U. S. Department of Commerce
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National Bureau of Standards
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National Bureau of Standards

Certificate

Standard Reference Material 2025

Second Surface Aluminum Mirror with Wedge for Specular Reflectance from 250 to 2500 nm

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This Standard Reference Material (SRM) is intended for use in calibrating the photometric scale of specular reflectometers. The aluminum mirror has been vacuum deposited on the back surface of a 2-mm thick optical quality vitreous quartz plate that has a wedge of 10 mrad (0.573°) between its long faces. This mirror is protected by a second vitreous quartz plate with a similar wedge that is cemented to the first plate in such a way that the front and back surfaces of the mirror are parallel to 10 μm.

When a collimated beam is incident to the first surface at $-6°$, beams are reflected at 6°, ~7.6°, ~9.3°, ~11.0°, etc. Essentially all of the reflected flux is contained in the first four beams. The angle of reflection is a function of both the wedge angle and its dispersion (which is a function of wavelength). Calibration of photometers can be accomplished by using any of the individual beams or by using the total reflectance. Only the first reflected beam and the total reflectance, however, are certified.

The specular spectral reflectance of a master second-surface mirror was measured at 25 wavelengths with a high-accuracy specular spectral reflectometer at 6° incidence. The first surface reflectance, ρ_1, of an uncoated plate was also measured with the same instrument at 6° incidence, with a detector that received only the beam reflected from the first surface. As the plate that was used for this SRM was cut from the same piece of optical quality vitreous quartz (and had identical polishing treatment) as the uncoated plate, it is assumed that the reflectance from the first surface is the same, within the uncertainty of the certified value. The 6°-hemispherical reflectance of this SRM was compared to that of the master standard at the same 25 wavelenghts with a high-precision integrating sphere reflectometer. The measured reflectance ratio was multiplied by the known reflectance of the standard at each wavelength to obtain the ρ_t spectral data reported in Table 1. The overall uncertainty of these measurements is ± 0.5 percent.

The Figure shows the spectral distribution of a typical second surface aluminum mirror. The wavelength scale of this plot is greatly compressed and the reflectance scale expanded to emphasize the absorption features. Note that the absorption band at 800 nm is an inherent characteristic of aluminum mirrors.

SRM 2025 can be cleaned by wiping the quartz first surface of the mirror with a soft tissue and isopropyl alcohol followed by a rinse with distilled water.

The calibration and certification were done by the Spectrophotometry Group of the Radiometric Physics Division. The overall direction and coordination of the preparation and technical measurements leading to the certification were performed under the chairmanship of J.C. Richmond.

The technical and support aspects involved in the certification and issuance of this SRM were coordinated through the Office of Standard Reference Materials by R.K. Kirby.

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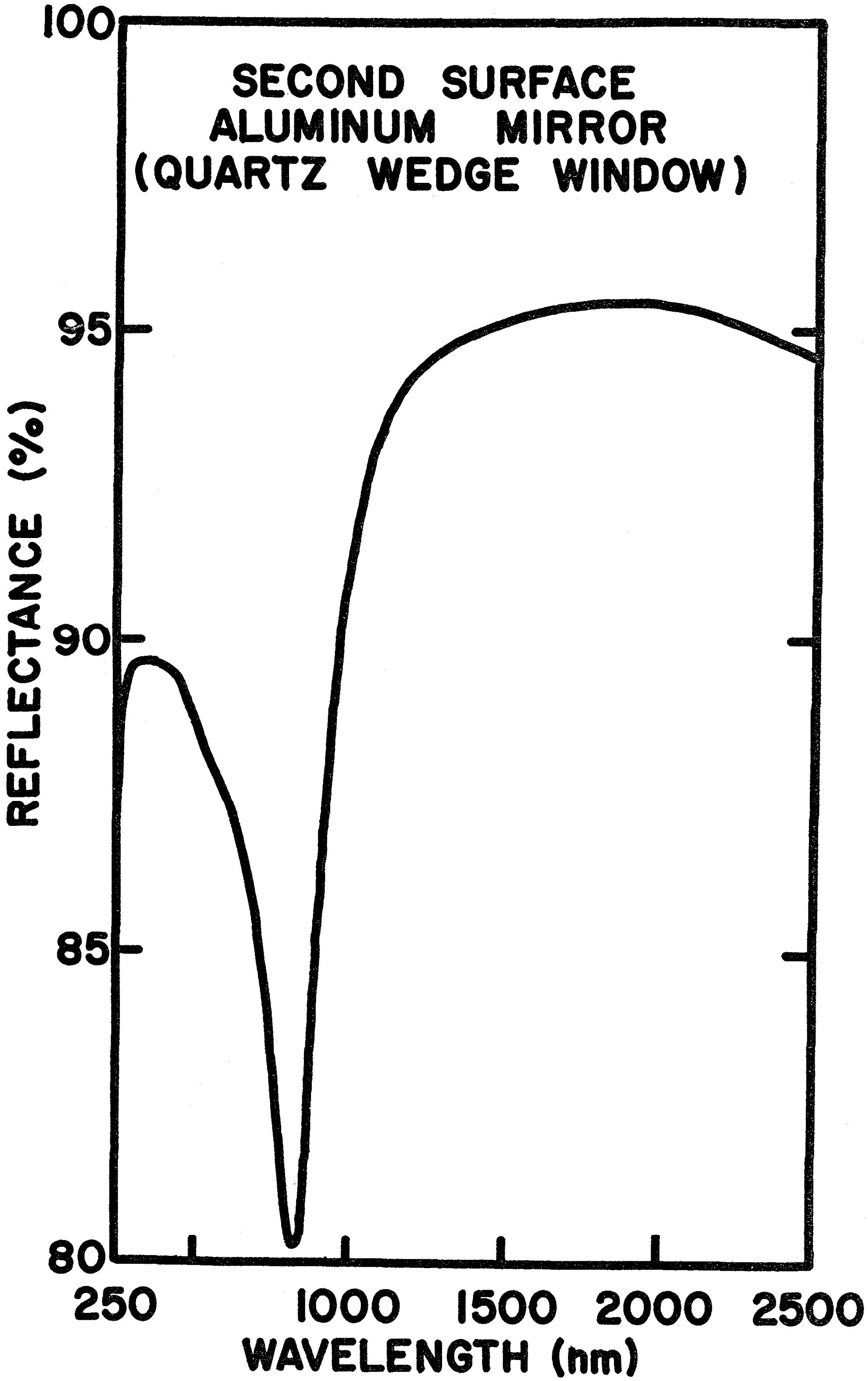
George A. Uriano, Chief
Office of Standard Reference Materials

