Comparison Measurements of Spectral Diffuse Reflectance

Saulius Nevas[1], Silja Holopainen[1], Farshid Manoocheri[1], Erkki Ikonen[1,2], Yuanjie Liu[3],
Tan Hwee Lang[3] and Gan Xu[3]

[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.B. 239, FI-00181 Helsinki, Finland
[3] National Metrology Centre, SPRING Singapore, 1 Science Park Drive, Singapore 118221

Abstract A comparison of the scales of spectral diffuse reflectance of the Helsinki University of Technology (TKK) and the Singapore National Metrology Centre (SPRING) was made. A PTFE-type reflectance standard with a nominal reflectance of 98% was measured for the 8/d reflectance factors over the wavelength range from 360 to 780 nm. A good agreement was found between the results of TKK and SPRING. Most of the measured values of spectral diffuse reflectance agreed within 0.36 %, the relative standard uncertainty of the comparison (1σ level).

Introduction

The diffuse reflectance characteristics of a sample under test are normally expressed in terms of reflectance factors that compare the reflectance of the test sample to that of the perfect reflecting diffuser under standardized geometric conditions. The reflectance factor is traceable to its definition and as such there are no fundamental standards physically available for the diffuse reflectance measurements. Therefore diffuse reflectance measurements are usually performed relative to a reference standard traceable to an absolute scale maintained by a national standards laboratory [1, 2, 3, 4, 5].

The reliability of the diffuse reflectance measurements by a national standards laboratory is normally verified via international comparisons [6, 7]. In this report we present results of the bilateral comparison measurements between the diffuse reflectance scales maintained by TKK and SPRING. The realization of the absolute scale of spectral diffuse reflectance at TKK is based on the gonioreflectometric method [5]. The diffuse reflectance scale at SPRING is also traceable to an absolute scale based on the gonioreflectometric method [4].

Instruments and methods

The important features and settings of the instruments used in this comparison are given in Table I. At TKK, the comparison measurements were carried out by using a gonioreflectometer [5]. The instrument consists of a light source and a goniometric detection systems controlled by a PC. The setup is mounted on a vibration-isolated optical table in a light-tight enclosure. The wavelength selection is accomplished with a double monochromator operating in subtractive-dispersion mode.

The hemispherical reflectance factor of a test sample at a selected wavelength is determined through the following procedure. First, the sample is moved out of the beam and the photodetector measures the intensity of the incident beam. Next, the photodetector is turned to the starting position of the angle-resolved measurements bounded to the horizontal plane of the detector movement. In the case of 0° incidence of the beam, the measurements are made over 10° to 85° polar angles with a 5° angle increment. They are also repeated for -10° to -85° angles and the average of the two results is used in the further calculations. The 0/*d* reflectance factor is calculated from the measurement results by spatial integration of the measured solid angles over the whole hemisphere excluding the specular component,

$$R = \frac{\int_{5^o}^{90^o} \frac{I(\theta)}{I_i} \frac{4L^2}{D^2 \cos(\theta)} \sin(2\theta) d\theta}{\int_{5^o}^{90^o} \sin(2\theta) d\theta}, \quad (1)$$

where $I(\theta)$ denotes the signal reading for the intensity that is reflected from the sample and collected by the detector aperture at a polar angle θ, I_i denotes the signal reading for the full-intensity of the incident beam, L is the distance between the detector aperture stop and the sample surface, and D is the diameter of the aperture. For the interpolation/extrapolation of the measured flux distribution at other than the measurement angles, we employed piecewise cubic hermite interpolating polynomial [8].

The comparison measurements at SPRING were carried out using a double-beam, double-monochromator spectrometer fitted with a 150 mm diameter integrating sphere. The 8/d spectral reflectance factors of the sample were measured with the specular components excluded. The measurements were carried out by substitute method using a reference standard traceable to National Physical Laboratory, UK.

Comparison sample and measurements

A commercially available Gigahertz-Optik's reflectance standard made from PTFE-based material (marketing name OP.DI.MA) with nominal reflectance of

Table I. Settings and features of the instruments at TKK and SPRING.

Laboratory	Geometry	Method	Bandpass (nm)	Beam size (mm)	Beam f/#	Beam polarization	Wavelength range and increment
TKK 2004	0/d	Absolute, gonioreflectometer	5.4	17	f/∞	Linear(s- and p-pol)	360-820, 20 nm
TKK 2005	0/d, 8/d	Absolute, gonioreflectometer	5.4	10	f/80	Linear(s- and p-pol)	360-820, 20 nm
SPRING	8/d	Double-beam spectrophotometer with 150mm integrating sphere	5.0	8x16	f/8	Non polarized	360-780, 5 nm

98% was used for the measurements in the comparison. The sample had a flat reflecting surface with the dimensions of 50x50 mm.

