National Institute of Standards & Technology

Certificate

Standard Reference Material® 2525

Linear Retardance Standard

Serial No.:

This Standard Reference Material (SRM) is intended primarily for use in calibrating optical instruments that measure linear retardance and polarimeters that require a known state of polarization for calibration. Each SRM unit is individually certified and consists of a packaged double-rhomb retarder, composed of two concatenated Fresnel rhombs carefully aligned so that the input and output beams are collinear. Retardance, δ, arises from four total internal reflections (TIR) and is stable within ± 0.1° retardance over input angle variations of ± 1°, wavelength variations at least 50 nm, and temperature variations at least 5 °C. Two apertures are provided to aid in the alignment of the SRM.

Table 1. Certified Retardance Value

Wavelength (in nm)	Retardance, δ (in °)	Uncertainty, U (in °)	Twist τ (in °)
± 1		±	±

Certified Values and Measurement Uncertainties: The certified retardance of this SRM unit is given in Table 1. The expanded uncertainty U uses a coverage factor $k = 2$ so that the true value of retardance, δ, lies within ± U approximately 95 % of the time [1,2]; users can use other coverage factors k and calculate expanded uncertainty $U = ku_c$ using the combined standard uncertainty u_c listed in Table 2. Twist is reported as it may impact retardance measurement in some systems (see Instructions for Use). Uncertainty analysis was performed in accordance with NIST requirements [2]; sources of uncertainty are listed in Table 2. Measurement accuracy was determined by intercomparisons with other methods [1,3,4].

Expiration of Certification: The certification of SRM 2525 is valid, within the measurement uncertainties specified, until January 1, 2007 provided that the SRM is handled in accordance with the instructions given in this certificate (see Instructions for Use). This certification is nullified if the SRM is modified or damaged (see Notice and Warnings to Users).

Notice and Warnings to Users: This device is fragile and must be handled with great care. Damage to the rhomb or package, or prolonged storage in humid environments can cause significant changes in retardance and will void the certification.

Upon receipt, allow the package to equilibrate overnight. Then remove the device from the shipping container and visually inspect the optical path. Do not open the protective aluminum housing.

When the SRM is not in use, store it at room temperature in a desiccator. The SRM temperature should be (22 ± 5) °C during use. Let the device equilibrate to room temperature for at least 24 h if it has been exposed to extreme temperatures.

The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the Standard Reference Materials Program by R.J. Gettings.

Gaithersburg, MD 20899
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Thomas E. Gills, Chief
Standard Reference Materials Program

Development of the SRM and supporting measurements were performed by K.B. Rochford, A.H. Rose, and P.A. Williams with assistance from S.M. Etzel, I.G. Clarke, G.W. Day, and P.D. Hale of the NIST Optoelectronics Division, and H. Kienlen on internship from the Institut Universitaire de Technologie Louis Pasteur de Strasbourg, France.

The certification measurements were performed by A.H. Rose and S.M. Etzel of the NIST Optoelectronics Division.

Statistical analyses leading to certification of this SRM were performed by C.M. Wang of the NIST Statistical Engineering Division.

Table 2. Tabulation of Uncertainties

Uncertainty Source	Method	Uncertainty (in °)
	Type A (measured) uncertainties	
Measurement noise	1σ (standard deviation) of repeated independent measurements	0.033
Beam position error	Nine retardance measurements across face	
	Type B (inferred) uncertainties	
Retardance axis misalignment during measurement	Estimated from alignment uncertainty	0.003
Incidence angle error	Calculated maximum error allowed by alignment blocks	0.01
Temperature	5 °C variation	≤ 0.01
Combined standard uncertainty	$u_c = [\Sigma u_i^2]^{½}$	
Expanded uncertainty	$U = 2u_c$	

Certification Measurement Procedure: Retardance measurements were made on each individual SRM unit using the polarimeter described in Reference [5]. The device was aligned within ± 0.3° of normal incidence using the alignment apertures and was measured with a (2 ± 0.1) mm diameter beam ($1/e^2$) centered on the input face of the device. Six measurements were taken and the mean value reported. The device was translated and additional sets of six measurements were made at eight positions about the center. A total of nine sets of six measurements, made on a square grid with 2 mm center spacings, was used to estimate the spatial uniformity of the retardance [6].

Instructions for Use: The measurement wavelength should be between 1.28 µm and 1.35 µm. The source coherence length should be less than 60 cm or multiple coherent reflections may alter the retardance. Wavelengths and/or coherence lengths outside this range may be acceptable, but refer to the section Correction for Coherent Sources and Other Wavelengths on page three to ascertain if the uncertainty must be adjusted. Use a collimated beam for measurement; beam divergence should be less than 10 mrad. The $1/e^2$ beam diameter should be 2 mm to attain the uncertainty stated in Table 1. See the section Accommodating Other Beam Diameters for larger beam diameters up to 6 mm.

