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LAYERTEC[®]
OPTICAL COATINGS · OPTICS

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PRECISION OPTICS

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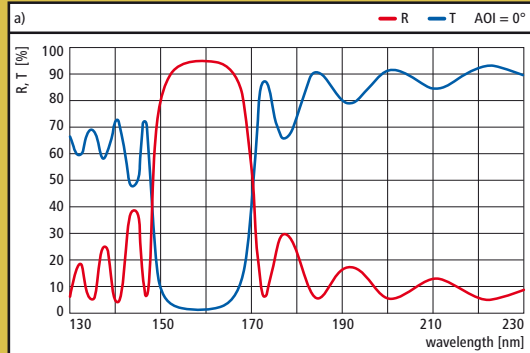


SELECTION OF OPTICAL COMPONENTS FOR COMMON LASER TYPES

COMPONENTS FOR F₂ LASERS

MIRRORS

Measurement



Measurement

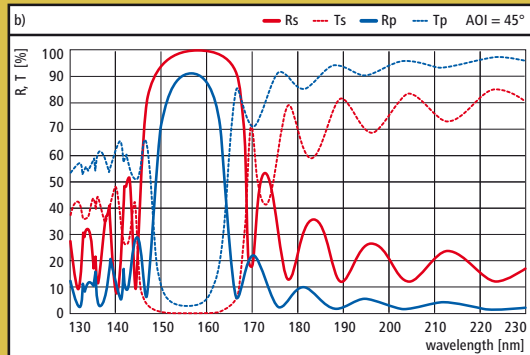


Figure 1: Measured reflectance and transmittance spectra of mirrors for 157 nm

- a) Laser mirror (AOI = 0°)
b) Turning mirror (AOI = 45°)

- Laser mirrors: R = 92 % ... 95 % at AOI = 0°.
- Turning mirrors (AOI = 45°):
Rs > 95 %
Rp > 90 %
Ru > 92 %.

OUTPUT COUPLERS AND LENSES

Measurement

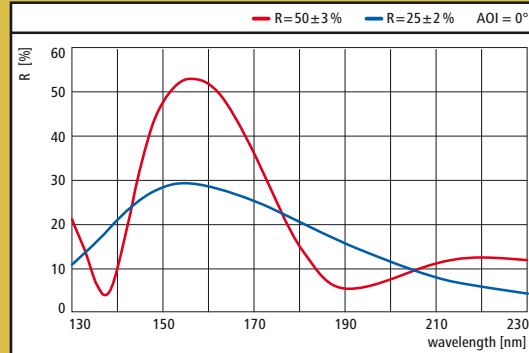


Figure 2: Measured reflectance spectra of standard output couplers with R = 50 % ± 3 % and R = 25 % ± 2 % (back side uncoated)

- High quality mirror substrates, windows and lenses of CaF₂ (193 nm excimer grade quality, HELMA Materials GmbH).
- Please note that the 157 nm excimer grade CaF₂ can no longer be offered. The market for this kind of material is too small compared to the huge effort necessary for the crystal manufacturers to test the material according to this quality standard. Thus, all optics for F₂ lasers will be manufactured using 193 nm excimer grade material in the future.
- PR coatings with tolerances of
± 2 % for R = 10 % ... 30 %
± 3 % for R = 30 % ... 75 %
and ± 2 % for R = 75 % ... 90 %.
- Development and production of customer specific components like beam splitters and variable attenuators on request.

VARIABLE ATTENUATORS

Measurement

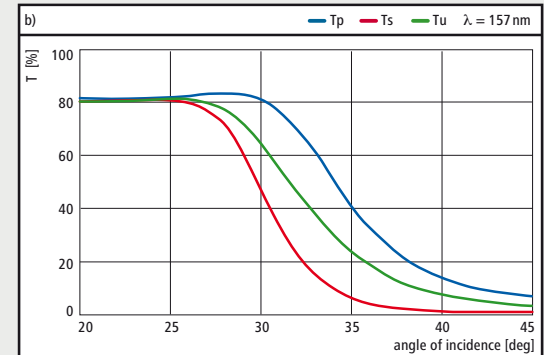
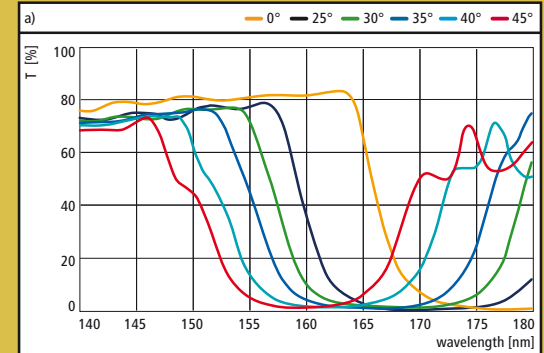


Figure 3: Measured transmittance spectra of a variable attenuator for 157 nm

- a) Transmittance vs. wavelength at different AOI
b) Transmittance at 157 nm vs. AOI for different polarizations
The transmittance varies from
T > 75 % at AOI = 0° to T < 5 % at AOI = 45°

157 nm

ALUMINUM MIRRORS FOR F₂ LASERS

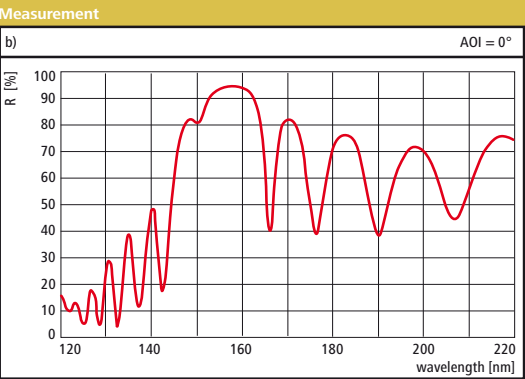
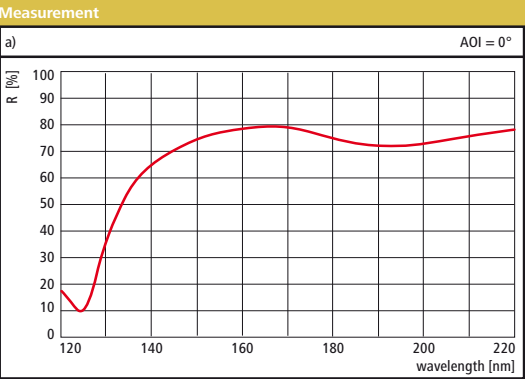


Figure 4: Reflectance spectra of aluminum mirrors
a) Protected aluminum mirror
b) Enhanced aluminum mirror for 157 nm

- Protected aluminum mirrors (optimized for 157 nm):
R = 74 % ... 78 %.
- Dielectrically enhanced aluminum mirrors: up to
R = 94 % at AOI = 0°.
- For more information on aluminum mirrors see
pages 122 – 123.

TECHNICAL DATA OF STANDARD F₂ LASER COMPONENTS

LIDT - INFO

Coating	Spectral performance	Lifetime tests
HR(0°, 157 nm)	R = 92 % ... 95 %	2 x 10 ⁸ – 1 x 10 ⁹ pulses*
HR(45°, 157 nm)	R = 90 % ... 94 % (unpol. light)	
PR(0°, 157 nm)	R = 50 % ± 3 %	2 x 10 ⁸ – 1 x 10 ⁹ pulses*
PR(0°, 157 nm)	R = 25 % ± 2 %	2 x 10 ⁸ – 1 x 10 ⁹ pulses*
Attenuator	T = 67 % ± 3 %	5 x 10 ⁷ pulses**, no damage
Attenuator	T = 33 % ± 3 %	1 x 10 ⁸ pulses***, no damage
Beam splitter	T = 20 % ± 3 %	1 x 10 ⁸ pulses***, no damage
AR(0°, 157 nm)	R = 0.3 % ... 0.7 %	

* Energy density: 25 mJ / cm², repetition rate: 800 Hz, pulse duration: 15 ns; tested at COHERENT AG, München
** Energy density: 15 mJ / cm², repetition rate: 200 Hz, pulse duration: 20 ns; tested at Institut für Photonische Technologien (IPHT) Jena
*** Energy density: 20 mJ / cm², repetition rate: 50 Hz, pulse duration: 20 ns; tested at Institut für Photonische Technologien (IPHT) Jena

COMPONENTS FOR THE FIFTH AND SIXTH HARMONIC OF Ti:SAPPHIRE LASERS

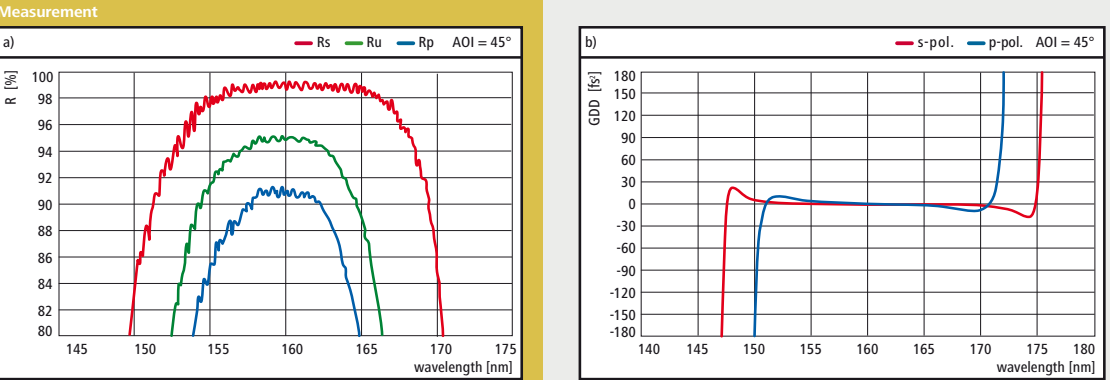


Figure 5: Reflectance and GDD - spectra of a turning mirror for 160 nm (AOI = 45°)
a) Reflectance vs. wavelength (measured)
b) GDD vs. wavelength (calculated)

Mirrors and separators for the 133 nm and 160 nm range are produced by coating techniques which were developed for F₂ laser coatings. For more information please see pages 94 – 95.

COMPONENTS FOR ArF LASERS

MIRRORS

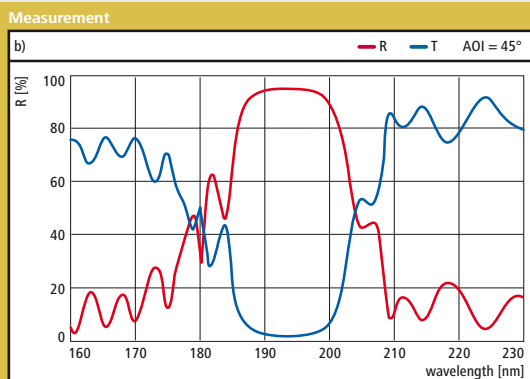
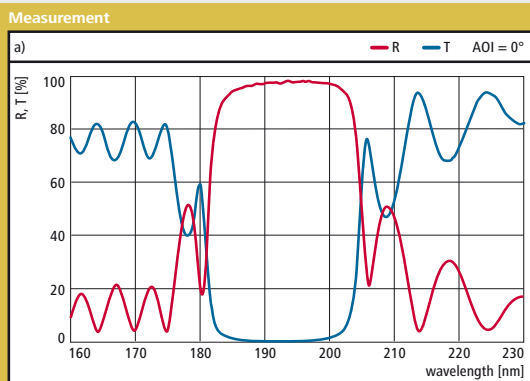


Figure 1: Measured reflectance and transmittance spectra of mirrors for 193 nm

- a) Laser mirror ($\text{AOI} = 0^\circ$)
b) Turning mirror ($\text{AOI} = 45^\circ$, unpolarized light)

- All fluoride systems guarantee high reflectance and high damage thresholds.
- High quality mirror substrates, windows and lenses of CaF_2 (193 nm excimer grade, HELMA Materials GmbH) and fused silica.
- Development and production of customer specific components such as beam splitters and variable attenuators on request.

OUTPUT COUPLERS AND LENSES

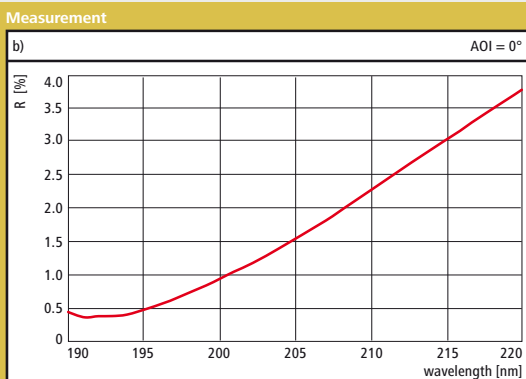
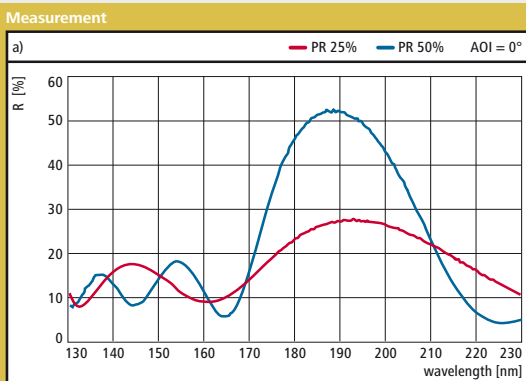


Figure 2: Measured reflectance spectra of output couplers and windows

- a) Output couplers with $\text{R}(0^\circ, 193 \text{ nm}) = 50\% \pm 3\%$ and $\text{R}(0^\circ, 193 \text{ nm}) = 25\% \pm 2\%$ (back side uncoated)
b) CaF_2 window coated on both sides with a fluoride AR coating for 193 nm

- PR coatings with tolerances of
 - $\pm 2\%$ for $\text{R} = 10\% \dots 30\%$
 - $\pm 3\%$ for $\text{R} = 30\% \dots 75\%$
 - $\pm 2\%$ for $\text{R} = 75\% \dots 90\%$
 - and $\pm 1\%$ for $\text{R} > 90\%$.
- Single wavelength AR coating with residual reflectance values of
 - $\text{R} < 0.25\%$ at $\text{AOI} = 0^\circ$ and
 - $\text{R} < 0.6\%$ at $\text{AOI} = 45^\circ$ (unpolarized light).
- Broadband and multiple wavelength AR coatings.

VARIABLE ATTENUATORS

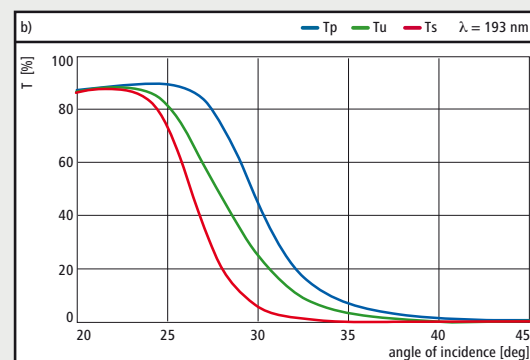
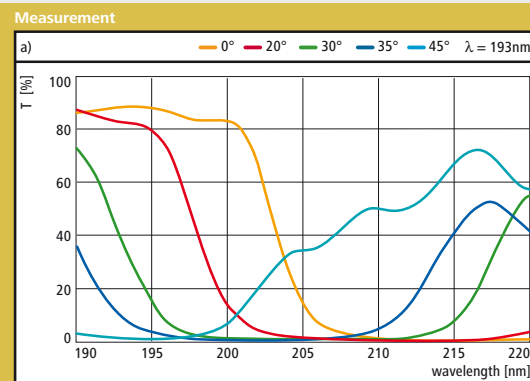


Figure 3: Measured transmittance spectra of a variable attenuator for 193 nm

- a) Transmittance vs. wavelength at different AOI
b) Transmittance at 193 nm vs. AOI for different polarizations
The transmittance varies from $\text{T} > 88\%$ at $\text{AOI} = 0^\circ$ to $\text{T} < 2\%$ at $\text{AOI} = 45^\circ$

- Attenuators with custom transmittance ranges on request.
- Attenuators can be delivered with AR coated compensation plates of CaF_2 or fused silica.

