National Institute of Standards & Technology

Certificate of Analysis

Standard Reference Material® 2538

Polarization-Mode Dispersion (Non-Mode-Coupled)

Serial No.: 003

This Standard Reference Material (SRM) is intended for use for the calibration of polarization-mode dispersion (PMD) measurements on non-mode-coupled devices. Certified data in this certificate apply only to the artifact with the serial number shown above.

Scope of Use: This SRM has been characterized for wavelength-averaged differential group delay (mean DGD), and this certificate supplies certified values over any wavelength range subject to the wavelength constraints listed.

In principle, the artifact (SRM) is certified for measurement by all PMD measurement techniques that give wavelength-averaged (mean) DGD over an allowed wavelength range. However, care must be taken as to how the DGD is averaged over the measurement range. **The certification contained in this document pertains to a uniformly weighted wavelength average of DGD.** For example, when low-coherence interferometry or the Fourier-Transformed Fixed Analyzer measurement techniques are used, the spectral shape of the source can weight the averaged DGD toward the wavelength where the source has the most power. Therefore, if these techniques are used without wavelength normalization, the DGD over a wavelength range where the source intensity is low will be weighted less than the DGD at a wavelength with high source intensity. The user should be aware of this when measuring this artifact with such techniques in order to properly interpret uncertainty statements.

Certified Values and Uncertainties: The mean DGD measurements were performed using the NIST Jones Matrix Eigenanalysis (JME) system [1], and verified with a Fixed Analyzer (Wavelength Scanning) measurement. This certificate reports mean DGD averaged over any range of wavelength within the 1250 nm to 1650 nm window subject to a 50 nm minimum span width. These wavelength range constraints are summarized as

$$\begin{gathered} \lambda_2 - \lambda_1 \geq 50 \text{ nm} \\ 1250 \text{ nm} \leq \lambda_1 \leq 1600 \text{ nm} \\ 1300 \text{ nm} \leq \lambda_2 \leq 1650 \text{ nm} \end{gathered} \tag{1}$$

where λ_1 and λ_2 are, respectively, the minimum and maximum wavelengths of the averaging range. The certified values of mean DGD are found in Table 1. Table 2 lists a "high-accuracy" value of mean DGD over the range of the JME measurement system. Table 1 reports the mean DGD of the artifact for averaging between a start wavelength, λ_1, and a stop wavelength, λ_2. Note that wavelengths are resolved only to 5 nm as this is sufficient for the DGD resolution provided. To use the table, find the nearest start wavelength (within 5 nm) on the top row and nearest stop wavelength (within 5 nm) on the left column. The intersection point of the row and column defined by these two wavelengths gives the certified mean DGD over the selected wavelength range. The associated uncertainty, given at the top of Table 1, represents a coverage factor of $k = 2$, yielding an approximate 95 % confidence interval.

Expiration of Certification: The SRM will remain in certification indefinitely, provided the cleaning and storage instructions are followed and the housing is not opened. A sudden increase in insertion loss or the sudden appearance of ripples in the DGD spectrum are indications that something has changed in the device. If this occurs, carefully clean the connectors, examining the fiber pigtails to be attached to the SRM, and repeat the measurement.

The support aspects involved with the certification and issuance of this SRM were coordinated through the NIST Standard Reference Materials Group by J.W.L. Thomas.

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Certificate Issue Date: 23 September 2002

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The research and development effort leading to this SRM included contributions from the following NIST personnel: S.M. Etzel, J.D. Kofler, and P.A. Williams (NIST Optoelectronics Division), and C.M. Wang (NIST Statistical Engineering Division). Questions regarding this device should be addressed to the NIST Optoelectronics Division at (303) 497-5342 or via email at optoelectronics@boulder.nist.gov.

INSTRUCTIONS FOR USE

This SRM unit is a pigtailed quartz plate with FC/APC style connectors (2.15 mm “wide key”). The temperature of the quartz plate is actively controlled to ensure a stable mean DGD value. This unit requires an AC power source (115 V, 60 Hz).

The SRM is a delicate optical instrument and should be handled carefully. Damage can easily occur if the device is dropped or jarred. The housing should not be opened, and the optical connectors should be cleaned carefully before each connection. When making connections to the SRM, use high quality FC/APC connectors (2.15 mm “wide key”). The cleanliness of the connectors is important. Use a dust free and residue-free air source and a commercial fiber endface cleaner before every connection. If such a cleaner is not available, then lens paper wetted with reagent-grade isopropyl alcohol can be used to wipe the ferrule endface and the air source used to dry the connector.

When not in use, the device should be stored at a temperature from 15 °C to 30 °C in a clean, dry environment.

Table 2. Certified Value of Mean DGD for SRM 2538 (Serial Number 003)
Over the "High-Accuracy" Wavelength Range

Wavelength (nm) ± 5 nm		Mean DGD (fs)	Expanded Uncertainty (fs)*
Start	Stop		
1481	1568	312.1	3.2

* Expanded uncertainty, $k = 2$, gives the half width of an approximate 95 % confidence interval.

