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Calibrating Reflectance Measurements

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Calibrating transmittance is easy, stable, and reliable. Calibrating reflectance is much more vulnerable to errors. Reflectance attachments for spectrophotometers are reviewed and their pitfalls. Working standards for reflectance are described. Linearity calibration is discussed. Suggestions for the fabrication of a near-100% reflectance working standard are provided at length.

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ABSTRACT

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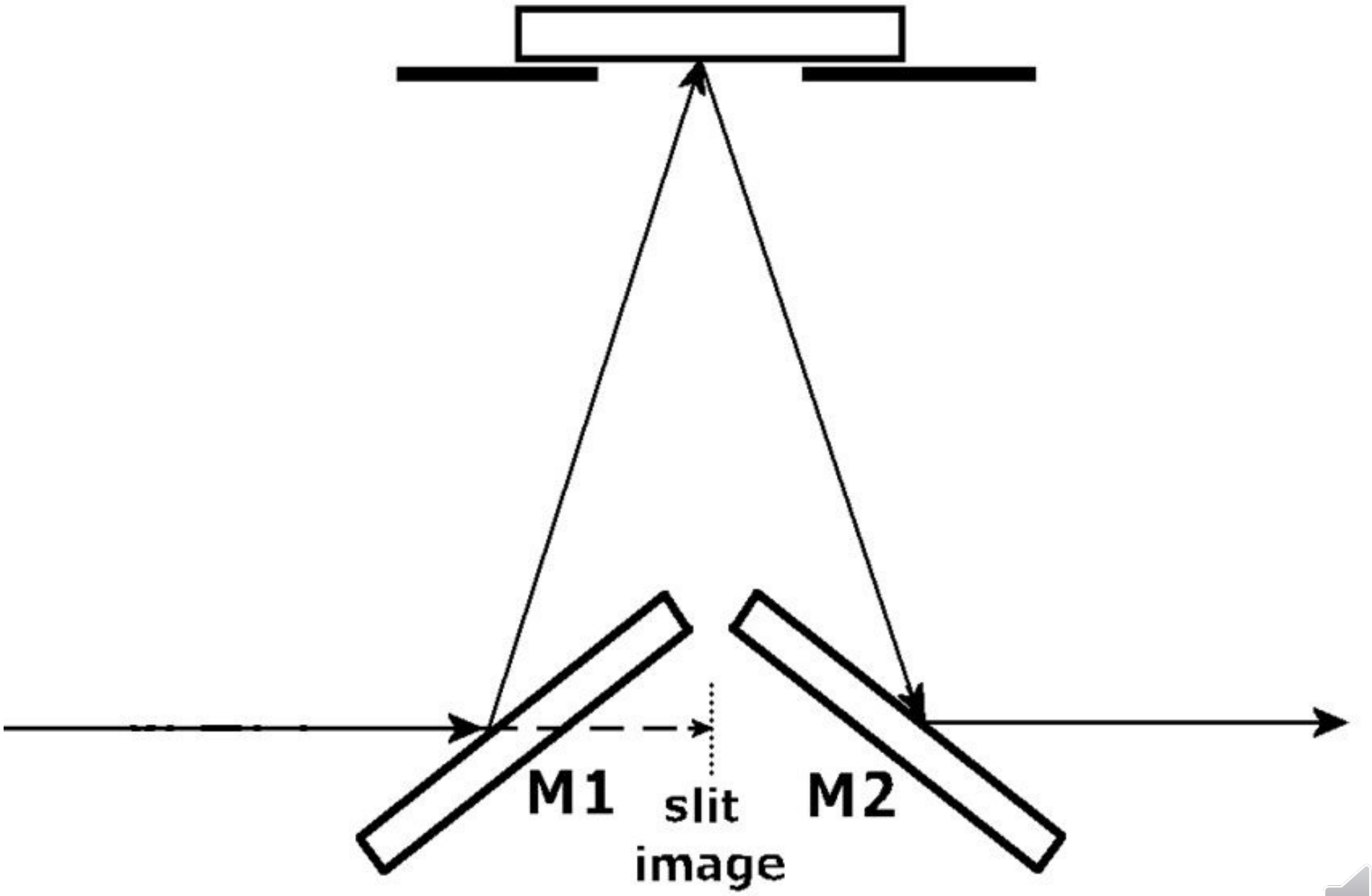
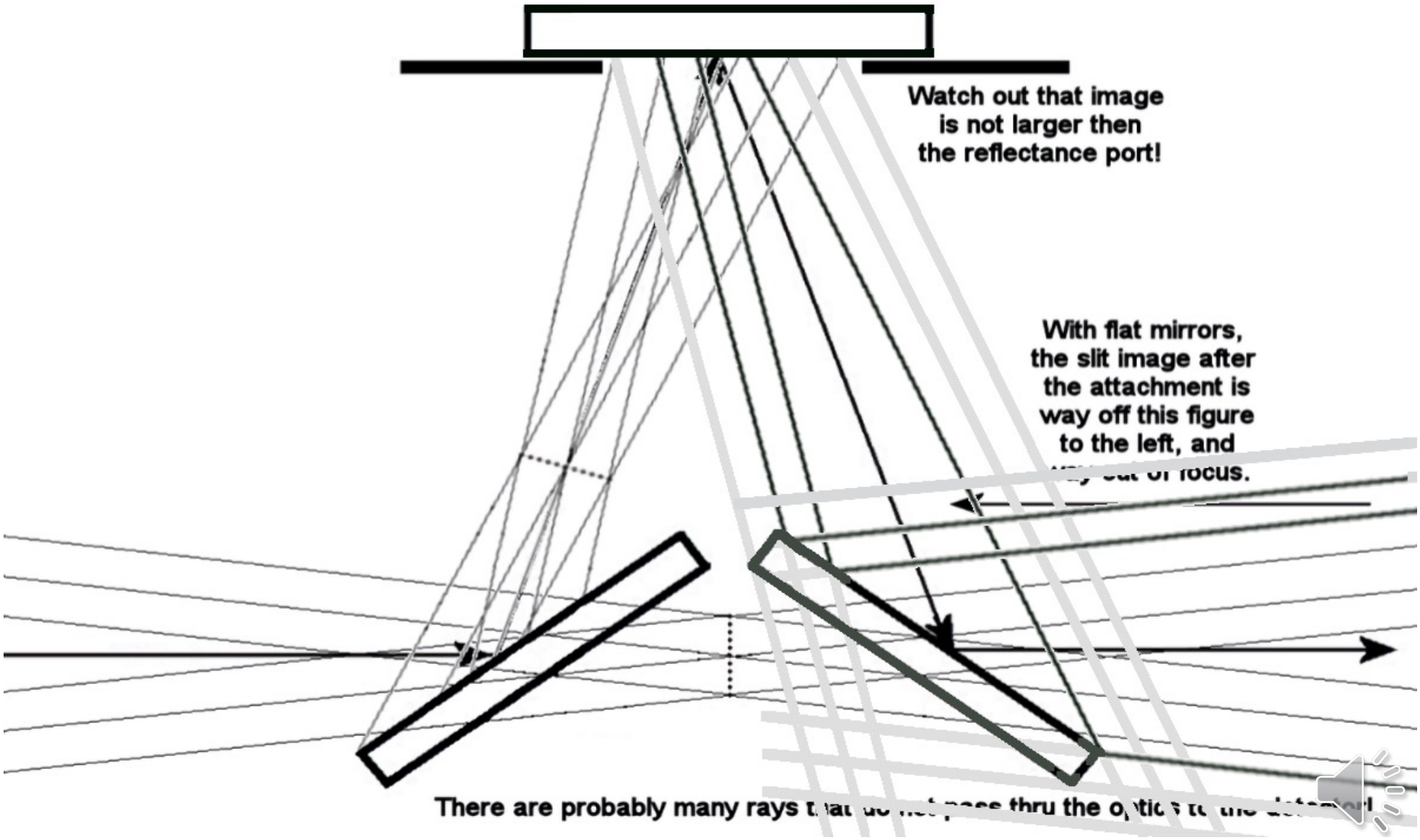
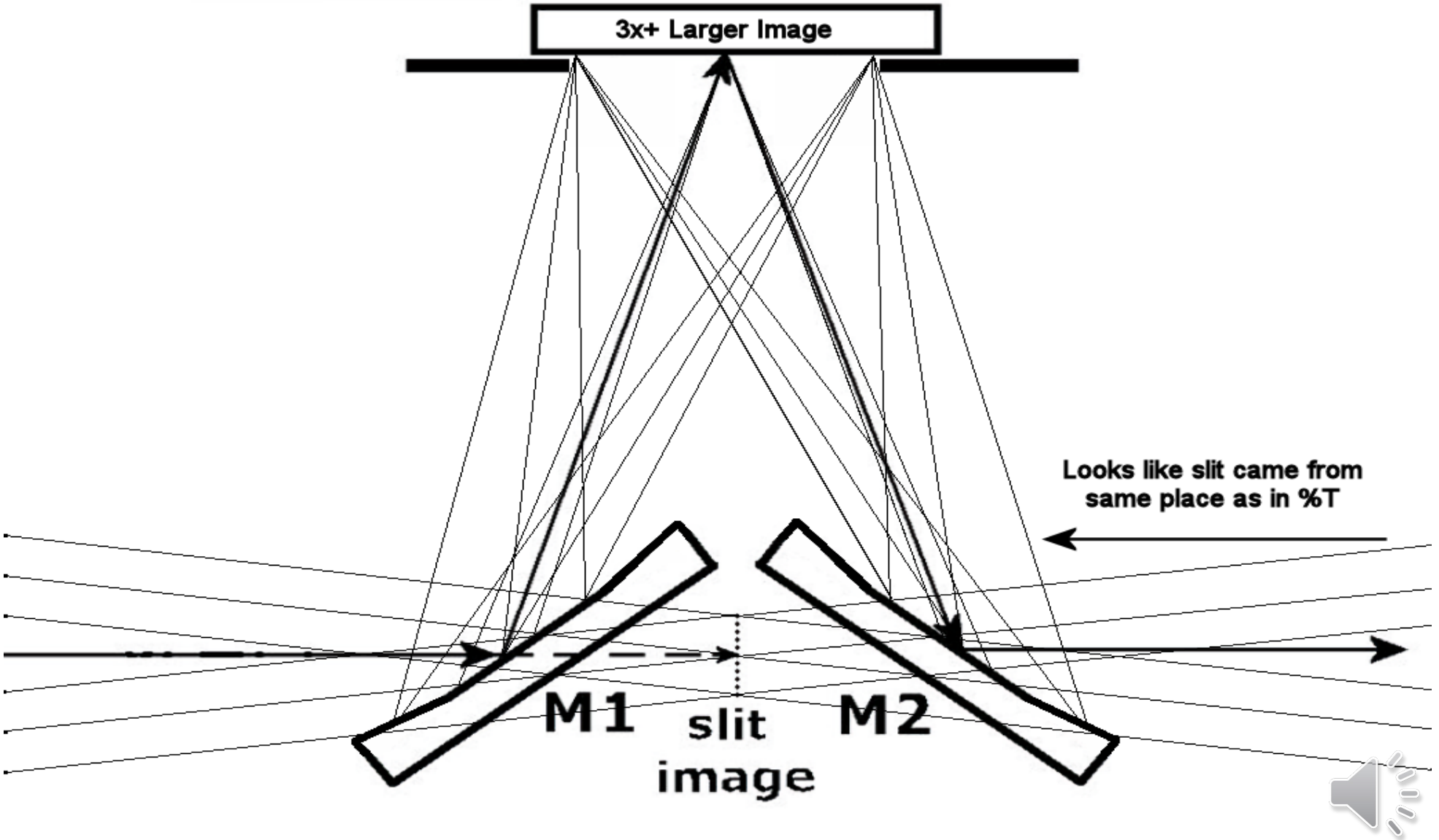
REFLECTANCE SAMPLE POSITION