For optical beam diameters less than or equal to 3 mm, optical alignment can be aided using the alignment blocks. Gently insert the blocks into the window openings; do not force the blocks as they must be removed without disturbing the SRM alignment. Place the SRM in the optical beam and adjust its position and angle to maximize transmission. For beams smaller than 3 mm, additional lateral translation may be required to center the beam. *Remove the alignment blocks before proceeding with the retardance measurement.*

All optical glasses with low retardance can exhibit Faraday rotation. For the rhomb device, Faraday rotation is negligible in magnetic fields less than 1 mT (10 G). This requirement is easily accommodated by insuring that no magnets or high currents are nearby (for example, currents within 10 m should be below 500 A).

Measurements should be made with low power (less than 50 mW), continuous-wave (greater than 10 % duty cycle) optical beams. High average powers may damage the optics, and high peak powers could change the retardance through nonlinear effects.

If the endfaces become dirty, they may be drag cleaned using lint-free lens tissue and a mild residue-free solvent such as spectrophotometer grade ethanol.

Correction for Coherent Sources and Other Wavelengths: If the measurement source is highly coherent (i.e., produces coherent interference for path mismatches greater than 60 cm), the retardance of the SRM can vary as the rhomb path length changes. The change in retardance depends on the source coherence, SRM retardance, and the reflectance of the SRM antireflection coatings. Table 3 lists the maximum and standard deviation of this retardance change assuming fully coherent interference [1].

Table 3. Retardance Changes Due to Coherent Effects

Wavelength (in nm)	Inner Coating Reflectance	Outer Coating Reflectance	Maximum Error (in °)	Standard Deviation, σ_S (in °)
1200	8×10^{-4}	2.3×10^{-3}	0.60	0.22
1250	5×10^{-4}	1.3×10^{-3}	0.33	0.11
1300	5×10^{-4}	6×10^{-4}	0.20	0.06
1320	6×10^{-4}	5×10^{-4}	0.18	0.05
1350	7×10^{-4}	4×10^{-4}	0.18	0.05
1400	1.3×10^{-3}	7×10^{-4}	0.30	0.08
1450	2.1×10^{-3}	1.3×10^{-3}	0.53	0.14

Because the mean error is zero, repeated measurements over small temperature (0.3 °C) variations can decrease the SRM retardance uncertainty even if the source is coherent. Use $u_S = \sigma_S/N^{½}$ for N measurements as the standard error due to coherent reflections, and form a new expanded uncertainty $U = 2\,(u_c^2 + u_S^2)^{½}$. See References [1] and [4] for details.

Accommodating Other Beam Diameters: The alignment blocks cannot be used to adequately fix alignment for beams larger than 3 mm. Monitor the back-reflection of a visible laser incident on the SRM endface to determine the incidence angle. The SRM should be aligned within ± 0.3° of normal incidence with the beam centered on the rhomb face. Under no circumstances should the device aperture be used to block an oversized beam.

For beam diameters other than 2 mm, an additional uncertainty u_b (Table 4) must be included to account for spatial nonuniformity. This can be included in the expanded uncertainty by calculating $U = 2\,(u_c^2 + u_b^2)^{½}$. This assumes the use of circular uniform or Gaussian beams. For other shapes, contact the NIST Optoelectronics Division at (301) 975-3064 for uncertainty statements.

Table 4. Uncertainty Arising from Other Beam Diameters

Beam Diameter (in mm)	1	2	3	4	5
u_b (in °)		0			

The spatial variation of retardance may also cause a correctable change in the retardance expected for various beam sizes. To obtain the corrected retardance value for $1/e^2$ beam diameters other than 2 mm, add the value δ_b from Table 5 to the retardance value δ in Table 1.

Table 5. Retardance Correction Required for Other Beam Diameters

Beam Diameter (in mm)	1	2	3	4	5
δ_b (in °)		0			

Effect of Twist: Twist, τ, may affect the accuracy of measurement systems that rely on knowledge of the principal retardance axes of the SRM or assume linear eigenpolarizations. Finding the principal axes by inserting the device between crossed polarizers will result in an uncertainty, $\Delta\theta = 2.4\ \tau$, in the axis location.

REFERENCES

[1] Rochford, K.B., Rose, A.H., Williams, P.A., Wang, C.M., Clarke, I.G., Hale, P.D., and Day, G.W., "Design and Performance of a Stable Linear Retarder," to be published in Applied Optics, May 1997.
[2] Taylor, B.N. and Kuyatt, C.E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurements," NIST Tech Note 1297, U.S. Government Printing Office, Washington DC, (1994).
[3] Rochford, K.B. and Wang, C.M., "Uncertainty of Null Polarimeter Measurements," NIST IR-5055 (1996).
[4] Rochford, K.B. and Wang, C.M., "Accuracy of Interferometric Retardance Measurements," to be published in Applied Optics, May 1997.
[5] Williams, P.A., Rose, A.H., and Wang, C.M., "Rotating-Polarizer Polarimeter for Accurate Retardance Measurement," to be published in Applied Optics, May 1997.
[6] Wang, C.M., et al., "Error Analysis of Spatial Retardance," unpublished.