193 nm

ALUMINUM MIRRORS

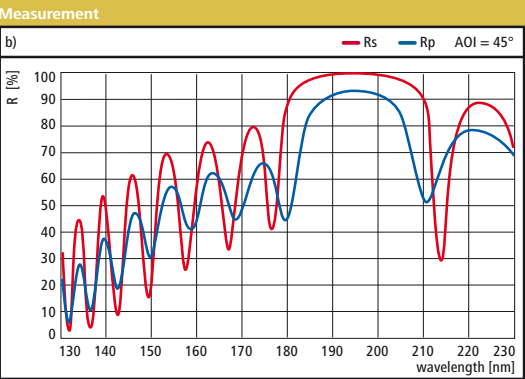
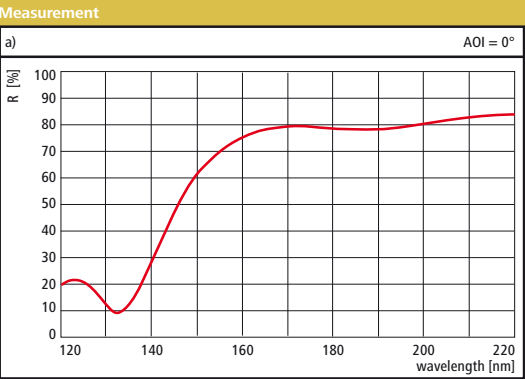


Figure 4: Reflectance spectra of aluminum mirrors
a) Protected aluminum mirror optimized for 193 nm
b) Enhanced aluminum mirror for 193 nm, AOI = 45°

Enhanced aluminum mirrors: Rp > 93 %
Rs > 98 %
Ru > 96 %.

For more information on aluminum mirrors see pages 122 – 123.

TECHNICAL DATA OF STANDARD ArF LASER COMPONENTS

LIDT - INFO

Coating/reflectance Fluoride coatings	Substrate	Damage threshold*	Lifetime test
AR (0°, 193 nm) R < 0.25 %	CaF ₂	4 – 5 J / cm ²	10 ⁸ pulses, no damage**
AR (0°, 193 nm) R < 0.25 %	fused silica	2 – 3 J / cm ²	
PR (0°, 193 nm) R = 25 %	CaF ₂	3 – 4 J / cm ²	10 ¹⁰ pulses, no damage**
PR (0°, 193 nm) R = 50 %	CaF ₂	2 – 3 J / cm ²	10 ¹⁰ pulses**
HR (0°, 193 nm) R > 96 %	CaF ₂	2 – 3 J / cm ²	10 ¹⁰ pulses **, no damage 4 x 10 ⁹ pulses ***, no damage
HR (45°, 193 nm) R > 95 % (unpolarized light)	CaF ₂	2 – 3 J / cm ²	

* 1000-on-1, 14 ns; measurements were performed at Laser Labor Göttingen, Laser Zentrum Hannover and at Friedrich-Schiller-University Jena
** Energy density: 55 mJ / cm², repetition rate: 1 kHz, pulse duration: 15 ns; tested at COHERENT AG, München
*** Energy density: 80 mJ / cm², repetition rate: 1 kHz, pulse duration: 12 ns; tested at COHERENT AG, München

COMPONENTS FOR THE 200 nm RANGE

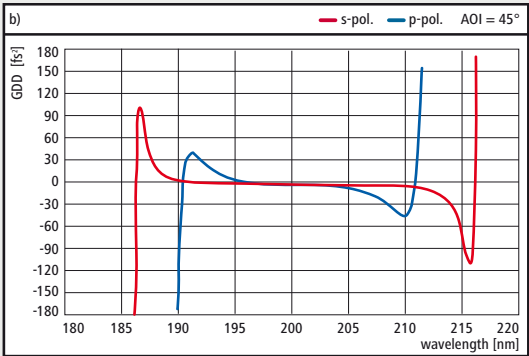
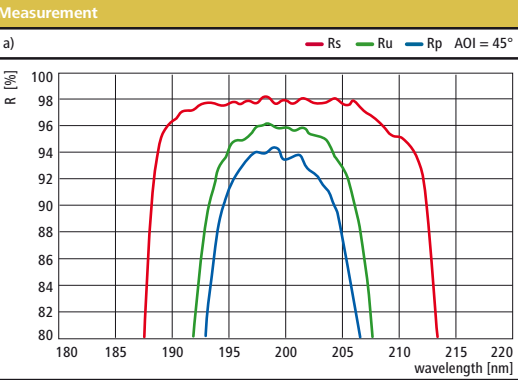


Figure 5: Reflectance and GDD - spectra of a turning mirror for 200 nm (AOI = 45°)
a) Reflectance vs. wavelength (measured)
b) GDD vs. wavelength (calculated)

Mirrors and separators for the 200 nm range are produced by coating techniques which were developed for ArF laser coatings. For more information please see pages 94 – 95.

COMPONENTS FOR KrF, XeCl and XeF LASERS

CAVITY MIRRORS

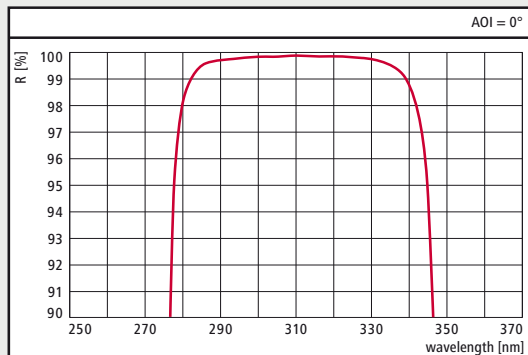


Figure 1: Reflectance spectrum of a 308 nm cavity mirror

- Oxide coatings for high mechanical stability.
- Coatings can be produced by IAD, magnetron sputtering or IBS.

OUTPUT COUPLERS

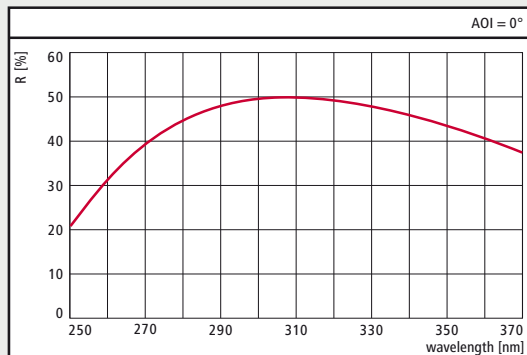


Figure 3: Reflectance spectrum of an output coupler for 308 nm
 $R(0^\circ, 308 \text{ nm}) = 50 \% \pm 3 \%$

- PR coatings with tolerances of
 - $\pm 2 \%$ for $R = 10 \% \dots 30 \%$
 - $\pm 3 \%$ for $R = 30 \% \dots 75 \%$
 - $\pm 2 \%$ for $R = 75 \% \dots 90 \%$
 - and $\pm 1 \%$ for $R > 90 \%$.

WINDOWS AND LENSES

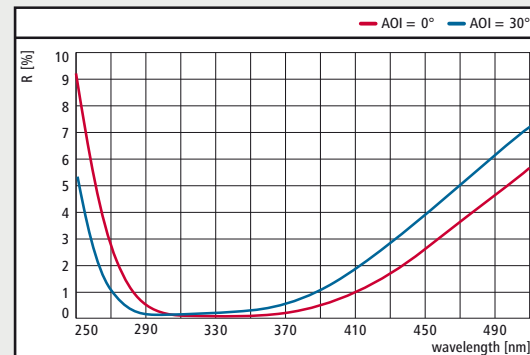


Figure 5: Reflectance spectra of an AR coating for 308 nm and
 $\text{AOI} = 0^\circ - 30^\circ$

- High quality mirror substrates, windows and lenses of fused silica.

FLUORINE RESISTANT CAVITY MIRRORS

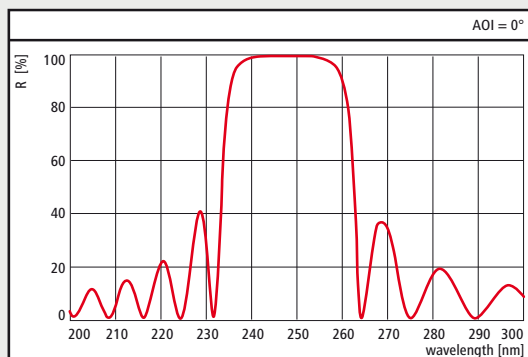


Figure 2: Reflectance spectrum of a fluoride KrF cavity mirror

- Fluoride coatings and CaF_2 substrates for high stability against fluorine and chlorine.
- Laser mirrors ($R > 98 \%$ at 248 nm, 308 nm and 351 nm).

FLUORINE RESISTANT OUTPUT COUPLERS

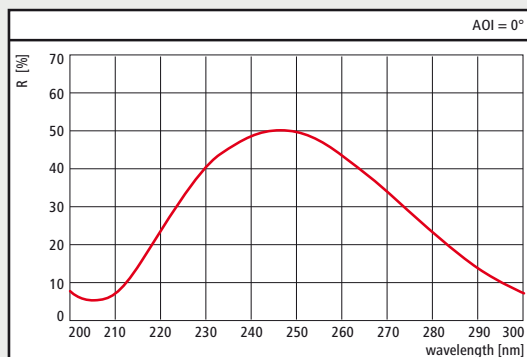


Figure 4: Reflectance spectrum of a fluoride output coupler with
 $R(0^\circ, 248 \text{ nm}) = 50 \% \pm 3 \%$

- PR coatings with tolerances of
 - $\pm 2 \%$ for $R = 10 \% \dots 30 \%$
 - $\pm 3 \%$ for $R = 30 \% \dots 75 \%$
 - and $\pm 2 \%$ for $R = 75 \% \dots > 90 \%$.

FLUORINE RESISTANT WINDOWS

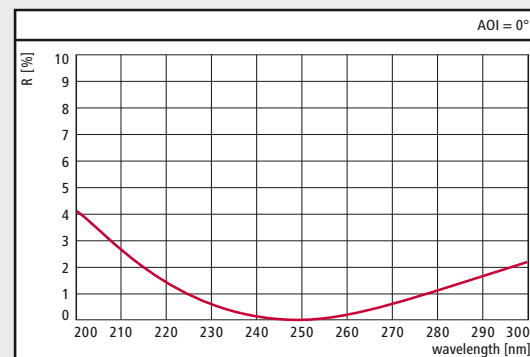


Figure 6: Reflectance spectrum of a fluoride AR coating for 248 nm

- High quality mirror substrates, windows and lenses of CaF_2 (248 nm excimer grade or UV quality, HELMA Materials GmbH).
- Extended lifetimes at high energy densities at 248 nm.

248 nm, 308 nm, 351 nm

TURNING MIRRORS

Measurement

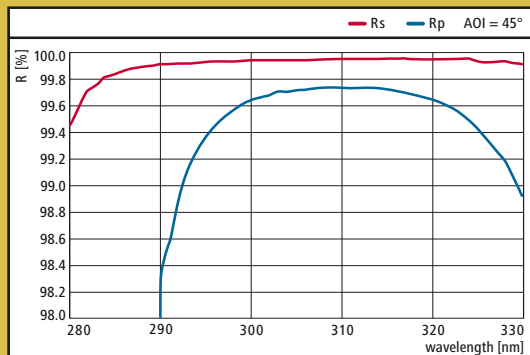


Figure 7: Reflectance spectra of a turning mirror for 308 nm produced by IBS
Reflectance measurement in s- and p-polarization by CRDS

Reflectance of turning mirrors (AOI = 45°):

Coating	Rs	Rp
248 nm IAD	> 99.5 %	> 99.0 %
248 nm sputtering	> 99.8 %	> 99.6 %
308 nm IAD	> 99.8 %	> 99.5 %
308 nm sputtering	> 99.9 %	> 99.7 %
351 nm IAD	> 99.9 %	> 99.7 %
351 nm sputtering	> 99.95 %	> 99.9 %

Reflectance of laser mirrors (AOI = 0°):

Coating	R
248 nm IAD	> 99.0 %
248 nm sputtering	> 99.7 %
308 nm IAD	> 99.7 %
308 nm sputtering	> 99.9 %
351 nm IAD	> 99.9 %
351 nm sputtering	> 99.95 %

ATTENUATORS

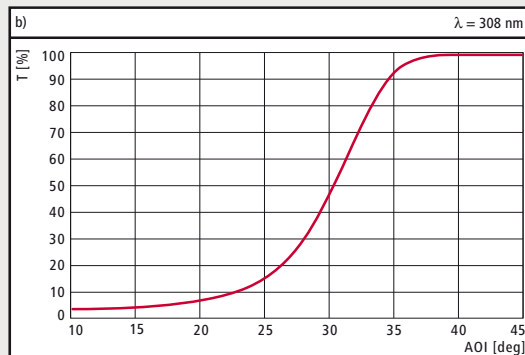
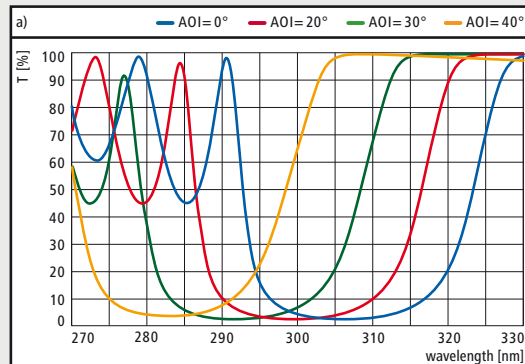


Figure 8: Measured transmittance spectra of a variable attenuator for 308 nm

- a) Transmittance vs. wavelength at different AOI
b) Transmittance at 308 nm vs. AOI for unpolarized light
The transmittance varies from $T < 10\%$ at $\text{AOI} = 0^\circ$ to $T > 90\%$ at $\text{AOI} = 40^\circ$

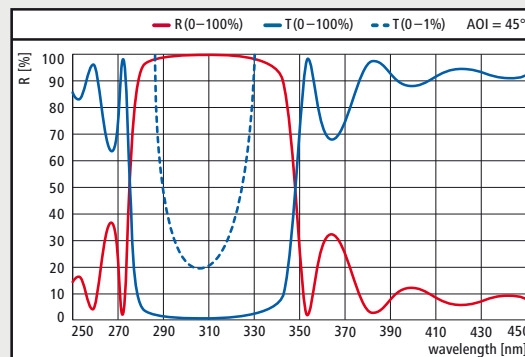


Figure 9: Transmittance spectrum of a sputtered attenuator for 308 nm with exactly adjusted and thermally stable transmittance of $T = 0.2\%$ at $\text{AOI} = 45^\circ$ (unpolarized light)

LIDT AND LIFETIME DATA

LIDT of oxide coatings:

Coating	LIDT* [J / cm ²]
HR (0°, 248 nm) IAD	10 J / cm ² (1-on-1) 5 J / cm ² (1000-on-1)
HR (45°, 248 nm) IAD	10 J / cm ² (1-on-1)

Lifetime of fluoride coatings:

Coating	Lifetime
HR (0°, 248 nm)	2×10^8 pulses**
PR (0°, 248 nm) = 50 %	2×10^8 pulses**
AR (0°, 248 nm)	2×10^8 pulses***
HR (0°, 308 nm)	2×10^8 pulses***
HR (0°, 351 nm)	2×10^8 pulses***
PR (0°, 351 nm) = 25 %	2×10^8 pulses***

* Measurements were performed at Laser Labor Göttingen and at Friedrich-Schiller-University Jena

** Energy density: 100 mJ / cm², repetition rate: 100 Hz, pulse duration: 15 ns; tested at COHERENT AG, München

*** Energy density: 55 mJ / cm², repetition rate: 100 Hz, pulse duration: 15 ns; tested at COHERENT AG, München

COMPONENTS FOR RUBY AND ALEXANDRITE LASERS

Ruby and Alexandrite Lasers are especially used for medical laser applications and work at 694 nm and 755 nm, respectively. LAYERTEC offers a wide range of laser optics for both wavelengths with high laser-induced damage thresholds and long lifetimes. Besides typical combinations with wavelengths for

the alignment of the optical system (e.g. 694 nm + 633 nm), a special feature of LAYERTEC products is the variety of combinations with other common wavelengths used for medical applications in the same device, but from different laser sources (e.g. 532 nm + 694 nm).

CAVITY MIRRORS

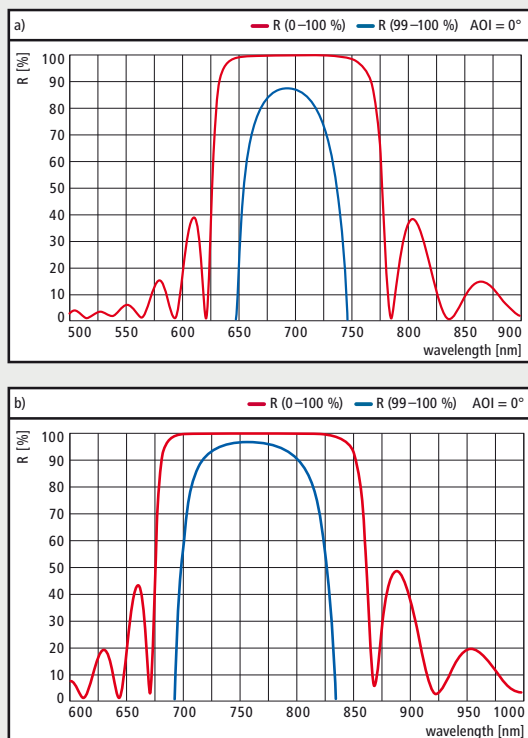


Figure 1: Reflectance spectra of cavity mirrors for

- a) 694 nm
- b) 755 nm

- Reflectance: $R > 99.8 \dots R > 99.9 \%$ at $\text{AOI} = 0^\circ$.