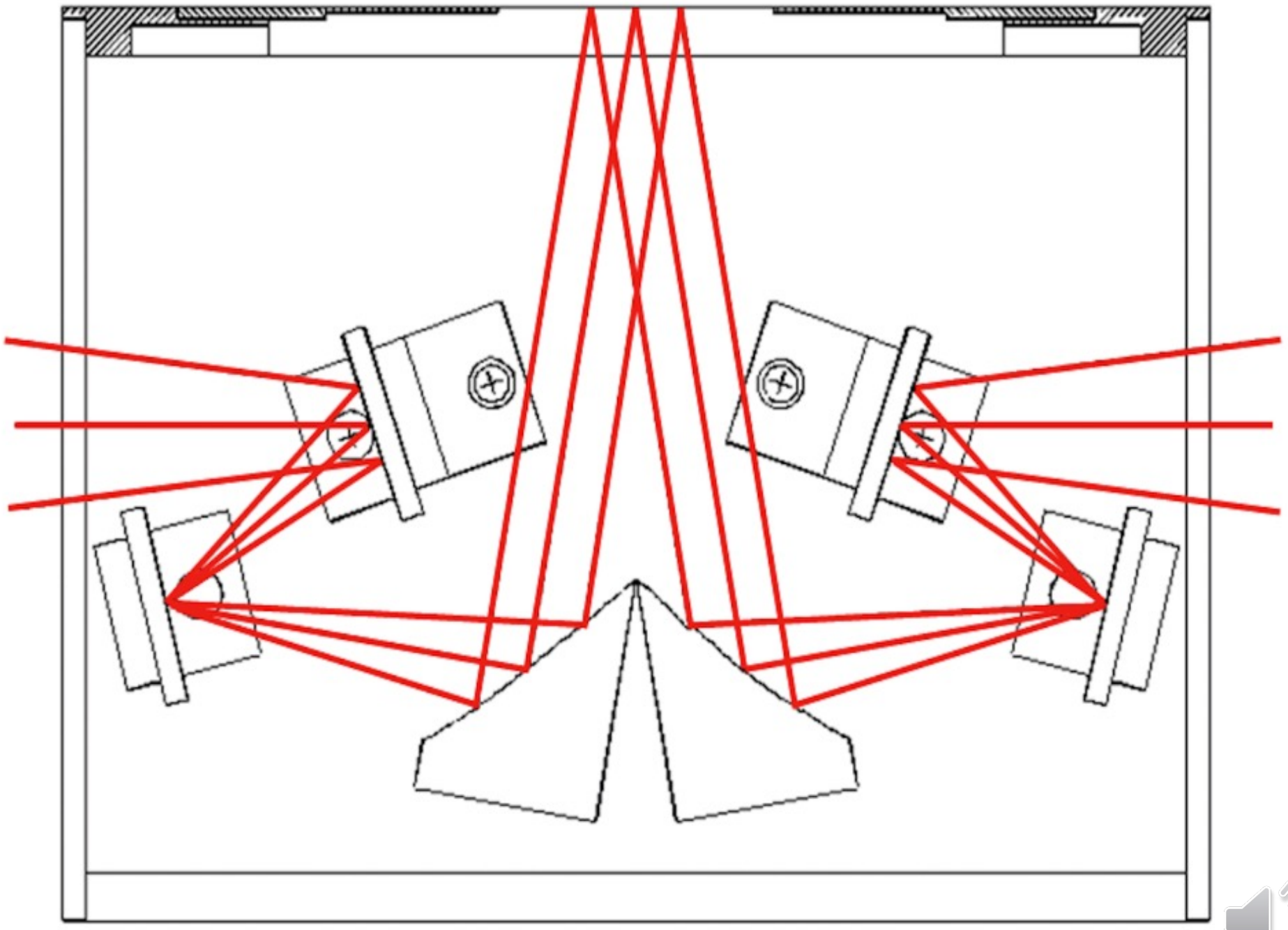
Problems With Flat Mirrors



Conic Section Mirrors Fix Focus



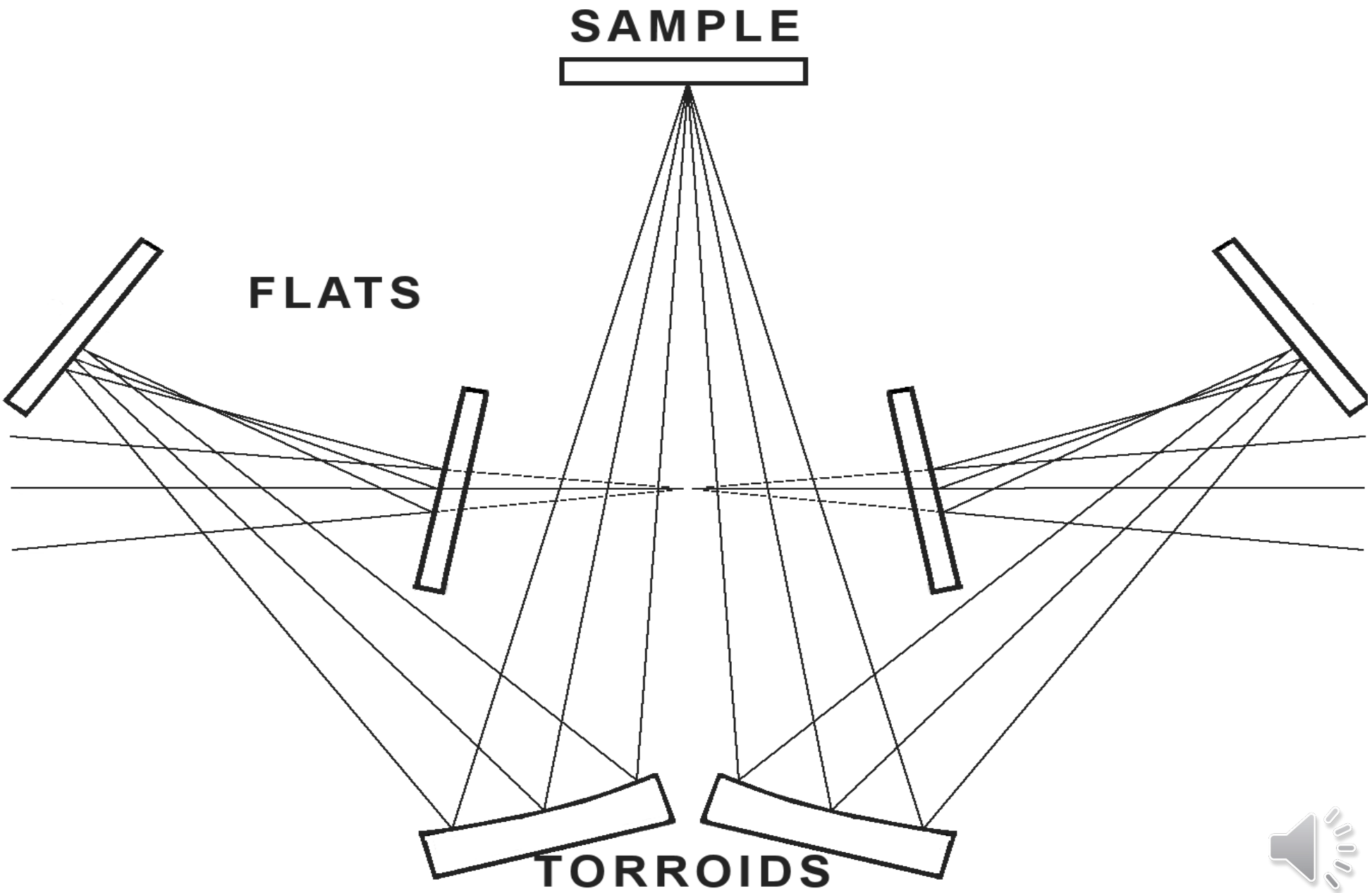
PIKETECH 10SPEC



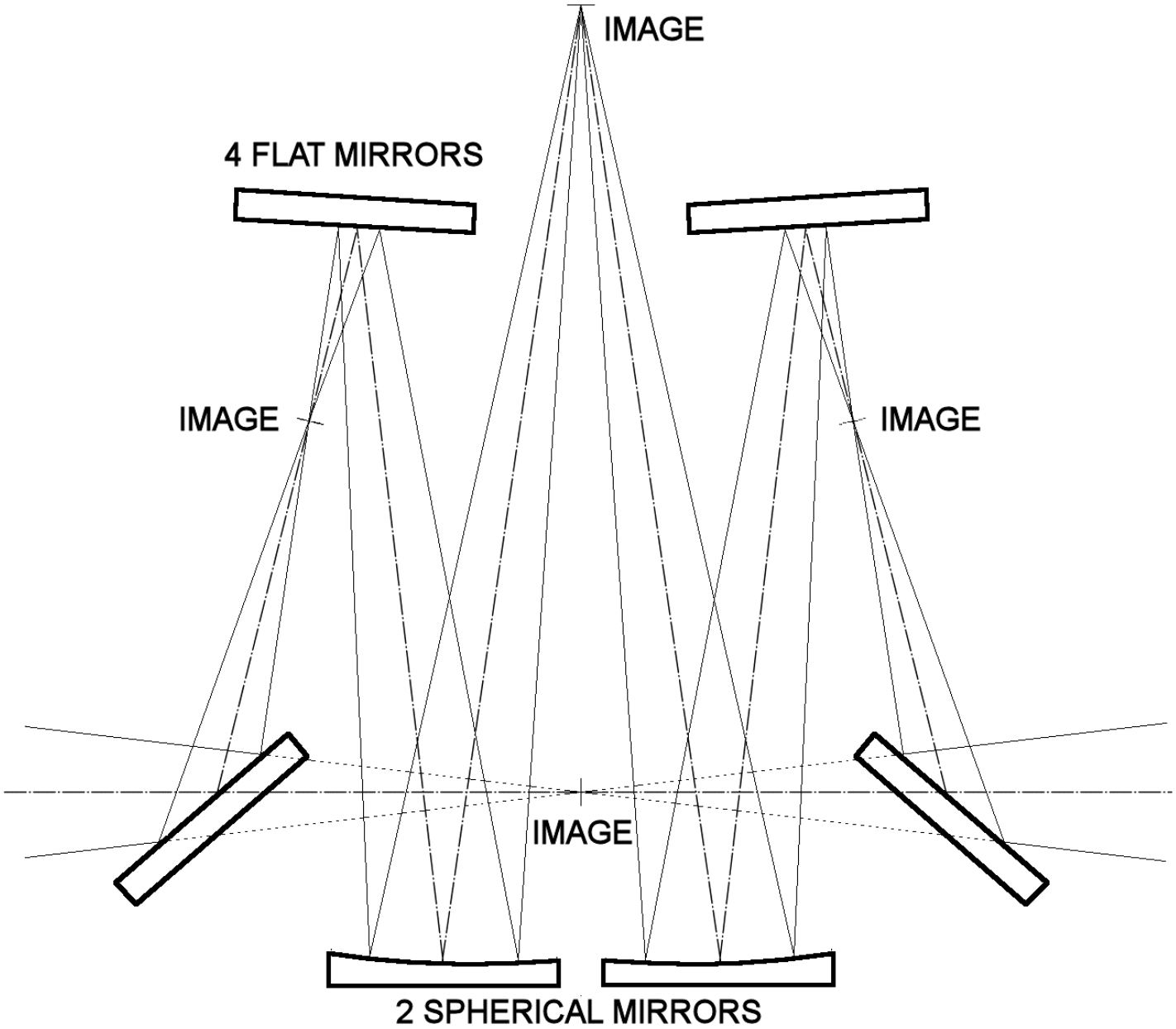
SHIMADZU REFLECTANCE

Fig. 1 Appearance of the SRM-8000
Specular Reflection Accessory

SHIMADZU REFLECTANCE

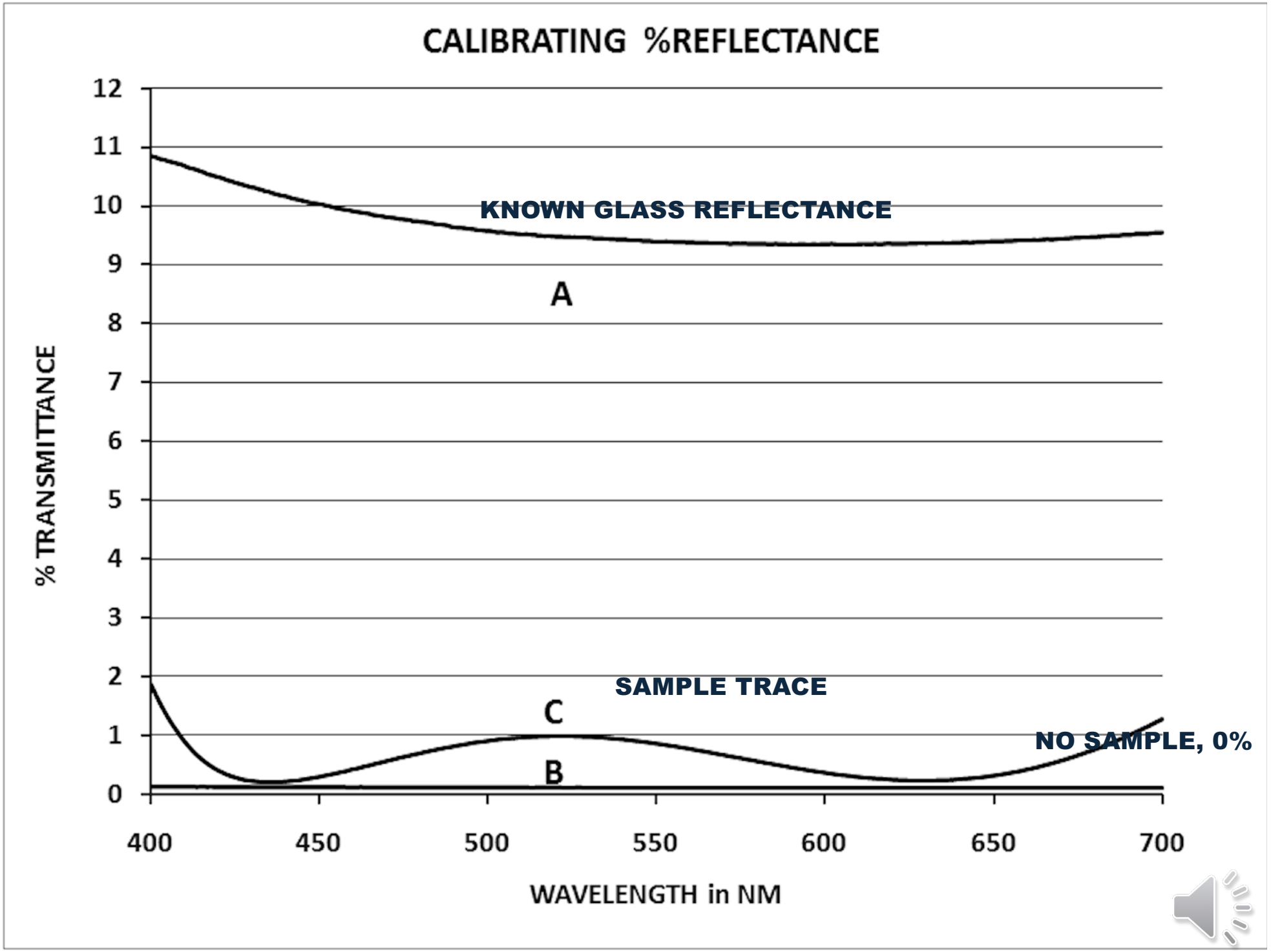


WILLEY REFLECTANCE



WILLEY REFLECTANCE

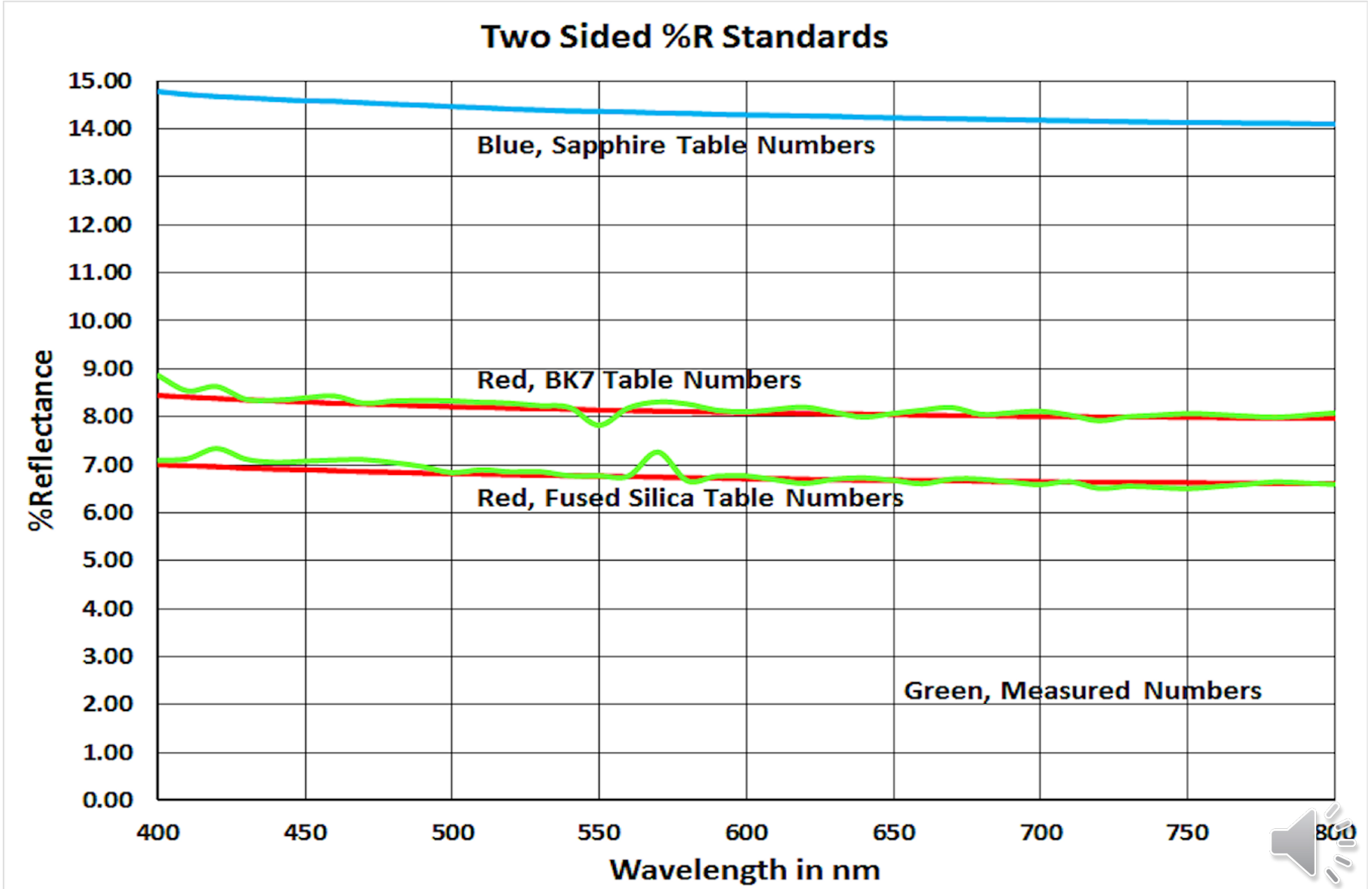
WILLEY REFLECTANCE

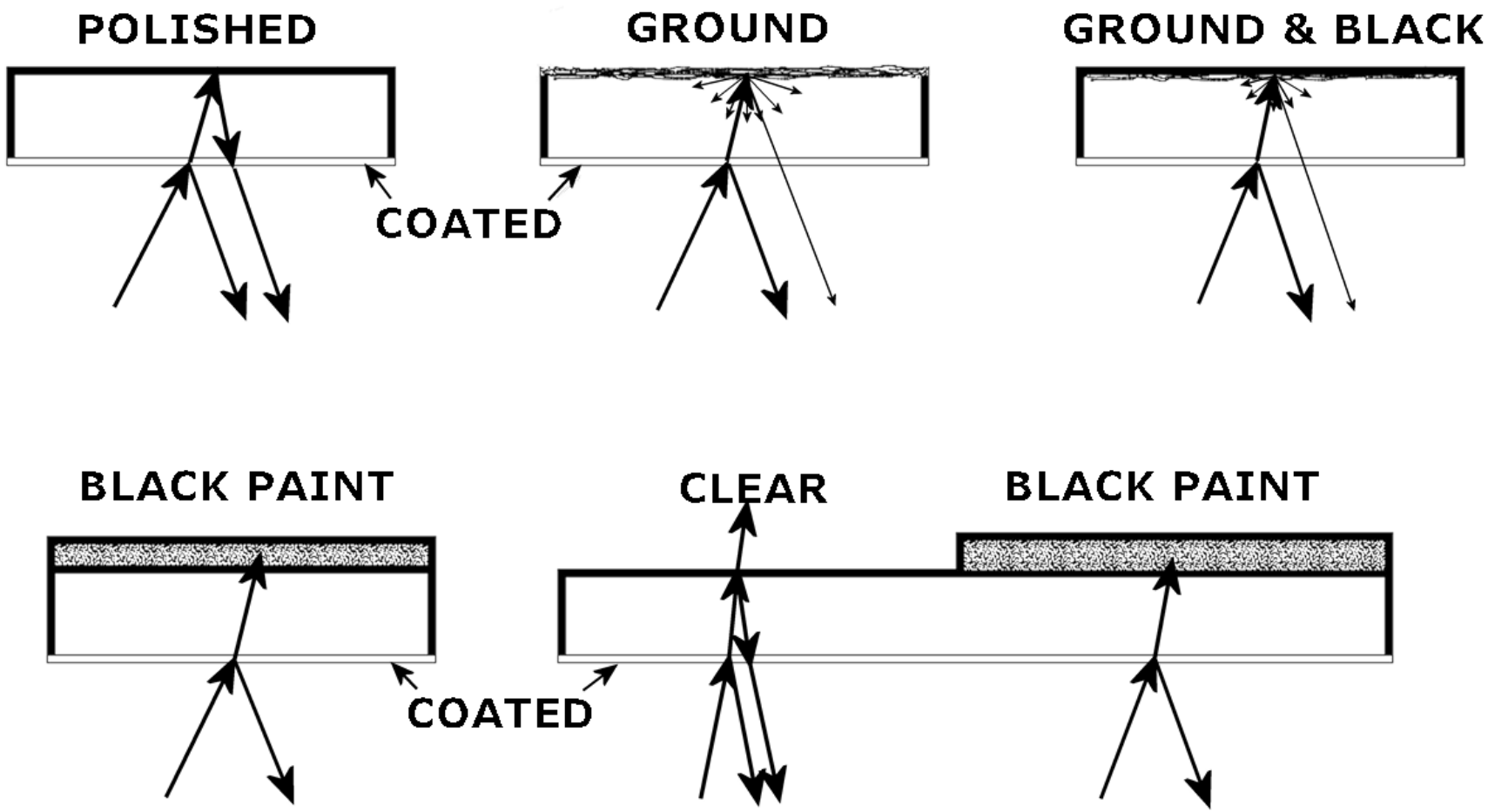

CALIBRATING %REFLECTANCE
12
11
10
9
8
7
6
5
4
3
2
1
0
% TRANSMITTANCE
KNOWN GLASS REFLECTANCE
A
SAMPLE TRACE
C
NO SAMPLE, 0%
B
400
450
500
550
600
650
700
WAVELENGTH in NM

