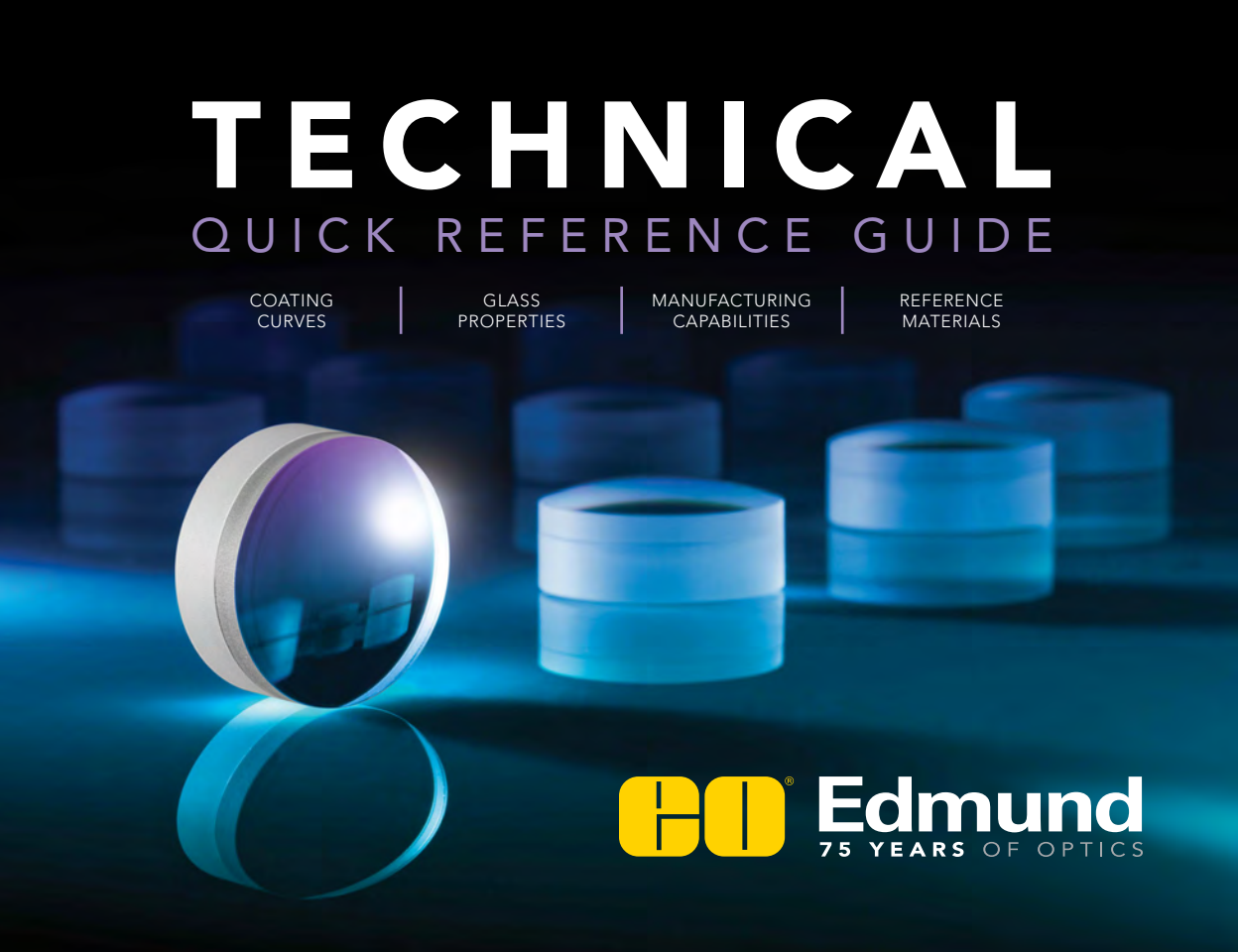
TECHNICAL

QUICK REFERENCE GUIDE

COATING CURVES | GLASS PROPERTIES | MANUFACTURING CAPABILITIES | REFERENCE MATERIALS



Edmund®
75 YEARS OF OPTICS

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WHY EDMUND OPTICS®?

RELIABILITY

- We process and ship **95% of orders the same day**
- With over **75 years in business**, EO's promise to customers is **MORE OPTICS, MORE TECHNOLOGY, AND MORE SERVICE**
- #1 Preferred Supplier of Optical Components - *Readex Research Survey*

QUALITY

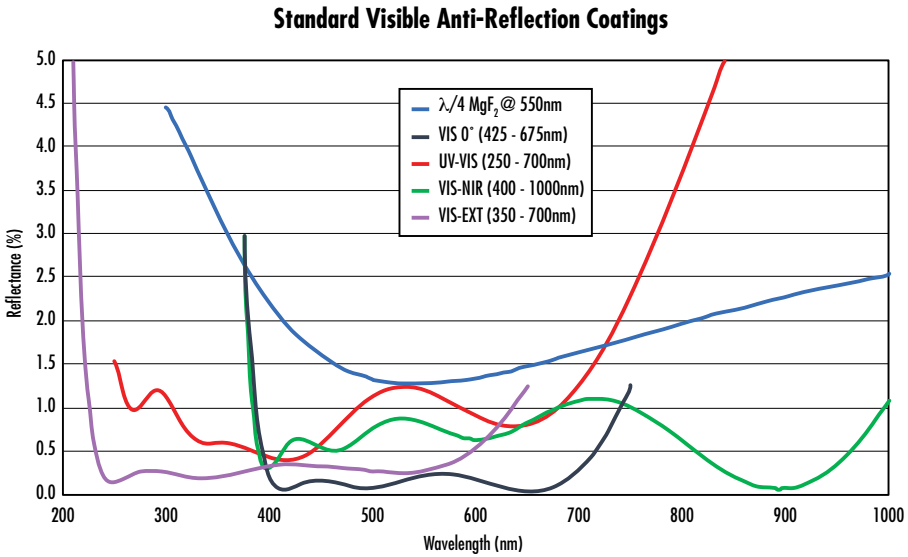
- ISO 9001 Certified and MIL-SPEC quality systems
- Complete testing and metrology services

CAPABILITIES AND SERVICE

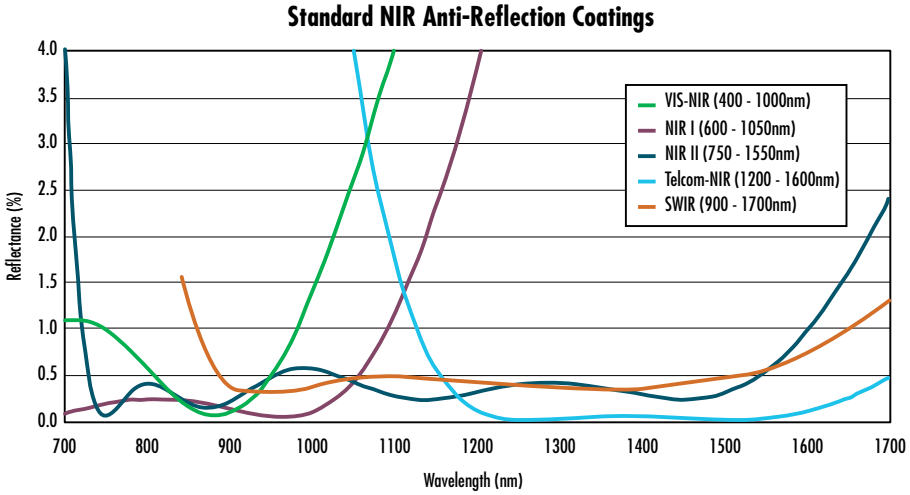
- Global optics manufacturing
- Staff of optical and mechanical designers worldwide
- Build-to-print manufacturing
- Custom design services emphasize designing for manufacturability – from prototype to volume production
- Fast turnaround of modification services