LIDT - INFO

800 MW / cm², 694 nm, 35 ns

TURNING MIRRORS

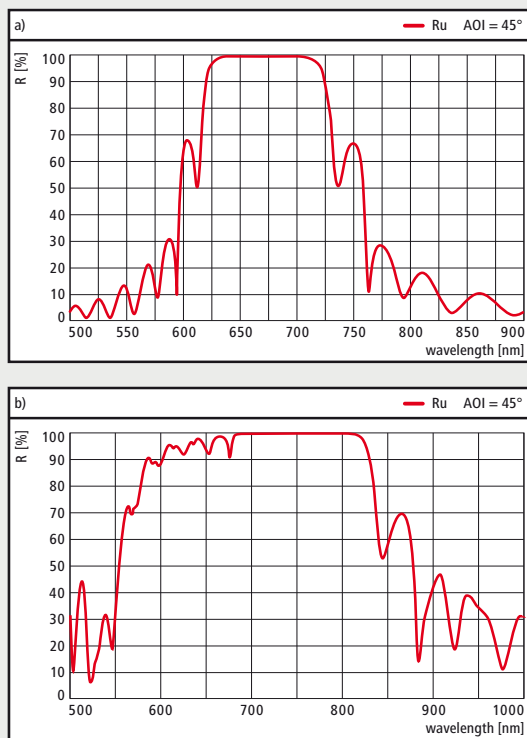


Figure 2: Reflectance spectra of turning mirrors for

- a) 694 nm
- b) 755 nm

- Reflectance: $R > 99.5 \%$ at $\text{AOI} = 45^\circ$ for unpolarized light.
- Easy combination with alignment beam (e.g. at 630 – 650 nm).

LIDT - INFO

800 MW / cm², 694 nm, 35 ns

BEAM COMBINERS

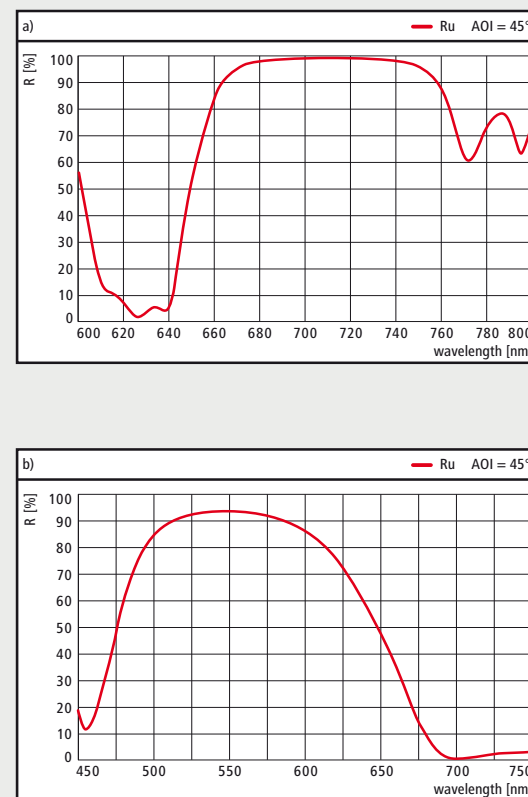


Figure 3: Reflectance spectra of special beam combiners for 694 nm and 633 nm:

- a) PRu (45°, 694 nm) = $99.0 \pm 0.3 \%$
+ Ru (45°, 633 nm) < 35 %
- b) Ru (45°, 630 - 640 nm) > 35 %
+ Rp (45°, 694 nm) < 0.3 %

- Precisely adjusted degree of reflectance by using sputtering technology.
- Easy combination with alignment beam (e.g. at 635 nm).
- High performance and cost-optimized solutions with special designs.

694 nm, 755 nm

OUTPUT COUPLERS

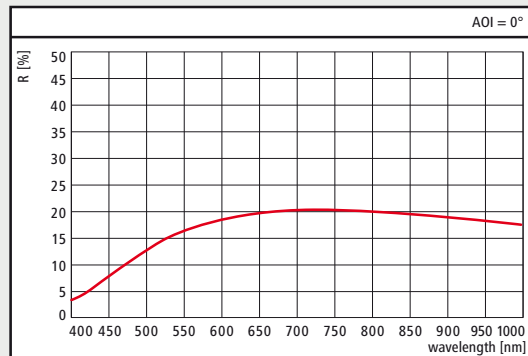


Figure 4: Reflectance spectrum of an output coupler for the ruby laser: PR (0°, 694 nm) = 20 % ± 2 %

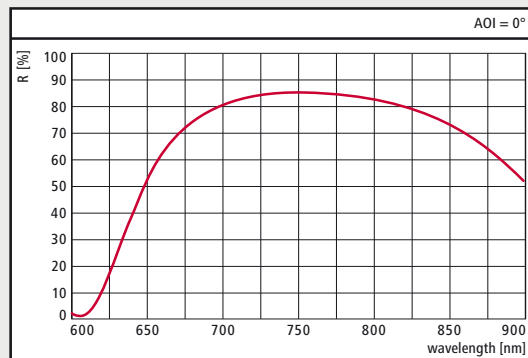


Figure 5: Reflectance spectrum of an output coupler for the alexandrite laser: PR (0°, 755 nm) = 85 % ± 2 %

- Output couplers with precisely adjusted degree of reflectance.

WINDOWS AND LENSES

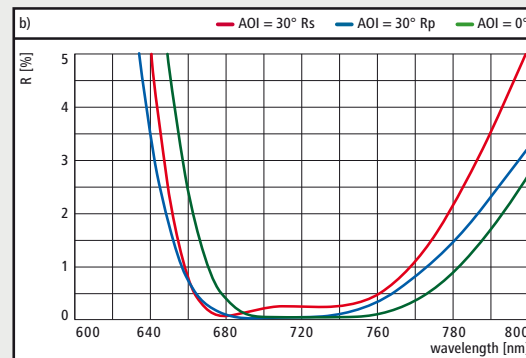
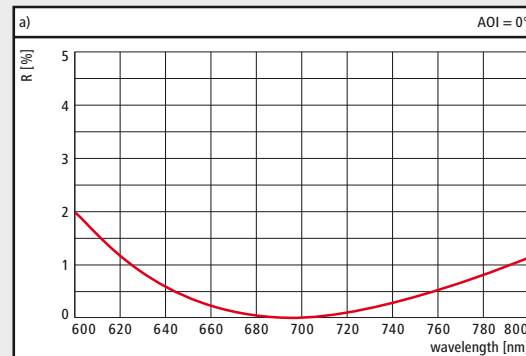


Figure 6: Reflectance spectra of AR coatings for 694 nm and 755 nm:
a) AR (0°, 694 nm) < 0.2 %
b) AR (0° – 30°, 694 + 755 nm) < 0.5 %

- AR coatings for a single wavelength with a residual reflectance of $R < 0.2$ % on the back side of output couplers as well as on both sides of lenses and windows made of fused silica.

COMPONENTS FOR COMBINING RUBY LASERS WITH OTHER HIGH POWER LASERS

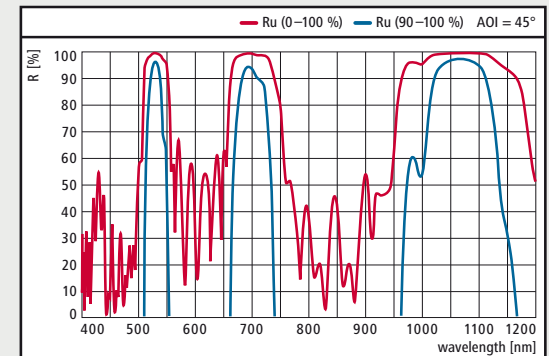


Figure 7: Reflectance spectrum of a triple wavelength turning mirror for 532 nm, 694 nm and 1064 nm (for unpolarized light)

- $R > 99$ % at all three wavelengths (AOI = 45°, unpolarized light).
- High laser damage thresholds.

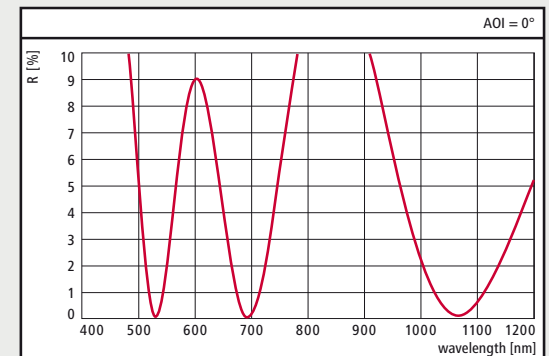


Figure 8: Reflectance spectrum of a triple wavelength AR coating for 532 nm, 694 nm and 1064 nm

COMPONENTS FOR Ti:SAPPHIRE LASERS IN THE ns REGIME

LAYERTEC offers a wide range of optical components for Ti:Sapphire lasers which operate with ns-pulses. Please note that all of these components are optimized for smooth group delay (GD) spectra in order to achieve wide tuning ranges. However, these components are not optimized for group delay dispersion (GDD). Such optics are necessary for fs-pulses and they will be introduced on pages 74 and following.

CAVITY MIRRORS

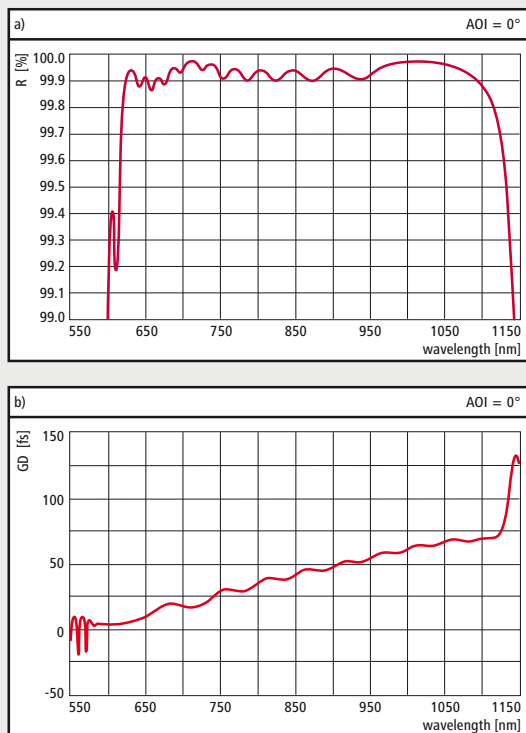


Figure 1: Reflectance and GD - spectra of a broadband laser mirror
a) Reflectance vs. wavelength
b) GD vs. wavelength

PUMP MIRRORS

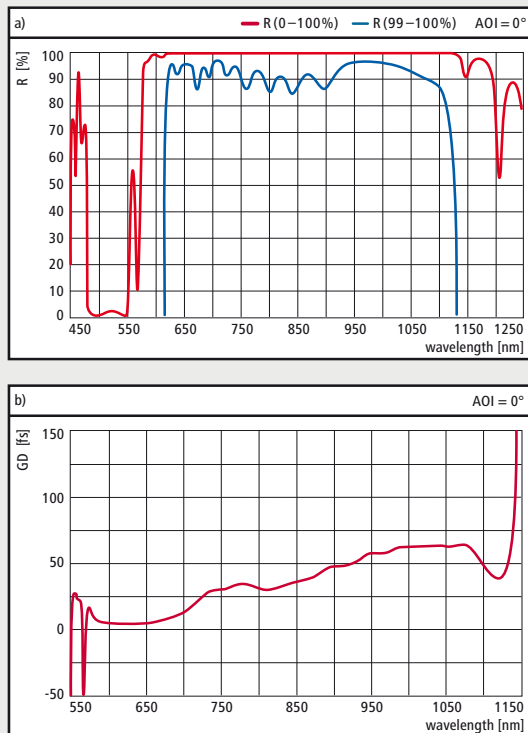


Figure 2: Reflectance spectra of a broadband pump mirror

a) Reflectance vs. wavelength
b) GD vs. wavelength

Special features:

- Very high reflectance of the mirrors: $R > 99.9\%$, depending on bandwidth $R > 99.98\%$ may also be achieved.
- Spectral tolerance: $\pm 1\%$ of center wavelength.
- Center wavelength, bandwidth and reflectance of partial reflectors according to customer specification.

TURNING MIRRORS

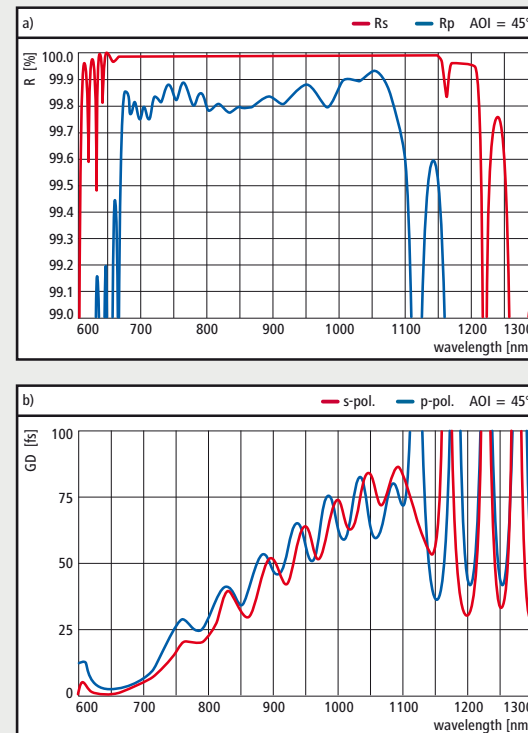


Figure 3: Reflectance and GD spectra of a broadband turning mirror

a) Reflectance vs. wavelength
b) GD vs. wavelength

550 – 1100 nm

OUTPUT COUPLERS AND BEAM SPLITTERS

Tolerances:

- Standard output couplers
(bandwidth: 120 – 150 nm):
 - $\pm 2.5 \%$ for $R = 10 \%$... 70%
 - $\pm 1.5 \%$ for $R = 70 \%$... 90%
 - $\pm 0.75 \%$ for $R = 90 \%$... 95%
 - $\pm 0.5 \%$ for $R = 95 \%$... 98%
 - $\pm 0.25 \%$ for $R > 98 \%$.

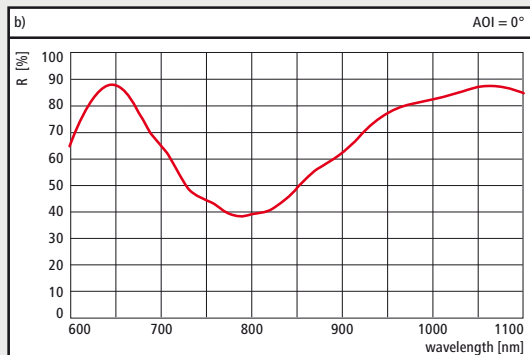
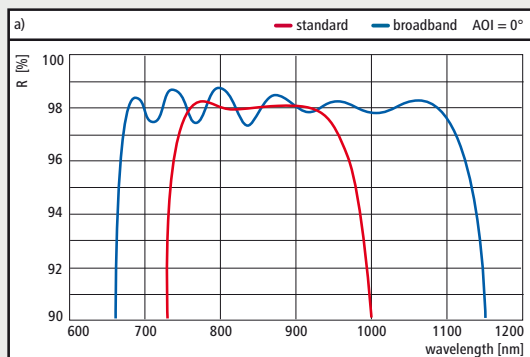


Figure 4: Reflectance spectra of several types of output couplers
 a) Standard and broadband output coupler
 b) Output coupler with a special reflectance profile which enables the compensation of the amplification characteristics of the laser; see also B. Jungbluth, J. Wueppen, J. Geiger, D. Hoffmann, R. Poprawe: "High Performance, Widely Tunable Ti:Sapphire Laser with Nanosecond Pulses" in: Solid State Lasers XV: Technology and Devices, Proc. of SPIE Vol. 6100, 6100 - 20, San Jose 2006

Tolerances:

- Broadband output couplers
(bandwidth: 200 – 600 nm):
 - $\pm 3 \%$ for $R = 10 \%$... 70%
 - $\pm 2 \%$ for $R = 70 \%$... 90%
 - $\pm 1 \%$ for $R = 90 \%$... 95%
 - $\pm 0.5 \%$ for $R = 95 \%$... 98% .

