National Institute of Standards & Technology

Certificate

Standard Reference Materials® 2046, 2047, 2048, 2049, 2050, 2051

Transmission Filters with Measured Optical Density at 1064 nm Wavelength

Serial No.

Standard Reference Materials (SRMs) 2046-2051 are a series of filters intended primarily for use in the calibration of transmittance measurements using lasers or infrared spectrophotometers; for attenuating the optical power with an accurately known transmittance at a wavelength of 1064 nm; and for characterizing the nonlinearity of detection systems. The filters are made of colored glass with uncoated, polished surfaces having dimensions of 51 mm x 51 mm. Each surface is flat to within one tenth of the helium-neon wavelength (633 nm), while the wedge angle is less than 5 μrad (1 arc s). The optical density (OD) of each filter has been determined at a wavelength of 1064 nm using a Nd-YAG laser and silicon diode detectors. The nominal optical density and the corresponding thickness of each SRM are given in Table 1.

Table 1. Nominal Optical Density with Corresponding Thickness

SRM Number	Nominal Optical Density	Thickness (mm)
2046	1	1.0
2047	2	2.2
2048	3	3.2
2049	4	4.2
2050	5	5.4
2051	6	6.4

Certified Values of the Optical Density: The certified optical density value and associated uncertainty for this filter are given in Table 2. The source and magnitude of each uncertainty component and the average temperature of the filter during the measurement are also listed in Table 2. The optical density is related to the transmittance, *T*, of the filter by $OD = -\log_{10} T$. An uncertainty of 0.001 in OD corresponds to a relative uncertainty $\Delta T/T$ of 0.23 % in transmittance. The certified OD value is the average of the measured values over the central 20 mm x 20 mm area of the filter. The certified values are for normal incidence (angle of incidence ≤ 2°).

Expiration of Certification: The certification of the SRM is valid until **30 June 2003**, within the measurement uncertainties specified, provided the SRM is handled and stored in accordance with the instructions given in this certificate (see Instructions for Use). However, this certification is nullified if the SRM is damaged, contaminated, or modified.

The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the Standard Reference Materials Program by J.W.L. Thomas and J.C. Colbert.

Gaithersburg, MD 20899
Certificate Issue Date: 9 July 1998

Thomas E. Gills, Chief
Standard Reference Materials Program

Overall Uncertainty Determination: The nonlinearity of the detector system was checked by measuring an OD 4 filter with different laser powers between 1 nW and 10 mW. The uncertainty associated with the detector nonlinearity was estimated to be 0.0002 for all filters. The reproducibility was determined from multiple measurements of OD 1, 2, and 3 filters performed on different dates. The interference effects added additional uncertainty for OD 1 and OD 2 filters. An uncertainty due to reference measurement is included in the combined standard uncertainty for OD 5 and OD 6 filters. The combined standard uncertainty was calculated as a prediction interval [1]. The uncertainty and its components for the given filter are listed in Table 3 [2].

Maintenance of SRM Certification: NIST will monitor these SRMs over the period of their certification. If substantive technical changes occur that affect the certification before the expiration of certification, NIST will notify the purchaser. Return of the attached registration card will facilitate notification.

The development of the instrumentation and the measurements used to certify these SRMs were performed by Z.M. Zhang, T.R. Gentile, and A.L. Migdall of the NIST Optical Technology Division.

The overall direction and coordination of the technical measurements leading to certification were performed under the supervision of R.U. Datla of the NIST Optical Technology Division.

Statistical consultation was provided by M.C. Croarkin and S.B. Schiller of the NIST Statistical Engineering Division.

Source of Material: The filters were fabricated and polished by Laser Optics, Inc., using the NG-9 glass materials manufactured by Schott of Mainz, Germany.[1]

NOTICE AND WARNINGS TO USERS

Storage and Handling: The SRMs are stored in a wooden box, designed to minimize the contamination of the filter surfaces. The air gap in the box prevents any contact between the middle portion of the surfaces and the walls of the storage container. The filter may be held by the edges with soft plastic, powder-free gloves, or optical lens tissue. No filter mount is provided. A metallic mount may be used to hold the edge of the filter (within 7 mm from the edge). Care must be taken not to break the glass filter. The central portion of the filter should never be touched by fingers or any hard objects. Dust may be removed by blowing with clean, dry air.

Instructions for Use: Only the central 20 mm x 20 mm area of the filter should be used. It is desirable to integrate over several positions on the filter.. The laser beam should be perpendicular (within 2° or 0.035 rad) to the filter surface since the filter attenuates the radiation through absorption. Because the optical density increases with increasing temperature at this wavelength, for filters with OD ≥ 3, a correction may be necessary if the filter temperature in the actual application differs from the value indicated in Table 2 (see the section entitled Temperature Dependence). The laser power on the filter should not exceed 20 mW (or 300 mW/cm^2) in order to avoid excessive heating.