To contact us visit **www.edmundoptics.com/contact**

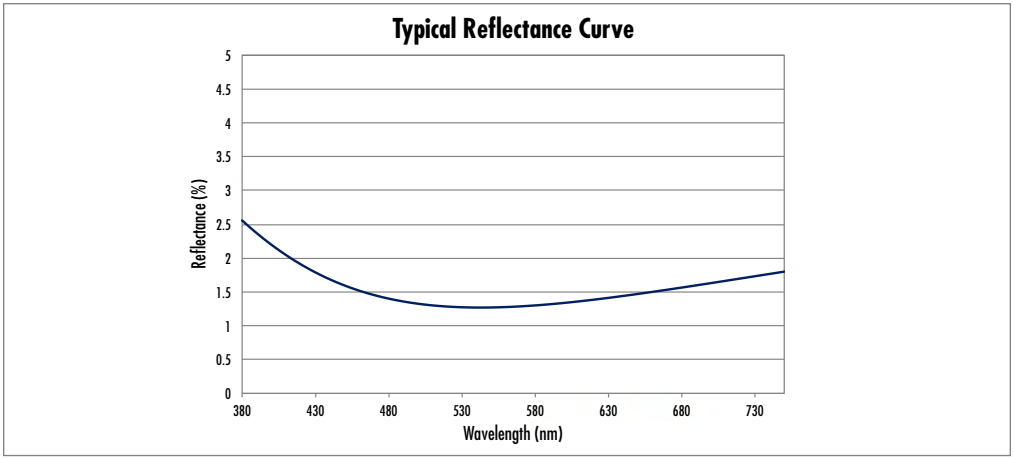
ANTI-REFLECTIVE (AR) COATINGS



ANTI-REFLECTIVE (AR) COATINGS

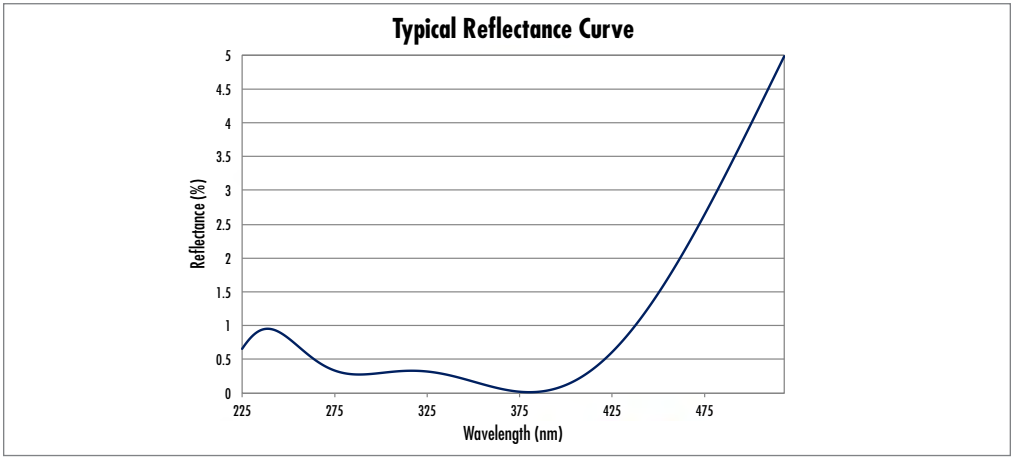


ANTI-REFLECTIVE (AR) COATINGS – MgF_2



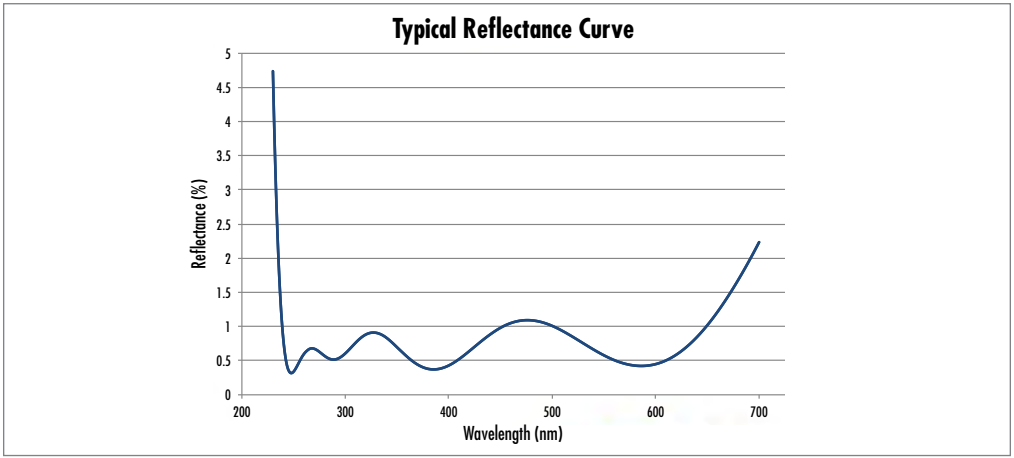
- R_{avg} ≤1.75% 400 - 700nm (N-BK7)
- The most commonly used anti-reflection coating for visible wavelengths
- Highly durable and economical
- Optimized for 550nm for normal incidence
- Easily customized for other wavelength bands
- Typical energy density limit: 10 J/cm^2 @532nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – UV-AR



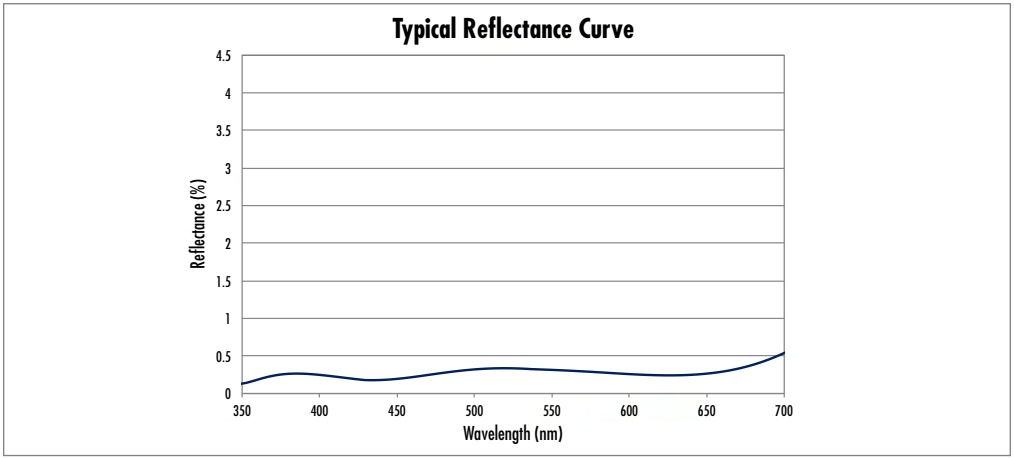
- R_{abs} ≤1.0% 250 - 425nm, R_{avg} ≤0.75% 250 - 425nm, R_{avg} ≤0.5% 370 - 420nm
- Frequently applied to UV fused silica lenses and windows
- Excellent broadband coverage from 250 - 425nm
- Optimized for 300nm for normal incidence
- Typical energy density limit: 3 J/cm^2 @355nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – UV-VIS