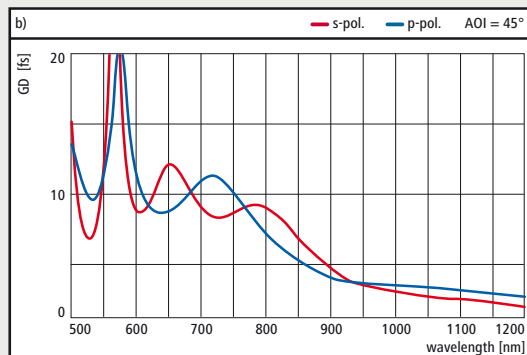
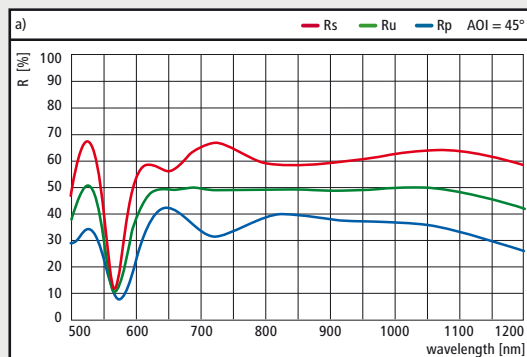


Figure 5: Reflectance and GD spectra of a broadband beamsplitter
 PRu (45°, 650 - 1050 nm) = 50 % \pm 3 %
 a) Reflectance vs. wavelength
 b) GD vs. wavelength

SPECIAL COMPONENTS

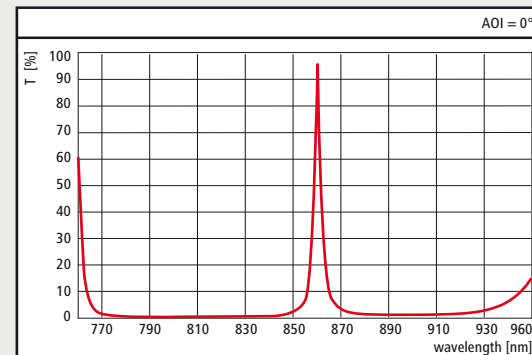


Figure 6: Transmittance spectrum of a narrow band intracavity filter for 860 nm which is used to select one wavelength from the Ti:Sapphire spectrum

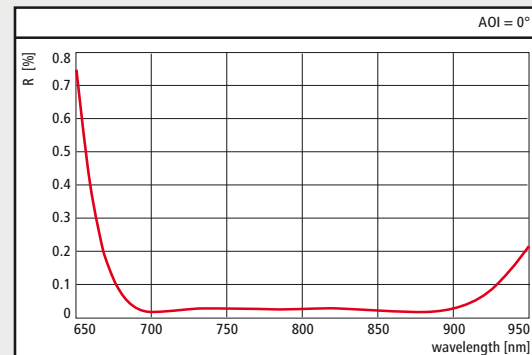


Figure 7: Reflectance spectrum of a broadband antireflection coating with extremely low residual reflectance:
 AR (0°, 700 – 900 nm) < 0.05 %

COMPONENTS FOR DIODE LASERS

Diode lasers are widely used for measurement applications, as alignment lasers, for pumping of solid-state lasers and for direct materials processing. Diode lasers do not require external resonator optics and are mostly coupled to fibers. Many applications require high quality beam steering optics such as beam combiners or scanning mirrors which are shown on the following pages. For more information on pump mirrors for solid-state lasers and combiners for diode lasers please see also pages 54 – 57 and 110 – 111.

TURNING MIRRORS

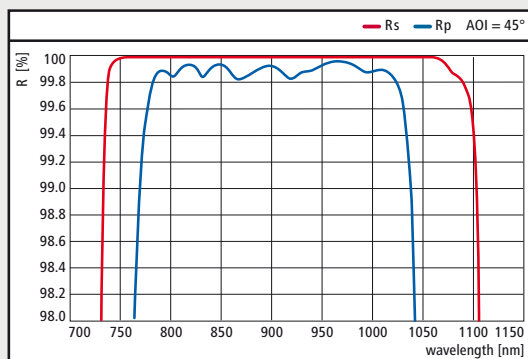


Figure 1: Reflectance spectra of a broadband turning mirror which can be used for all diode lasers between 808 nm and 980 nm (AOI = 45°, s- and p-polarization)

SCANNING MIRRORS

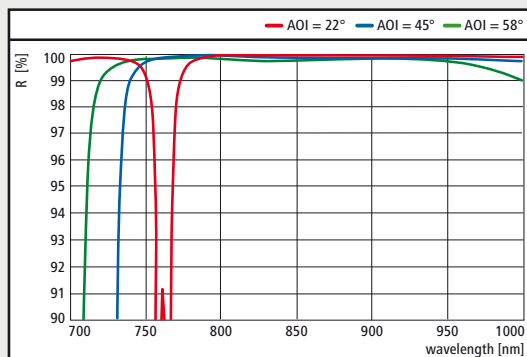
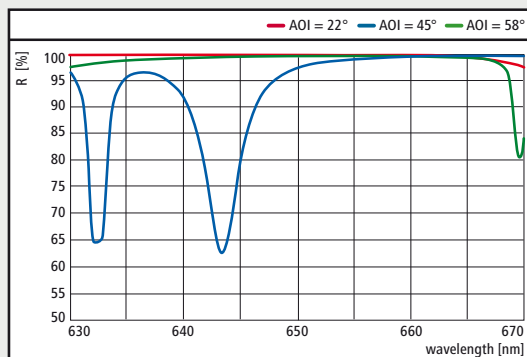


Figure 2: Reflectance spectra of a scanning mirror for diode lasers between 805 and 940 nm combined with $R > 50\%$ between 630 and 670 nm (alignment laser):
 HRu (22°–58°, 805–940 nm) $> 99.3\%$
 + Ru (22°–58°, 630–670 nm) $> 50\%$

- Scanning mirrors with other specifications on request.
- For more information and examples about scanning mirrors please see pages 108 – 109 and 120 – 121.

THIN FILM POLARIZERS

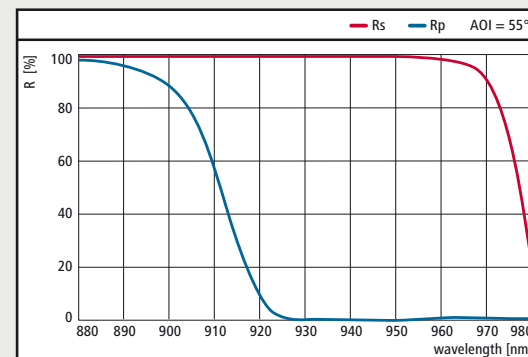


Figure 3: Reflectance spectra of a thin film polarizer for 940 nm, AOI = 55°

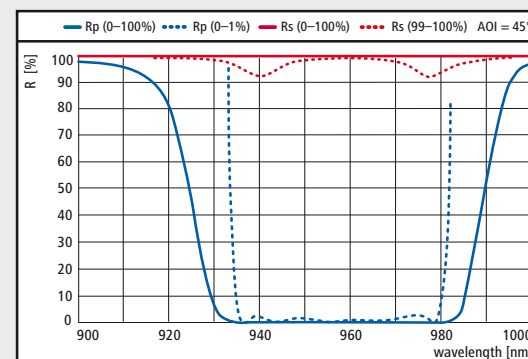


Figure 4: Reflectance spectra of a broadband thin film polarizer for 940 – 970 nm: HRs (45°, 940 – 970 nm) $> 99.9\%$
 + Rp (45°, 940 – 970 nm) $< 1\%$

- Thin film polarizers are especially useful for polarization coupling of high power laser diodes.
- For high power 940 nm radiation we recommend to use SUPRASIL 300® or SUPRASIL 3001/3002® as substrate material because standard fused silica shows an absorption band around this wavelength (see page 20).

620 – 680 nm , 808 – 990 nm

CONVENTIONAL STEEP EDGE COMBINERS FOR DIODE LASERS

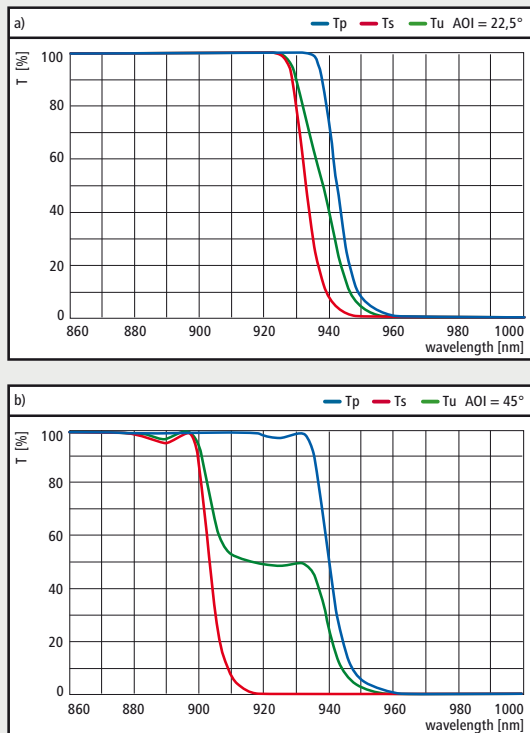


Figure 5: Transmittance spectra of conventional steep edge filters
 HR (980 nm) > 99.9 % + R (915 nm) < 5 % which are used
 as combiners for pump laser diodes at 915 nm and 980 nm;
 a) HRs,p (22.5°, 980 nm) > 99.9 % + Rs,p (22.5°, 915 nm) < 2 %
 b) HRs,p (45°, 980 nm) > 99.9 % + Rp (45°, 915 nm) < 2 %

- At AOI = 22.5° the conventional steep edge filter separates 915 nm and 980 nm for p- and s-polarized and unpolarized light.
- To preserve the steep edge at AOI = 45° the radiation must be polarized and only one polarization can be used. Unpolarized light changes the slope of the edge significantly.

SPECIAL STEEP EDGE COMBINERS FOR UNPOLARIZED LIGHT

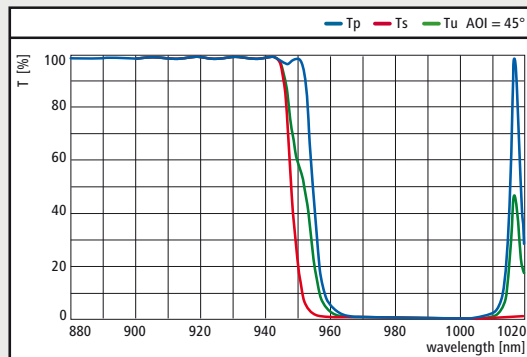


Figure 6: Transmittance spectra of a special steep edge filter
 HRu (45°, 980 nm) > 99.8 % + Ru (45°, 940 nm) < 3 %

- Filters of this type can be used as separators or combiners for s- and p-polarized light even at 45° incidence.
- The cut-on / cut-off edges for the two polarizations only show a spectral separation of about 10nm.
- Consequently, these filters can be applied as combiners for unpolarized light of 940 nm and 980 nm diodes at AOI = 45°.

- High quality substrates and lenses of fused silica.
- SUPRASIL 300® or SUPRASIL 3001/3002® substrates on request.
- Broadband and multiple wavelength AR coatings according to customer specifications.

WINDOWS AND LENSES

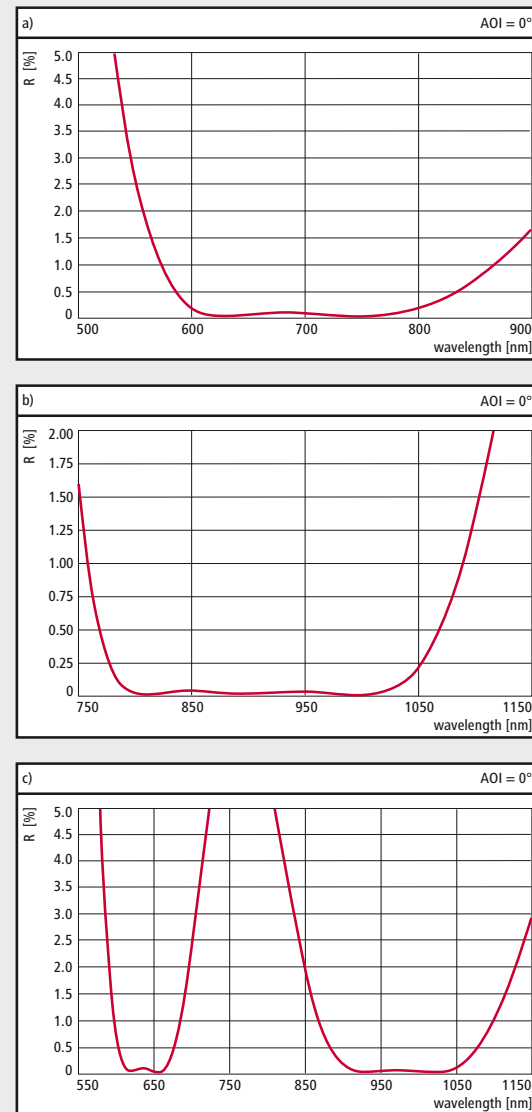


Figure 7: Reflectance spectra of broadband AR coatings for several types of laser diodes:
 a) AR (0°, 600 – 800 nm) < 0.5 %
 b) AR (0°, 790 – 1050 nm) < 0.5 %
 c) Broadband AR coating which is combined with an AR coating for an alignment laser:
 AR (0°, 633 + 900 – 1000 nm) < 0.5 %

COMPONENTS FOR Yb:YAG, Yb:KGW AND Yb-DOPED FIBER LASERS

In recent years, lasers using Yb-doped crystals or fibers have seen an increase in importance. Yb:YAG thin disk lasers as well as Yb-doped fiber lasers were developed to achieve high cw output power of about 10 kW and excellent beam quality. Yb:YAG and Yb:KGW lasers can also be operated as high-power lasers in the ns to fs range.

MIRRORS

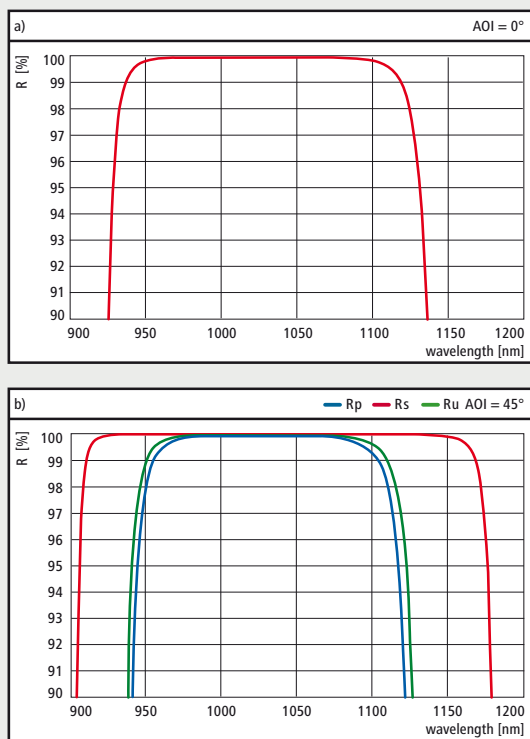


Figure 1: Reflectance spectra of HR mirrors for 1030 nm
a) Cavity mirror b) Turning mirror

Lasers with **extremely high output power** (e.g. >10 kW cw) are often based on Yb:YAG. LAYERTEC has developed different coating designs for handling extraordinarily high fluences. The designs **are optimized either for cw radiation, ns pulses or ps pulses**.