Details on the certification procedures and the associated uncertainties are given in Reference 2. The uncertainties associated with each certified value are reported as "expanded uncertainty", meaning a coverage factor of 2 is used to give an approximate 95 % confidence interval [3].

MEASUREMENT CONDITIONS

Device Warm Up: Before measuring the SRM, the power should be turned on and the unit allowed to warm up for at least one hour. The internal temperature can be checked by measuring the voltage across the BNC style connector on the back panel of the device. The output voltage is proportional to the internal temperature in kelvins (10 mV/K). The voltage should read 3.149 V ± 0.05 V. If the voltage reading is outside this range, or if the device has not been powered up for at least one hour, the mean DGD is not certified.

Wavelength Range: The certified values of mean DGD are valid for measurements where the DGD is averaged over the stated wavelength ranges. All wavelengths reported are vacuum wavelengths.

The start and stop wavelengths are defined as the wavelength locations associated with the first and last DGD measurements (with uniformly spaced samples in between). This could cause confusion. For example, in the case of JME measurements, to measure the DGD at a given wavelength point requires the measurement of the Jones matrix of the device under test at two wavelengths on either side of the target wavelength. For example, a JME measurement of the DGD at 1480.5 nm might come as the result of measurements of the Jones transfer matrices at say 1480 nm and 1481 nm. The wavelength start and stop values of Tables 1 and 2 refer to the wavelengths at which the DGD values were measured (not wavelengths at which the Jones matrix was measured). So, for this JME example, if this was the first measurement point, the start wavelength would be reported as 1480.5 nm.

For the values in Table 1, the minimum wavelength-averaging scan range must be at least 50 nm. This prevents incorrect measurements due to possible multiple reflections within the device.

Care should be taken that the PMD measurement actually measures the mean DGD and not a weighted mean, as discussed in Scope of Use section.

Lead Birefringence: Lead birefringence on the PMD measurement system can impose an uncertainty on the measurement. Our calibrations were performed with a short lead length (~80 cm total) on the JME measurement system, and the PMD of the leads was measured and added to the uncertainty statement of Tables 1 and 2. Orientation of the system fiber leads was randomized in between measurements in order to average away as much of the lead birefringence as possible. It is recommended that the user of this SRM do the same. Note that the most complete randomization of the leads must include orientations where the fibers do not always lie in a single plane. Take care in reorienting the fiber leads that significant bending, which increases the fiber birefringence, is not introduced. Bend birefringence goes as R^{-2}, where R is the bend radius of the fiber [4]. It is recommended that any bends in the fiber leads be restricted to radii greater than 5 cm. Some fraction of the lead birefringence might not average to 0, due to an inability to completely randomize the lead orientation or due to fixed sources of extraneous PMD, such as in the fiber connectors. Therefore, it is recommended that the shortest possible leads be used and that orientational averaging of lead birefringence be employed for the best measurement. A measurement of the lead birefringence in the absence of the SRM gives an estimate of the uncertainty that can be expected due to lead birefringence.

Multiple Reflections: Multiple reflections in the optical path can cause incorrect measurements of device DGD. The most probable cause of multiple reflections is poor connections. The bulkhead connectors on the SRM unit are the FC/APC type (2.15 mm “wide key”). The cleanliness of the connectors is important. Accumulation of dust or dirt in the bulkhead adapter or on the connector ferrule endface can cause multiple reflections across the specimen, which will add a random (with wavelength and temperature) noise to the measurement. Other sources of reflection in the measurement system are equally important. If the reflections cannot be reduced, multiple measurements can be made at slightly different wavelength sampling points or temperatures in order to average out the effects of multiple reflections.

REFERENCES

[1] Williams, P.A.; *Rotating Waveplate Stokes Polarimeter for Differential Group Delay Measurements of Polarization-Mode Dispersion*, *Applied Optics*; **38**, pp. 6508-6515 (1999).

[2] Williams, P.A.; Etzel, S.M.; Kofler, J.D.; Wang, C.M.; *Standard Reference Material 2538 for Polarization-Mode Dispersion (Non-Mode-Coupled)*; NIST Special Publication 260-145 (2002).

[3] Taylor, B.N.; Kuyatt, C.E.; Eds.; *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*; NIST Technical Note 1297 (1994).

[4] Jeunhomme, Luc B.; *Single-Mode Fiber Optics: Principles and Applications*; (Mercel Dekker, Inc., New York, p. 74 (1990).

Users of this SRM should ensure that the certificate in their possession is current. This can be accomplished by contacting the SRM Program at: telephone (301) 975-6776; fax (301) 926-4751; e-mail srminfo@nist.gov; or via the Internet http://www.nist.gov/srm.