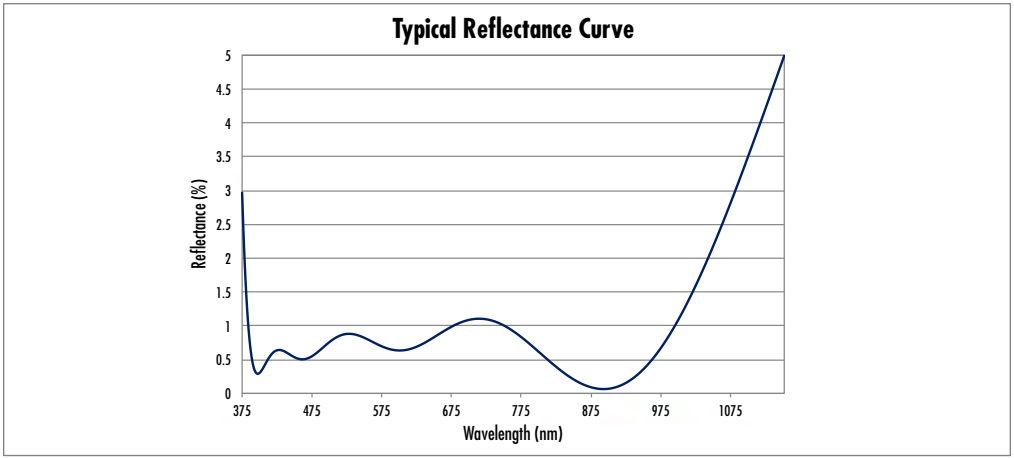
- R_{abs} ≤1.0% 350 - 450nm, R_{avg} ≤1.5% 250 - 700nm
- Like the UV-AR coating, it is commonly applied to UV fused silica lenses and windows to increase transmission in the UV
- Designed for extended performance into the visible spectrum
- Typical energy density limit: 3 J/cm^2 @355nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – VIS-EXT



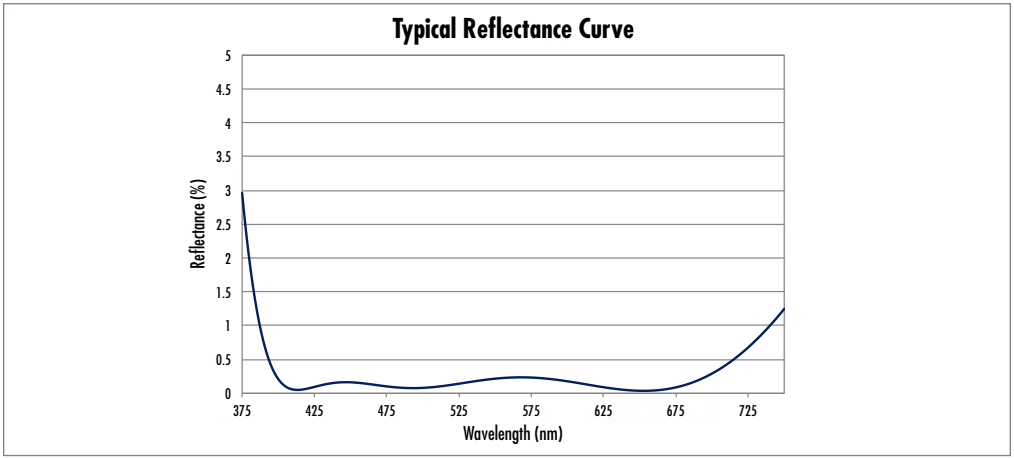
- R_{avg} <0.5% 350 - 700nm
- Broadband AR coating with low reflectance from 350 - 700nm
- Designed to cover more fluorescent wavelengths below 400nm
- Ideal for multi-spectral and hyper-spectral applications
- Typical energy density limit: 5 J/cm^2 @532nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – VIS-NIR



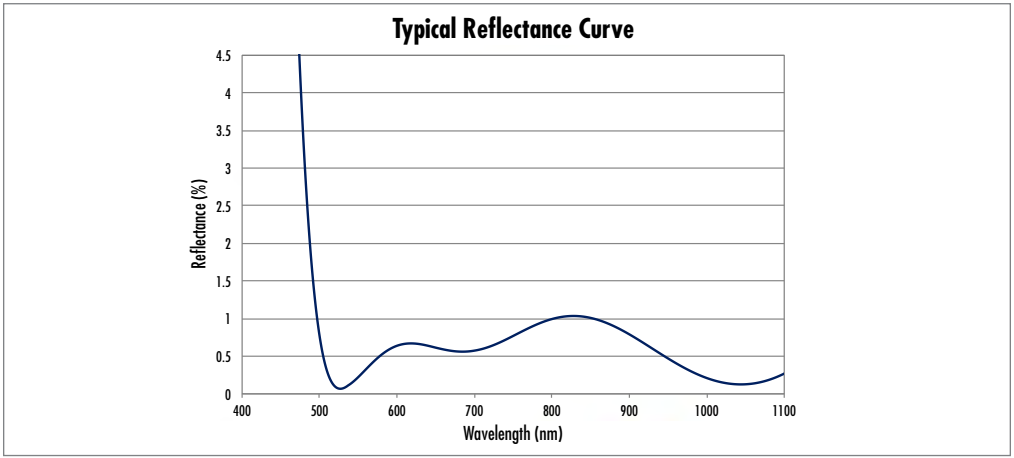
- R_{abs} ≤0.25% 880nm, R_{avg} ≤1.25% 400 - 870nm, R_{avg} ≤1.25% 890 - 1000nm
- Broadband AR coating designed to yield maximum transmission (>99%) in both the visible and NIR
- Optimized for 890nm for normal incidence
- Typical energy density limit: 5 J/cm^2 @532nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – VIS 0°



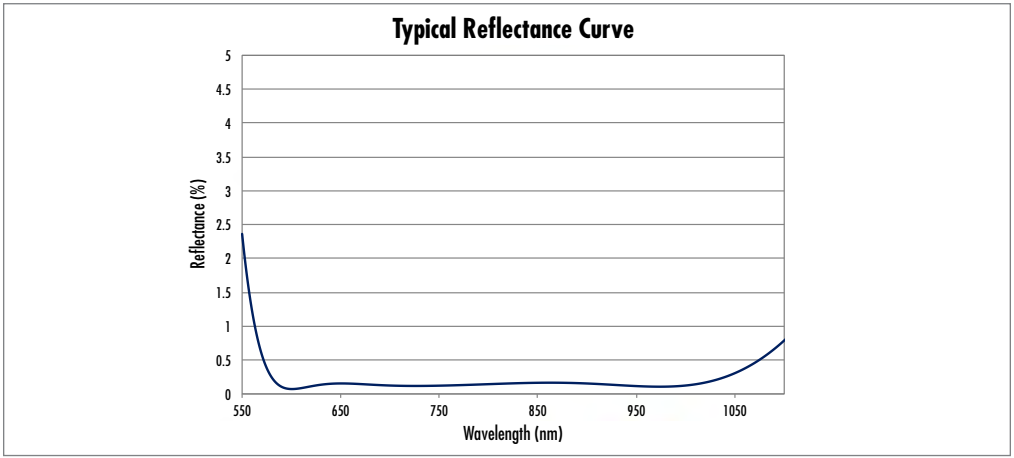
- R_{avg} ≤0.4% 425 - 675nm
- Optimized transmission for 0° angle of incidence
- Preferred over MgF_2 for visible applications requiring high transmission
- Typical energy density limit: 5 J/cm^2 @532nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – YAG-BBAR



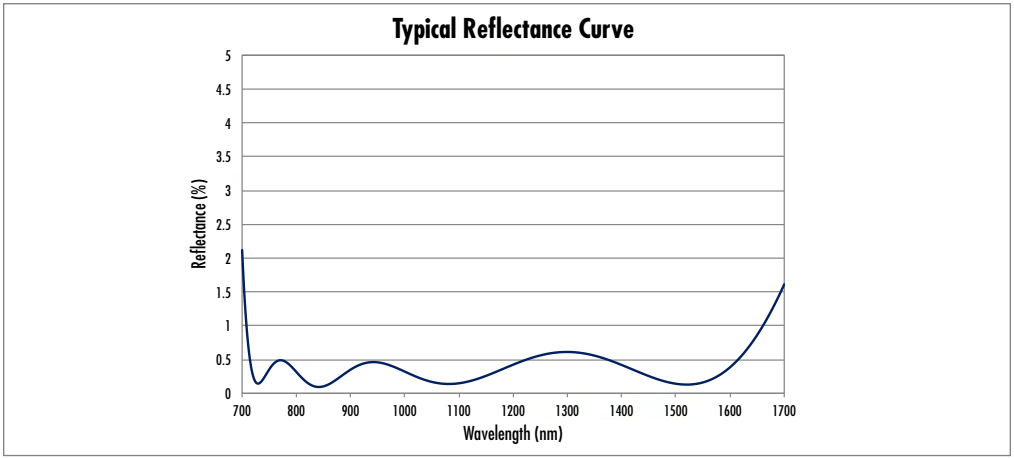
- R_{abs} <0.25% 532nm, R_{abs} <0.25% 1064nm, R_{avg} <1.0% 500 - 1100nm
- Optimized to minimize reflection at 1064nm and 532nm
- Typical energy density limit: 5 J/cm^2 @532nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – NIR I