EDGE FILTERS AND PUMP MIRRORS

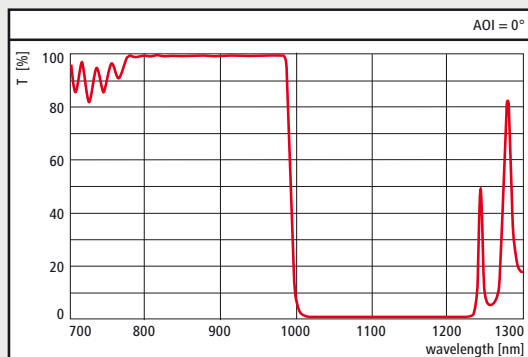


Figure 2: Transmittance spectrum of a steep edge short-wavelength pass filter
HR (0°, 1030 nm) > 99.9 % + R (0°, 808 – 980 nm) < 0.5 %
(back side AR coated)

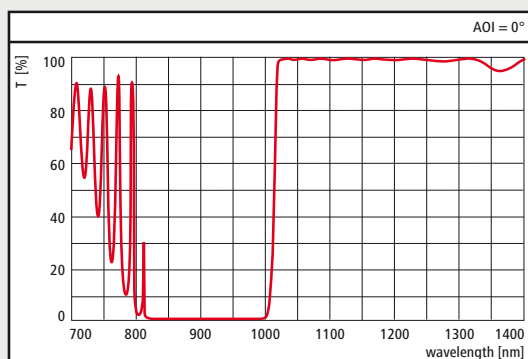


Figure 3: Transmittance spectrum of a steep edge long-wavelength pass filter
HR (0°, 915 – 980 nm) > 99.8 %
+ R (0°, 1030 – 1200 nm) < 3 %
for use as output mirror of a fiber laser (back side AR coated)

Special features:

- Short-wavelength pass filters with a very steep edge which are utilized as a pump mirror for solid-state lasers based on Yb-doped materials (e.g. Yb:YAG, Yb:KGW, Yb-doped fiber).
- Also useful for Nd-doped and Yb-Nd-co-doped materials.

SPECIAL OUTPUT COUPLERS

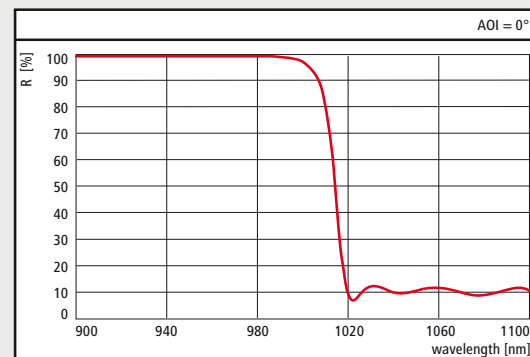


Figure 4: Reflectance spectrum of an output mirror for a fiber laser
HR (0°, 976 – 980 nm) > 99.9 %
+ PR (0°, 1030 – 1100 nm) = 10 % ± 2 %
which blocks the diode radiation at 980 nm and has partial reflectance for 1030 – 1100 nm (back side AR coated)

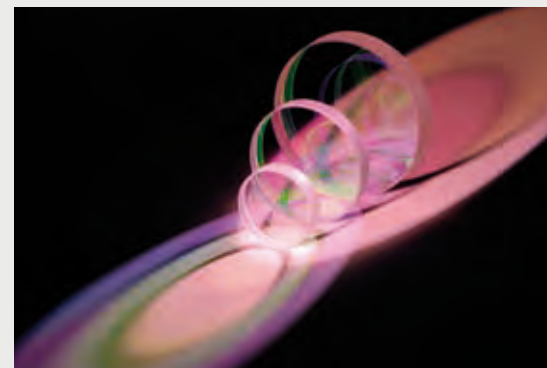
Special features:

- Transmittance $T > 99\%$ at 808 nm – 990 nm, reflectance $R > 99.9\%$ at 1030 nm, i.e. transition from the high transmittance range to the high reflectance range within 4 % of the laser wavelength.
- Environmentally stable.

LIDT - INFO

100 MW / cm², 1064 nm, cw

Measured with a high power fiber laser at Institut für Angewandte Physik, Friedrich-Schiller-Universität Jena



1020 – 1080 nm

THIN FILM POLARIZERS

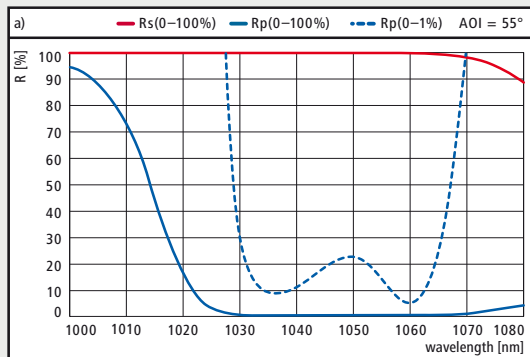


Figure 5a: Reflectance spectra for s- and p-polarized light of a broadband thin film polarizer showing a bandwidth of 25 nm with $R_p < 0.2\%$ ($AOI = 55^\circ$)

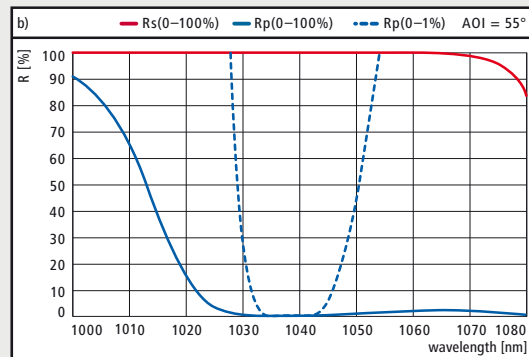


Figure 5b: Reflectance spectra for s- and p-polarized light of a narrow band thin film polarizer which is optimized for very low R_p values and easy angle adjustment for the optimization of the polarizer performance ($AOI = 55^\circ$)

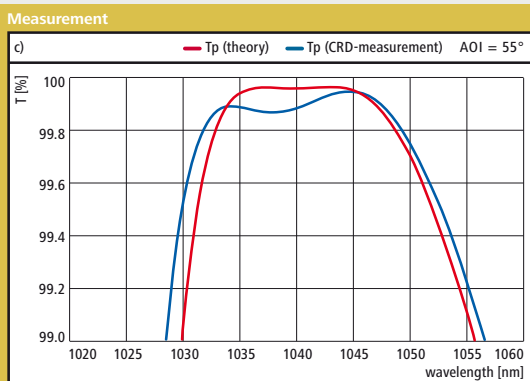


Figure 5c: Calculated and measured transmittance spectra for p-polarized light of a narrow band thin film polarizer according to the design shown in fig. 5b ($AOI = 55^\circ$). $T_p > 99.8\%$ is reached with a bandwidth of 15 nm and $T_p > 99.9\%$ can be achieved within a bandwidth of 5 nm. The spectral position of this transmittance maximum can be adjusted to any wavelength between 1035 nm and 1045 nm by angle adjustment.

Thin film polarizers are key elements for regenerative amplifiers in ns- and ps-lasers. LAYERTEC optimizes its polarizer designs for high laser-induced damage thresholds. Figure 5 shows examples of a broadband polarizer with $R_p(55^\circ) < 0.2\%$ within a bandwidth of 25 nm in the wavelength range of Yb-doped fiber lasers (fig.5a) and a narrow band polarizer which is optimized for very low R_p values

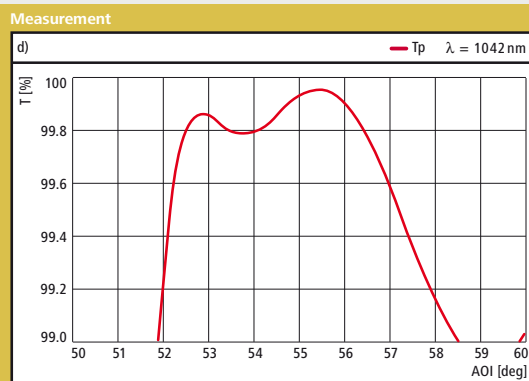


Figure 5d: Transmittance spectrum T_p vs. AOI at 1042 nm measured at the polarizer shown in fig.5c

at a single wavelength (fig.5b). Figure 5c shows a comparison of the calculated transmittance spectrum for p-polarized light and a measurement in a CRD setup. Figure 5d shows T_p vs. AOI for the same polarizer (measured at 1042 nm). These measurements prove that **$T_p > 99.9\%$** can be reached by **angle adjustment**. This is important especially for intra-cavity applications.

PICOSECOND LASERS ON THE BASIS OF Yb-DOPED MATERIALS

Picosecond lasers, i.e. lasers with pulse lengths of some hundred fs to 10 ps, can be built based on Yb:YAG, Yb:KGW and Yb:KYW. These lasers enable materials to be processed without unwanted thermal effects such as melting, which results in unprecedented accuracy of the processes. Moreover, ps lasers do not require chirped pulse amplification which reduces the cost compared to fs lasers. Laser systems with an average power in the kW range are available.

Picosecond laser optics require specially designed optics to achieve high laser damage thresholds. For detailed information please see pages 88 – 89. For GTI mirrors which are often used for pulse compression from the ps range down to a few hundred fs please see pages 96 – 97.

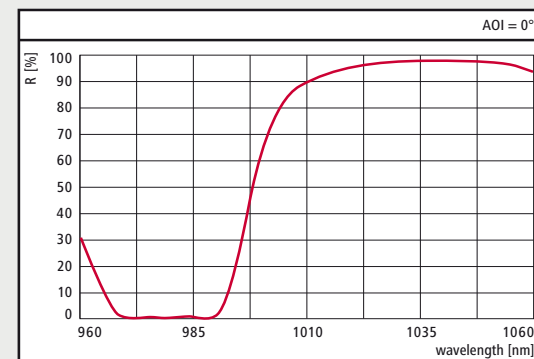


Figure 6: Reflectance spectrum of a special output coupler with high transmittance for the pump radiation:
 $PR(0^\circ, 1040\text{ nm}) = 98\% + R(0^\circ, 975 - 985\text{ nm}) < 2\%$.
 Moreover, this output coupler exhibits $|GDD| < 20\text{ fs}^2$ around 1040 nm

LIDT - INFO

4 - 6 J / cm² depending on design,
 1030 nm, 10 ps, 1 kHz, Ø 50 µm

Measurements were performed by Lidaris Ltd., Lithuania.

COMPONENTS FOR Nd:YAG/Nd:YVO₄ LASERS

CAVITY MIRRORS

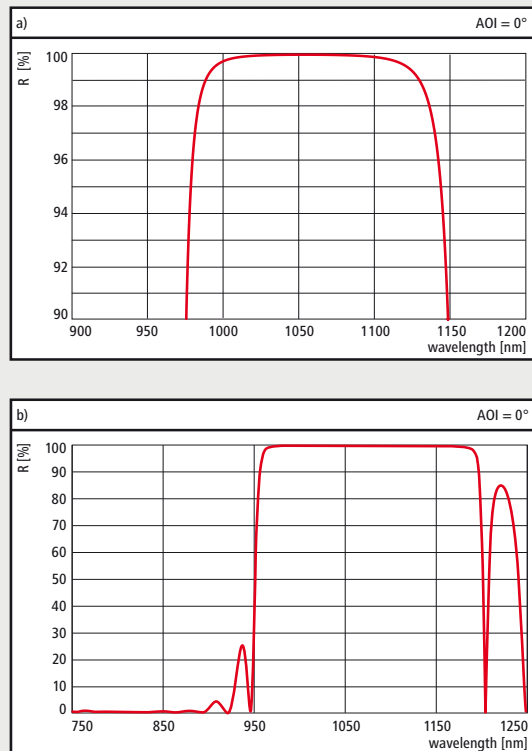


Figure 1: Reflectance spectra of HR mirrors for 1064 nm

- a) High power cavity mirror
b) Pump mirror
HR (0°, 1064 nm) > 99.9 % + R (0°, 808 nm) < 2 %

- HR cavity mirrors with $R > 99.9 \%$.
- Typical reflectance: $R > 99.95 \%$.
- On request, LAYERTEC guarantees $R > 99.99 \%$ (delivery with Cavity Ring-Down measurement report).
- Spectral bandwidth of about 70 nm
- Pump mirrors
HR (0°, 1064 nm) > 99.9 % + R (0°, 808 nm) < 2 %.

TURNING MIRRORS, SEPARATORS AND COMBINERS

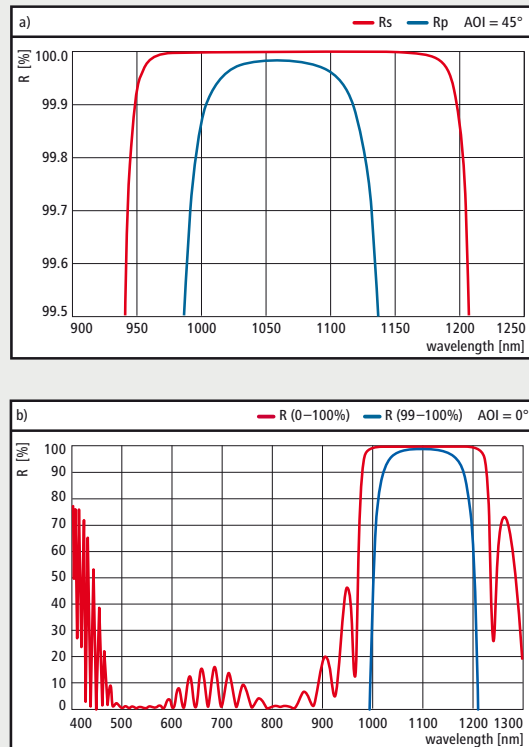


Figure 2: Reflectance spectra of special mirrors for 1064 nm

- a) High power turning mirror
b) Separator for the second harmonic from the fundamental
HR (0°, 1064 nm) > 99.9 % + R (0°, 532 + 808 nm) < 3 %

- HR turning mirrors with $R > 99.9 \%$ for s- and p-polarization.
- Optics for the harmonics of the Nd:YAG /Nd:YVO₄ laser are presented on pages 58 – 63.

ALIGNMENT AND PROCESS MONITORING

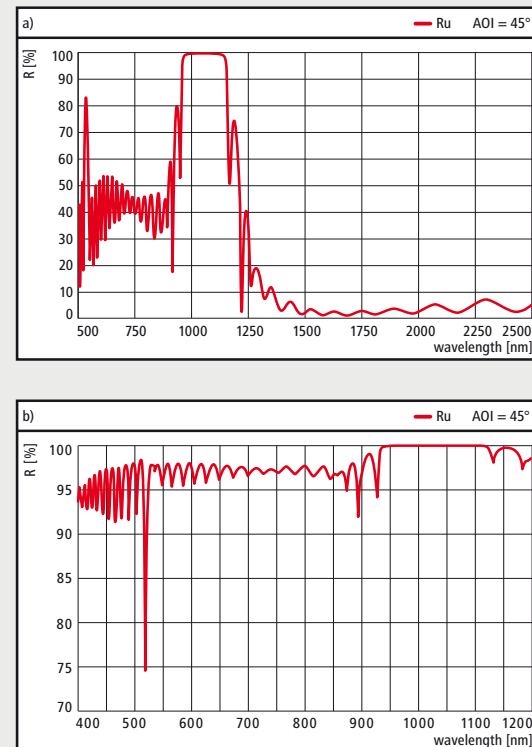


Figure 3: Reflectance spectra of turning mirrors with special features for alignment and process monitoring

- a) Turning mirror for the laser beam with a partial reflector for the alignment laser and high IR transmittance for process monitoring
b) Silver based turning mirror with $R_u(45^\circ, 1064 \text{ nm}) > 99.8 \%$ and with $R_u > 80 \%$ for an alignment laser in the red spectral range

LIDT - INFO

> 50 MW / cm², 1064 nm, cw, 1-on-1
> 50 J / cm², 1064 nm, 10 ns, 1-on-1
> 100 J / cm² on request for 10 ns pulses

1064 nm

THIN FILM POLARIZERS

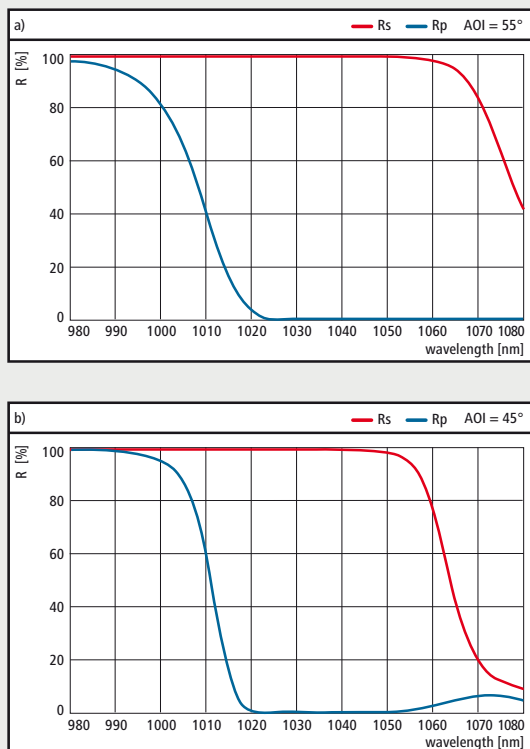


Figure 4: Reflectance spectra of thin film polarizers for 1040 nm

- a) Standard TFP (AOI = 55°)
b) Special TFP (AOI = 45°)

Thin film polarizers working at the Brewster angle exhibit a considerably broader bandwidth than those working at AOI = 45°:

Bandwidth for $T_p/T_s > 1000$

- Standard: AOI = 55° → 40 – 60 nm
- Special: AOI = 45° → 15 – 25 nm

depending on design.