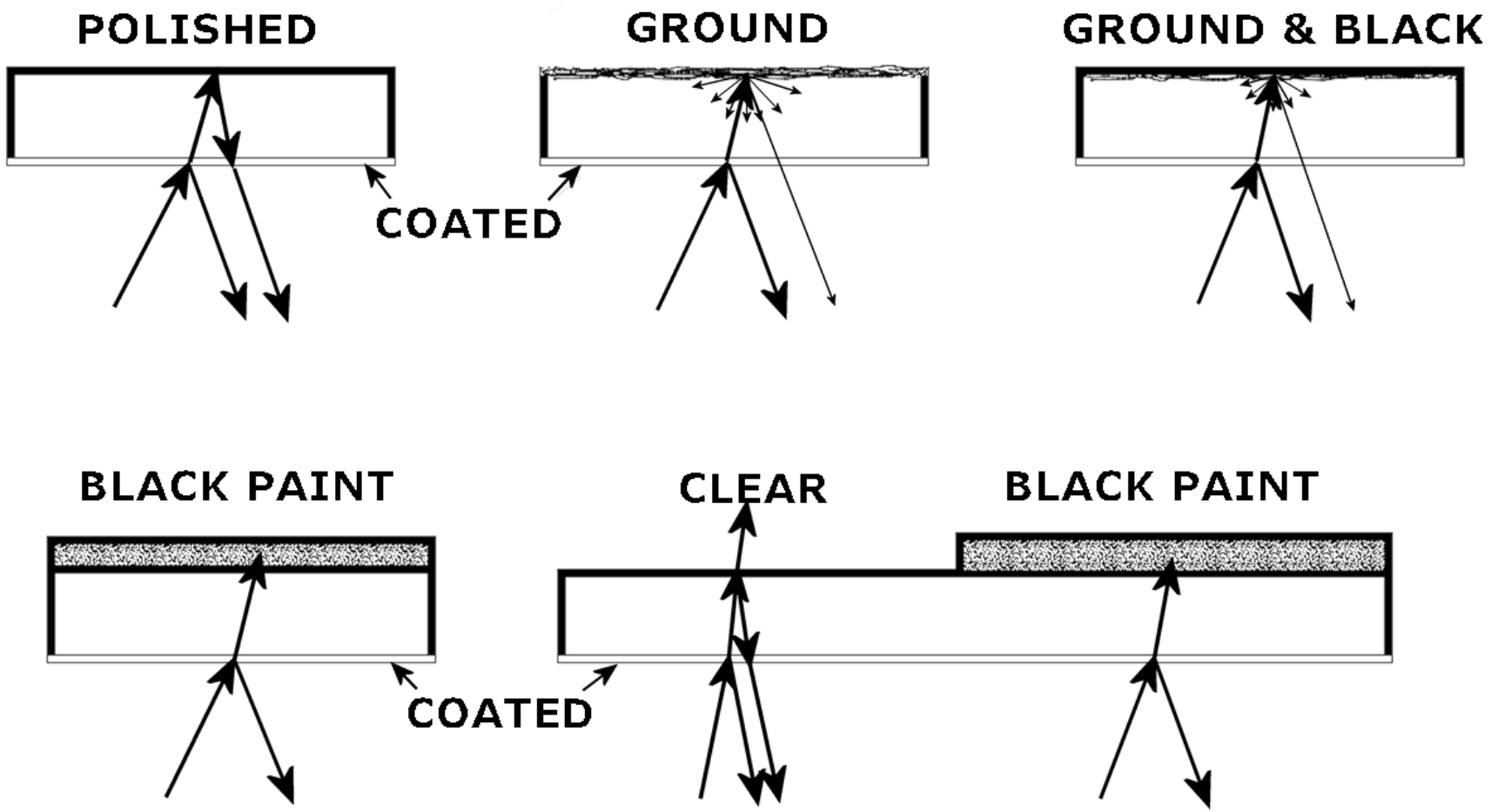
CALIBRATION

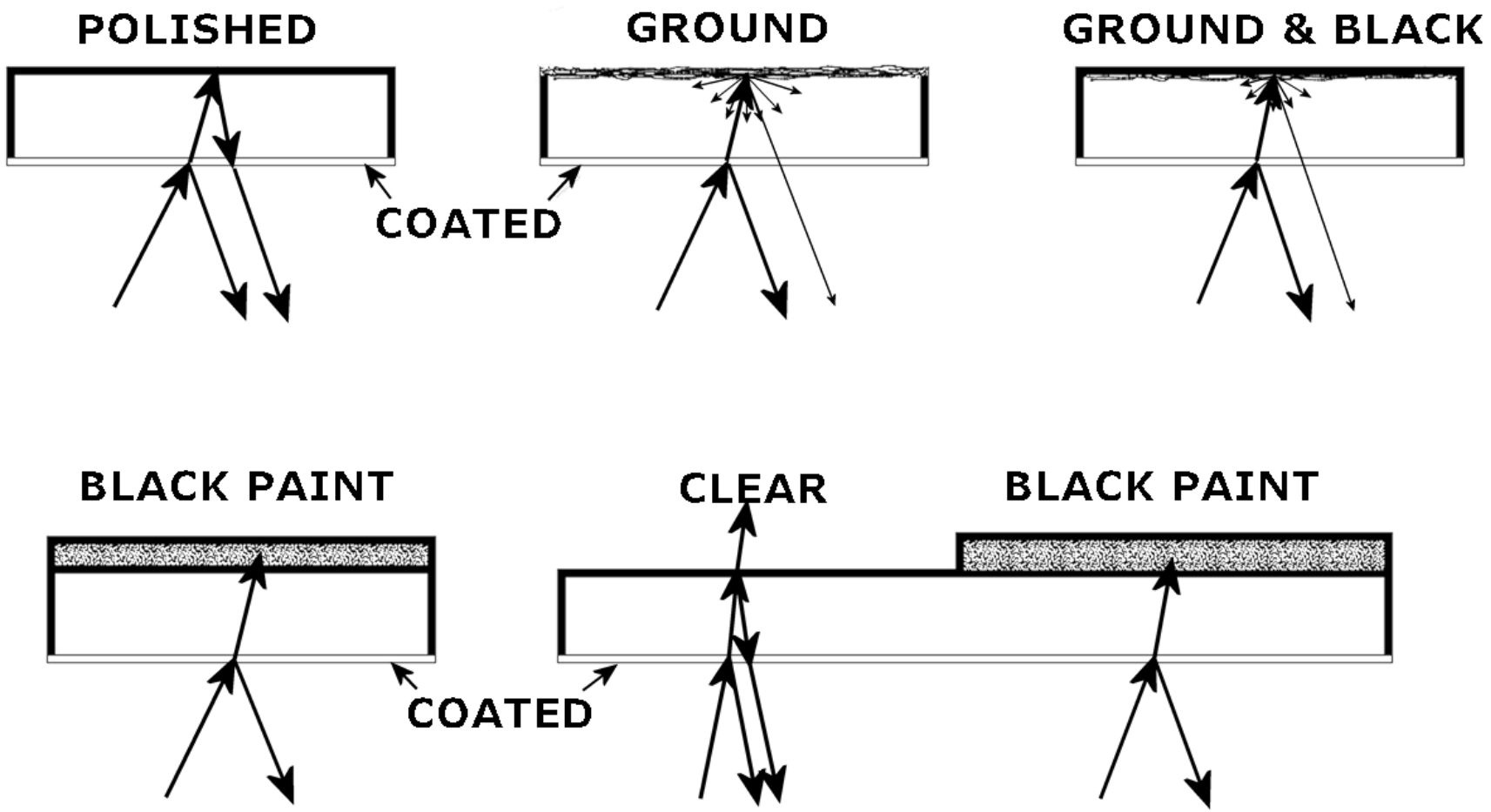
$$\%R = \%R(Known) \times (C-B)/(A-B)$$

CALIBRATION

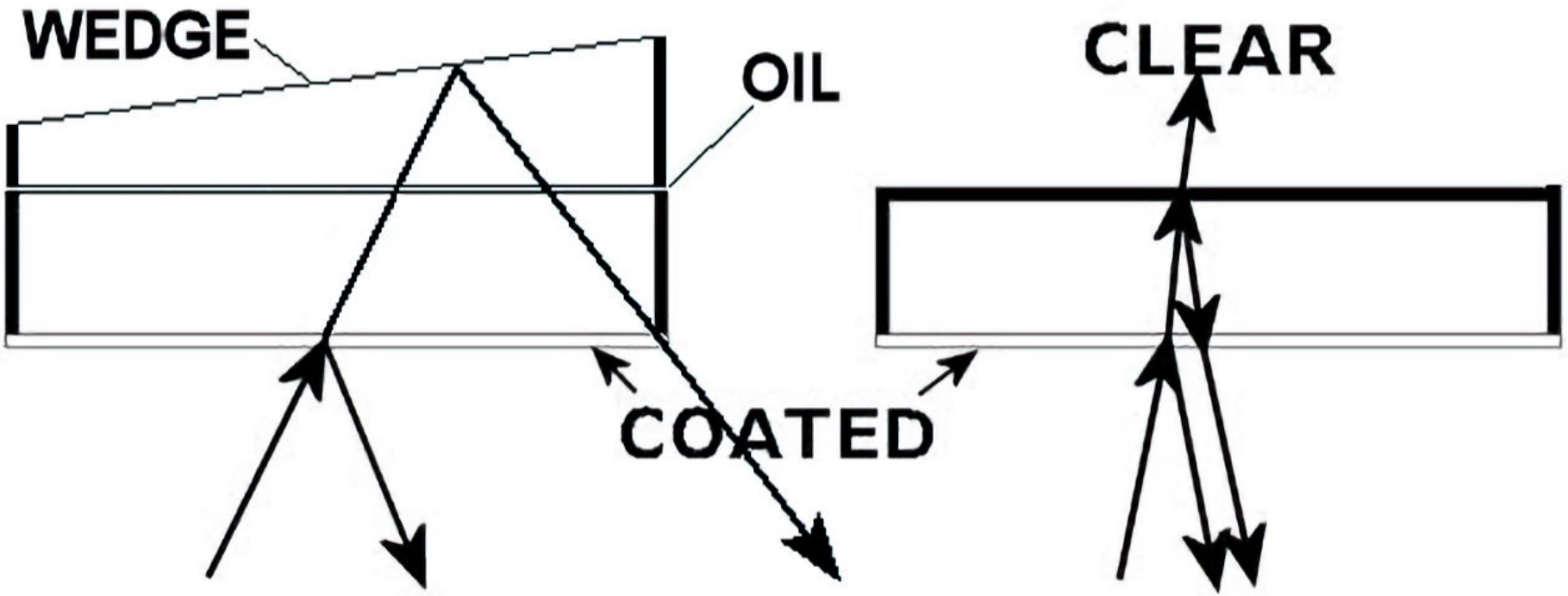


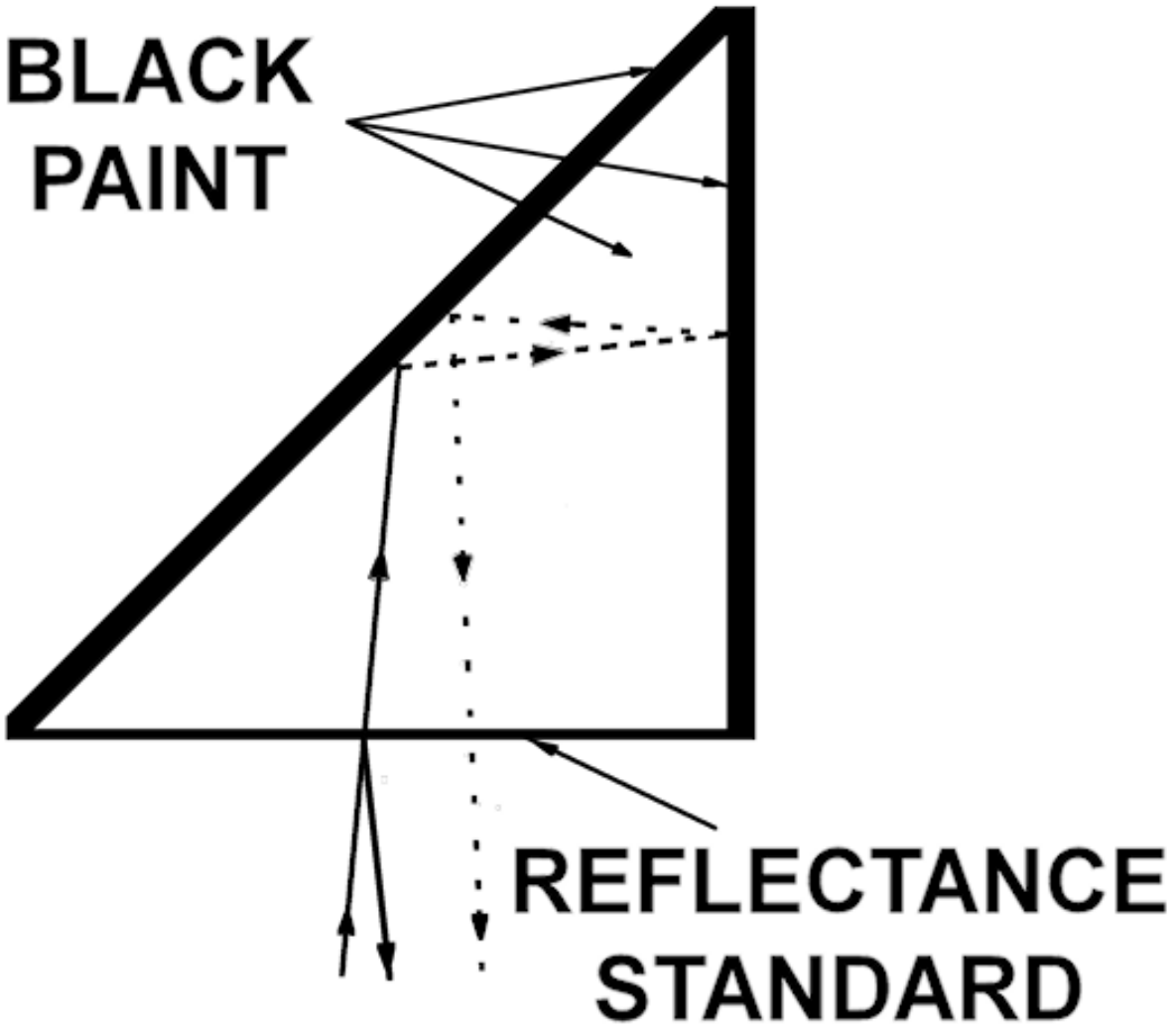

POLISHED
GROUND
GROUND & BLACK
COATED
BLACK PAINT
CLEAR
BLACK PAINT
COATED

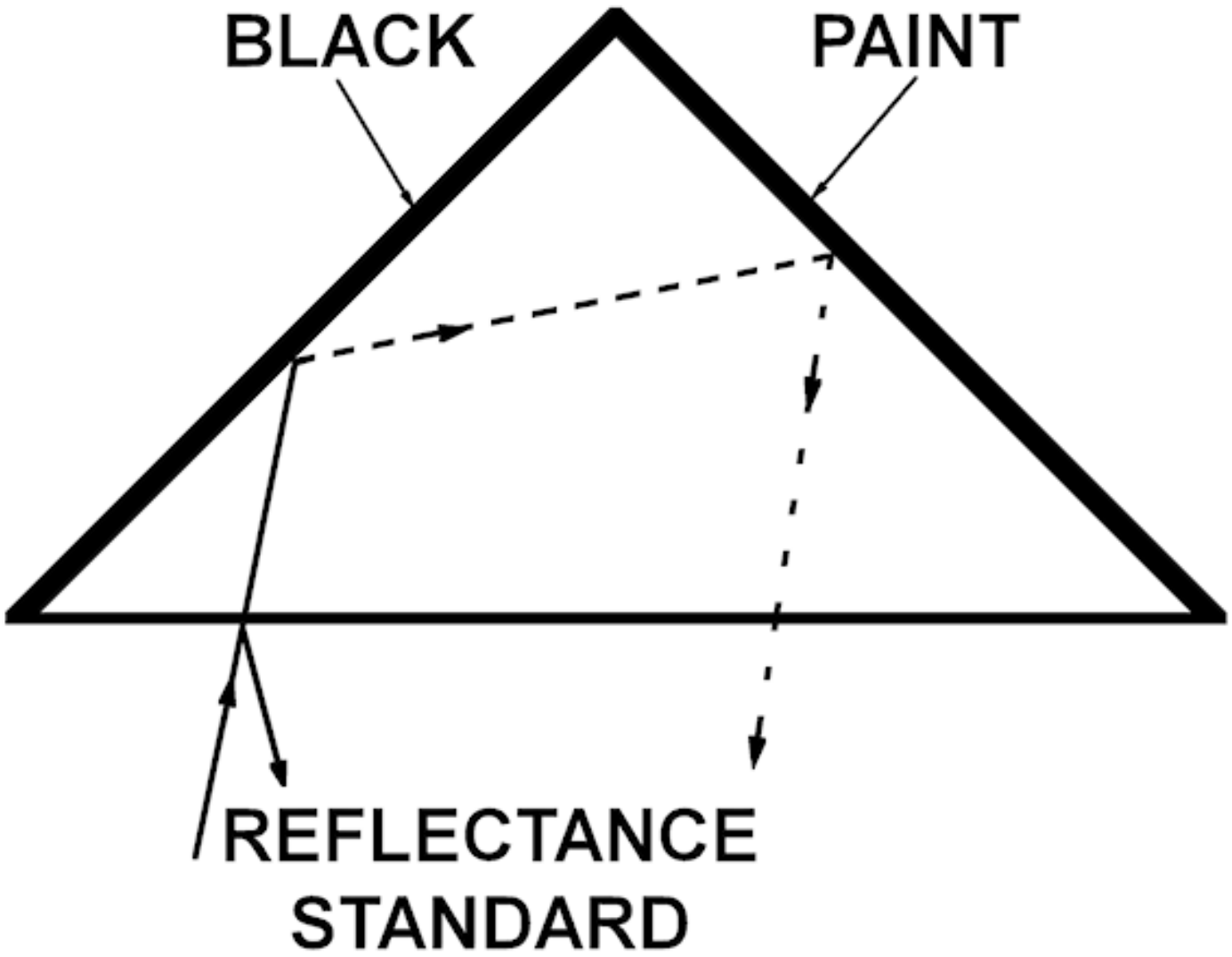

POLISHED
GROUND
GROUND & BLACK
COATED
BLACK PAINT
CLEAR
BLACK PAINT
COATED


POLISHED
GROUND
GROUND & BLACK
COATED
BLACK PAINT
CLEAR
BLACK PAINT
COATED

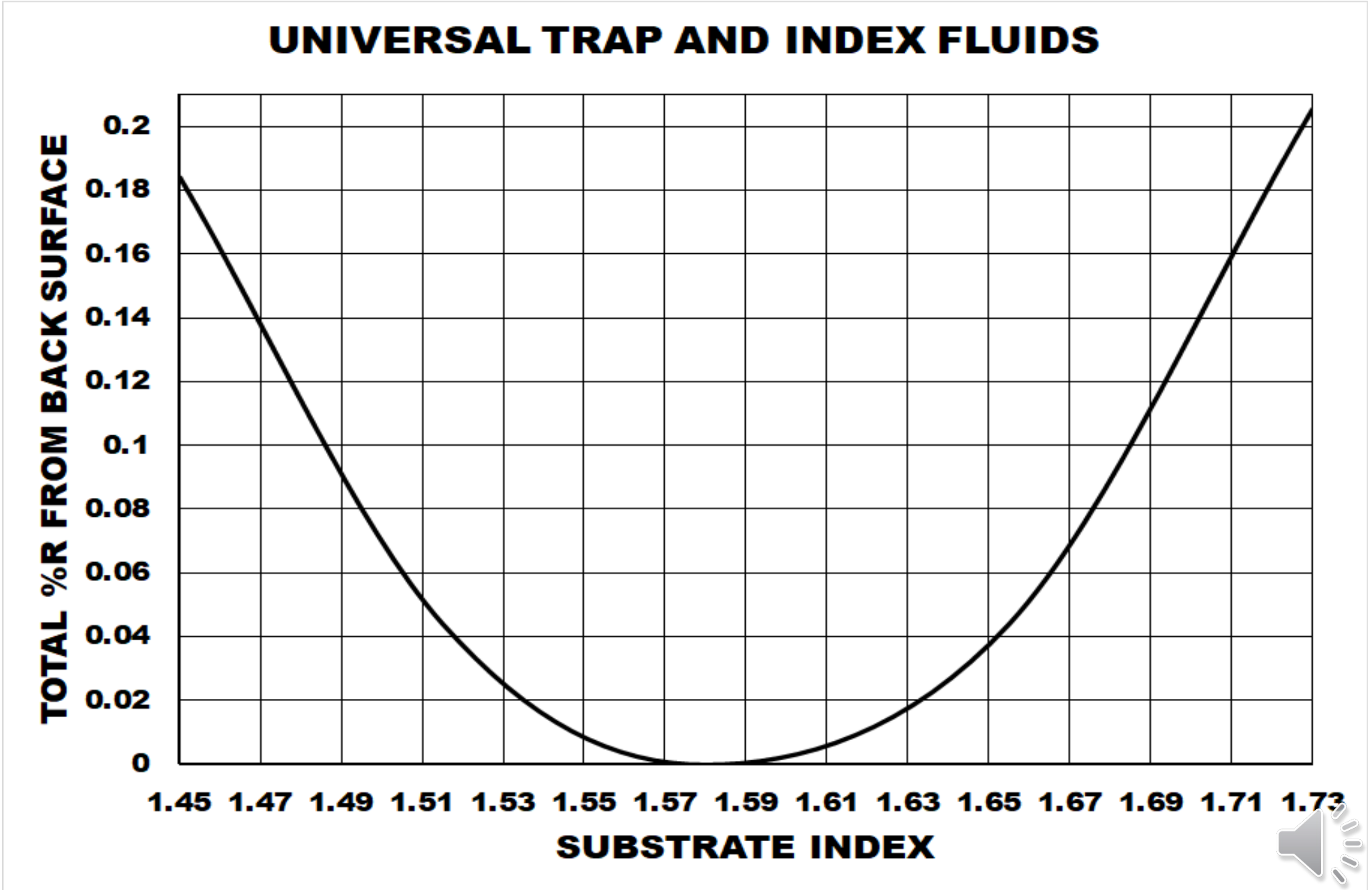
WEDGE APPROACH



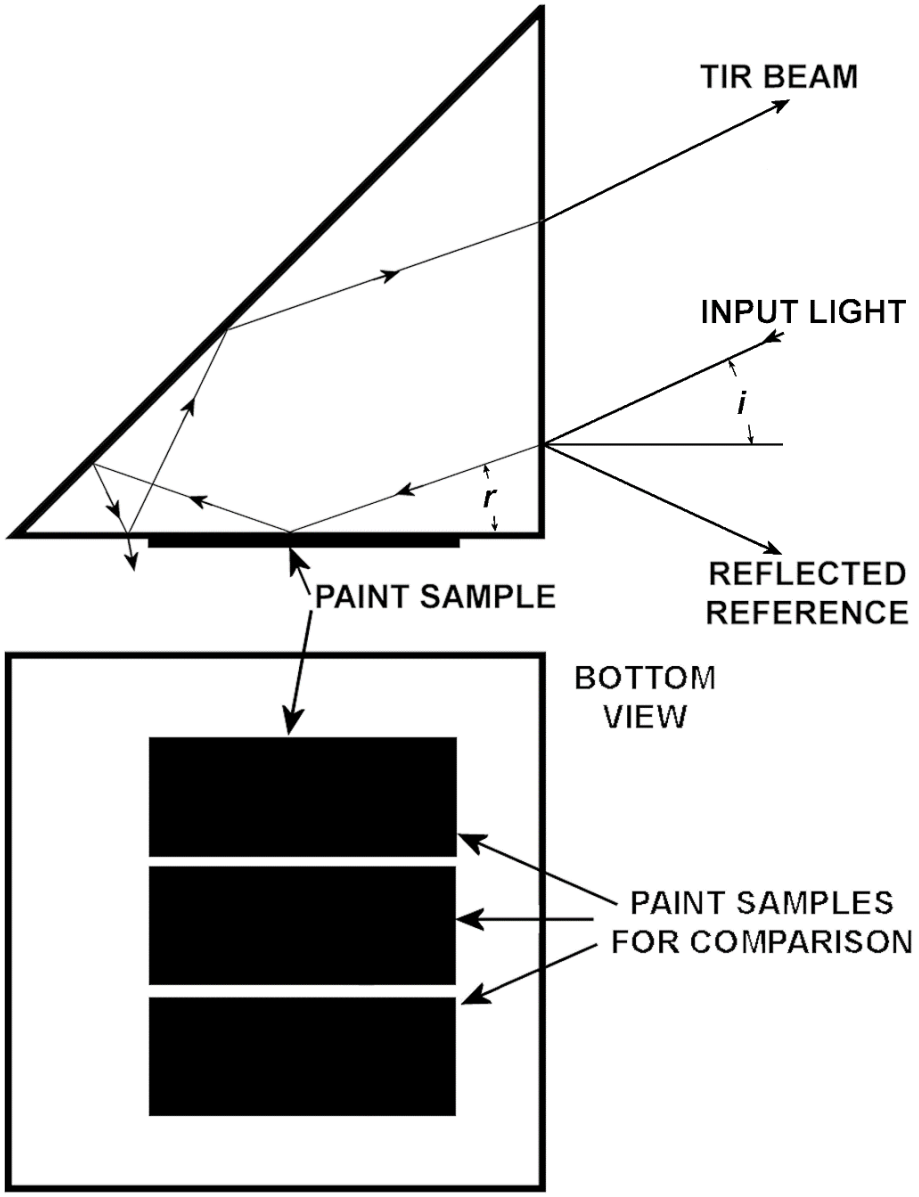

BLACK
PAINT
REFLECTANCE
STANDARD

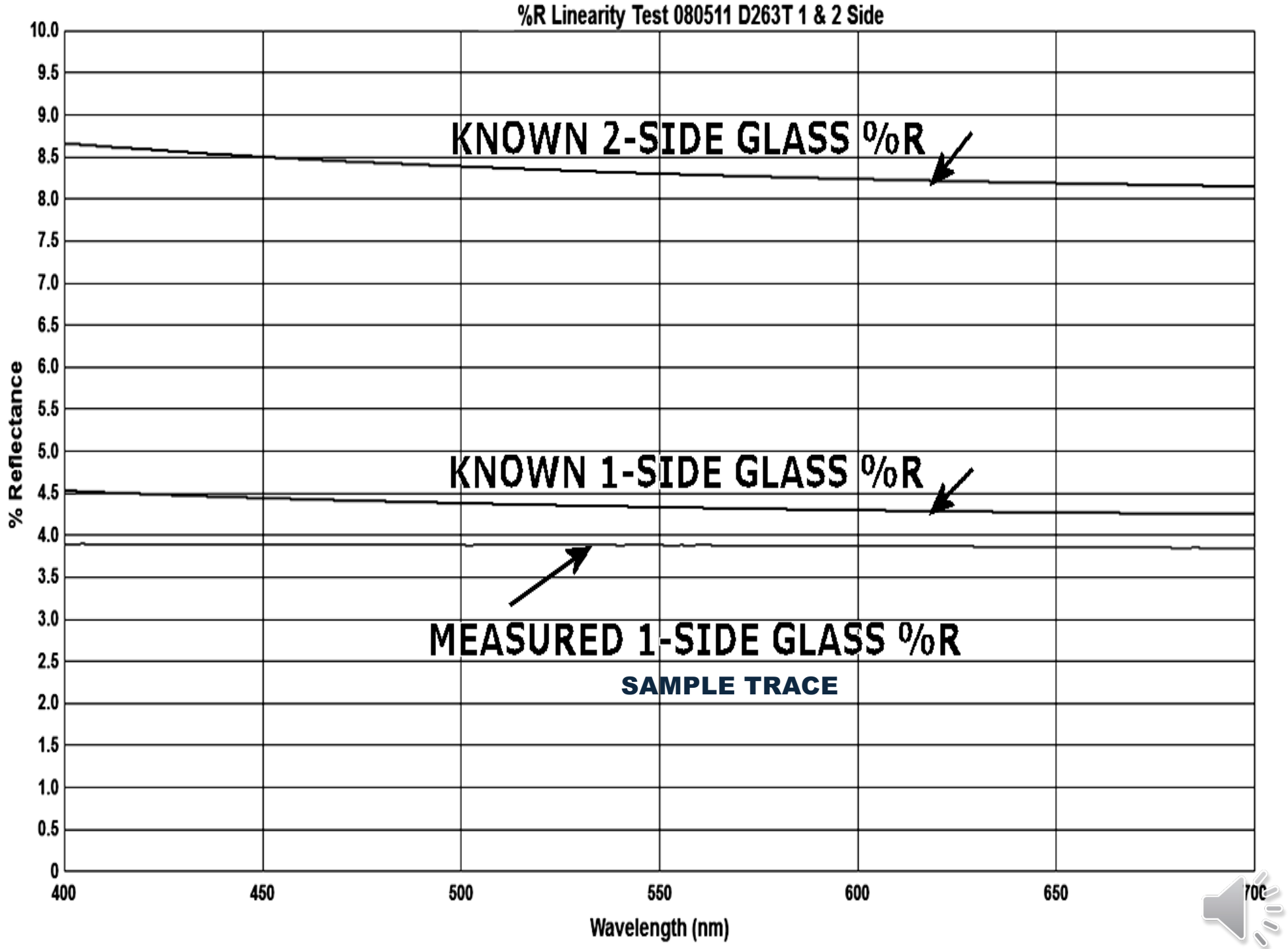

BLACK
PAINT
REFLECTANCE
STANDARD

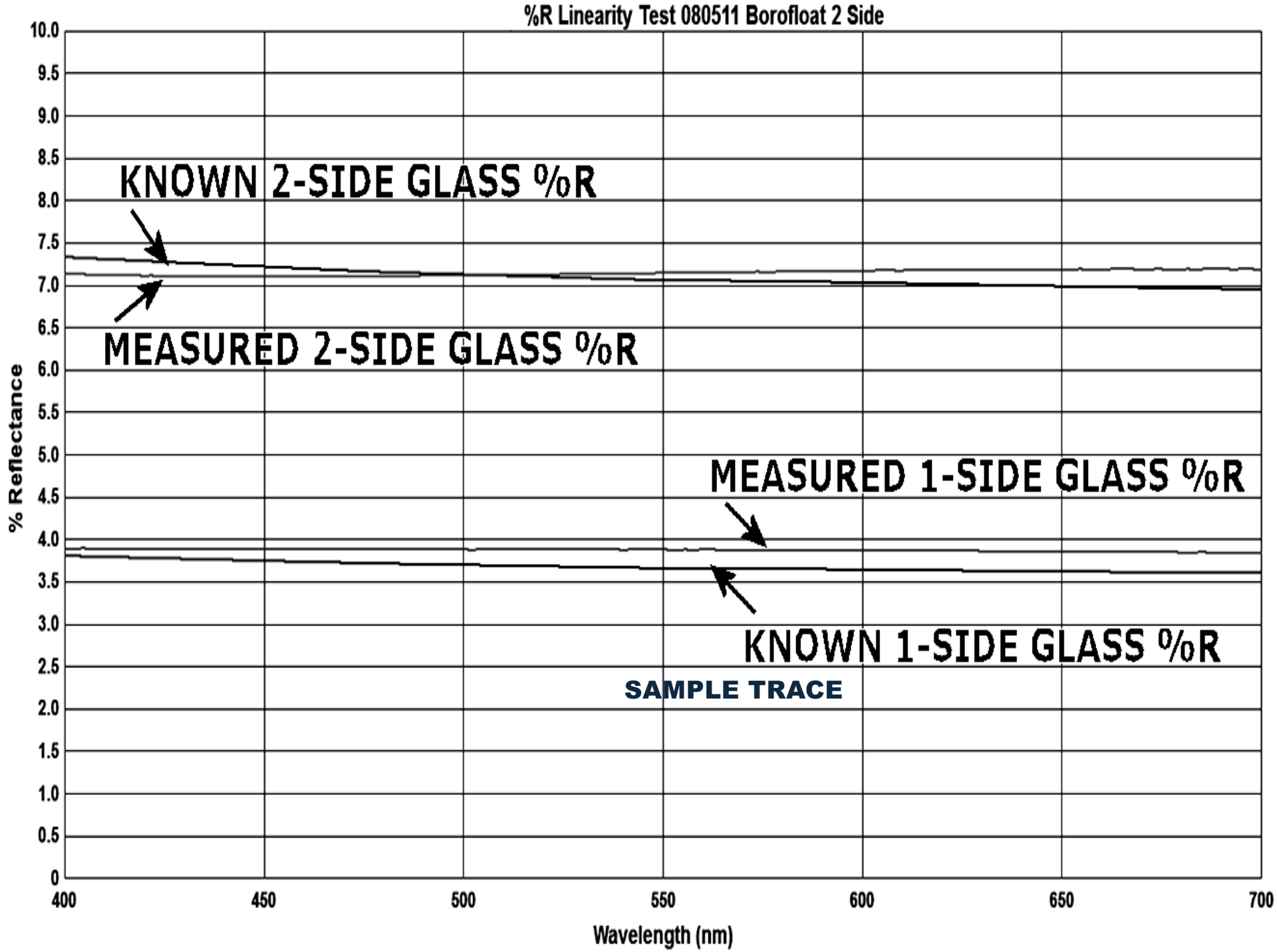
INDEX MATCH COMPARISON



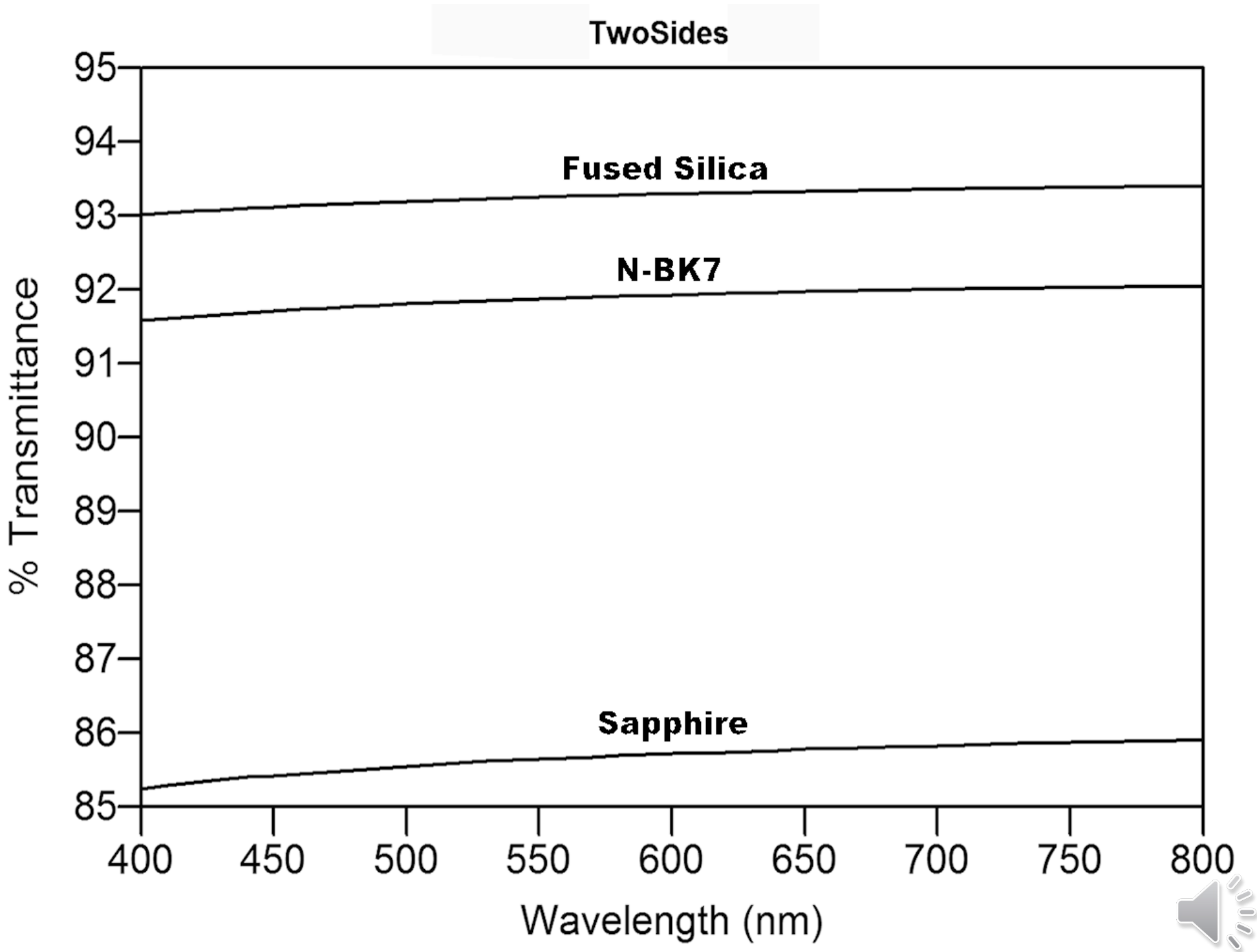
INDEX MATCH COMPARISON

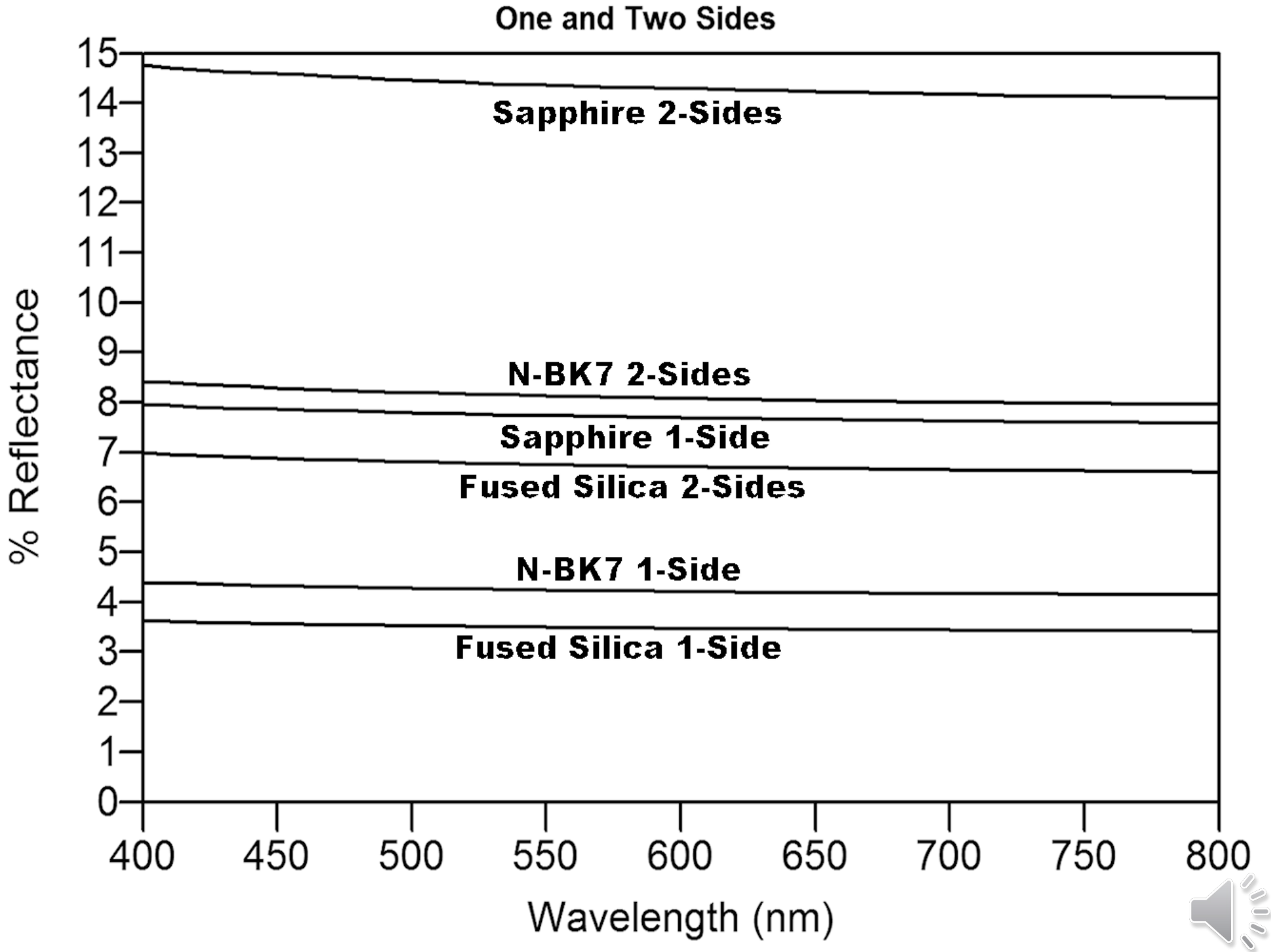



%R Linearity Test 080511 D263T 1 & 2 Side
KNOWN 2-SIDE GLASS %R
KNOWN 1-SIDE GLASS %R
MEASURED 1-SIDE GLASS %R
SAMPLE TRACE
% Reflectance
Wavelength (nm)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
400
450
500
550
600
650

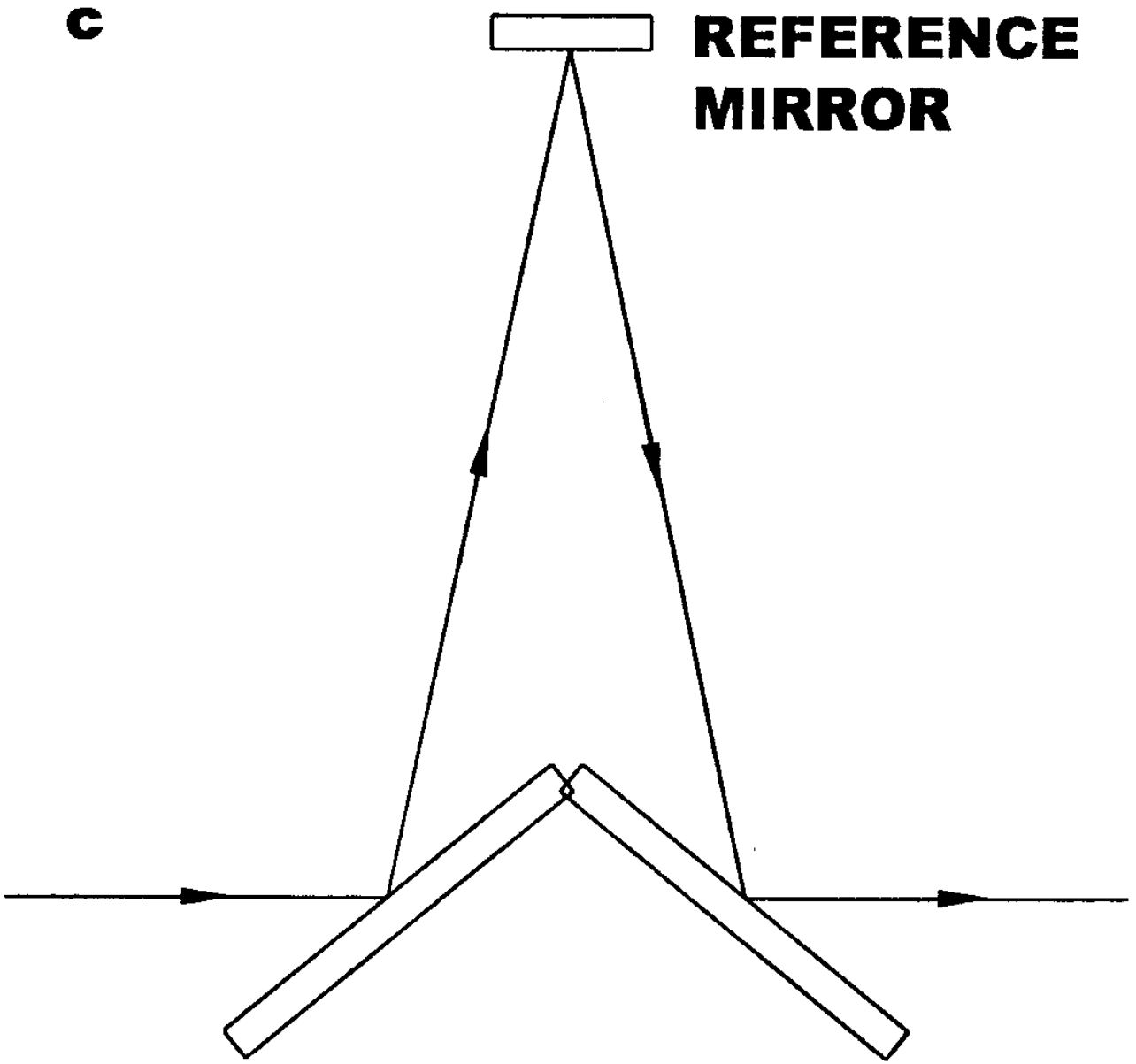

%R Linearity Test 080511 Borofloat 2 Side
KNOWN 2-SIDE GLASS %R
MEASURED 2-SIDE GLASS %R
MEASURED 1-SIDE GLASS %R
KNOWN 1-SIDE GLASS %R
SAMPLE TRACE
% Reflectance
Wavelength (nm)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
400
450
500
550
600
650
700

	N-BK7	N-BK7	N-BK7	Sapphire	Sapphire	Sapphire	Silica	Silica	Silica
	Two-Side	Two-Side	One-Side	Two-Side	Two-Side	One-Side	Two-Side	Two-Side	One-Side
WL in nm	%R	%T	%R	%R	%T	%R	%R	%T	%R
400	8.43	91.57	4.40	14.77	85.23	7.97	6.99	93.01	3.62
410	8.40	91.60	4.38	14.71	85.29	7.94	6.97	93.03	3.61
420	8.37	91.63	4.37	14.67	85.33	7.92	6.95	93.05	3.60
430	8.34	91.66	4.35	14.64	85.36	7.90	6.92	93.08	3.59
440	8.32	91.68	4.34	14.61	85.39	7.88	6.90	93.10	3.58