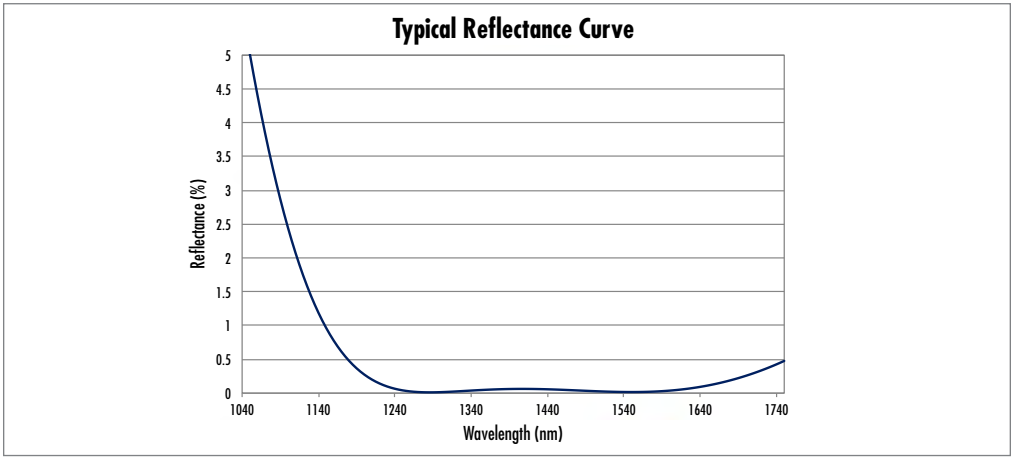
- R_{avg} ≤0.5% 600 - 1050nm
- Commonly used with fiber optics, laser diode modules, and NIR LED lights
- Typical energy density limit: 7 J/cm^2 @1064nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – NIR II



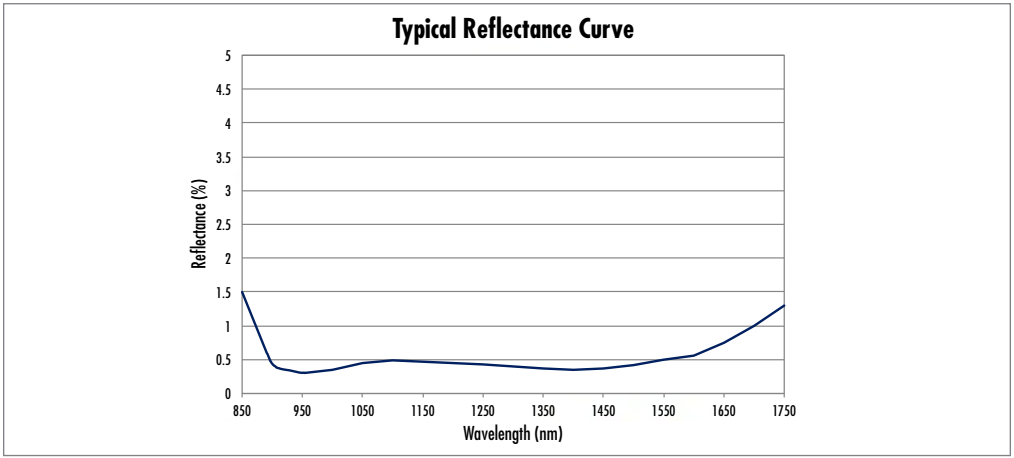
- R_{abs} ≤1.5% 750 - 800nm, R_{abs} ≤1.0% 800 - 1550nm, R_{avg} ≤0.7% 750 - 1550nm
- Works at slightly longer wavelengths than the NIR I coating
- Commonly used with fiber optics, laser diode modules, and NIR LED lights
- Typical energy density limit: 8 J/cm^2 @1064nm, 10ns

ANTI-REFLECTIVE (AR) COATINGS – TELECOM-NIR



- R_{abs} ≤0.25% 1295 - 1325nm, R_{abs} ≤0.25% 1535 - 1565nm, R_{avg} ≤0.25% 1200 - 1600nm
- Popular in telecommunications applications

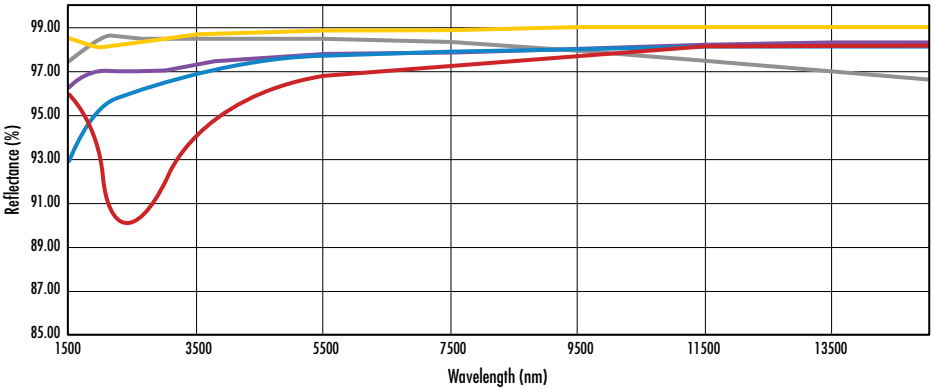
ANTI-REFLECTIVE (AR) COATINGS – SWIR



- R_{abs} ≤1.5% 900 - 1700nm, R_{avg} ≤1.0% 900 - 1700nm
- Commonly used in SWIR applications including inspection of electronics or solar cells, surveillance, and anti-counterfeiting

METALLIC MIRROR COATINGS

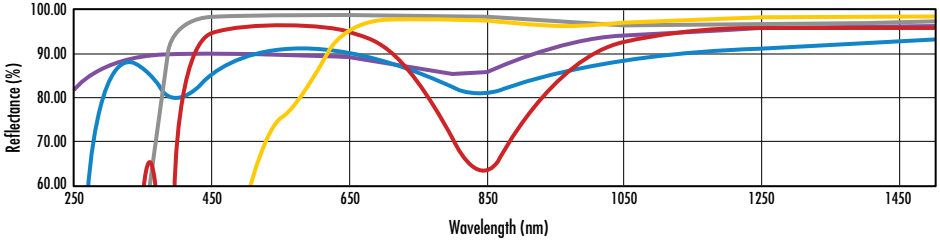
Typical Reflectance Curve for Metallic Mirror Coatings NIR - IR Range



Protected Aluminum		Enhanced Aluminum		UV Ehanced Aluminum		Protected Gold		Protected Silver	
Range (µm)	% Reflection	Range (µm)	% Reflection	Range (µm)	% Reflection	Range (µm)	% Reflection	Range (µm)	% Reflection
0.4 - 0.7	85	0.45 - 0.65	95	0.25 - 0.45	89	0.7 - 2.0	96	0.45 - 2.0	98
0.4 - 2.0	90	–	–	0.25 - 0.70	85	2.0 - 10.0	96	2.0 - 10.0	98

