera lens applications, the end user seeks minimised light losses across the entire field of view. This is one of many examples to show the importance of producing reliable spectral reflectance characteristic data, not only in the lens centre but also in the lens periphery.

2 Non-destructive front-side reflection measurement

Many disadvantages of the classical destructive process described above can be avoided when the rear-side reflection is fully suppressed by means of an innovative measuring head concept. When the scanning spectrophotometer is replaced with a diode array spectrometer, light from a broadband source is guided through an optical fibre to the measuring head and then focused onto the lens surface at almost normal – under an angle of incidence of 8° (**figure 3**).

In accordance with the law of reflection, this light is reflected under an angle of -8°, and then collected by another optical fibre to be guided to the entrance slit of a spectrograph. A diode array located in the exit-slit plane of that spectrograph records the reflected light's intensity distribution. Therefore, the integration of focus and tilt sensors into the measuring head enables a precise and consistent alignment of the measuring head in terms of distance and angle anywhere on the lens surface, not only in the lens centre but also in the lens periphery[2].

Sufficient geometrical separation of the front- and rear-side reflections is accomplished at the chosen 8° angle of incidence. Only the front-side reflection is imaged onto the receiving optics. Besides, deviations from measurement at normal incidence, as well as effects of the direction of polarisation of the incident light, can still be neglected. An additional spatial filter helps to separate front- and rear-side reflections. This enables measurements of lenses as thin as 2 mm without roughening and blackening them on the reverse side (**figure 4**).

Because this test method is of a comparative nature, its achievable photometric accuracy strongly depends on the accuracy of the spectral reflectance of the reference sample. Uncoated glass substrates of known materials are exceptionally well suited to this non-destructive technique [2]. The dispersion curve of that known material, and hence its spectral reflectance characteristics, can be calculated with excellent precision using Sellmeier coefficients, which are tabulated in glass catalogues [3].

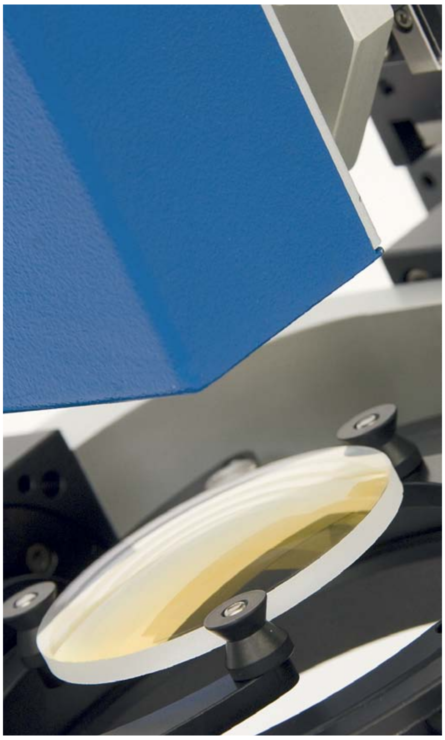
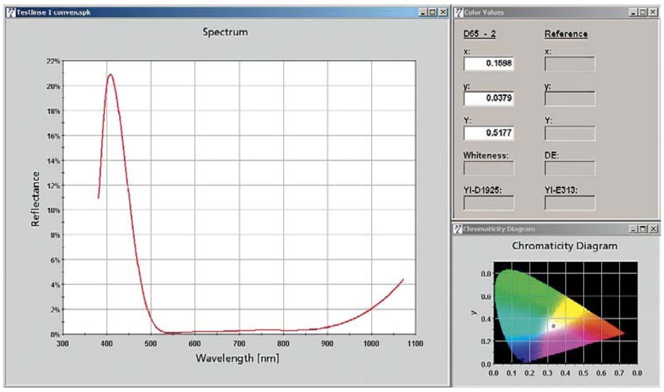


Figure 4: Contactless optical measurement succeeds even with relatively thin lenses, without the need to roughen or blacken them on the reverse side

Furthermore, the accuracy of measurements can be verified – first by referencing with an uncoated glass sample of one known material and then by measuring an uncoated glass sample of another known material. This technique enables photometric accuracy of about ±0.5% of the spectral reflectance of the utilised reference. For example, if N-BK10 with R = 4% is used as reference, an accuracy of ΔR < ±0.02% can be achieved.