450	8.30	91.70	4.33	14.58	85.42	7.87	6.89	93.11	3.57
460	8.27	91.73	4.32	14.57	85.43	7.86	6.87	93.13	3.56
470	8.26	91.74	4.31	14.54	85.46	7.84	6.85	93.15	3.55
480	8.24	91.76	4.30	14.51	85.49	7.82	6.84	93.16	3.54
490	8.22	91.78	4.29	14.49	85.51	7.81	6.82	93.18	3.53
500	8.20	91.80	4.28	14.46	85.54	7.79	6.81	93.19	3.53
510	8.19	91.81	4.27	14.44	85.56	7.78	6.80	93.20	3.52
520	8.17	91.83	4.26	14.41	85.59	7.77	6.79	93.21	3.51
530	8.16	91.84	4.25	14.39	85.61	7.75	6.78	93.22	3.51
540	8.15	91.85	4.25	14.37	85.63	7.74	6.77	93.23	3.50
550	8.13	91.87	4.24	14.36	85.64	7.74	6.76	93.24	3.50
560	8.12	91.88	4.23	14.35	85.65	7.73	6.75	93.25	3.49
570	8.11	91.89	4.23	14.33	85.67	7.72	6.74	93.26	3.49
580	8.10	91.90	4.22	14.32	85.68	7.71	6.73	93.27	3.48
590	8.09	91.91	4.22	14.30	85.70	7.70	6.72	93.28	3.48
600	8.08	91.92	4.21	14.29	85.71	7.69	6.71	93.29	3.47
610	8.07	91.93	4.21	14.28	85.72	7.69	6.71	93.29	3.47
620	8.06	91.94	4.20	14.27	85.73	7.68	6.70	93.30	3.47
630	8.05	91.95	4.20	14.26	85.74	7.67	6.69	93.31	3.46
640	8.05	91.95	4.19	14.24	85.76	7.67	6.68	93.32	3.46
650	8.04	91.96	4.19	14.23	85.77	7.66	6.68	93.32	3.45
660	8.03	91.97	4.18	14.22	85.78	7.65	6.67	93.33	3.45
670	8.02	91.98	4.18	14.21	85.79	7.65	6.67	93.33	3.45
680	8.02	91.98	4.18	14.20	85.80	7.64	6.66	93.34	3.44
690	8.01	91.99	4.17	14.19	85.81	7.64	6.65	93.35	3.44
700	8.00	92.00	4.17	14.18	85.82	7.63	6.65	93.35	3.44
710	8.00	92.00	4.17	14.17	85.83	7.63	6.64	93.36	3.44
720	7.99	92.01	4.16	14.16	85.84	7.62	6.64	93.36	3.43
730	7.99	92.01	4.16	14.15	85.85	7.61	6.64	93.36	3.43
740	7.99	92.01	4.16	14.14	85.86	7.61	6.63	93.37	3.43
750	7.98	92.02	4.16	14.13	85.87	7.60	6.63	93.37	3.43
760	7.98	92.02	4.15	14.13	85.87	7.60	6.62	93.38	3.42
770	7.97	92.03	4.15	14.12	85.88	7.60	6.62	93.38	3.42
780	7.97	92.03	4.15	14.12	85.88	7.59	6.61	93.39	3.42
790	7.96	92.04	4.15	14.11	85.89	7.59	6.61	93.39	3.42
800	7.96	92.04	4.15	14.10	85.90	7.58	6.61	93.39	3.42