CERTIFICATION ANALYSIS

Measurement Conditions: A continuous-wave (CW) Nd-YAG laser with an output wavelength of 1064 nm was used. The beam spot was approximately 3 mm in diameter (full width at half maximum). The laser beam incident on the filter was perpendicular to its surface. The temperature of the sample was monitored by a thermistor attached to the filter holder. The temperature and humidity in the measurement laboratory were between 22 °C and 24 °C and between 40 % and 60 %, respectively.

[1] Certain commercial materials and equipment are identified in order to adequately specify the experimental procedure. Such identification does not imply a recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for this purpose.

Determination of the Optical Density: A Nd-YAG laser and three silicon diode detectors were used to measure the normal transmittance of the filters at 1064 nm. The root-mean-square (rms) fluctuation of the laser power is less than 0.3 % over several hours of operation using a stabilizer. A wedged quartz beamsplitter was used. One of the reflected beams goes to a feedback detector that controls the laser stabilizer. The other beam reflected by the wedge is used to simultaneously monitor the laser power via the monitor detector. The transmitted beam passes through a shutter and the sample filter (or a reference), and then to the signal detector. The relative transmittance is

$$T_{relative} = \frac{[(V_{s1} - V_{s0}) / V_m]_{sample}}{[(V_{s1} - V_{s0}) / V_m]_{reference}} \qquad (1)$$

where V is the output voltage from the dc voltmeter, subscripts s and m indicate signal detector and monitor detector, respectively, and subscripts 0 and 1 indicate shutter closed and open, respectively. The detectors are placed inside a light-tight enclosure. The signal when the shutter is closed (V_{s0}) is subtracted from the output signal V_{s1} to eliminate background. For filters with OD ≤ 4, the reference is air (blank). Therefore, the sample transmittance is equal to the relative transmittance given in Equation 1. A reference filter with OD near 3 was used for filters with OD ≥ 5. The transmittance of the reference filter, $T_{reference}$, is measured at a fixed position. The transmittance of OD ≥ 5 filters is determined by

$$T_{sample} = T_{relative} \times T_{reference} \qquad (2)$$

The dynamic range and linearity of the detector and amplifier electronics are discussed in References [3] and [4]. The temperature of the filter is monitored by measuring the resistance of a thermistor on the filter holder during the data acquisition process. Detailed discussions of the theory and measurements are given in Reference [1].

Spatial Nonuniformity: The spatial variation in OD among different locations depends on the filter. Measurements were performed either on nine positions in a 3 x 3 matrix with 10 mm spacing or on 25 positions in a 5 x 5 matrix with a 5 mm spacing around the center of the filter. Because of the extremely flat and parallel surfaces of these filters, the spatial variation is attributed to the inhomogeneity of the material. For SRM 2046 OD 1 filters, interference between multiple reflections may also affect the spatial uniformity [3]. The measurement repeatability at the same position is better than 0.000 06 for OD 1 and 2 filters; 0.0002 for OD 3, 5, and 6 filters; and 0.000 67 for OD 4 filters (due to a lower signal-to-noise ratio). The uncertainty given in Table 3 associated with the nonuniformity ($\sigma_{spatial}$) is the standard deviation of the measurements on different positions of the filter, which includes the repeatability component.

Temperature Dependence: The OD increases slightly with temperature because of a change in the absorption coefficient of the material. The absorption coefficient of the glass material is 2.16 mm^{-1} at 25 °C with a temperature coefficient of 0.026 %/°C at a wavelength of 1064 nm [3]. Therefore, a correction in the measured OD may be necessary for measurements at temperatures different from that indicated in this certificate. The correction depends on the nominal OD values. Table 4 lists the change in OD per 1 °C temperature change at temperatures between 21 °C and 27 °C for different OD filters. The standard uncertainty resulting from the temperature variation of ± 0.5 °C is given in Table 3. The higher the OD of the filter is, the larger the standard uncertainty due to temperature variation.

REFERENCES

[1] Taylor, B.N. and Kuyatt, C.E., *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, U.S. Government Printing Office, Washington DC, (1994).

[2] Zhang, Z.M., Gentile, T.R., Migdall, A.L., and Datla, R.U., *Optical Density Measurements for Infrared Filters at 1064 nm Wavelength*, NIST Special Publication 260-128, (1997).

[3] Eppeldauer, G. and Hardis, J.E., "Fourteen-Decade Photocurrent Measurements with Large-Area Silicon Photodiodes at Room Temperature," Applied Optics **30**, pp. 3091-3099, (1991).

[4] Migdall, A.L. and Winnewisser, C., "Linearity of a Silicon Photodiode at 30 MHz and Its Effect on Heterodyne Measurements," Journal of Research of the NIST **96**, pp. 143-146, (1991).

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 (select "Certificates"), Fax (301) 926-4751, e-mail srminfo@nist.gov, or via the Internet http://ts.nist.gov/srm.