On potential discrepancies between goniometric and sphere-based spectral diffuse reflectance

F. Manoocheri[1], S. Holopainen[1], S. Nevas[1] and E. Ikonen[1,2]

[1] Metrology Research Institute, Helsinki University of Technology (TKK), P.O. Box 3000, FI-02015 TKK, Finland

[2] Centre for Metrology and Accreditation (MIKES), P. O. Box 239, FI-00181 Helsinki, Finland

Abstract. The potential discrepancies between the gonioreflectometer based and integrating-sphere based methods in the measurement of spectral diffuse reflectance are studied. Errors due to scattered light around the measurement beam in gonioreflectometers are a potential cause of such discrepancies. Procedures used to determine such errors and the required corrections are presented. At TKK, the corrections varied from -1,1% to -0,2% for the studied two cases. The measurement results for our diffuse reflectance reference materials with the appropriate corrections in both cases are in excellent agreement.

Introduction

Measurements of spectral diffuse reflectance are usually performed relative to a reference standard that is traceable to an absolute scale. The absolute scales of spectral diffuse reflectance are mainly based on integrating-sphere techniques [1, 2, 3]. An alternative approach to these techniques is angular integration of the gonioreflectometric measurement results [4, 5, 6]. The gonioreflectometer-based methods are becoming more popular among National Metrology Institutes for the measurements and realization of absolute scale of spectral diffuse reflectance [7, 8, 9]. However, some discrepancies between the gonioreflectometric and the integrating-sphere based methods have been reported thus raising questions about the origin of the deviations [8].

As a result of recent modifications in the light source system of our gonioreflectometer, the spatial properties of the measurement beam were improved. The most important outcome was a significant reduction in the applied correction necessary to account for the effects of light scattered about main beam. This source of error is shown to be under control in our gonioreflectometer, as proved by the good reproducibility of the test measurement results. If such effects are not properly accounted for, significant deviations may occur. The trends of such deviations are similar to those reported earlier when comparing gonioreflectometer- and integrating sphere-based measurement results of hemispherical reflectance factors [8].

Measurement setup

In the gonioreflectometer at TKK, the sample is illuminated at fixed angles and the reflected light can be measured over the polar angles in the horizontal plane. The total diffuse reflectance is determined by integrating the measured angular distribution of the reflected flux over the hemisphere.

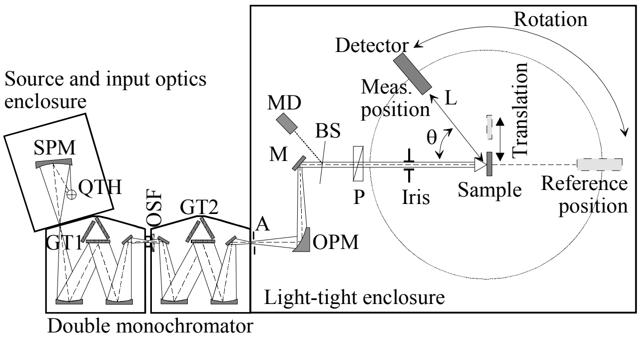

Figure 1. Schematic of the gonioreflectometer setup**:** QTH, quartz–tungsten–halogen lamp; SPM, spherical mirror; GT1, GT2, grating turrets; OSF, order-sorting filter; M, flat mirror; A, aperture; OPM, off-axis parabolic mirror; BS, beam splitter; P, prism polarizer; MD, monitor detector; L, distance between sample and detector.

The present measurement setup is shown schematically in Figure 1. The setup consists of a source system and a goniometric detection system in a light-tight enclosure. Main components of the source system are a quartz-tungsten-halogen lamp and a double monochromator. The beam is collimated and directed towards the sample by an off-axis parabolic mirror and a flat mirror. A beam splitter channels a fraction of the beam to a monitor detector for minimizing the effects of light-source instability. The rest of the beam propagates through a polarizer and an iris before irradiating the sample. The reflected light is probed by the detector over a range of polar angles selected by the detector turntable. The full intensity of the incident light is measured at the reference position of the turntable (Figure 1). During this measurement the sample is moved out of the beam path by using a linear translator. The sample is positioned on another turntable, coaxial with that rotating the detector, which allows adjusting the angle of incidence of the beam [9].

The present double monochromator makes use of toroidal mirrors. This reduces the astigmatism of the output beam to a large extent. Thus the astigmatism correction became unnecessary and some of the optical components in the light-source system became redundant. In the previous setup, a tilted spherical mirror was used for the astigmatism compensation and an extra flat mirror was also needed to guide the beam. Therefore the alignment of the source system is now less complicated than it was in the previous setup. The other important improvement is a significant reduction in the light scattered about the main beam previously referred to as isochromatic stray light [9]. Lower stray light now requires a smaller correction and introduces a lower uncertainty component.