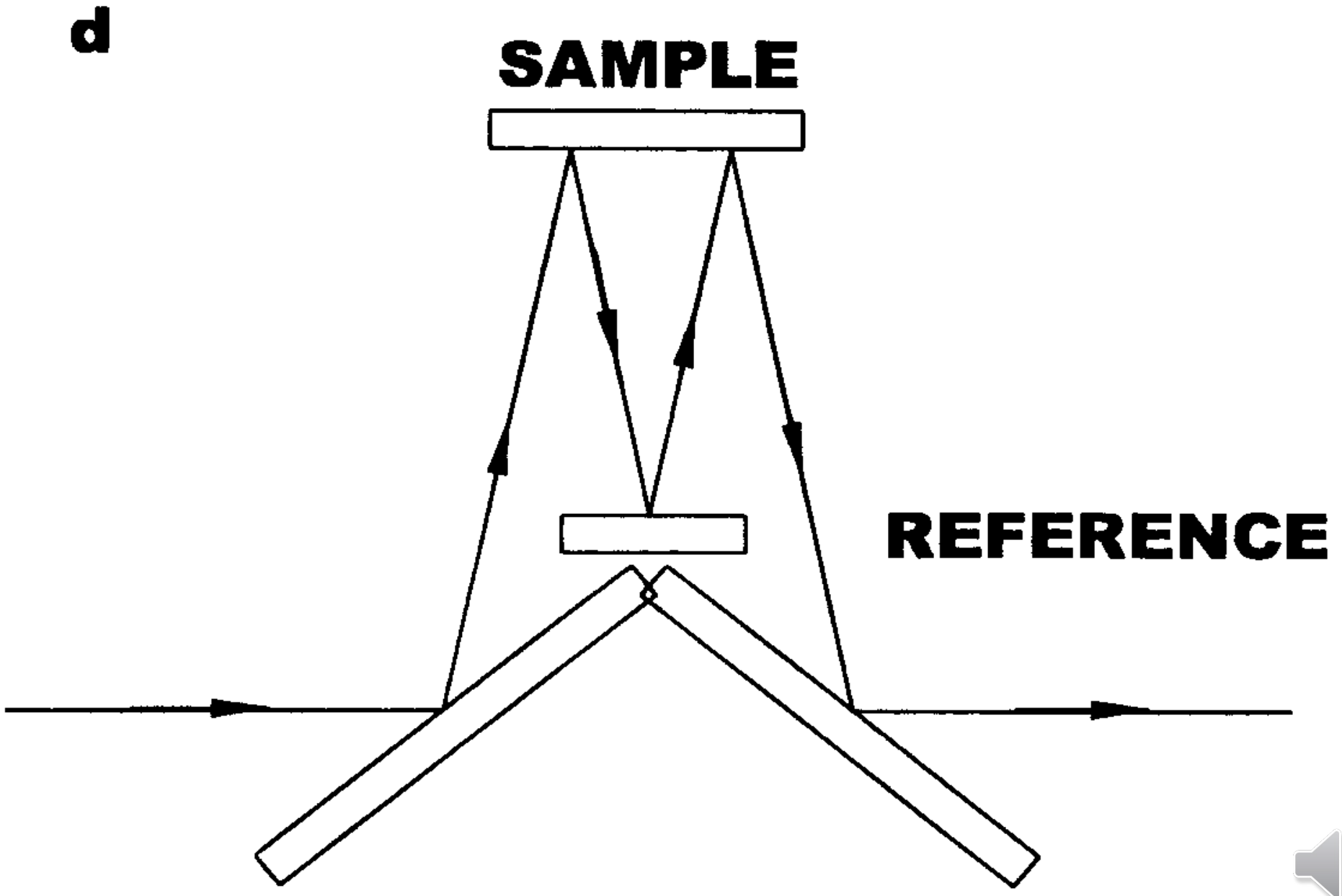

TwoSides
95
94
93
92
91
90
89
88
87
86
85
% Transmittance
Fused Silica
N-BK7
Sapphire
400
450
500
550
600
650
700
750
800
Wavelength (nm)


One and Two Sides
% Reflectance
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Sapphire 2-Sides
N-BK7 2-Sides
Sapphire 1-Side
Fused Silica 2-Sides
N-BK7 1-Side
Fused Silica 1-Side
400
450
500
550
600
650
700
750
800
Wavelength (nm)

V-W ATTACHMENT IN V MODE



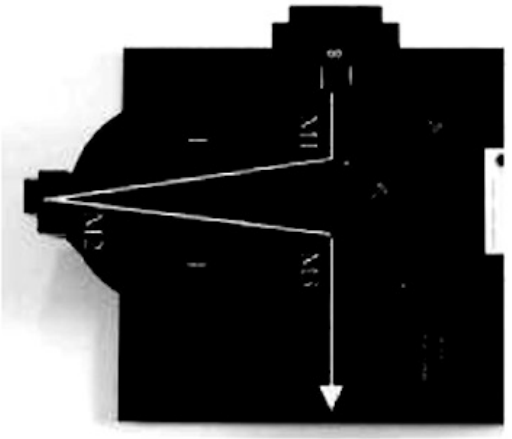
V-W ATTACHMENT IN W MODE

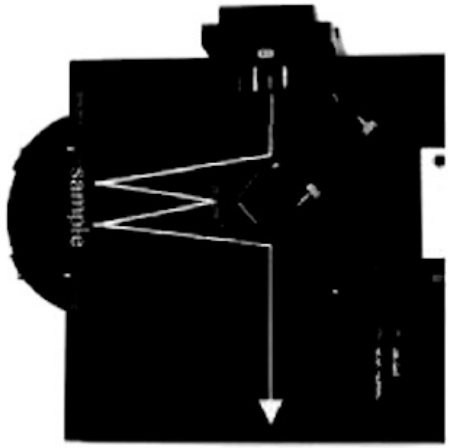


V-W ATTACHMENT

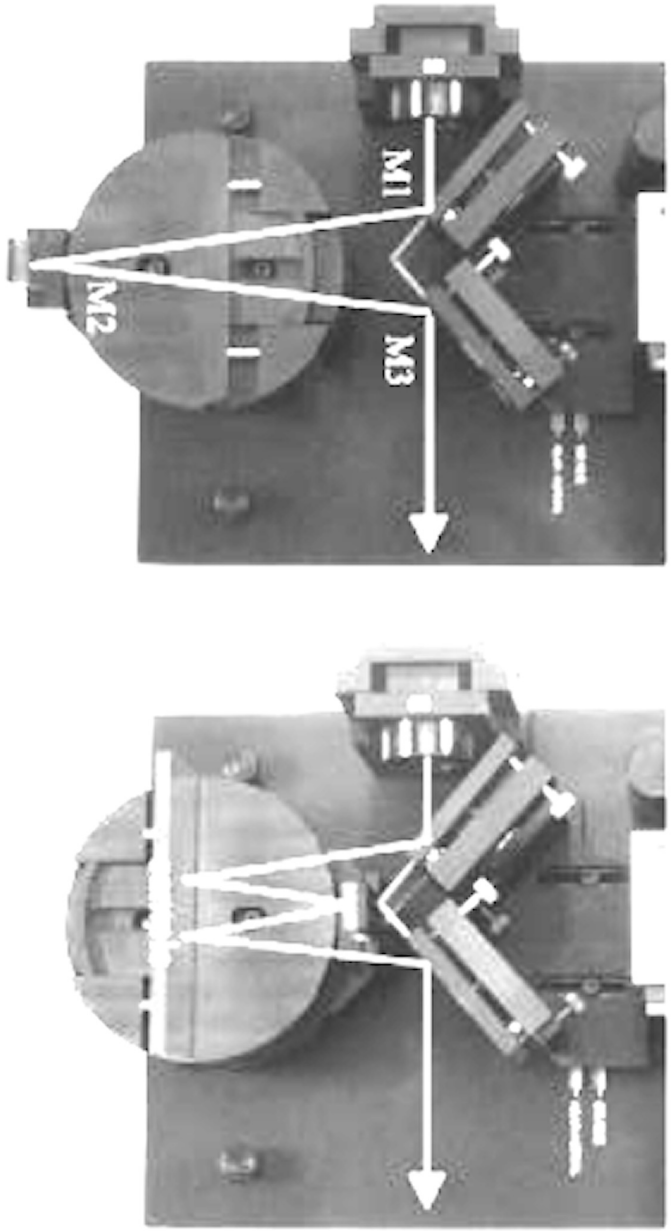
How do you Measure High Reflectivity?

- Relative (requires a standard mirror)
  - Fixed/Var Angle "V" types Δ 0.5-2% R≤98-99.5%
- Absolute (no standard required)
  - URA type: Δ~2% R≤97% (*99.8% w/standard*)
  - Fixed Angle "VN" type: Δ~3% R≤97%
  - Fixed/Variable Angle "VW" types:
    - ✓ Δ = 0.2% in the visible range R≤99.8%
    - ✓ Δ = 0.4% in the UV and NIR range R≤99.6%