The first set of the comparison measurements was completed at TKK in January 2004. The 0/d reflectance of the sample was measured over 360-820 nm wavelength range with a 20 nm step. In October 2004, SPRING measured the 8/d reflectance of the sample over 360-780 nm wavelengths with a 5 nm step. After half a year, in April 2005 the sample was measured again at TKK for both 0/d and 8/d reflectance.

Results

The results of the comparison measurements are provided in Table II. In the table, only the overlapping spectral values of the measurements at TKK and SPRING are listed. The TKK results shown in the second column were obtained by calculating the average of the 0/d values in 2004 and 2005 and applying a correction factor for the difference between the 0/d and 8/d geometries. The correction is provided by the 8/d and 0/d reflectance factor values measured in April 2005 and is below 0.1 % for most of the spectral range. The third column lists the results of the measurements at SPRING. The next columns denoted by u_{TKK}, u_{SPRING} and u_c represent the combined uncertainties of the measurements at TKK, SPRING and those of the comparison at 1σ level, respectively.

The combined uncertainty of the comparison u_c was calculated by adding in quadrature u_{TKK} and u_{SPRING}. The last column of the table shows the relative percent-difference between the 8/d reflectance measurement results at SPRING and at TKK.

All spectral values of 8/d diffuse reflectance factor determined by TKK and SPRING are shown in Figure 1. The relative differences between the measurements at SPRING and those at TKK with the associated uncertainty of the comparison are plotted in Figure 2.

Table II. Results of the comparison measurements. The values presented are in percent units.

λ	TKK (av)	SPRING	u_{TKK}	u_{SPRING}	u_c	δR
nm	8/d	8/d	(σ=1)	(σ=1)	(σ=1)	[%]
360	98.41	98.51	0.30	0.30	0.42	0.11
380	98.66	98.86	0.25	0.30	0.39	0.19
400	98.58	98.82	0.25	0.30	0.39	0.25
420	98.72	99.01	0.22	0.30	0.37	0.29
440	98.82	99.12	0.22	0.30	0.37	0.31
460	98.87	98.86	0.22	0.30	0.37	-
480	98.81	98.77	0.20	0.30	0.36	-
500	98.88	98.91	0.20	0.30	0.36	0.03
520	98.91	98.88	0.20	0.30	0.36	-
540	98.94	98.94	0.20	0.30	0.36	0.00
560	98.92	98.91	0.20	0.30	0.36	-
580	98.96	98.90	0.20	0.30	0.36	-
600	98.94	98.89	0.20	0.30	0.36	-
620	98.94	98.95	0.20	0.30	0.36	0.01
640	98.95	98.83	0.20	0.30	0.36	-
660	98.99	99.00	0.20	0.30	0.36	0.01
680	99.01	98.86	0.20	0.30	0.36	-
700	99.02	98.58	0.20	0.30	0.36	-
720	99.02	98.66	0.20	0.30	0.36	-
740	99.02	98.77	0.20	0.30	0.36	-
760	99.03	98.23	0.20	0.30	0.36	-
780	99.03	98.86	0.20	0.30	0.36	-

Conclusions

The comparison verifies a good agreement between the diffuse reflectance scales of TKK and SPRING. The deviations are well within the combined standard uncertainty of the comparison, except for a few values at the edges of the spectral range over which the measurements were made.

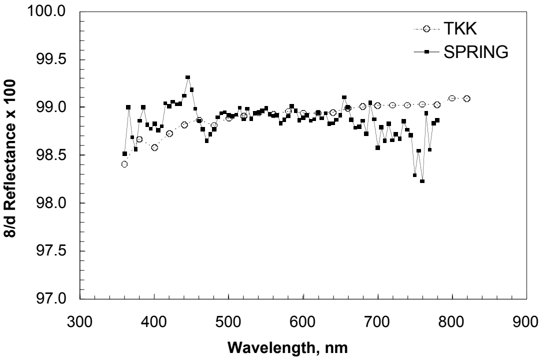

Figure 1. Results for 8/d reflectance factor values of the sample used in the comparison.

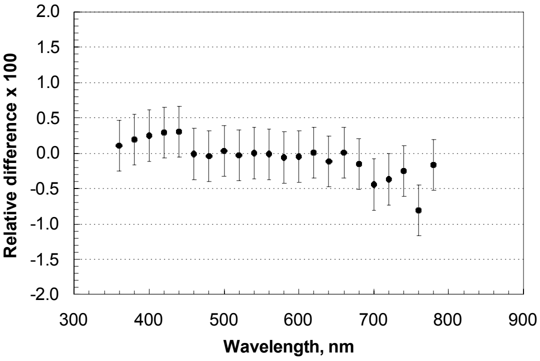

Figure 2. Relative difference in the measurement results between SPRING and TKK. The error bars indicate the relative values of the combined standard uncertainty of the comparison (1σ level).

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