Results

The corrections required for the scattered light were determined by measuring the beam intensity and comparing the signal readings when the detector with interchanging apertures was at the reference position and when it was near the sample plane. The simplest way to test for the existence of such scattered light is to compare the readings obtained when we use the same aperture as in the actual reflectance measurements with those obtained without aperture for the detector at the reference position.

The corrections required for the old and for the new setups are presented in Figure 2. The magnitude of the correction for the new setup has not only decreased but also has become wavelength independent.

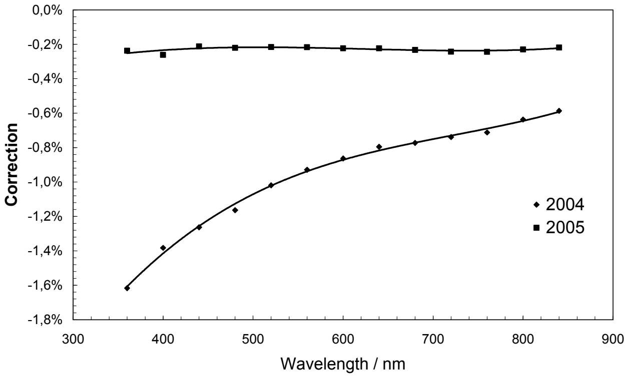

Figure 2. Correction for the scattered light in the old (2004) and the new (2005) setups.

To validate the performance of the instrument after the changes in the source system, test measurements were performed. Figure 3 presents 0/d reflectance of a Spectralon sample measured with the old and the new setups. Agreement between the measurements with the old and new setups is well within 0.1% and well below the uncertainty of the scale realization.

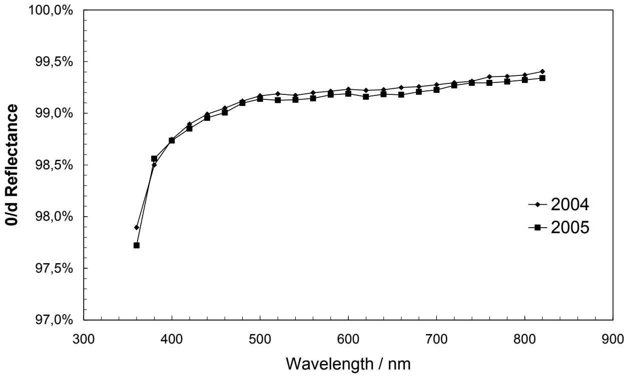

Figure 3. Spectral diffuse reflectance of a white spectralon sample measured with the old (2004) and new (2005) setups.

Conclusions

Recently some modifications were made to the gonioreflectometer at TKK leading to improvements in the spatial properties of the measurement beam. The amount of scattered light decreased significantly resulting in a drop of the correction required from about -1,1 % to -0,2 %. Since the agreement between measurements performed before and after the modifications is very good, we believe that scattering of light about the main beam has been properly accounted for. Furthermore, this effect might be one of the reasons for the discrepancies reported previously between measurements based on gonioreflectometric and integrating-sphere techniques [8]. Considering the magnitude of the correction required before the modifications, it is obvious that definite errors will occur if scattered light is not taken into account when designing and characterizing a gonioreflectometer. We will present more of our validating measurements during the NEWRAD conference and more detailed test procedures in a full paper.

Acknowledgments Silja Holopainen appreciates the support of TES and KAUTE foundations.

References

1. W Budde, and C. X. Dodd, “Absolute reflectance measurements in the d/0° geometry,” Die Farbe **19**, 94-102 (1970).
2. W. Erb, “Requirements for reflection standards and the measurements of their reflection values,” Applied Optics **14**, 493-499 (1975).
3. W. H. Venable, J. J. Hsia, and V. R. Weidner, “Establishing a scale of directional-hemispherical reflectance factor: The Van den Akker method,” Journal of Research of the National Bureau of Standards **82**, 29-55 (1977).
4. Comission Internationale de l’Eclairage, *Absolute Methods for Reflection Measurements*, Publ. CIE 44 (CIE, Vienna, 1979).
5. L. Morren, “Mesure absolue des facteurs de luminance et de réflexion,” Lux **45**, 448-453 (1967).
6. W. Erb, “Computer-controlled gonioreflectometer for the measurement of spectral reflection characteristics,” Applied Optics **19**, 3789-3794 (1980).
7. J. E. Proctor and P. Y. Barnes, “NIST high accuracy reference reflectometer-spectrometer,” Journal of Research of the National Institute of Standards and Technology **101**, 619-627 (1996).
8. C. J. Chunnilall, A. J. Deadman, L. Crane and E. Usadi, “NPL scales for radiance factor and total diffuse reflectance,” Metrologia **40**, S192-S195 (2003).
9. S. Nevas, F. Manoocheri and E. Ikonen, ”Gonioreflectometer for measuring spectral diffuse reflectance,” Appl. Opt. **43**, 6391-6399 (2004).