BEAM SPLITTERS AND OUTPUT COUPLERS

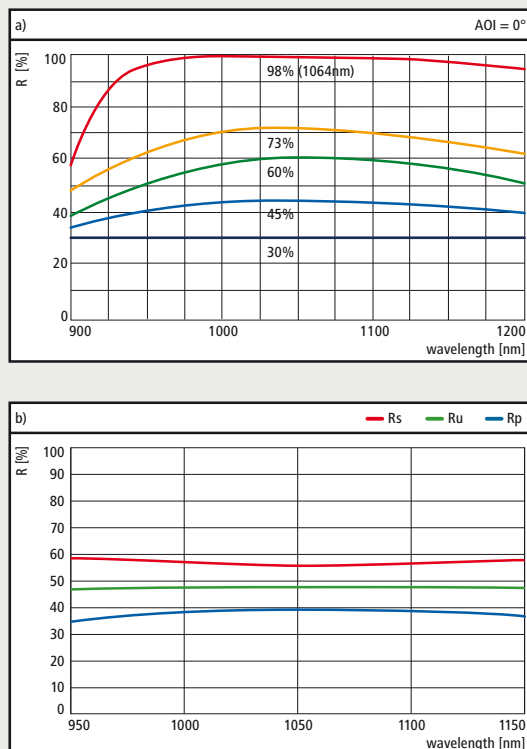


Figure 5: Reflectance spectra of output couplers and beam splitters

- a) Output couplers with different degrees of reflectance
b) Common 50 : 50 beam splitter for unpolarized light

Beam splitters and output couplers can be produced with a precisely adjusted degree of reflectance:

Reflectance	Tolerance
R > 95 %	± 0.5 %
R = 80 % ... 95 %	± 1 %
R = 10 % ... 80 %	± 2 %

NON-POLARIZING BEAM SPLITTERS

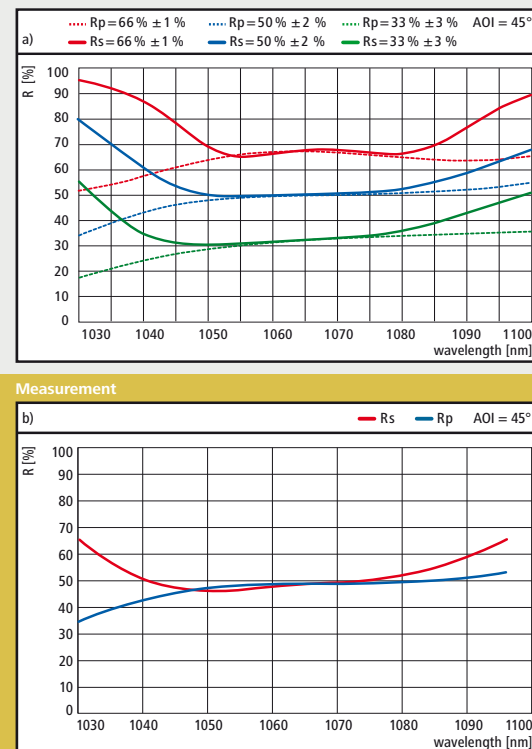


Figure 6: Non-polarizing beam splitters

- a) Calculated reflectance spectra of 3 types of non-polarizing beam splitters for AOI = 45°
b) Measured reflectance spectra of the 50 % beam splitter

- Beam splitters with $R_s \approx R_p$ ($|R_s - R_p| < 1.5 \%$) for AOI = 45° and different degrees of reflectance.
- Common types: $R_{s,p} = 66 \% \pm 1 \%$
 $R_{s,p} = 50 \% \pm 2 \%$
 $R_{s,p} = 33 \% \pm 3 \%$.
- All non-polarizing beam splitters with rear side AR ($R_s \approx R_p \leq 0.6 \%$).

COMPONENTS FOR THE SECOND HARMONIC OF Nd:YAG, Nd:YVO₄ AND Yb:YAG LASERS

The harmonics of Nd:YAG, Nd:YVO₄ and Yb:YAG lasers are widely used for materials processing as well as for measurement applications. Moreover, the second harmonic of these lasers is often used as a pump source for Ti:Sapphire lasers. LAYERTEC offers a variety of optics for 532 nm: dual wavelength mirrors, separators, thin film polarizers and non-polarizing beam splitters, but also cavity optics for compact diode pumped lasers of different configurations. Coatings for 515 nm are available as well. All designs are calculated according to customer specification.

DUAL WAVELENGTH TURNING MIRRORS

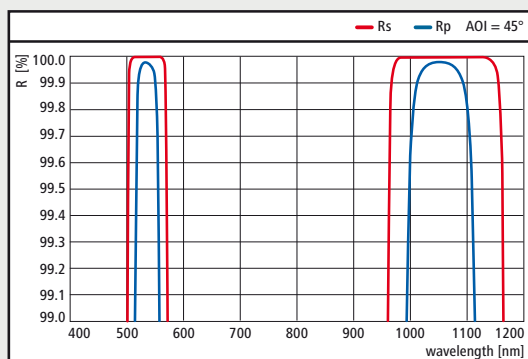


Figure 1: Reflectance spectra of a dual wavelength turning mirror
HRs,p (45°, 532 + 1064 nm) > 99.9 %

DUAL WAVELENGTH CAVITY MIRRORS

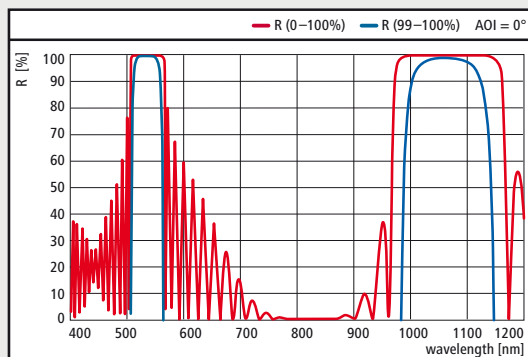


Figure 2: Reflectance spectra of a dual wavelength cavity mirror with high transmittance for the pump wavelength (808 nm)

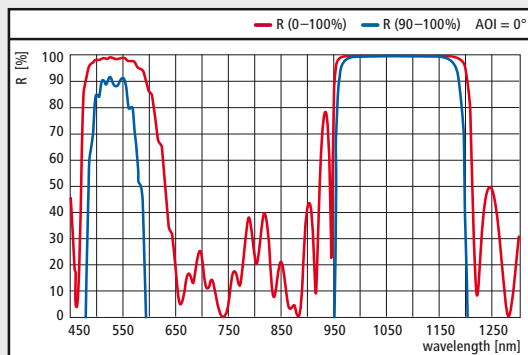


Figure 3: Reflectance spectra of a HR mirror for 1064 nm with additional output coupler for 532 nm:
HR (0°, 1064 nm) > 99.9 %
+ R (0°, 532 nm) = 99 % ± 0.3 %

SEPARATORS FOR THE SECOND HARMONIC AND THE FUNDAMENTAL WAVE

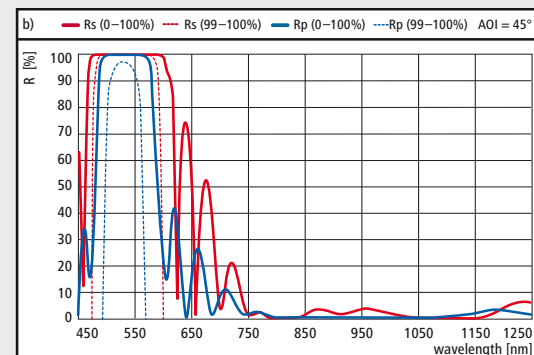
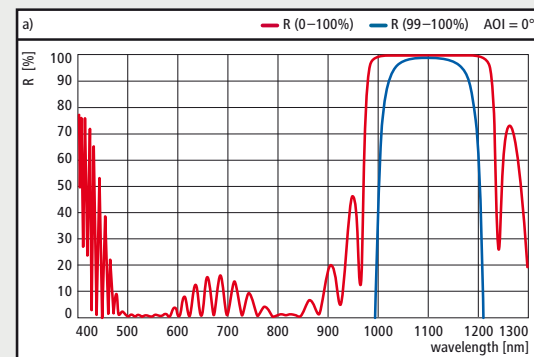


Figure 4: Reflectance spectra of separators for the second harmonic and the fundamental wavelength:
a) HR(0°, 1064 nm) > 99.9 % + R (0°, 532 + 808 nm) < 3 %
b) HRs,p (45°, 532 nm) > 99.9 %
+ Rs,p (45°, 808 + 1064 nm) < 2 %

Separators with different features are available according to customer specifications.

515 nm, 532 nm

THIN FILM POLARIZERS

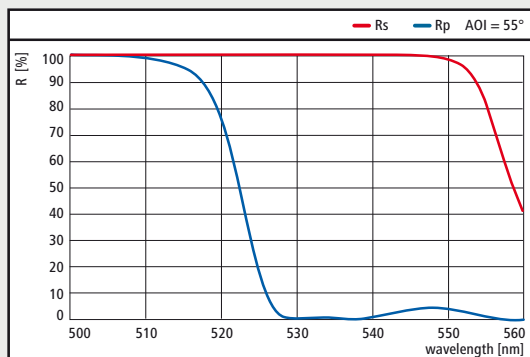


Figure 5: Reflectance spectra of a thin film polarizer for 532 nm

The transmittance of thin film polarizers for p-polarized light can be measured in-house with high accuracy using a modified Cavity Ring-Down setup.

NON-POLARIZING BEAM SPLITTERS

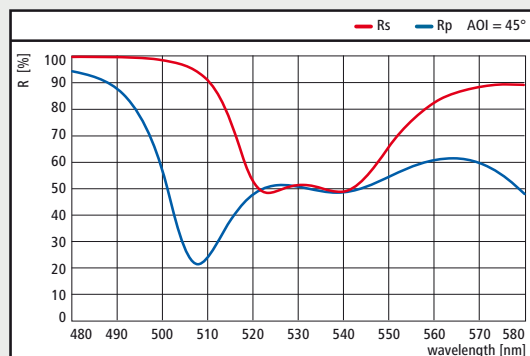


Figure 6: Reflectance spectra of a non-polarizing beam splitter for 532 nm with $R_s = R_p = 50 \pm 2\%$ ($|R_s - R_p| < 3\%$)

COMPONENTS FOR THE SECOND AND THIRD HARMONIC

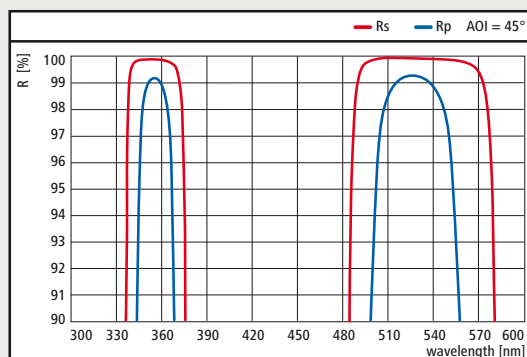
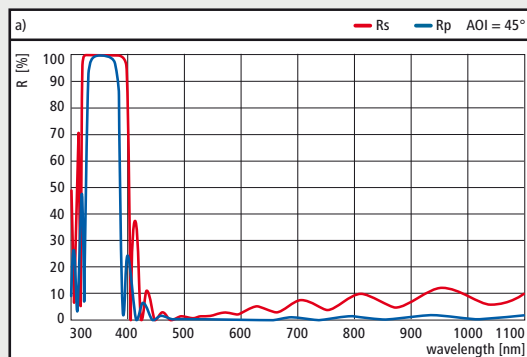


Figure 7: Reflectance spectra of mirrors and separators
a) Separator for the third harmonic and the second harmonic and the fundamental wave
b) Dual wavelength turning mirror for 355 nm and 532 nm

For common specifications of separators for the harmonics in the UV spectral range please see table on page 63. Please do not hesitate to contact us for separators or mirrors with other angles of incidence.

COATINGS ON NONLINEAR OPTICAL CRYSTALS

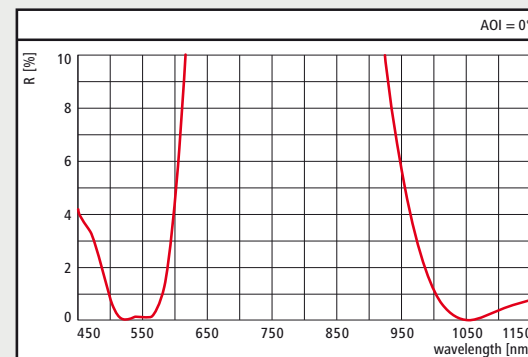


Figure 8: Reflectance spectrum of a dual wavelength antireflection coating on KTP for 532 nm and 1064 nm

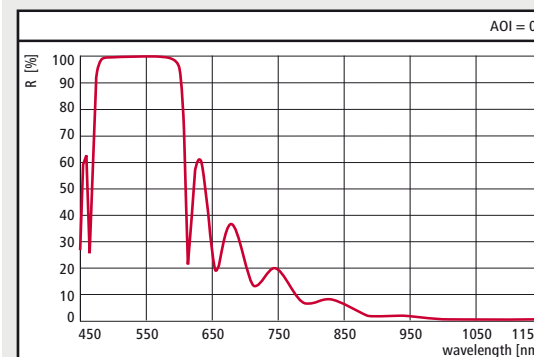


Figure 9: Reflectance spectrum of a dichroic mirror on KTP:
 $HR(0^\circ, 532 \text{ nm}) > 99.98\% + R(0^\circ, 1064 \text{ nm}) < 0.2\%$
optimized for very high transmittance at 1064 nm

Nonlinear optical crystals are the key elements for frequency conversion. LAYERTEC offers a variety of coatings on crystals like KTP and lithium niobate. For more information about coatings on crystals see pages 116 – 117.

COMPONENTS FOR THE THIRD HARMONIC OF Nd:YAG, Nd:YVO₄ AND Yb:YAG LASERS

STANDARD COMPONENTS

The third harmonic of Nd:YAG, Nd:YVO₄ and Yb:YAG lasers has gained importance in the field of materials processing, for measurement applications and as pump source for optical parametric oscillators. LAYERTEC manufactures a wide range of optics for 355 nm: single and multiple wavelength mirrors, separators, thin film polarizers and antireflection coatings. The coating designs shown here are calculated for 355 nm, but designs for 343 nm are available as well. In general, the designs are calculated according to customer specifications.