D65 - 2
x: 0.1598
y: 0.0379
Y: 0.5177
Whiteness:
YI-D1925:

Reference
x:
y:
Y:
DE:
YI-E313:

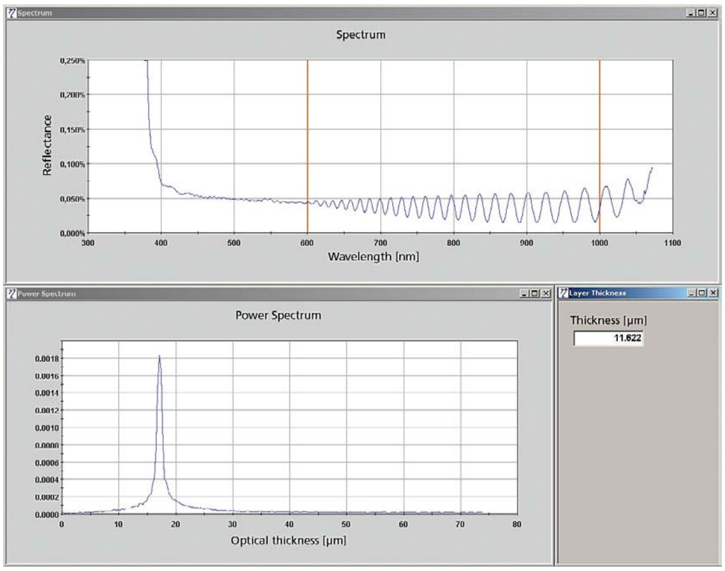
Figure 5: Typical result of a measurement including determination of chromaticity values x and y as well as tristimulus value Y (brightness) for CIE 1931 2° Standard Observer and Standard Illuminant D65

3 Colour appearance and layer thickness of hard coatings

If the spectrum φ(λ) = S(λ)·ρ(λ), as recorded by the spectrometer, is regarded as a colour stimulus function, where S(λ) describes the spectrum emitted by the light source and ρ(λ) denotes the spectral reflectance, chromaticity values x and y as well as tristimulus values X, Y and Z of the coating's colour stimulus can immediately be calculated from that function – as shown in **figure 5** – in 1931 CIE colour space [4].

Determination of the chromaticity definitely makes sense when analyzing AR coatings, as it will enable colour matching

[2] In order to reach conclusions about the layer thickness in the lens periphery it does make sense to measure reflectance in this area too at almost normal incidence. In fact, generally speaking, light rays are hitting the lens periphery of e.g. a camera lens to some extent at pretty flat angles rather than in normal incidence. This is leading to an additional blue shift of the coating's AR effect, which, however, can be factored in by powerful optical design programs if the layer thickness variation towards the lens periphery has been typed in properly.



Thickness [µm] 11.622

Figure 6: Reflectance spectrum used for the determination of the cement layer thickness of compound lenses. The reflectance spectrum reveals modulations typical for layers in the range of a few micrometers

of individual lenses – a very desirable feature when assembling binoculars and in sorting ophthalmic lenses.
The non-destructive reflectance measurement techniques described here offer ways to obtain the actual thickness of a single layer coating on the lens surface, as measured from spectral reflectance, provided that the refractive index (or the dispersion curve) of the coating material is known. For layer thickness above 1 µm a Fast Fourier Transformation can be used, whereas for thinner layers a curve fit is applied.
With compound lenses, the option of measuring the lens and coating layer thicknesses can also be used to measure the thickness of cement layers, so long as it is located between two lens elements that are at least 2 mm thick each (**figure 6**). Because the measuring spot diameter is considerably smaller than 1 mm, and because the technique supports measuring at arbitrary positions, it is even possible to study the homogeneity of the cement layers.

4 Summary and outlook

The innovative spectral reflectance measurement procedures presented here enable very fast, direct, and non-destructive ways of gathering spectral reflectance data anywhere on a curved AR coated lens surface by applying a fiberoptic-based measuring head concept. Any reflection from the reverse side of the test specimen can be fully suppressed. Additional benefits in quality assurance, R&D, and operations stem from the feasibility of testing actual products instead of from testing witness samples alone. While avoiding laborious sample preparations, these measurement techniques achieve accuracies comparable with conventional measurements taken by high-end spectrophotometers. Therefore, the technique offers both an alternative and a useful complement to the classical reflectance measuring process.

Literature:

[1] M. Schulz-Grosser, *Reale Transmission von Objektiven und optischen Systemen*, Talk presented at 7th DUV/VUV-Optics workshop, Dresden, Sept. 28, 2004
[2] H. Frey, G. Kienel (Hrsg.), *Dünnschichttechnologie*, VDI Verlag, Düsseldorf, 1987, p. 282
[3] J. Bliedtner, G. Gräfe, *Optiktechnologie*, Fachbuchverlag Leipzig, 2008, p. 49
[4] M. Richter, *Einführung in die Farbmetrik*, Walter de Gruyter, Berlin 1981, 2nd edition, p. 68 ff

Author contact:

Lothar Völker
Jos. Schneider Optische Werke GmbH
Ringstr. 132
55543 Bad Kreuznach
Germany
Tel. +49/671/601-336
Fax +49/671/601-81-336
eMail: voelkerl@schneiderkreuznach.com
Internet: www.schneiderkreuznach.com

Dr. Rüdiger Kubitzek
Managing Director
AudioDev GmbH
Borsigstr. 78
52525 Heinsberg
Germany
Tel. +49/2452/96001-521
Fax +49/2452/64433
eMail: ruediger.kubitzek@audiodev.com
Internet: www.audiodev.com