(over)


SECOND SURFACE
ALUMINUM MIRROR
(QUARTZ WEDGE WINDOW)
REFLECTANCE (%)
100
95
90
85
80
250
1000
1500
2000
2500
WAVELENGTH (nm)

The index of refraction of the plate, at each wavelength, was computed from the measured first surface reflectance by use of the equation for reflectance at normal incidence,

$$\rho_1 = \left(\frac{1-n}{1+n}\right)^2$$

These values are given in Table 2.

The angles of reflection for the first four beams reflected from the SRM were computed for each wavelength from the index of refraction. The plane of incidence is taken as a plane normal to the surface and parallel to the long sides of the mirror. All angles between normal and the thin end of the wedge are negative, and those between normal and the thick end are positive.

The direction θ_1 of the first beam, with reflectance ρ_1, is 6° since there is no refraction. The directions of the other three beams are:

$$\theta_2 = \sin^{-1} \{n \sin[2\alpha + \sin^{-1} (\tfrac{1}{n} \sin 6°)]\}$$

$$\theta_3 = \sin^{-1} \{n \sin[4\alpha + \sin^{-1} (\tfrac{1}{n} \sin 6°)]\}$$

$$\theta_4 = \sin^{-1} \{n \sin[6\alpha + \sin^{-1} (\tfrac{1}{n} \sin 6°)]\}$$

where $\alpha = 0.573°$.

These directions for each wavelength are given in Table 2.

Note that the angle of reflection is a function of both the wedge effect of the plate and its dispersion. The wedge effect is independent of wavelength. The dispersion angle changes with wavelength because the index of refraction of the plate changes with wavelength. If the wedge standards are used to calibrate a specular spectral reflectometer at different wavelengths, using beam 2 reflected once from the second-surface aluminum coating, the dispersion effect may make it necessary or desirable to shift the optical path slightly when changing wavelength. If spectrally total reflectance measurements are made, there will be a slight spread (about 0.1° for beam 2, 0.2° for beam 3 and about 0.35° for beam 4) in the reflected beam, due to the dispersion of the plate and a slightly larger detector may be required for spectrally total measurements than for spectral measurements.

Because pratically all of the flux reflected from the wedge is contained in the first four beams, the total specular reflectance, ρ_t, can be approximated in terms of the reflectance of the first surface, ρ_1, the transmittance of the quartz surface, $\tau = 1-\rho_1$, and the reflectance of the aluminum surface, ρ_s, as

$$\rho_t = \rho_1 + \tau_1^2 \rho_s + \tau_1^2 \rho_1 \rho_s^2 + \tau_1^2 \rho_1^2 \rho_s^3 .$$

Using the measured values of ρ_t and ρ_1, the values of ρ_2, ρ_3, and ρ_4 can be calculated as

$$\rho_2 = \tau_1^2 \cdot \rho_s$$

$$\rho_3 = \tau_1^2 \cdot \rho_1 \cdot \rho_s^2$$

$$\rho_4 = \tau_1^2 \cdot \rho_1^2 \cdot \rho_s^3$$

where

$$\rho_s = \frac{\rho_t - \rho_1}{\tau_1^2 + \rho_1 (\rho_t - \rho_1)}$$

The computed values for ρ_2, ρ_3, and ρ_4 are given in Table 3.