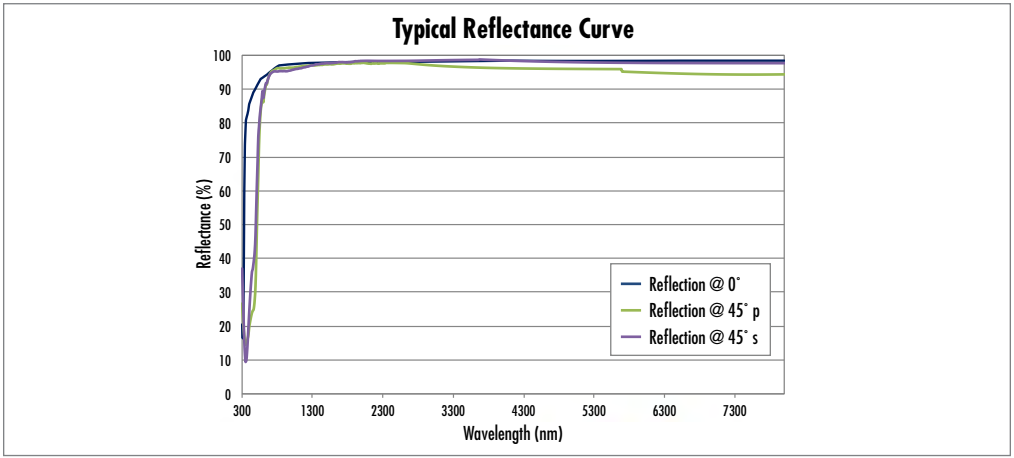
METALLIC MIRROR COATINGS

Typical Reflectance Curve for Metallic Mirror Coatings UV - NIR Range



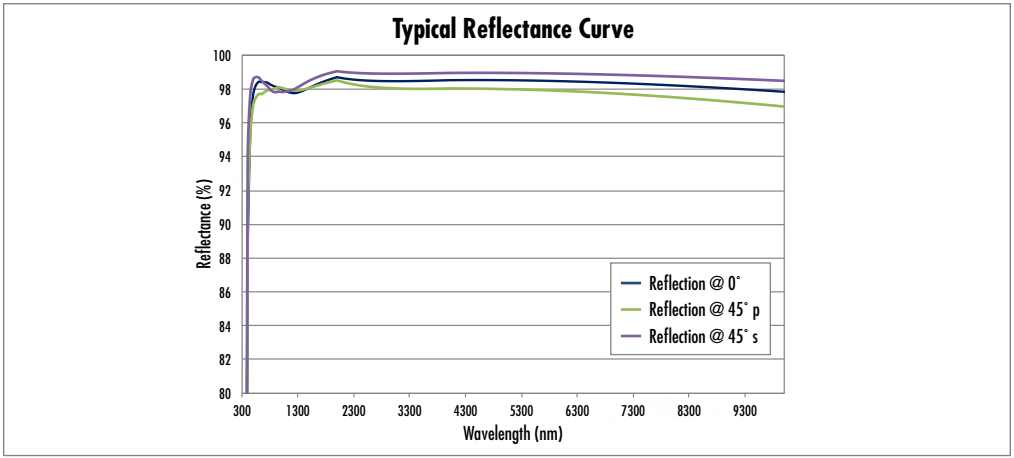
Protected Aluminum		Enhanced Aluminum		UV Ehanced Aluminum		Protected Gold		Protected Silver	
Range (µm)	% Reflection	Range (µm)	% Reflection	Range (µm)	% Reflection	Range (µm)	% Reflection	Range (µm)	% Reflection
0.4 - 0.7	85	0.45 - 0.65	95	0.25 - 0.45	89	0.7 - 2.0	96	0.45 - 2.0	98
0.4 - 2.0	90	–	–	0.25 - 0.70	85	2.0 - 10.0	96	2.0 - 10.0	98

METALLIC MIRROR COATINGS – PROTECTED GOLD



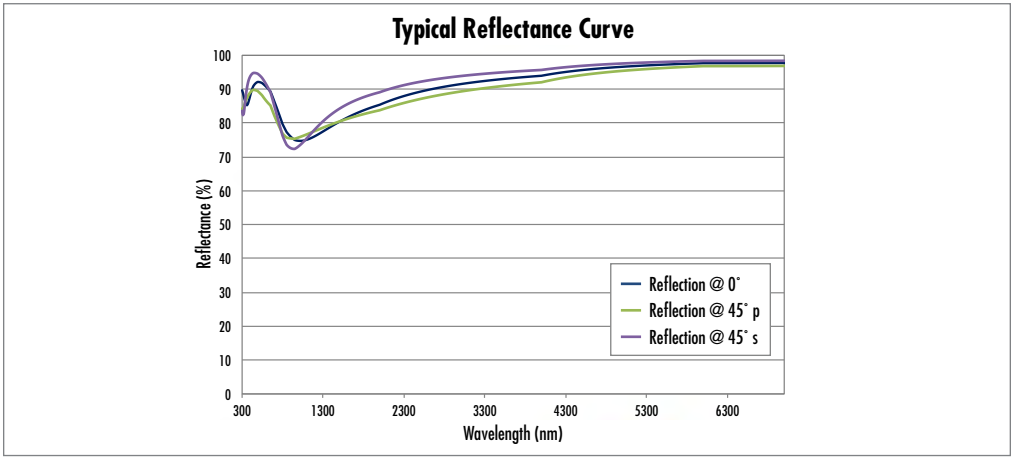
- R_{avg} >96% 700 - 10000nm
- High reflectance in the NIR and IR regions
- Durable coating with protective overcoat
- Performance of gold is maintained along with a more durable finish
- Typical energy density limit: 0.8 J/cm^2 @1064nm, 10ns

METALLIC MIRROR COATINGS – PROTECTED SILVER



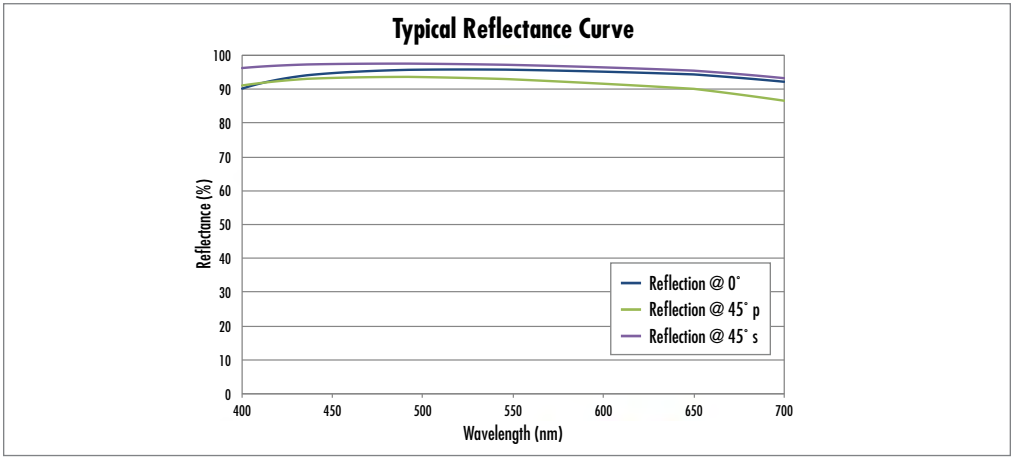
- R_{avg} >98% 450 - 10000nm
- Excellent choice for broadband applications that span multiple spectral regions
- The protective coating reduces tendency to tarnish
- Best performance in low humidity environments
- Typical energy density limit: 0.5 J/cm^2 @532nm & 1064nm, 10ns