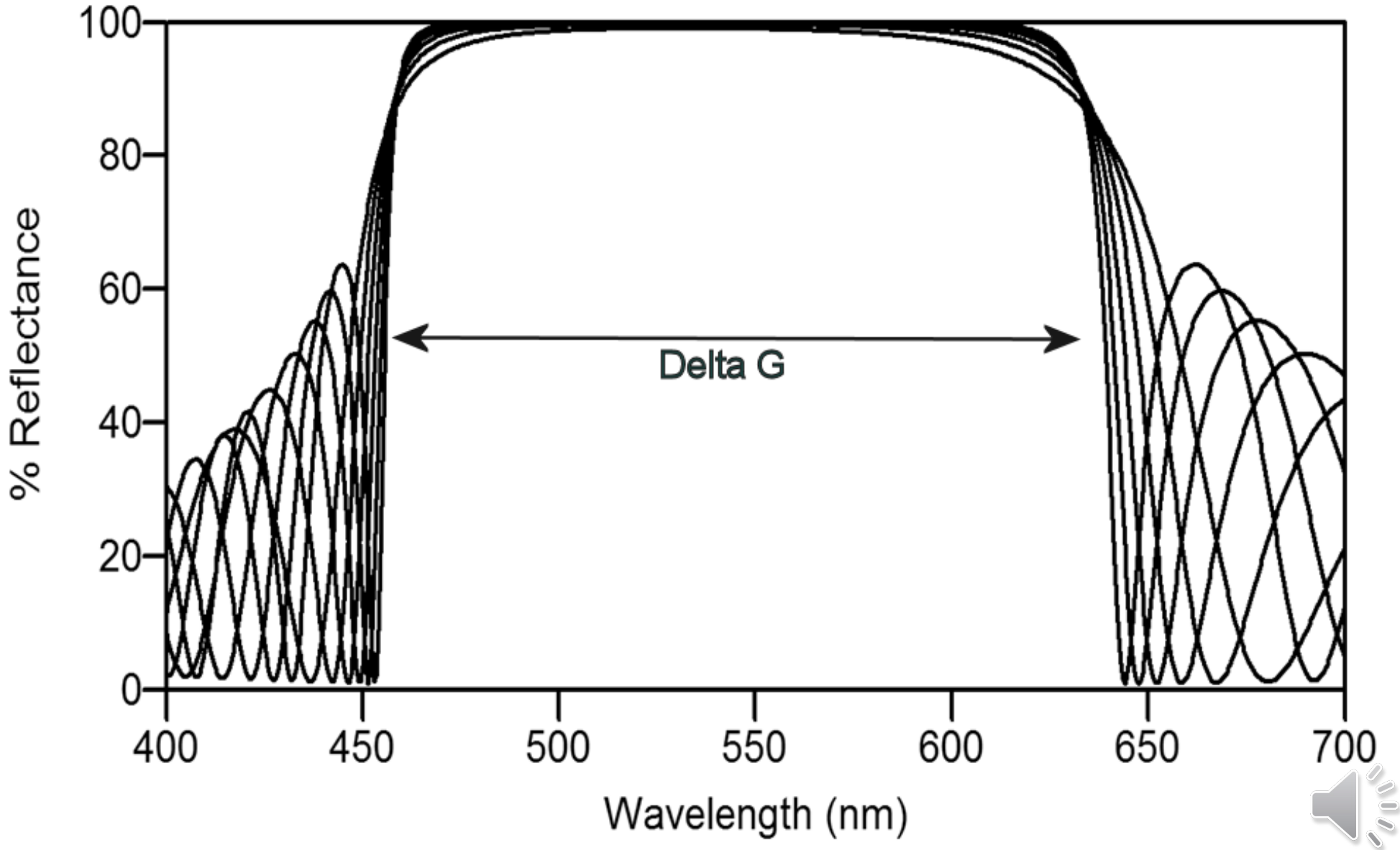


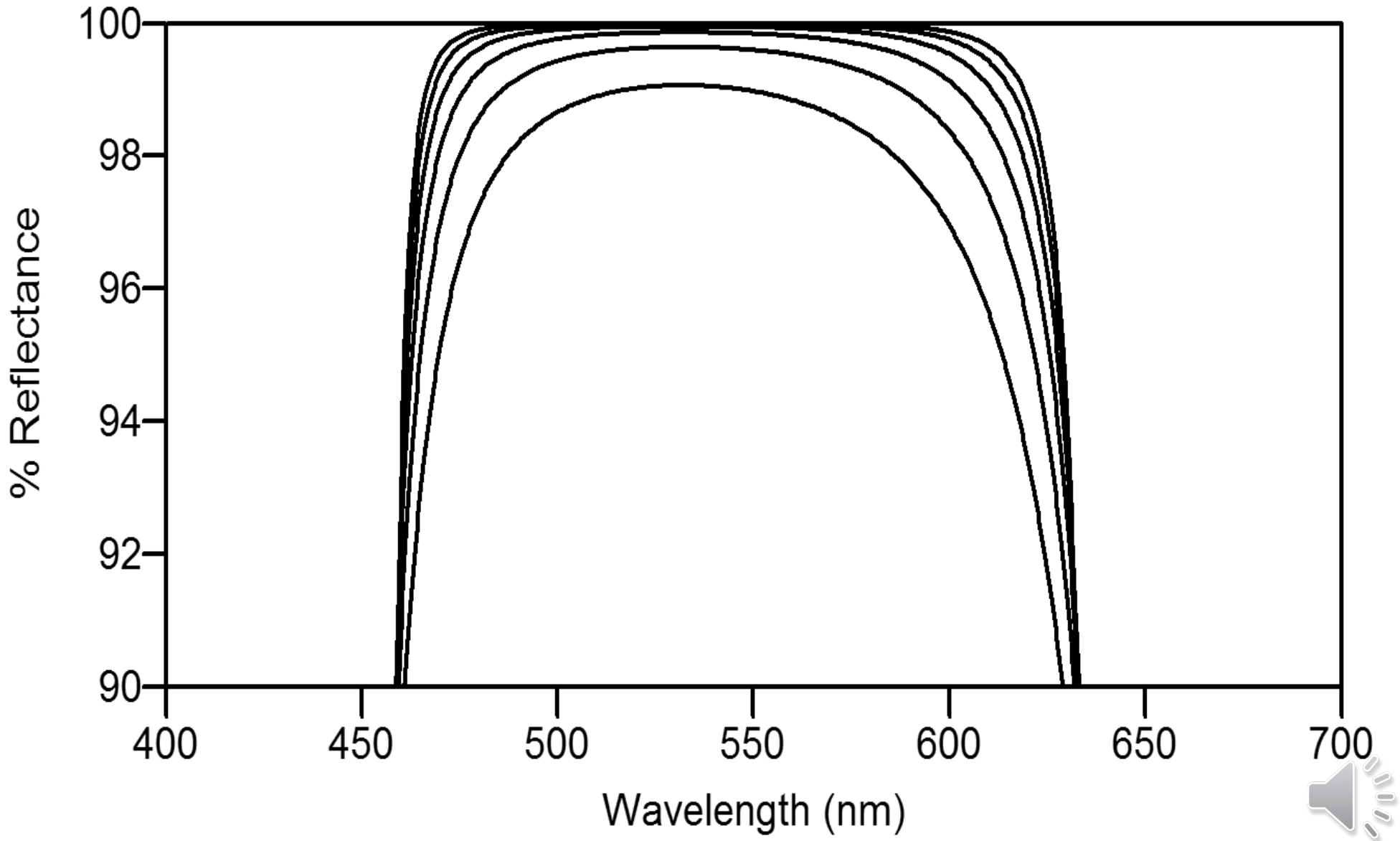
V-W ATTACHMENT

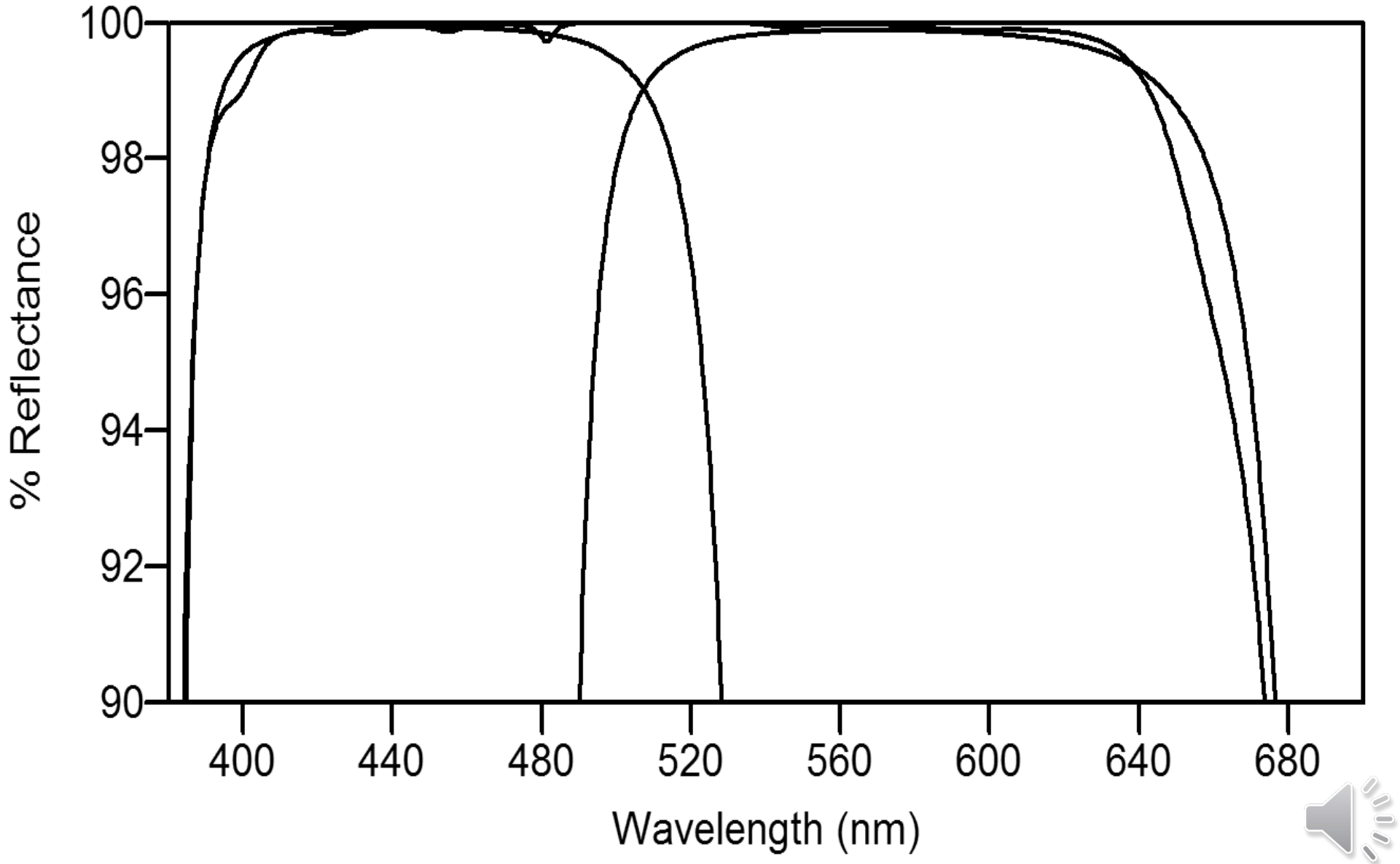


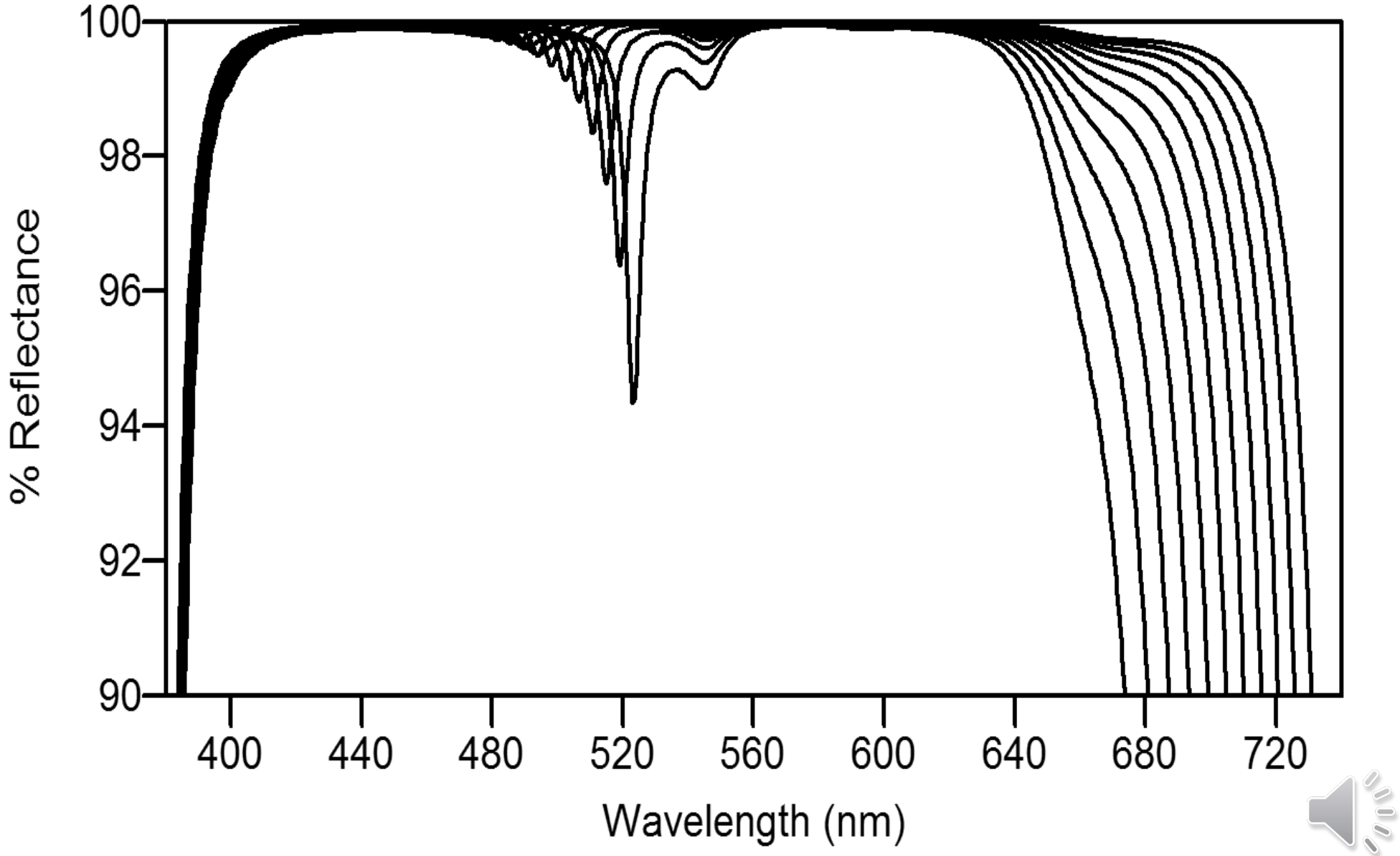
DIELECTRIC MIRRORS

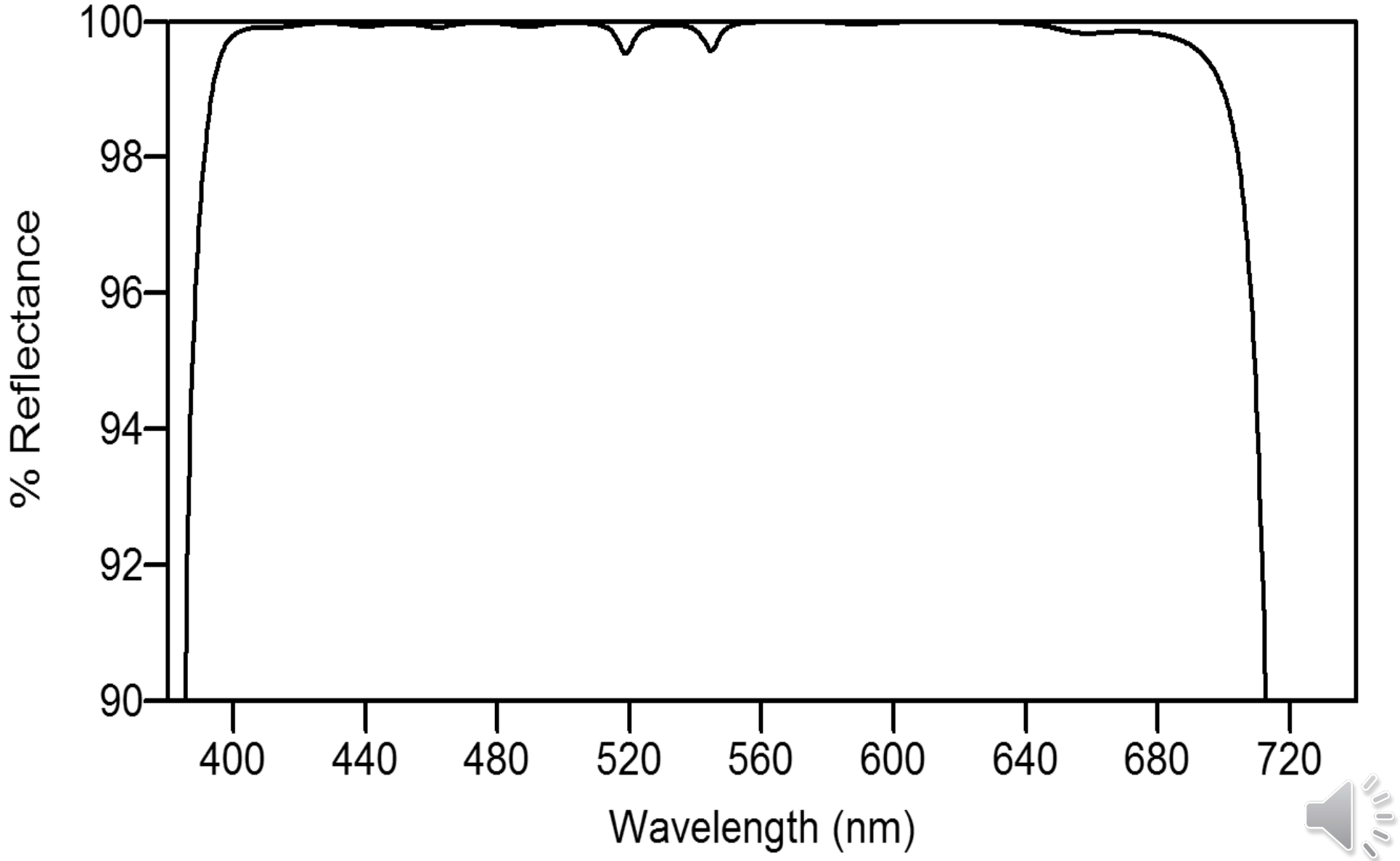
BANDWIDTH LIMITATION

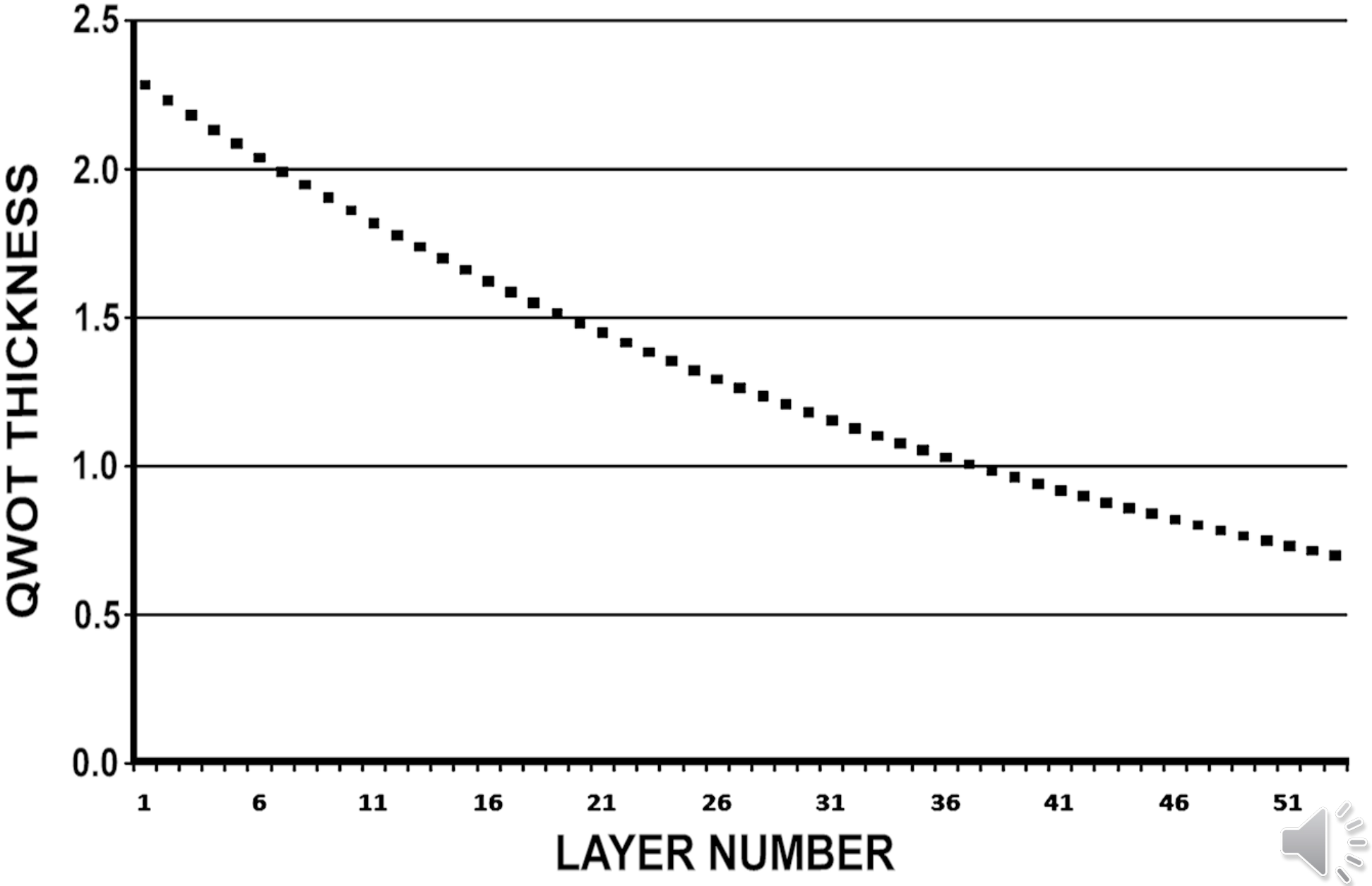


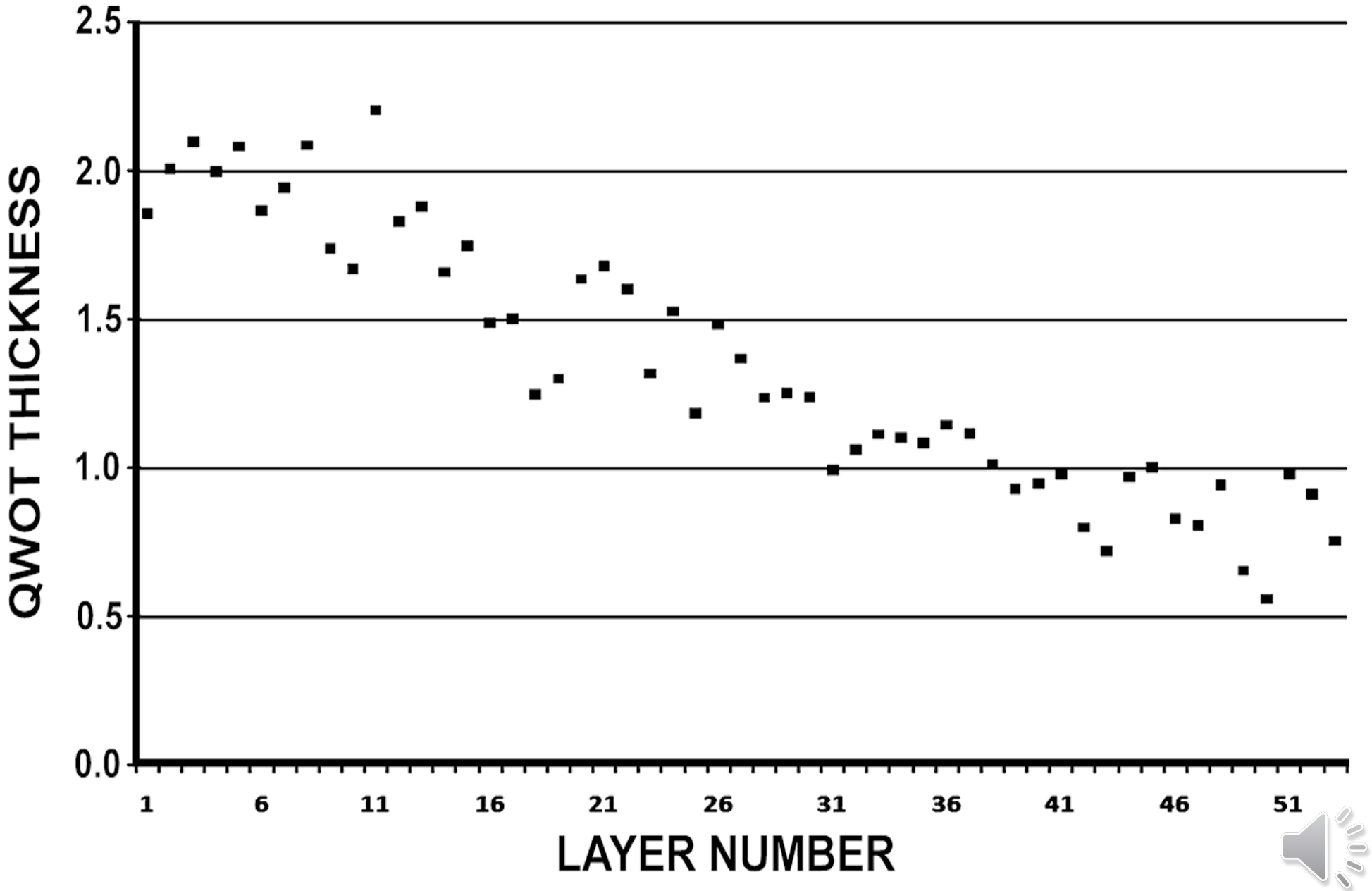

100
98
96
94
92
90
% Reflectance
400
450
500
550
600
650
700
Wavelength (nm)

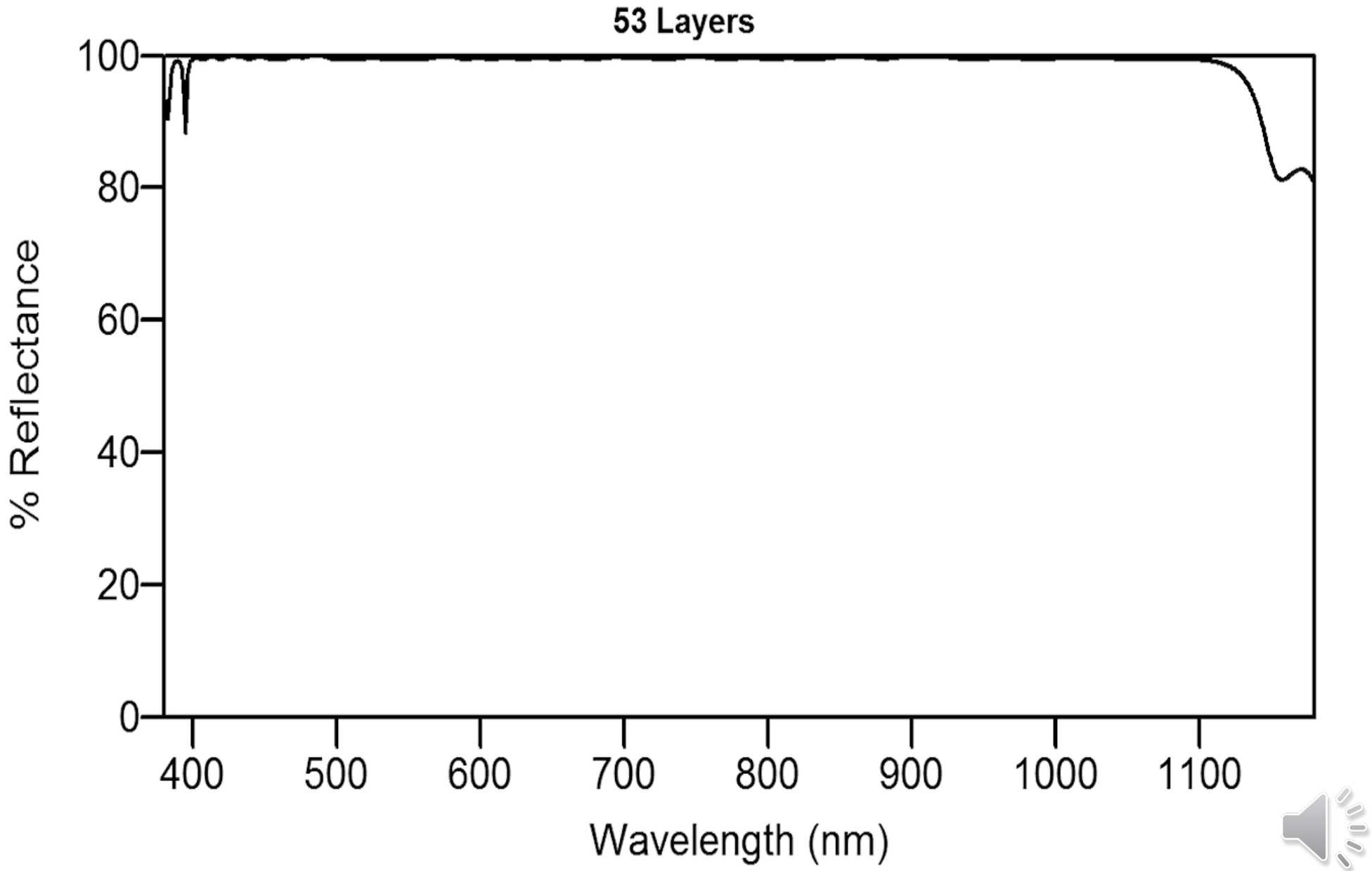

100
98
96
94
92
90
% Reflectance
400
440
480
520
560
600
640
680
Wavelength (nm)


100
98
96
94
92
90
% Reflectance
400
440
480
520
560
600
640
680
720
Wavelength (nm)