These equations were derived on the basis of two assumptions; (1) that there is no internal absorptance in the vitreous quartz (there is some slight absorptance at 250 nm, but essentially none at 300 nm and above); and (2) that the values of τ_1, ρ_1 and ρ_s are independent of the direction of incidence over the range of angles of incidence involved. This is essentially true for angles of incidence of less than 15°. The computed reflectance for a material with index of refraction of 1.5 is 0.040000 at normal incidence, 0.040002 at 6° incidence and 0.040081 at 15° incidence. The fractional error due to the assumption that the reflectance is independent of the angle of incidence is thus well within the uncertainty of the measured values.

This is just a sample of Table 1.

Table 1

Total Specular Spectral Reflectance (ρ_t), for 6° Incidence, and First Surface Reflectance (ρ_1) of Fused Quartz Plate

Mirror No. ~~107W~~

Wavelength (nm)	(ρ_t)	(ρ_1)
250	0.869	0.0406
300	.894	.0379
350	.895	.0364
400	.893	.0355
450	.888	.0350
500	.884	.0347
550	.878	.0344
600	.874	.0342
632.8	.868	.0342
650	.865	.0342
700	.853	.0339
750	.835	.0338
800	.807	.0337
850	.800	.0335
900	.847	.0334
1000	.911	.0333
1060	.925	.0332
1100	.932	.0332
1200	.942	.0330
1300	.947	.0328
1500	.952	.0325
1750	.955	.0321
2000	.955	.0317
2250	.951	.0313
2500	.949	.0310

TABLE 2

Index of Refraction, n, of Cover Plate and Direction, in Degree from Normal, of First Four Reflected Beams

(These Values Are Not Certified)

Wavelength nm	Index of Refraction	Θ_1 deg.	Θ_2 deg.	Θ_3 deg.	Θ_4 deg.
250	1.5047	6.000	7.731	9.466	11.207
300	1.4834	6.000	7.707	9.417	11.132
350	1.4715	6.000	7.693	9.389	11.090
400	1.4643	6.000	7.684	9.372	11.065
450	1.4603	6.000	7.680	9.363	11.051
500	1.4578	6.000	7.677	9.357	11.042
550	1.4554	6.000	7.674	9.352	11.034
600	1.4538	6.000	7.672	9.348	11.028
632.8	1.4538	6.000	7.672	9.348	11.028
650	1.4538	6.000	7.672	9.348	11.028
700	1.4513	6.000	7.669	9.342	11.019
750	1.4505	6.000	7.668	9.340	11.017
800	1.4497	6.000	7.668	9.338	11.014
850	1.4481	6.000	7.666	9.335	11.008
900	1.4473	6.000	7.665	9.333	11.005
1000	1.4464	6.000	7.664	9.331	11.002
1060	1.4456	6.000	7.663	9.329	10.999
1100	1.4456	6.000	7.663	9.329	10.999
1200	1.4440	6.000	7.661	9.325	10.994
1300	1.4423	6.000	7.659	9.321	10.988
1500	1.4399	6.000	7.656	9.316	10.979
1750	1.4365	6.000	7.652	9.308	10.968
2000	1.4322	6.000	7.648	9.300	10.956
2250	1.4299	6.000	7.645	9.292	10.944
2500	1.4274	6.000	7.642	9.287	10.935

This is just a sample of Table 3.

Table 3

Reflectances ρ_2, ρ_3, and ρ_4

Reflected by the Wedge Mirrors, Computed from the Measured First Surface Reflectance of the Plate and the Total Specular Spectral Reflectance for a Collimated Beam Incident at -6°

(THESE VALUES ARE NOT CERTIFIED)

Mirror No. ~~107W~~

Wavelength (nm)	(ρ_2)	(ρ_3)	(ρ_4)
250	0.7992	0.0282	0.0010
300	.8271	.0280	.0009
350	.8306	.0270	.0009
400	.8303	.0263	.0008
450	.8265	.0257	.0008
500	.8233	.0252	.0008
550	.8181	.0247	.0007
600	.8147	.0243	.0007
632.8	.8091	.0240	.0007
650	.8062	.0238	.0007
700	.7954	.0230	.0007
750	.7786	.0219	.0006
800	.7523	.0204	.0006
850	.7460	.0200	.0005
900	.7906	.0223	.0006
1000	.8511	.0258	.0008
1060	.8644	.0265	.0008
1100	.8710	.0269	.0008
1200	.8807	.0274	.0009
1300	.8858	.0275	.0009
1500	.8911	.0276	.0009
1750	.8946	.0274	.0008
2000	.8954	.0271	.0008
2250	.8923	.0266	.0008
2500	.8911	.0262	.0008