METALLIC MIRROR COATINGS – PROTECTED ALUMINUM



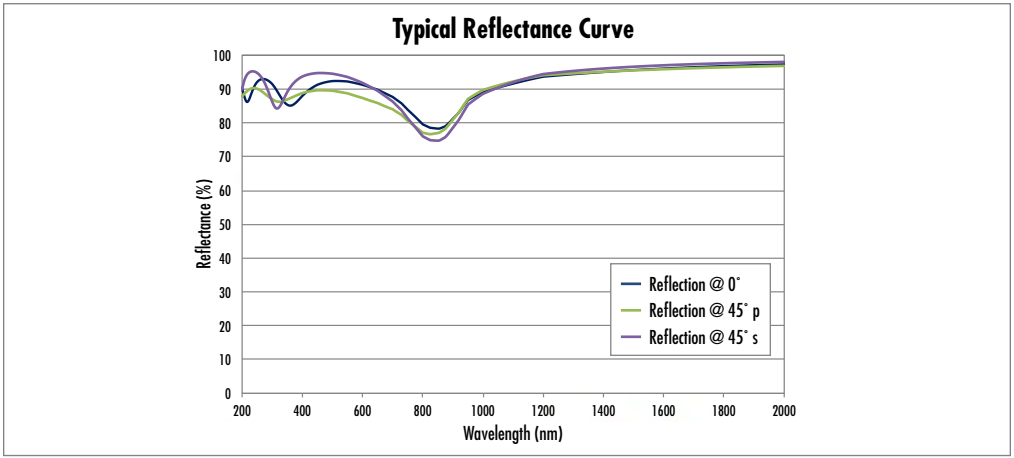
- R_{avg} >85% 400 - 700nm, R_{avg} >90% 400 - 2000nm
- Our most popular coating for applications in the visible and NIR spectra
- λ/2 SiO overcoat protects the delicate aluminum and provides an abrasion-resistant surface
- Typical energy density limit: 0.3 J/cm^2 @532nm & 1064nm, 10ns

METALLIC MIRROR COATINGS – ENHANCED ALUMINUM



- R_{avg} >95% 450 - 650nm
- Enhanced reflectance in visual spectrum
- Same Improved handling characteristics of the protected aluminum coating
- Typical energy density limit: 0.2 J/cm^2 @532nm, 10ns

METALLIC MIRROR COATINGS – UV ENHANCED ALUMINUM



- R_{avg} >89% 250 - 450nm, R_{avg} >85% 450 - 700nm
- Optimized reflectance in the UV spectrum
- Matches the handling characteristics of the protected aluminum coating
- Typical energy density limit: 0.5 J/cm^2 @355nm, 10ns

RELATIVE COATING COST

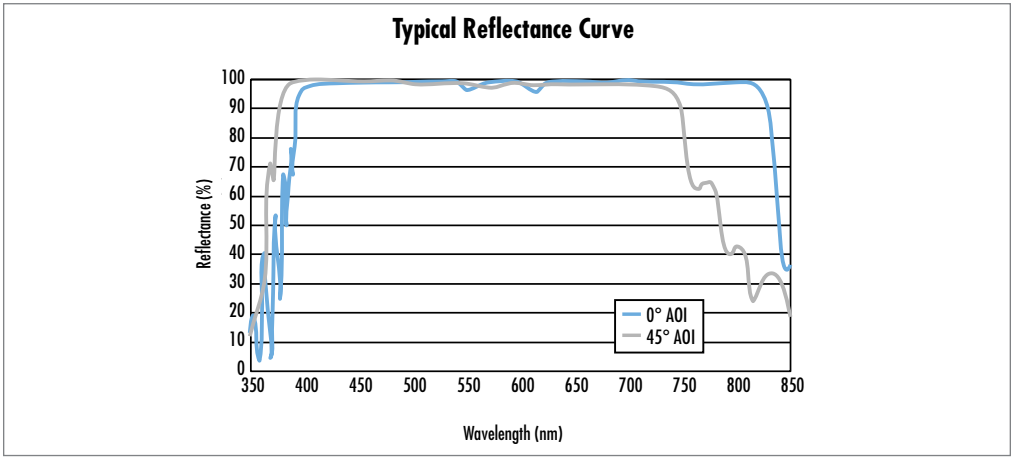
AR Coating	Relative Cost
MgF_2	1
UV-AR	1.44
UV-VIS	1.67
VIS-EXT	1.33
VIS-NIR	1.78
VIS 0°	1.22
YAG-BBAR	1.78
NIR I	1.67
NIR II	1.89
Telecom-NIR	1.78
SWIR	1.89

Metallic Mirror Coating	Relative Cost
Protected Aluminum	1
Enhanced Aluminum	1.22
UV Enhanced Aluminum	1.22
Protected Gold	2.4
Protected Silver	2.0

BARRINGTON, NJ COATING CELL

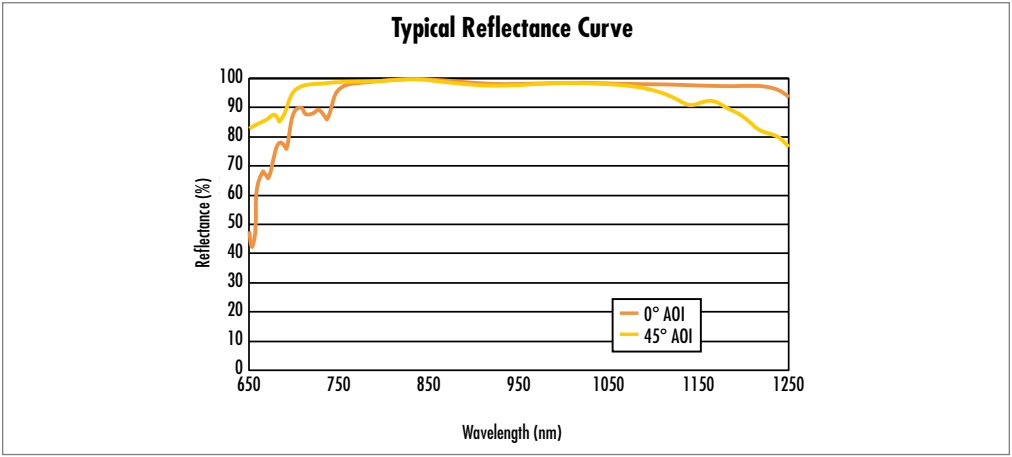
In addition to our global coating facilities for volume production, we have a coating cell in Barrington, NJ for quick coating runs of small quantities, prototyping, and research and development.

DIELECTRIC MIRROR COATINGS – 400 - 750nm



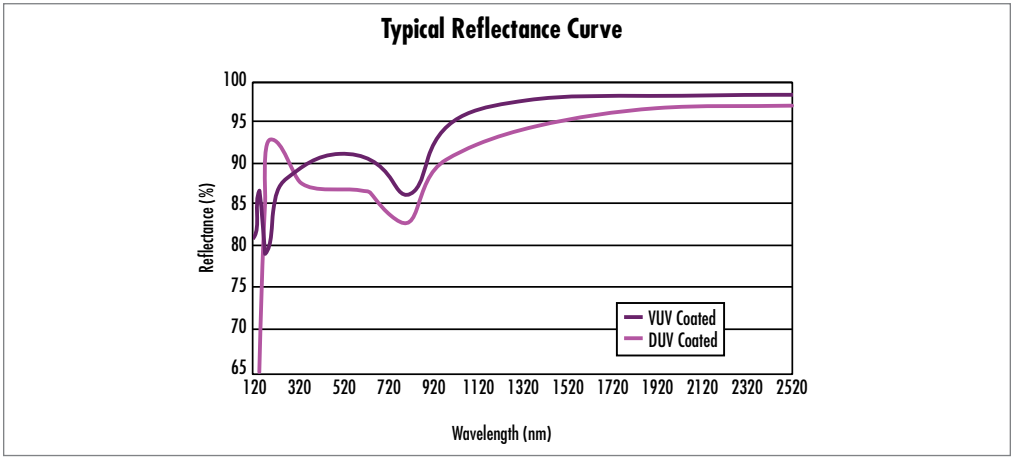
- R_{avg} ≥98% @ 0 - 45° all polarizations, R_{avg} ≥99% @ 0° all polarizations
- Ideal for beam steering or applications utilizing multiple laser sources
- Superior reflectance from 0 to 45° AOI