TURNING MIRRORS

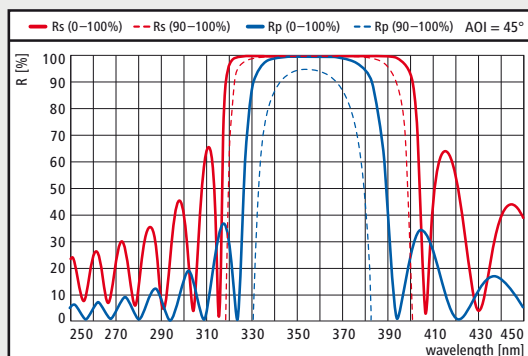


Figure 1: Reflectance spectra of a turning mirror
HRs (45°, 355 nm) > 99.9 %
+ HRp (45°, 355 nm) > 99.5 %

SPECIAL SEPARATORS

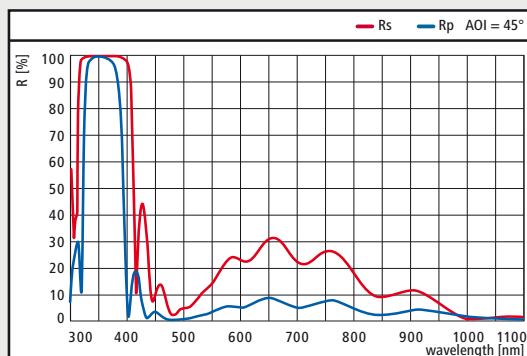


Figure 3: Reflectance spectra of a special separator optimized for low reflectance at 1064 nm:
HRs (45°, 355 nm) > 99.9 % + HRp (45°, 355 nm) > 99.5 %
+ Rp (45°, 532 + 1064 nm) < 2 % + Rs (45°, 532 nm) < 5 %
+ Rs (45°, 1064 nm) < 2 %

WINDOWS AND LENSES

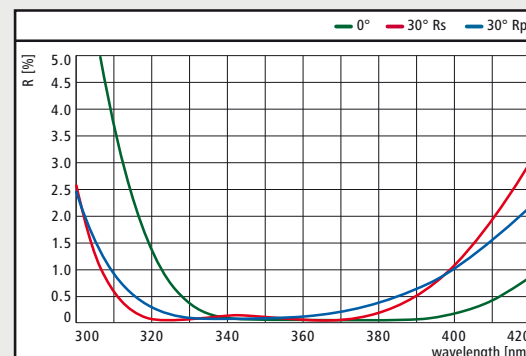


Figure 5: Reflectance spectra of a single wavelength AR coating for 355 nm optimized for AOI = 0°-30°

STANDARD SEPARATORS

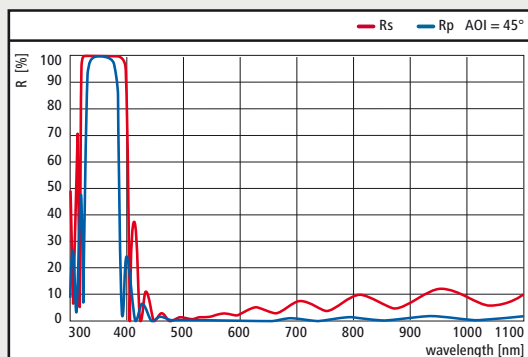


Figure 2: Reflectance spectra of a standard separator reflecting the third harmonic and transmitting the second harmonic and the fundamental wave:
HRs (45°, 355 nm) > 99.9 % + HRp (45°, 355 nm) > 99.5 %
+ Rp (45°, 532 + 1064 nm) < 2 % + Rs (45°, 532 nm) < 5 %
+ Rs (45°, 1064 nm) < 10 %

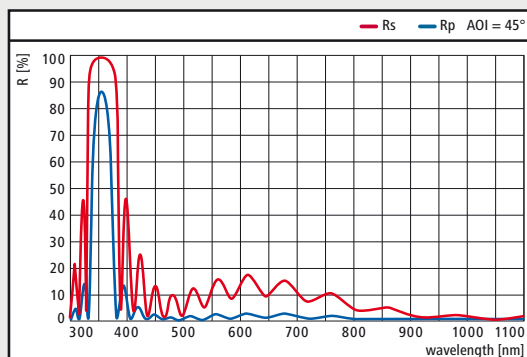


Figure 4: Reflectance spectra of a special separator reflecting the third harmonic and transmitting the second harmonic and the fundamental wavelength:
HRs (45°, 355 nm) > 95 % + Rp (45°, 532 nm) < 2 %
+ Rs,p (45°, 1064 nm) < 2 %; substrate and coatings consist of fluoride materials

Separators based on fluorides show an extended lifetime at high power densities.

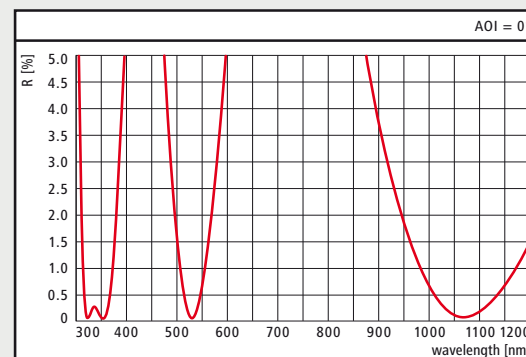


Figure 6: Reflectance spectrum of a triple wavelength antireflection coating on fused silica for 355 nm, 532 nm and 1064 nm

343 nm, 355 nm

SPUTTERED COMPONENTS

MULTIPLE WAVELENGTH MIRRORS

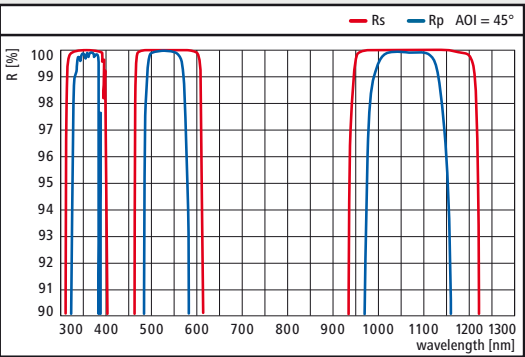


Figure 7: Reflectance spectra of a triple wavelength turning mirror for 355 nm, 532 nm and 1064 nm

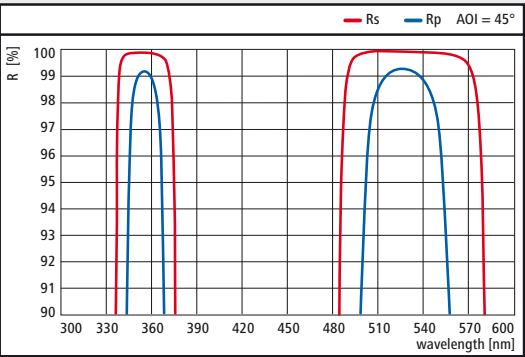


Figure 8: Reflectance spectra of a dual wavelength turning mirror for 355 nm and 532 nm

SEPARATORS WITH HIGH TRANSMITTANCE IN THE UV RANGE

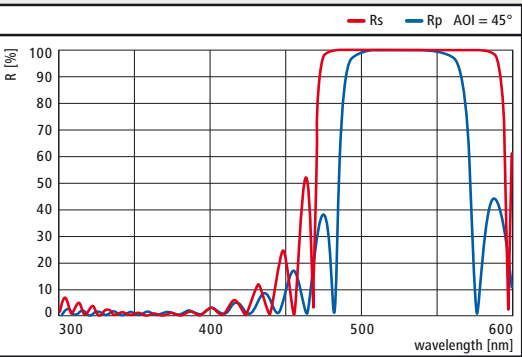


Figure 9: Reflectance spectra of a special separator for the third harmonic and the second harmonic:
HRs,p (45°, 532 nm) > 99.8 % + Rs,p (45°, 355 nm) < 2 %

Due to the low scattering losses of sputtered components a transmittance of $T > 98\%$ is achieved for this type of separators.

THIN FILM POLARIZERS

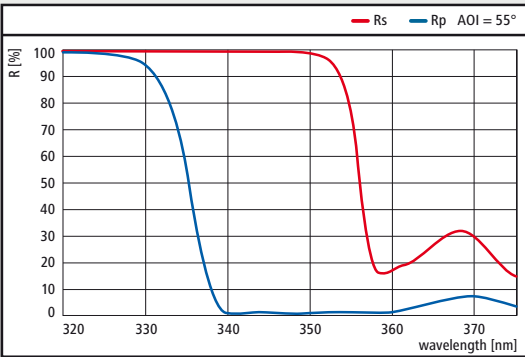


Figure 10: Reflectance spectra of a thin film polarizer for 343 nm:
HRs (55°, 343 nm) > 99.5 % + Rp (55°, 343 nm) < 2 %

The transmittance of p-polarized light can be optimized by angle adjustment. Tilting the polarizer by $\pm 2^\circ$ shifts the minimum of Rp to longer or shorter wavelengths which can improve the polarization ratio significantly.

TECHNICAL DATA OF MIRRORS AND SEPARATORS

Type of coating	Standard	Sputtered
Mirror for AOI = 0°	R > 99.7 %	R > 99.9 %
Turning mirror	Rs > 99.9 %, Rp > 99 %	Rs > 99.95 %, Rp > 99.8 %
Separator AOI = 45°	Rs (355 nm) > 99.9 % Rp (355 nm) > 99 % Rs (532 nm) < 5 % Rp (532 nm) < 2 % Rs (1064 nm) < 10 %, Rp (1064 nm) < 2 %	Rs (355 nm) > 99.9 % Rp (355 nm) > 99.7 % Rs (532 nm) < 2 % Rp (532 nm) < 1 % Rs (1064 nm) < 2 %, Rp (1064 nm) < 1 %

COMPONENTS FOR THE HIGHER HARMONICS OF Nd:YAG AND Nd:YVO₄ LASERS

The harmonics of Nd:YAG and Nd:YVO₄ lasers are widely used for materials processing as well as for measurement applications. LAYERTEC offers a variety of optics utilizing the fourth (266 nm) and fifth (213 nm) harmonic. All designs are calculated according to customer specifications.

MULTIPLE WAVELENGTH MIRRORS

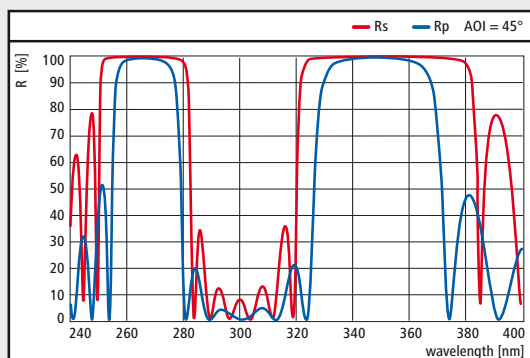


Figure 1: Reflectance spectra of a dual wavelength turning mirror for 266 nm and 355 nm

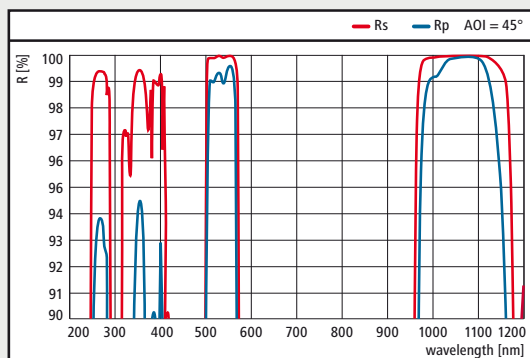


Figure 2: Reflectance spectra of a four wavelength turning mirror:
HRs (45°, 266 nm + 355 nm) > 99 %
+ HRs (45°, 532 nm + 1064 nm) > 99.9 %

SEPARATORS FOR THE FOURTH HARMONIC

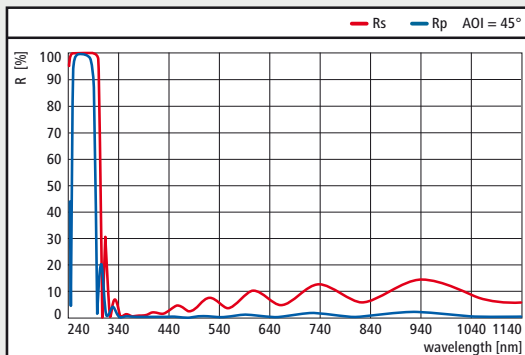


Figure 3: Reflectance spectra of a separator reflecting the fourth harmonic and transmitting the lower harmonics and the fundamental

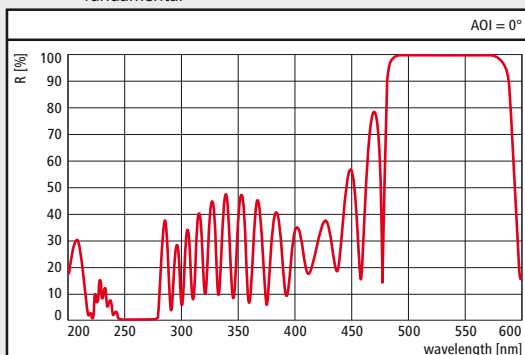


Figure 4: Reflectance spectrum of a special separator for the second harmonic and the fourth harmonic:
HR (0°, 532 nm) > 99.95 % + R (0°, 266 nm) < 5 %

SEPARATORS FOR THE FIFTH HARMONIC

Measurement

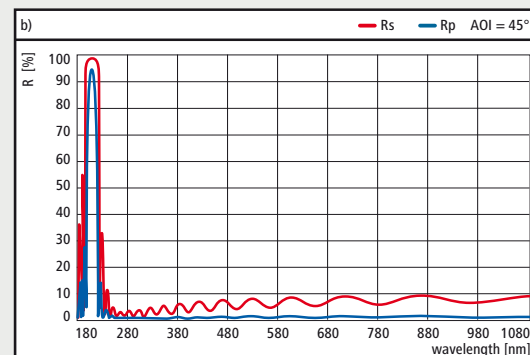
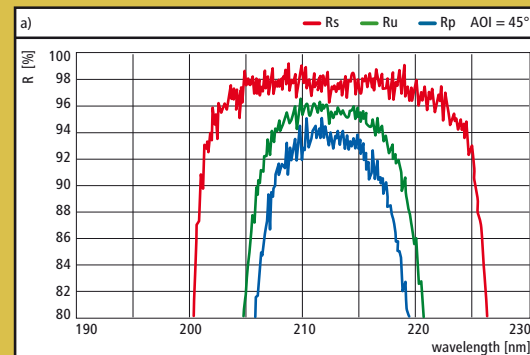


Figure 5: Reflectance spectra of fluoride coatings on CaF₂:
a) Turning mirror for the fifth harmonic (measured spectra)
b) Separator reflecting the fifth harmonic and transmitting the lower harmonics and the fundamental

For high power applications LAYERTEC recommends fluoride coatings on calcium fluoride which are manufactured according to the technology for ArF-excimer laser mirrors.

213 nm, 266 nm

SPECIAL SEPARATORS

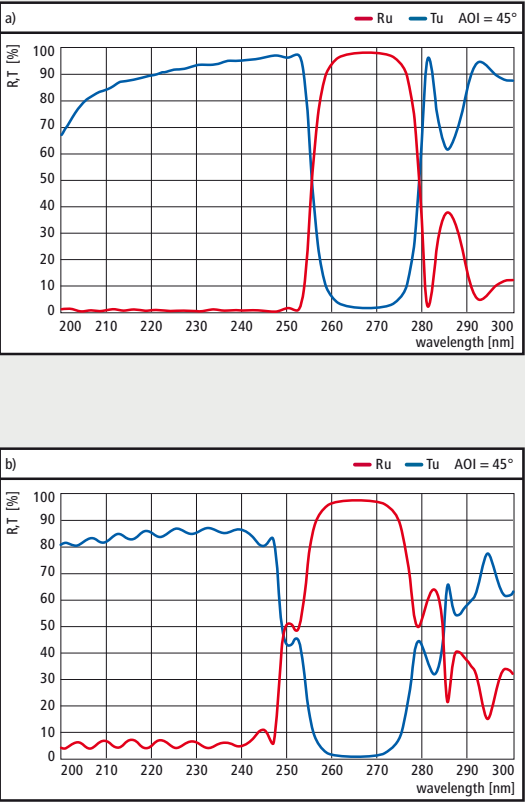


Figure 6: Reflectance spectra of separators for the fourth and fifth harmonics:
HRu (45°, 266 nm) > 98 % + Ru (45°, 213 nm) < 10 % for unpolarized light
a) Oxide coatings optimized for low scattering losses
b) Fluoride coatings for high laser induced damage thresholds

The fifth harmonic at 213 nm is a critical wavelength for oxide coatings because the absorption edge of aluminum oxide begins in this wavelength range. However, aluminum oxide is the only high index oxide material which can be used for 213 nm.
Compared to fluorides, oxide coatings are hard and show low scattering losses. Fluorides exhibit higher LIDT values and extended lifetime for medium and high power applications.

THIN FILM POLARIZERS

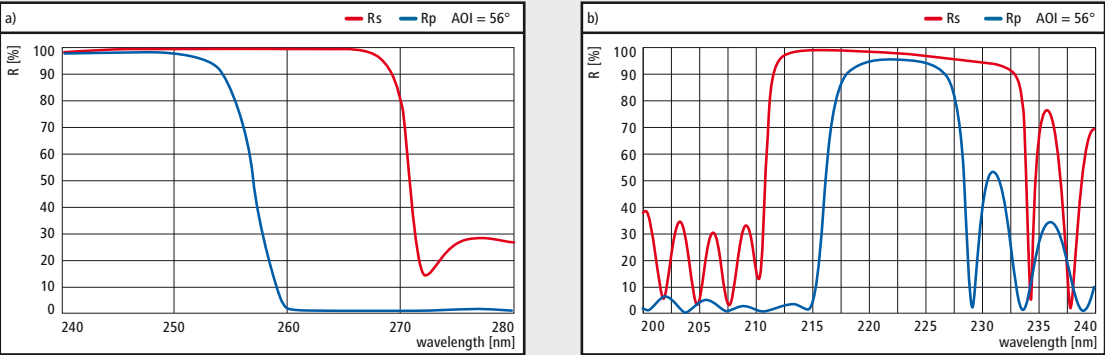


Figure 7: Reflectance spectra of thin film polarizers for 266 nm and 213 nm:
a) HRs (56°, 266 nm) > 98 % + Rp (56°, 266 nm) < 5 %, Tp (56°, 266 nm) ≈ 95 %
b) HRs (56°, 213 nm) > 97 % + Rp (56°, 213 nm) < 5 %, Tp (56°, 213 nm) ≈ 75 %

Sputtering techniques enable LAYERTEC to offer thin film polarizers also for the fourth and fifth harmonic of the Nd:YAG laser.