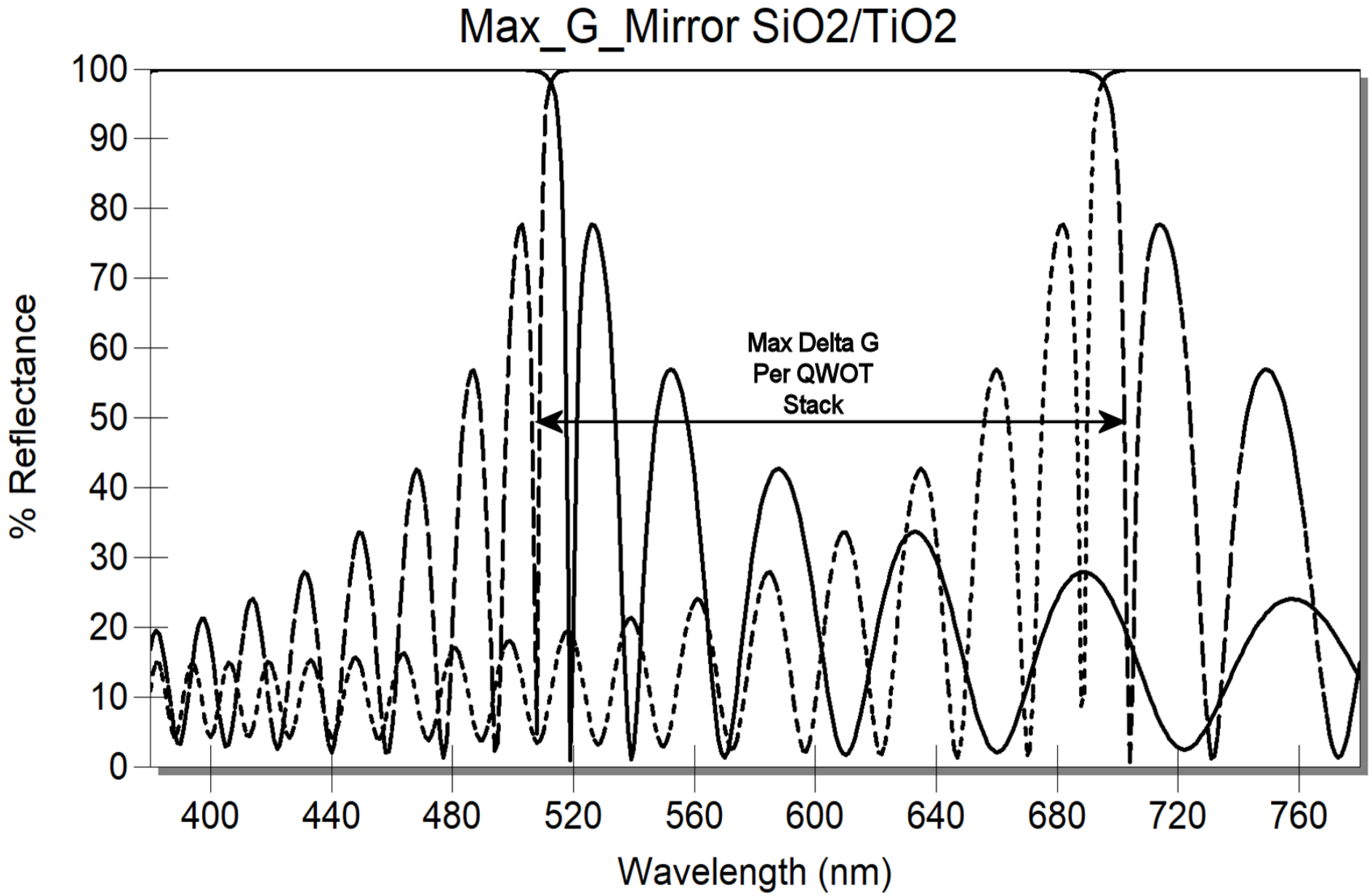

100
98
96
94
92
90
% Reflectance
400
440
480
520
560
600
640
680
720
Wavelength (nm)


2.5
2.0
1.5
1.0
0.5
0.0
QWOT THICKNESS
1
6
11
16
21
26
31
36
41
46
51
LAYER NUMBER

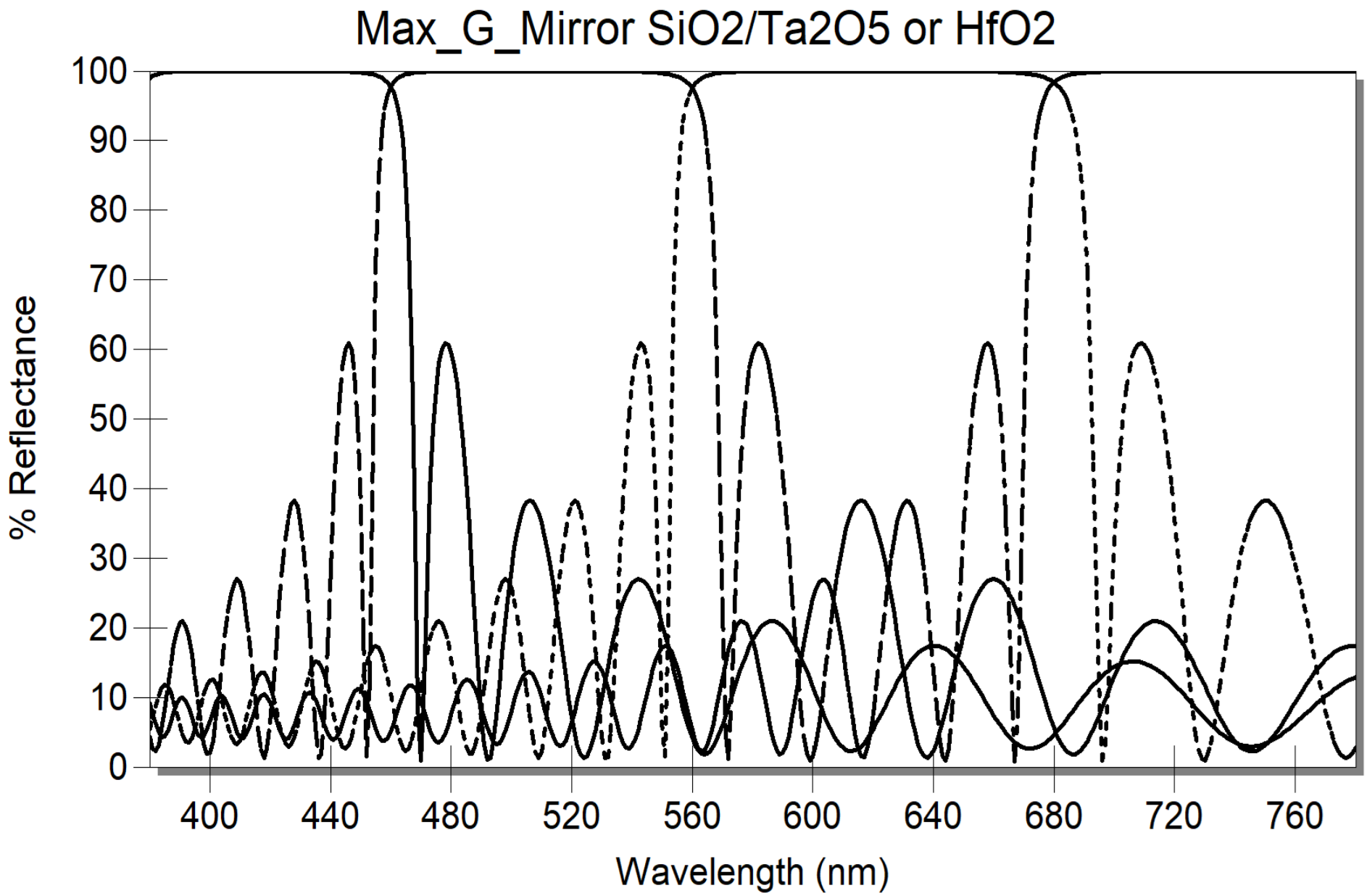

QWOT THICKNESS
2.5
2.0
1.5
1.0
0.5
0.0
1
6
11
16
21
26
31
36
41
46
51
LAYER NUMBER


53 Layers
100
80
60
40
20
0
% Reflectance
400
500
600
700
800
900
1000
1100
Wavelength (nm)

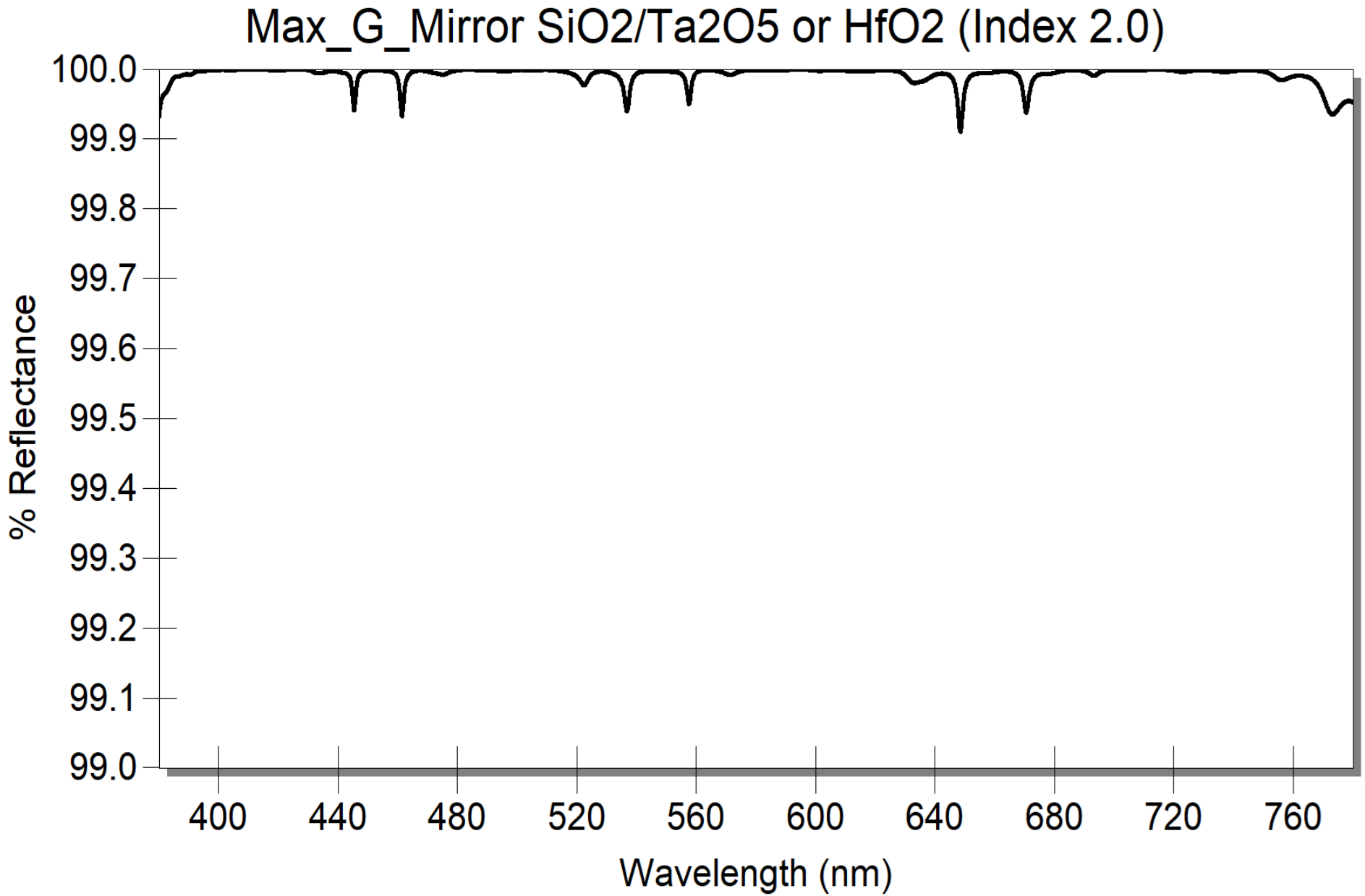
Three Stacks for ~100%



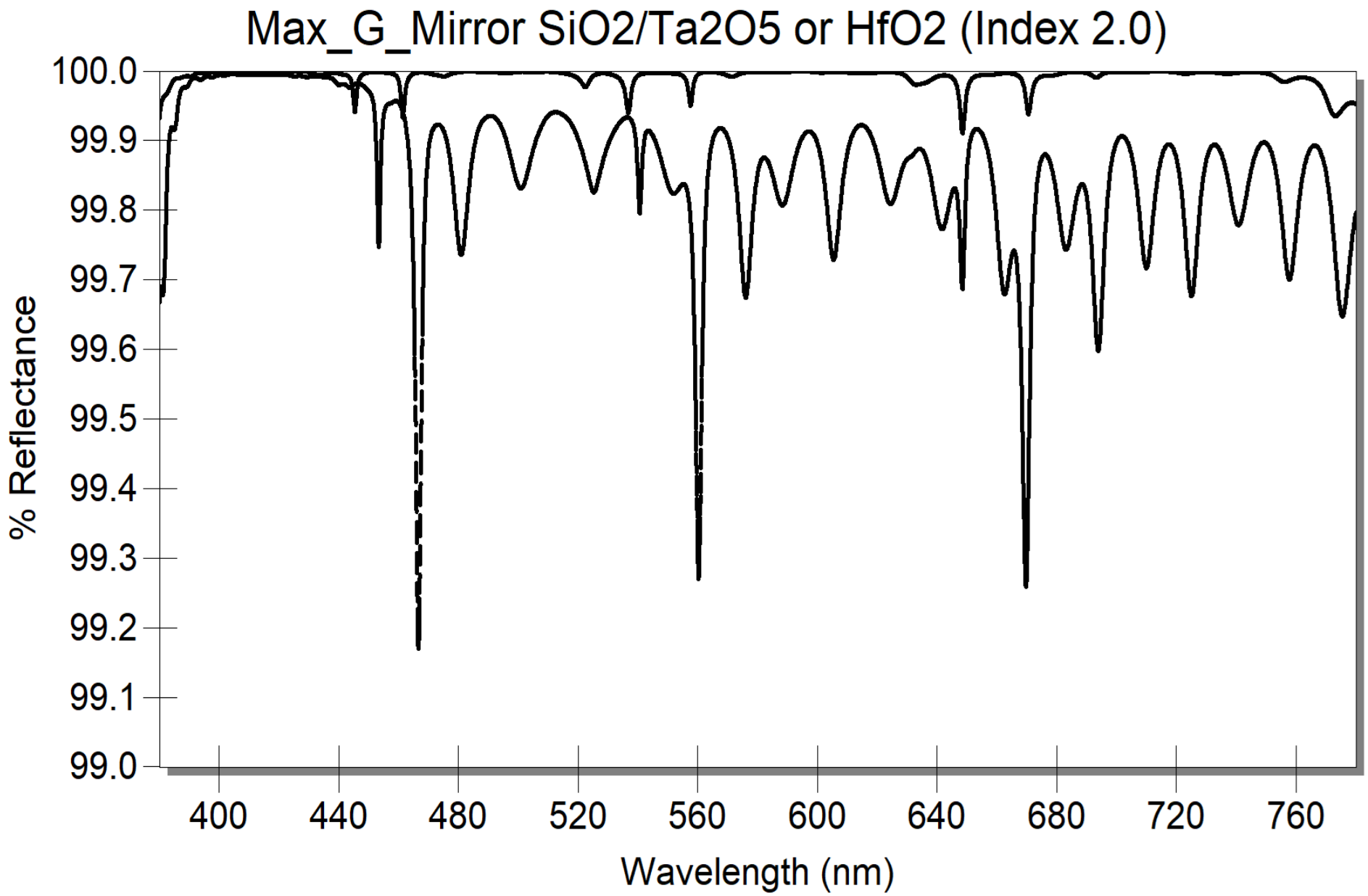
Four Stacks for ~100%



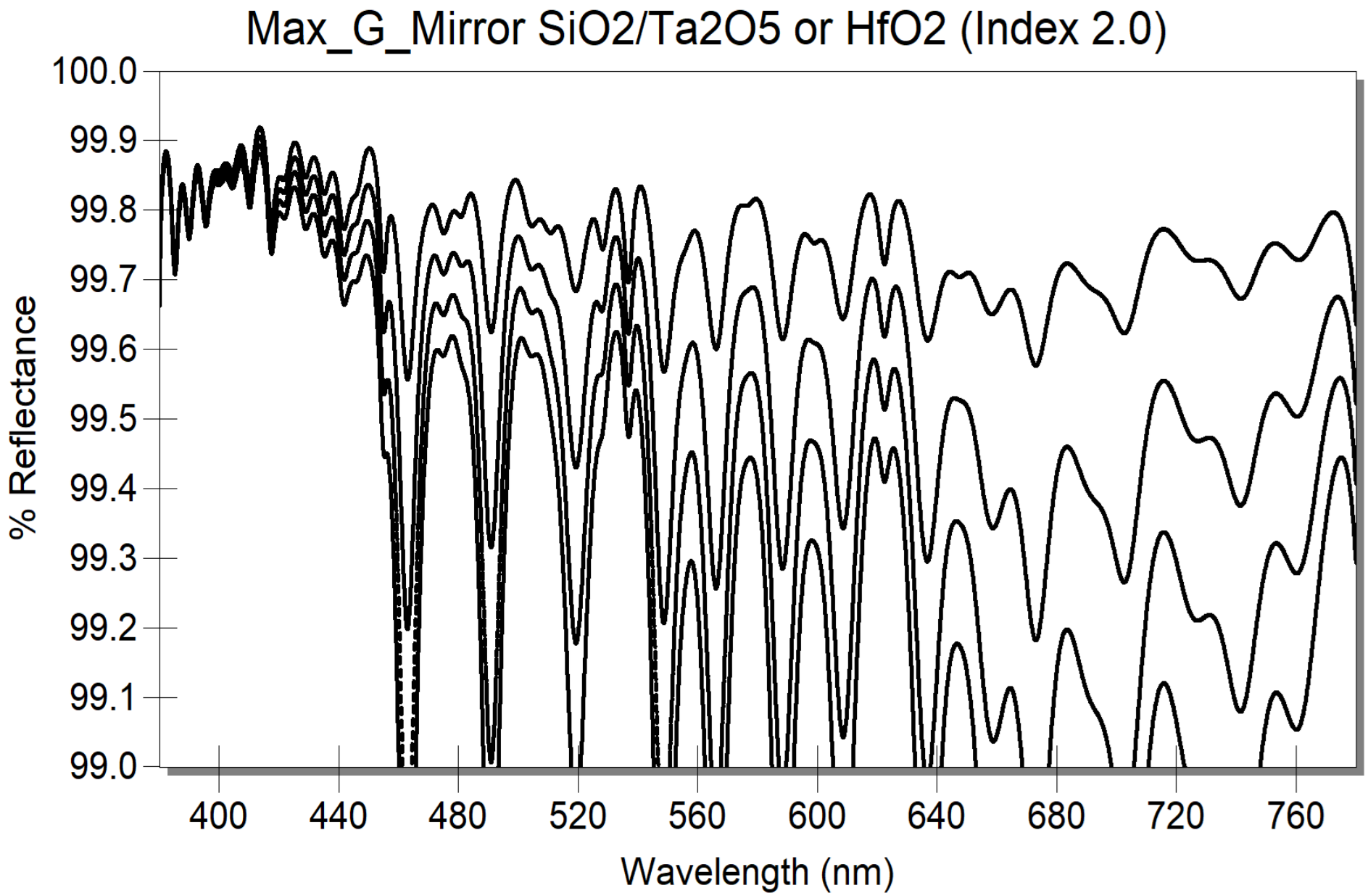
~Perfect, No Absorptance



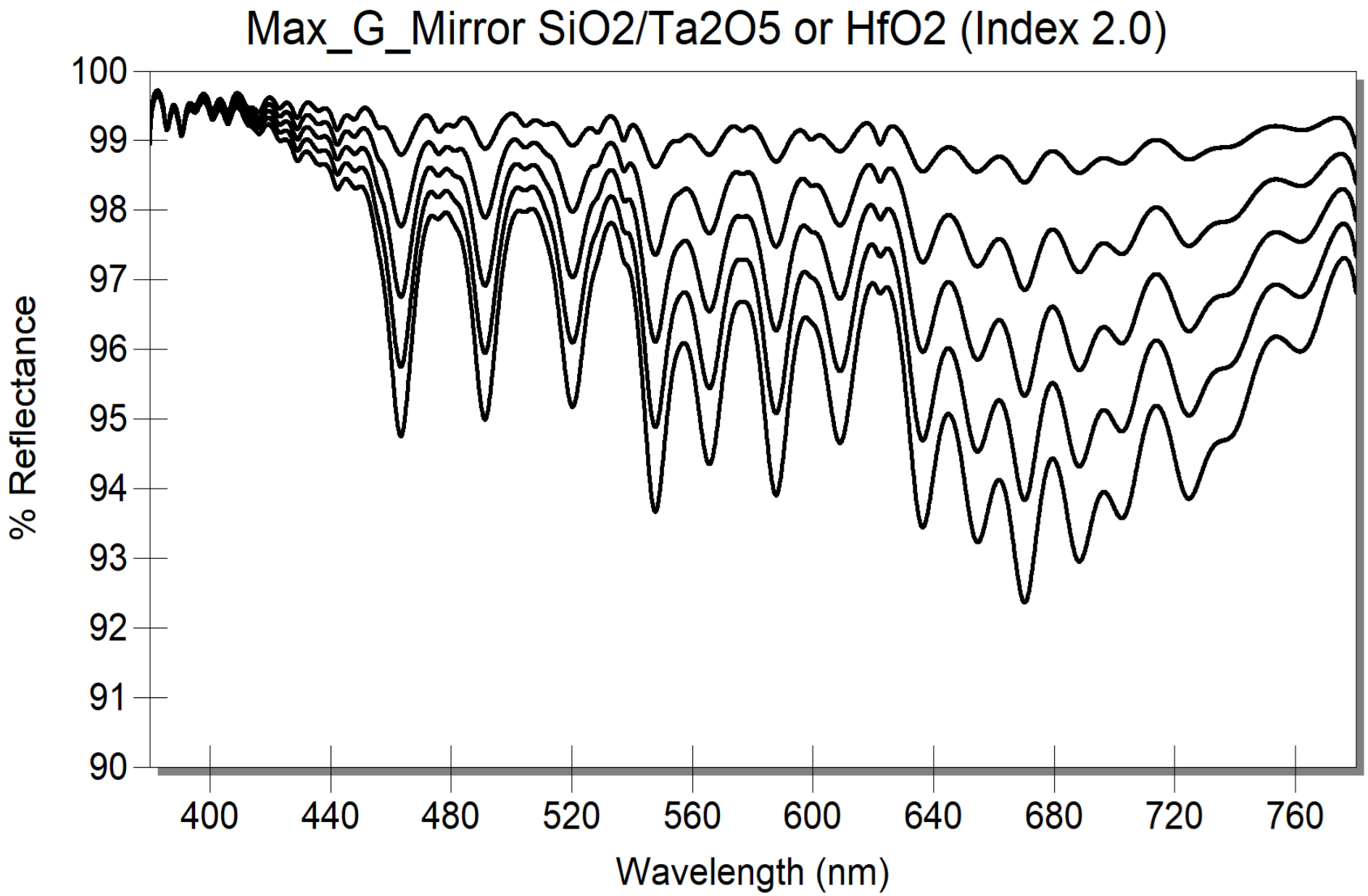
K = 0.00001


Max_G_Mirror SiO2/Ta2O5 or HfO2 (Index 2.0)
100.0
99.9
99.8
99.7
99.6
99.5
99.4
99.3
99.2
99.1
99.0
% Reflectance
400
440
480
520
560
600
640
680
720
760
Wavelength (nm)