DIELECTRIC MIRROR COATINGS – 750 - 1100nm



- R_{avg} ≥98% @ 0 - 45° all polarizations, R_{avg} ≥99% @ 0° all polarizations
- Ideal for beam steering or applications utilizing multiple laser sources
- Exceptional reflectance for *s*- and *p*-polarization

DIELECTRIC MIRROR COATINGS – VUV AND DUV



- VUV Coating: R_{avg} ≥78% @ 120 - 125nm, R_{avg} ≥85% @ 120 - 600nm
- DUV Coating: R_{avg} ≥88% @ 190 - 195nm, R_{avg} ≥85% @ 200 - 600nm
- Designed for 0° AOI
- Maintains a broadband reflectance throughout the UV and visible spectrum

OTHER COATING CAPABILITIES

- Filters – Fluorescence, Dichroic, Narrow Bandpass, Multi-Bandpass, Notch, Edge (SWP and LWP)
- Laser V-Coatings and Double V-Coatings
- Beamsplitters – Polarizing, Non-Polarizing
- ITO Conductive
- "Hot" and "Cold" Dielectric Mirrors
- Specialized Designs – Build-to-Print, Custom Design and Development for UV, Visible, Infrared (NIR, MWIR, SWIR, LWIR)

COMMON EQUATIONS

Fresnel Equations

$$R_s = \left| \frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t} \right|^2$$

$$R_p = \left| \frac{n_1 \cos\theta_t - n_2 \cos\theta_i}{n_1 \cos\theta_t + n_2 \cos\theta_i} \right|^2$$

At normal incidence: $R = \left| \frac{n_1 - n_2}{n_1 + n_2} \right|^2$

Critical Angle for TIR

$\theta_C = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ where $n_1 > n_2$

Brewster's Angle

$$\theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right)$$

Abbe Number

$$V_D = \frac{n_D - 1}{n_F - n_C}$$

Thin-Film AR Coating Index for 0% Reflectance

$$n_f = (n_0 n_S)^{1/2}$$

where n_f is the index of the film, n_0 is the index of the incident material (1 for air), and n_s is the substrate index

Snell's Law

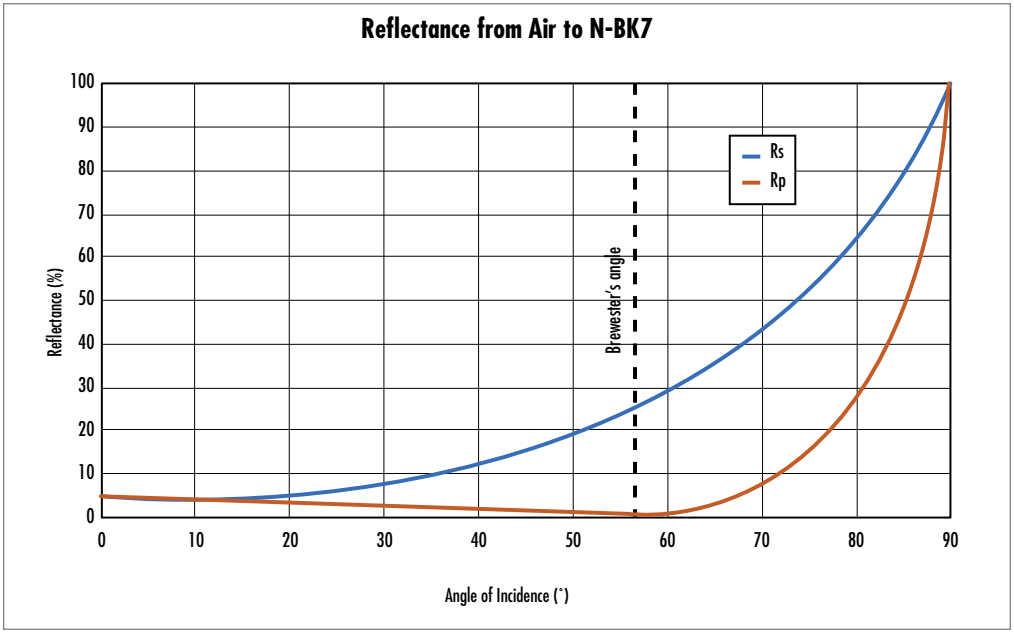
$$n_1 \sin\theta = n_2 \sin\theta$$

Malus' Law For Polarizers

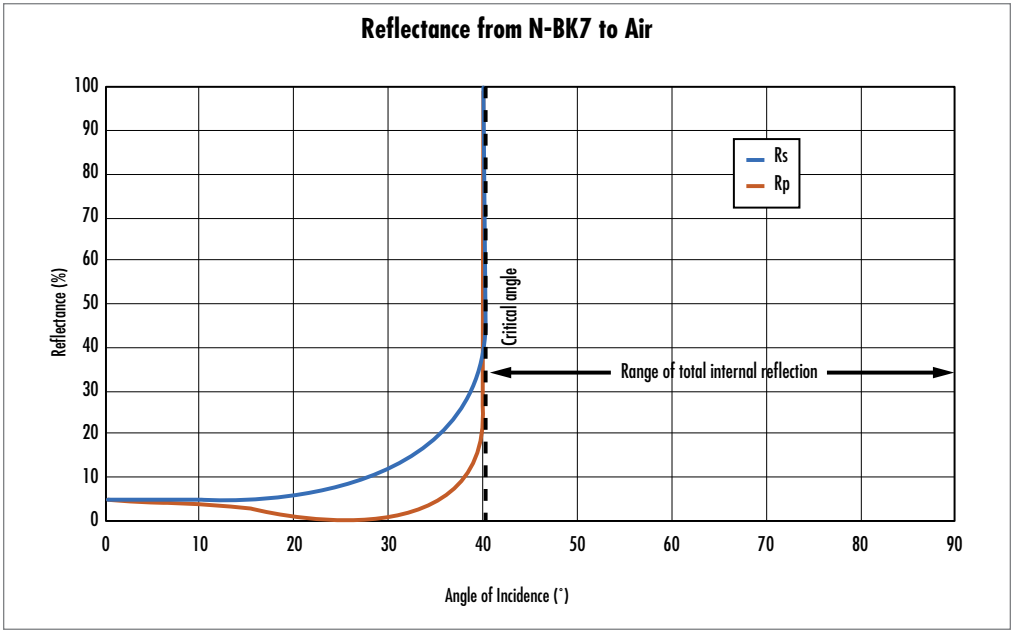
$$I = I_0 \cos^2\theta$$

where θ is the angle between the analyzer and polarizer

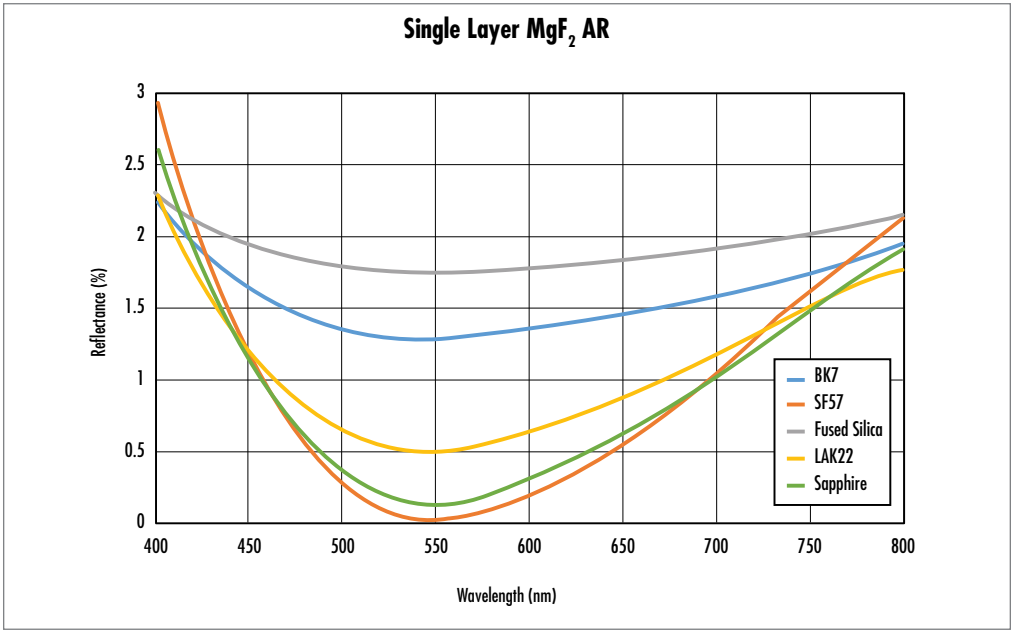
REFLECTANCE FROM AIR TO N-BK7



REFLECTANCE FROM N-BK7 TO AIR



MgF_2 PERFORMANCE ON DIFFERENT MATERIALS



EO GLASS SHOP MATERIAL PROPERTIES

Material	Refractive Index (n_d)	Abbe Number (v_d)	Density (g/cm^3)	Coefficient of Thermal Expansion	Max Operating Temp (°C)
N-BK7	1.517	64.20	2.46	7.10	557
FUSED SILICA	1.458	67.70	2.20	0.55	1000
N-SF57	1.847	23.80	5.51	8.30	414
N-SF11	1.785	25.80	5.41	6.20	503
N-LAK22	1.651	55.89	3.73	6.60	689
N-F2	1.620	36.40	3.61	8.20	432
N-SF6	1.805	25.39	3.37	9.00	605
BOROFLOAT®	1.472	65.70	2.20	3.25	450
N-LASF9	1.850	32.20	4.44	7.40	698
N-BAK4	1.569	56.10	3.10	7.00	555
N-LAK8	1.713	53.83	3.75	5.60	643
S-FSL5	1.487	70.20	2.46	9.00	457
B270	1.523	58.50	2.55	8.20	533
N-SF2	1.648	33.90	3.86	8.40	441
N-SF15	1.699	30.20	2.92	8.04	580
N-LASF44	1.803	46.40	4.46	6.20	666

WAVELENGTH AND FREQUENCY CONVERSION CHART

Visible Color	Wavelength			Frequency (THz)	Wave Number (cm^{-1})	Common Source
	Å	nm	µm			
●	1 930	193	0.193	1 553.3288	51 813.4715	ArF Excimer
●	2 480	248	0.248	1 208.8406	40 322.5806	KrF Excimer
●	2 660	266	0.266	1 127.0393	37 593.9850	Nd:YAG
●	3 080	308	0.308	973.3521	32 467.5325	XeCl Excimer
●	3 371	337.1	0.3371	889.3280	29 664.7879	N^2
●	3 510	351	0.351	854.1096	28 490.0285	Ar-Ion or XeF Excimer
●	3 550	355	0.355	844.4858	28 169.0141	Nd:YAG or Nd:YVO^4
●	4 050	405	0.405	740.2283	24 691.3580	InGaN Diode
●	4 579	457.9	0.4579	654.7116	21 838.8294	Ar-Ion
●	4 861	486.1	0.4861	616.7300	20 571.8988	Fraunhofer F Line (H)
●	4 880	488	0.488	614.3288	20 491.8033	Ar-Ion or Xe or InGaAs Diode
●	5 145	514.5	0.5145	582.6870	19 436.3460	Ar-Ion
●	5 320	532	0.532	563.5197	18 796.9925	Nd:Yag or Nd:YVO^4
●	5 876	587.6	0.5876	510.1982	17 018.3799	Fraunhofer d Line (He)
●	6 328	632.8	0.6328	473.7555	15 802.7813	He:Ne
●	6 350	635	0.635	472.1141	15 748.0315	AlGaInP Diode
●	6 563	656.3	0.6563	456.7918	15 236.9343	Fraunhofer C Line (H)
●	6 600	660	0.66	454.2310	15 151.5152	AlGaInP Diode
●	7 800	780	0.78	384.3493	12 820.5128	AlGaAs Diode
●	8 085	808.5	0.8085	370.8008	12 368.5838	InGaAsP Diode
●	8 300	830	0.83	361.1957	12 048.1928	AlGaAs Diode
●	9 800	980	0.98	305.9107	10 204.0816	InGaAs or InGaAsP Diode
●	10 640	1064	1.064	281.7598	9 398.4962	Nd:Yag or Nd:YVO^4
●	12 900	1290	1.29	232.3973	7 751.9380	InGaAsP Diode
●	15 500	1550	1.55	193.4145	6 451.6129	InGaAsP Diode
●	106 000	10600	10.6	28.2823	943.3962	CO^2

SPHERICAL LENS MANUFACTURING CAPABILITIES

	Commercial	Precision	High Precision
Diameter	4 - 200mm	4 - 200mm	4 - 200mm
Diameter Tolerance	+0/-0.100mm	+0/-0.025mm	+0/-0.010mm
Thickness	±0.100mm	±0.050mm	±0.010mm
Surface Sag	±0.050mm	±0.025mm	±0.010mm
Clear Aperture	80%	90%	90%
Radius	±0.3%	±0.1%	Fix to Test Plate
Power (P - V)	3.0λ	1.5λ	λ/2
Irregularity (P - V)	1.0λ	λ/4	λ/20
Centering (Beam Deviation)	3 arcmin	1 arcmin	0.5 arcmin
Bevel (Face width @45 degrees)	<1.0mm	<0.5mm	<0.25mm
Surface Quality	80-50	40-20	10-5

ASPHERIC LENS MANUFACTURING CAPABILITIES

	Commercial	Precision	High Precision
Diameter	10 - 150mm	10 - 150mm	10 - 150mm
Diameter Tolerance	+0/-0.100mm	+0/-0.025	+0/-0.010
Asphere Figure Error (P - V)	5µm	0.632 - 1.5µm	<0.312µm
Vertex Radius (Asphere)	±1%	±0.1%	±0.05%
Radius (Spherical)	±0.3%	±0.1%	±0.025%
Power (Spherical)	2λ	λ/2	λ/10
Irregularity (Spherical)	λ/2	λ/4	λ/20
Sag	25mm max	25mm max	25mm max
Typical Slope Tolerance	1µm/mm	0.35µm/mm	0.15µm/mm
Centering (Beam Deviation)	3 arcmin	1 arcmin	0.5 arcmin
Center Thickness Tolerance	±0.100mm	±0.050mm	±0.010mm
Surface Quality (Scratch Dig)	80-50	40-20	10-5
Aspheric Surface Metrology	Profilometry	Profilometry	Profilometry

OPTICAL PRISM MANUFACTURING CAPABILITIES

	Commercial	Precision	High Precision
Dimensions	2 - 200mm	2 - 150mm	2 - 75mm
Dimensional Tolerance	+0/-0.1mm	+0/-0.025mm	+0/-0.01mm
V-Height	±0.25mm	±0.1mm	±0.03mm
Irregularity	1.0λ	λ/4	λ/20
Prism Physical Angle Tolerance	±3 arcmin	±30 arcsec	45° & 90° ±0.5 arcsec
Penta Prism Deviation	5 arcmin	3 arcmin	0.5 arcsec
Bevel Tolerance (Face Width @ 45°)	±0.2mm	±0.1mm	±0.05mm
Surface Quality (Scratch Dig)	80-50	40-20	10-5
Bonded Prism Assembly Beam Deviation	5 arcmin	3 arcmin	0.5 arcmin
Surface Quality	80-50	40-20	10-5

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