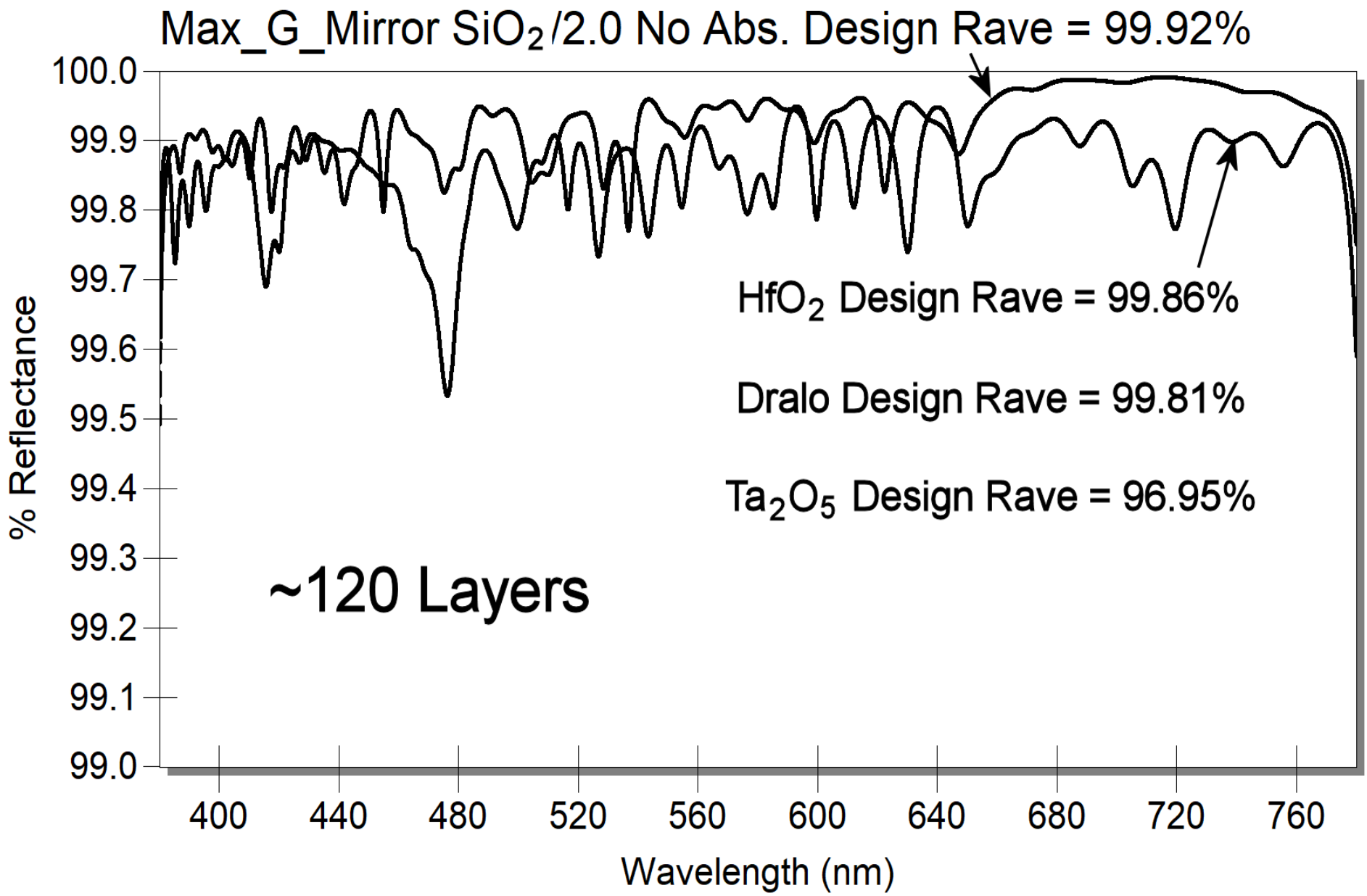
K = 2.0E-5, 4, 6, & 8.0E-5



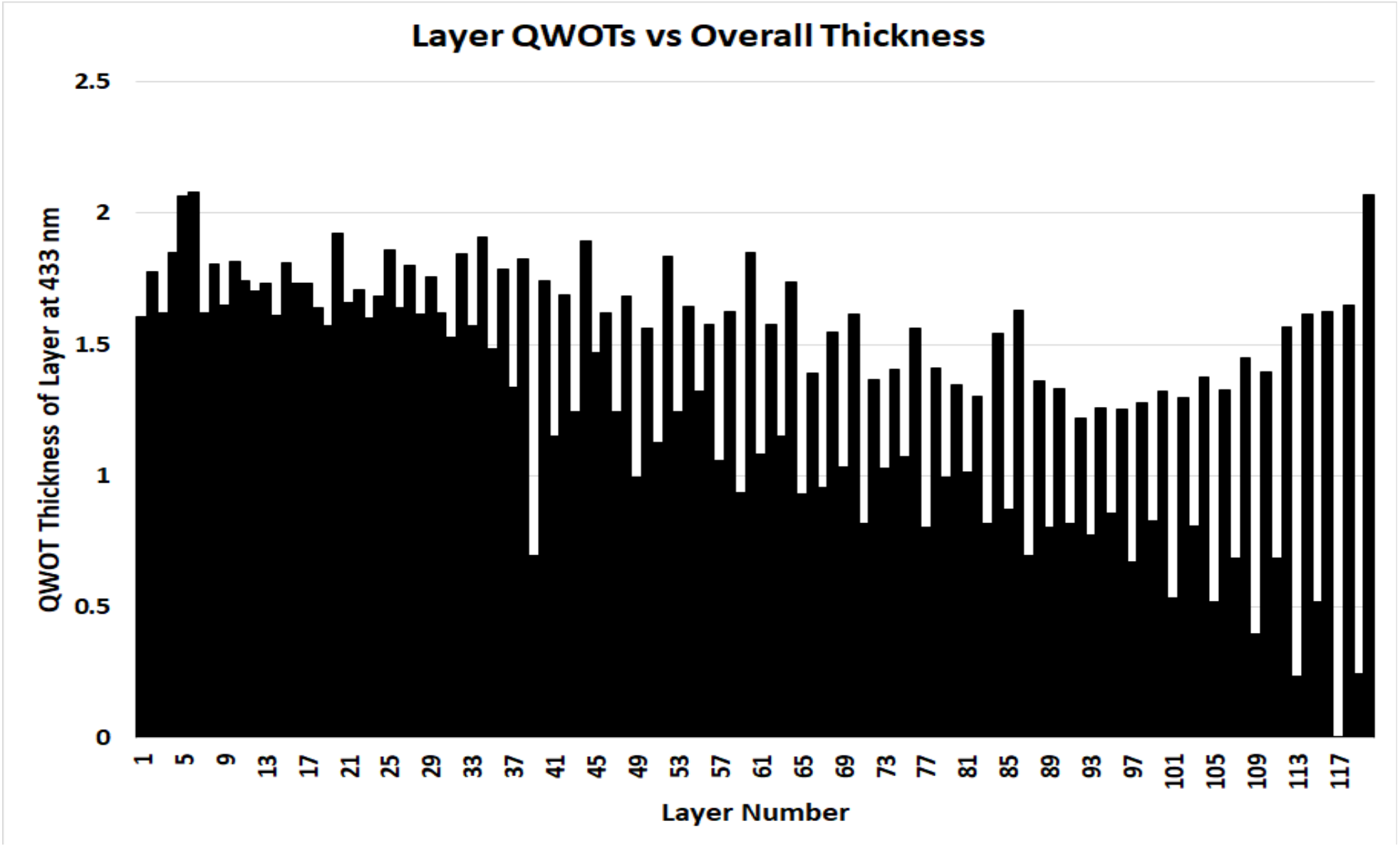
K = 1.0E-4, 2, 3, 4, & 5.0E-4



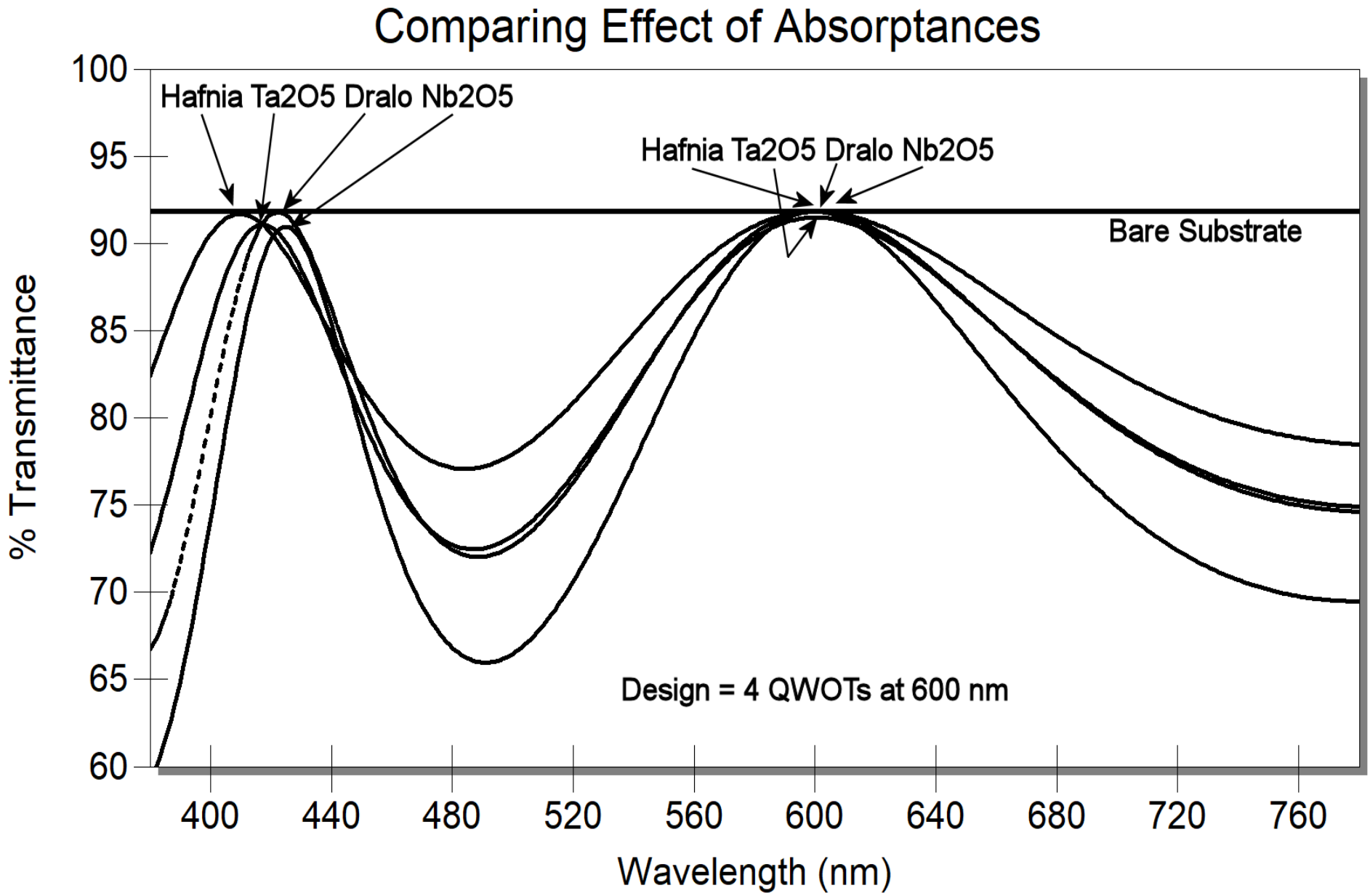
HfO_2 Looks Best, Dralo Next



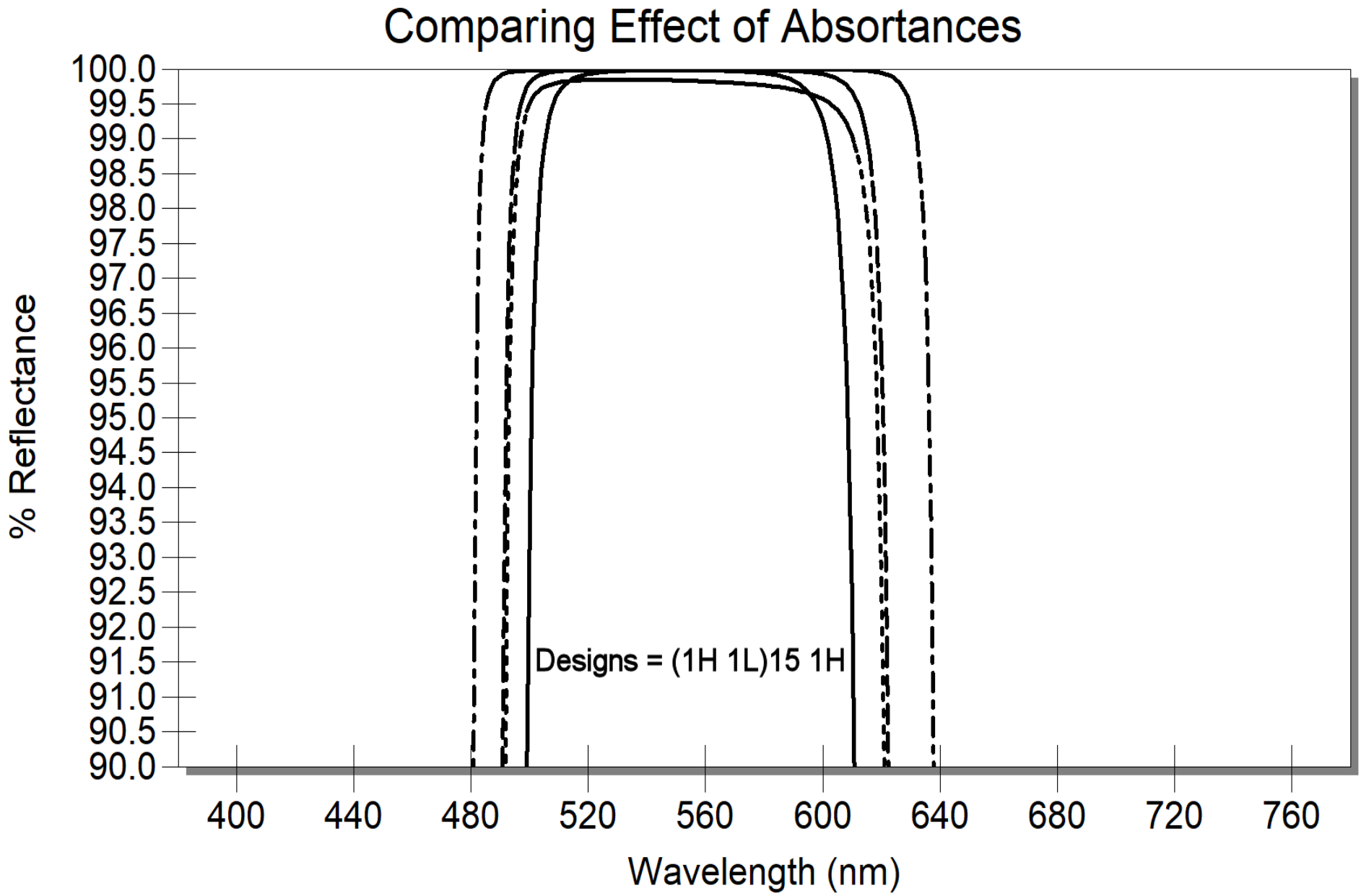
Note Diminishing High Index Thickness Due to K



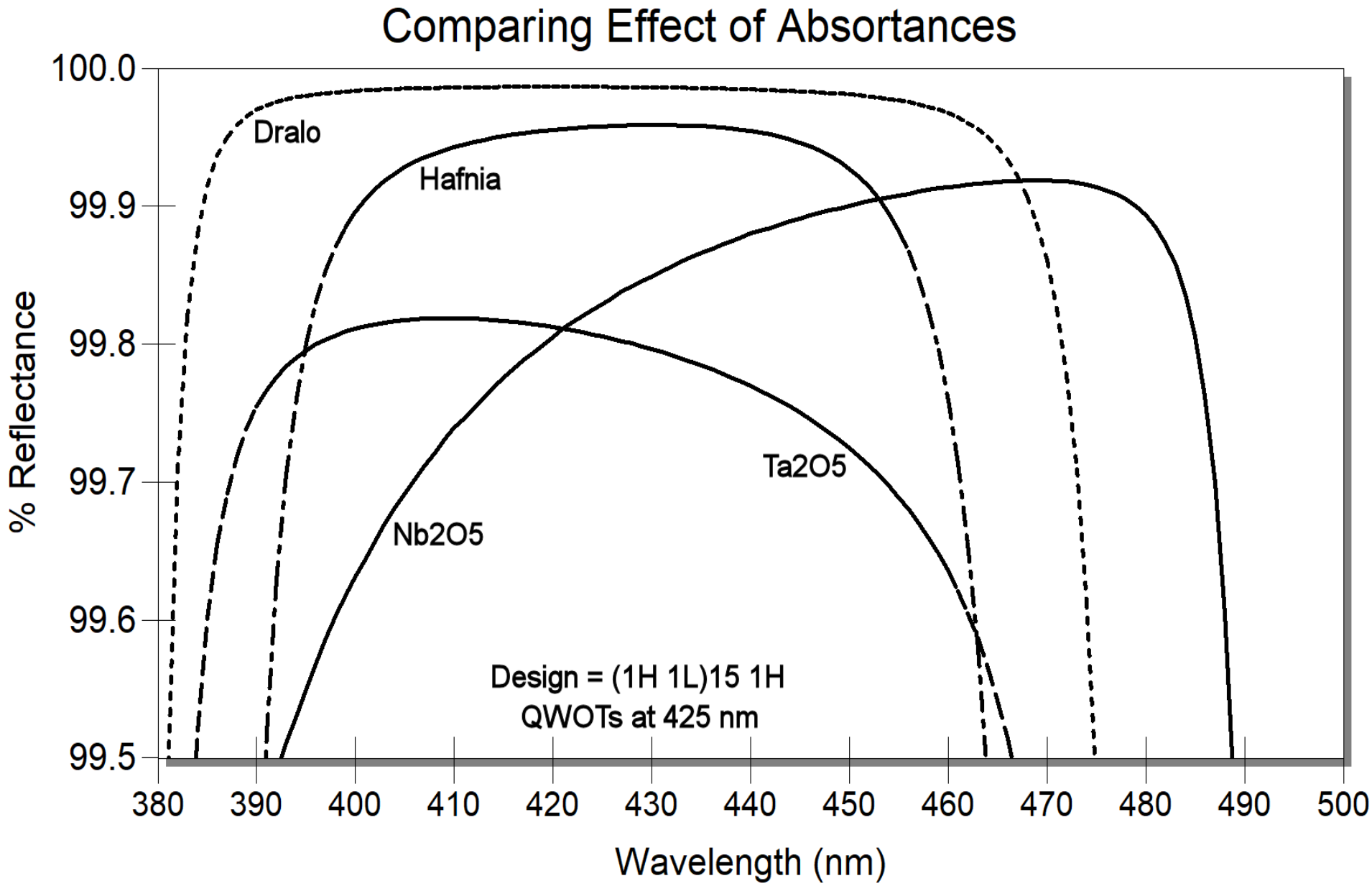
Not for 99% if Absorptance



Check for Absorptance



Better Check, Absorptance



CONCLUSION

The need for reflectance calibration working standards has been described.

It has been shown that mirrors with over 99% reflectance can probably be fabricated with today's technology.

Such mirrors would be a good working standard for any facility doing reflectance measurements.

It is hoped that some organization will undertake to provide these to the marketplace.