Common specifications of separators for the harmonics in the UV spectral range:

Separator type	Type	Reflectance at center wavelength [%]		Reflectance at the corresponding longer Nd:YAG wavelengths [%]							
				266 nm		355 nm		532 nm		1064 nm	
		Rs	Rp	Rs	Rp	Rs	Rp	Rs	Rp	Rs	Rp
3 rd harmonic, 355 nm	IAD	> 99.9	> 99.5					< 5	< 2	< 10	< 2
	sputtered	> 99.9	> 99.8					< 2	< 1	< 2	< 1
4 th harmonic, 266 nm	IAD	> 99.7	> 99.4			< 5	< 2	< 10	< 2	< 10	< 2
	sputtered	> 99.8	> 99.5			< 5	< 1	< 2	< 1	< 2	< 1
5 th harmonic, 213 nm*	evaporated	> 97	> 93	< 5	< 2	< 10	< 2	< 10	< 2	< 10	< 2

Table 1: Common specifications of separators for the harmonics in the UV
*Fluoride coating on CaF₂

COMPONENTS FOR WEAK Nd:YAG OR Nd:YVO₄ LASER LINES

Neodymium doped crystals exhibit laser transitions at different wavelengths. Tables 1 and 2 give an overview about the laser wavelengths of the most common Nd-doped materials Nd:YAG and Nd:YVO₄.

Nd:YAG	
Laser lines	Second harmonic
946 nm	473 nm
1064 nm	532 nm
1123 nm	561 nm
1319 nm	659 nm

Table 1: Laser lines and corresponding wavelengths of the second harmonic of Nd:YAG

Nd:YVO ₄	
Laser lines	Second harmonic
915 nm	457 nm
1064 nm	532 nm
1340 nm	670 nm

Table 2: Laser lines and corresponding wavelengths of the second harmonic of Nd:YVO₄

A variety of laser lines in the VIS and NIR can be obtained from these crystals. This process is utilized to build compact diode pumped solid state lasers with a variety of wavelengths which are used for measurement applications as well as for projection systems (RGB lasers).

The strongest laser transition in both materials is the 1064 nm line. Efficient laser radiation at other wavelengths is only possible by suppressing this line. LAYERTEC offers a variety of laser mirrors for this application.

Compact laser designs also include the pump diode (808 nm) and a unit for the second harmonic generation. This is the reason why coatings for Nd:YAG or Nd:YVO₄ wavelengths apart from 1064 nm mostly show several spectral regions of high transmittance as well as high reflection. All coatings are designed according to customer specifications, because the specifications depend on the laser design. All examples on these pages are for Nd:YAG wavelengths. Coatings for Nd:YVO₄ can be designed and produced as well.

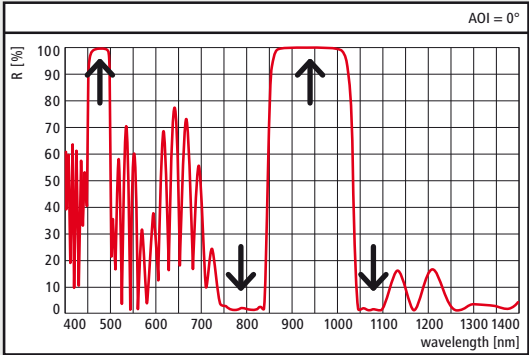


Figure 1: Reflectance spectrum of a dual wavelength mirror for a weak laser line and its second harmonic with high transmittance for the pump wavelength and the strongest laser line: HR (0°, 473 nm) > 99.85 %
+ HR (0°, 946 nm) > 99.95 %
+ R (0°, 808 nm) < 2 %
+ R (0°, 1064 nm) < 5 %

Feature	Reflectance
Suppression of the strongest laser line	R (0°, 1064 nm) < 5 %
HR mirror for the weak laser line	R (0°, 946 nm) > 99.95 %
High transmittance for the pump wavelength	R (0°, 808 nm) < 2 %
HR mirror for the second harmonic of the weak laser line	HR (0°, 473 nm) > 99.85 %

915 nm, 946 nm, 1123 nm, 1340 nm

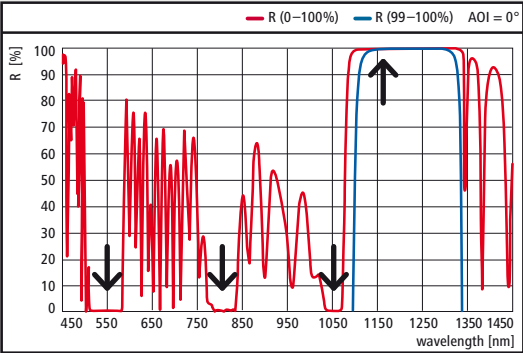


Figure 2: Reflectance spectrum of a dichroic mirror with high transmittance for the pump wavelength which also suppresses the 1064 nm line:
HR (0°, 1123 nm) > 99.9 %
+ R (0°, 561 nm) < 2 %
+ R (0°, 808 nm) < 10 %
+ R (0°, 1064 nm) < 50 %

Feature	Reflectance
HR mirror for the weak laser line	HR(0°, 1123 nm) > 99.9 %
Suppression of the strongest laser line	R(0°, 1064 nm) < 50 %
High transmittance for the pump wavelength	R(0°, 808 nm) < 10 %
High transmittance for the second harmonic of the weak laser line	R(0°, 561 nm) < 2 %

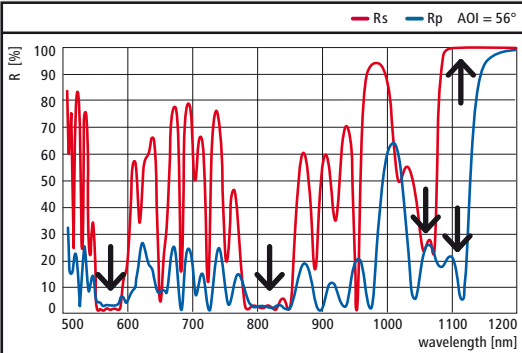


Figure 3: Reflectance spectra of a thin film polarizer with high transmittance for the pump wavelength and the second harmonic which also suppresses the 1064 nm line:
HRs (56°, 1123 nm) > 99.9 %
+ Rp (56°, 1123 nm) < 50 %
+ Rs,p (56°, 561 nm + 808 nm) < 10 %
+ Rs,p (56°, 1064 nm) < 50 %

Feature	Reflectance
HR for s-polarized light of the weak laser line	HRs (56°, 1123 nm) > 99.9 %
Suppression of p-polarized light of the weak laser line	Rp (56°, 1123 nm) < 50 %
Suppression of the strongest laser line	Rs,p (56°, 1064 nm) < 50 %
High transmittance for the pump wavelength	Rs,p (56°, 808 nm) < 10 %
High transmittance for the second harmonic of the weak laser line	Rs,p (56°, 561 nm) < 10 %

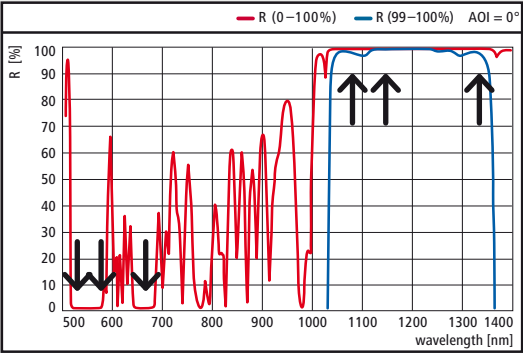


Figure 4: Reflectance spectrum of a dichroic mirror with high reflectance for the NIR wavelengths and high transmittance for the corresponding second harmonic wavelengths:
HR (0°, 1064 nm + 1123 nm + 1319 nm) > 99.9 %
+ R (0°, 532 - 561 nm + 659 nm) < 2 %

Feature	Reflectance
Broadband HR mirror for several laser lines	HR (0°, 1064 nm + 1123 nm + 1319 nm) > 99.9 %
High transmittance for the second harmonics of these laser lines	R (0°, 532 - 561 nm + 659 nm) < 2 %

COMPONENTS FOR Ho:YAG AND Tm:YAG LASERS

Ho:YAG and Tm:YAG lasers emitting at wavelengths of 2010 nm and 2100 nm are widely used for medical applications. LAYERTEC offers optical coatings for this wavelength range with high laser-induced damage thresholds and long lifetimes.

CAVITY MIRRORS

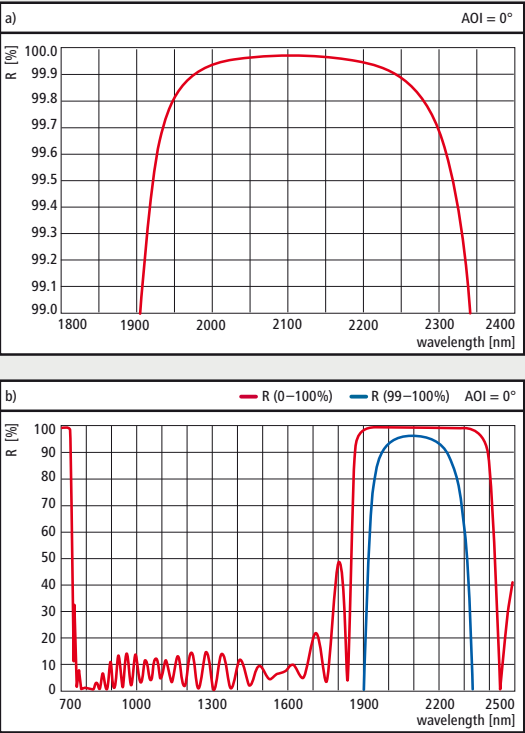


Figure 1: Reflectance spectra of cavity mirrors
a) HR cavity mirror
b) Pump mirror with high transmittance around 808 nm.

- HR cavity and pump mirrors with $R > 99.9\%$.
- High laser-induced damage thresholds.

TURNING MIRRORS

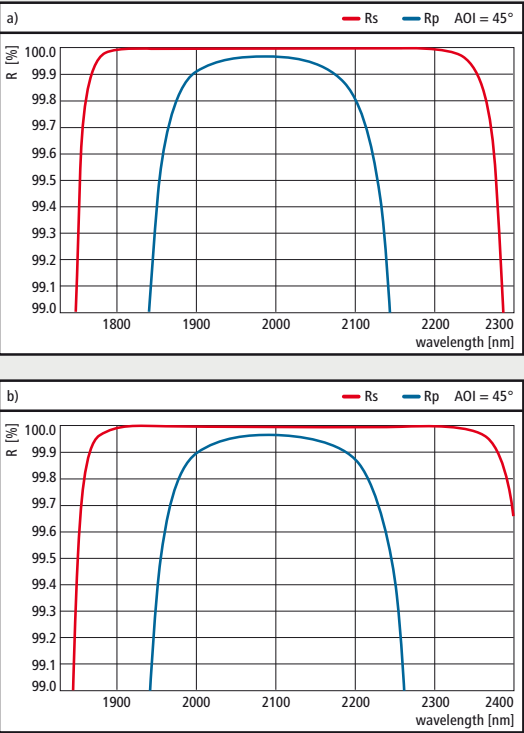


Figure 2: Reflectance spectra of turning mirrors for
a) 2010 nm
b) 2100 nm

The coating materials are chosen to guarantee high laser-induced damage thresholds. To achieve the maximum reflectance for p-polarized light, mirrors should be specified for either 2010 nm or 2100 nm.

- Turning mirrors with $R > 99.9\%$ for s-polarized light and $R > 99.8\%$ for p-polarized light at $\text{AOI} = 45^\circ$.
- High laser-induced damage thresholds.

OUTPUT COUPLERS

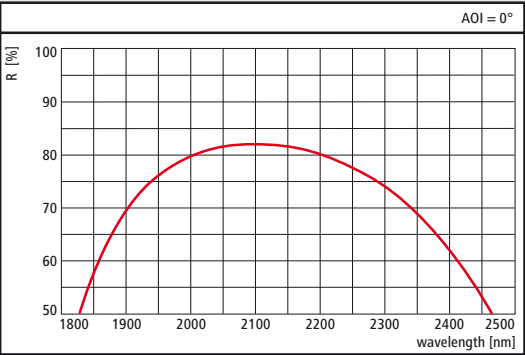
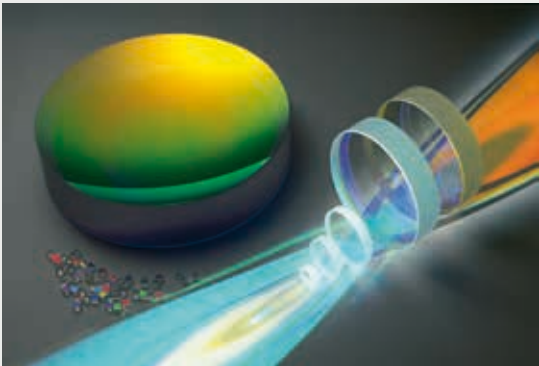


Figure 3: Reflectance spectrum of an output coupler with
 $R = 82\% \pm 1\%$ at 2100 nm

Output couplers with precisely adjusted degrees of reflectance:

Reflectance	Tolerance
$R > 95\%$	$\pm 0.5\%$
$R = 80 \dots 95\%$	$\pm 1\%$
$R = 10\% \dots 80\%$	$\pm 2\%$



2010 nm, 2100 nm

EDGE FILTERS

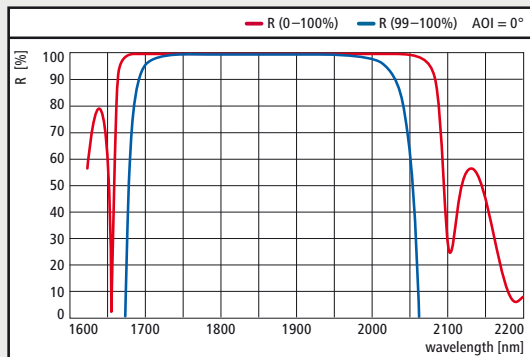


Figure 4: Reflectance spectra of a cavity mirror for 2010 nm suppressing the 2100 nm line

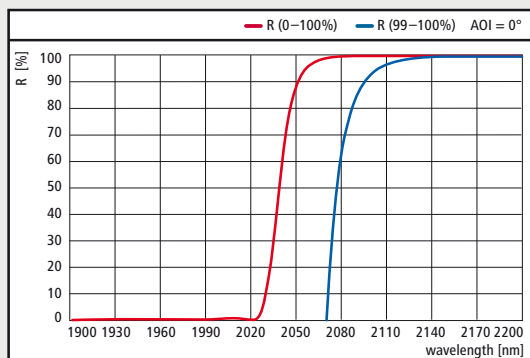


Figure 5: Reflectance spectra of a steep edge filter for the separation of the 2010 nm and 2100 nm lines

THIN FILM POLARIZERS

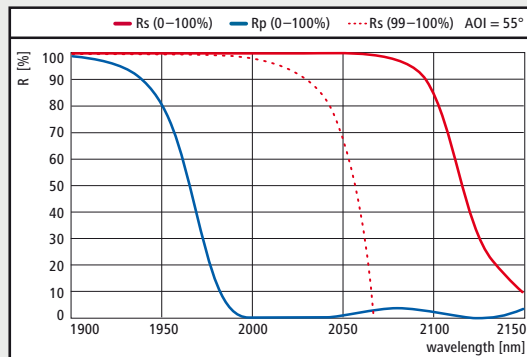


Figure 6: Reflectance spectra of a thin film polarizer for 2010 nm ($R_s > 99.8\%$, $R_p < 2\%$, $\text{AOI} = 55^\circ$)

- Separation of the s- and p-polarized component of the light (s-polarized light is reflected and p-polarized light is transmitted).
- Thin film polarizers designed at Brewster angle ($\approx 55^\circ$) exhibit a higher T_p / T_s ratio and a considerably broader bandwidth than those at $\text{AOI} = 45^\circ$.

- Lens materials according to customer specifications.
- Infrasil®, sapphire and undoped YAG can be used.
- Special AR coatings for high index materials such as GGG on request.

WINDOWS AND LENSES

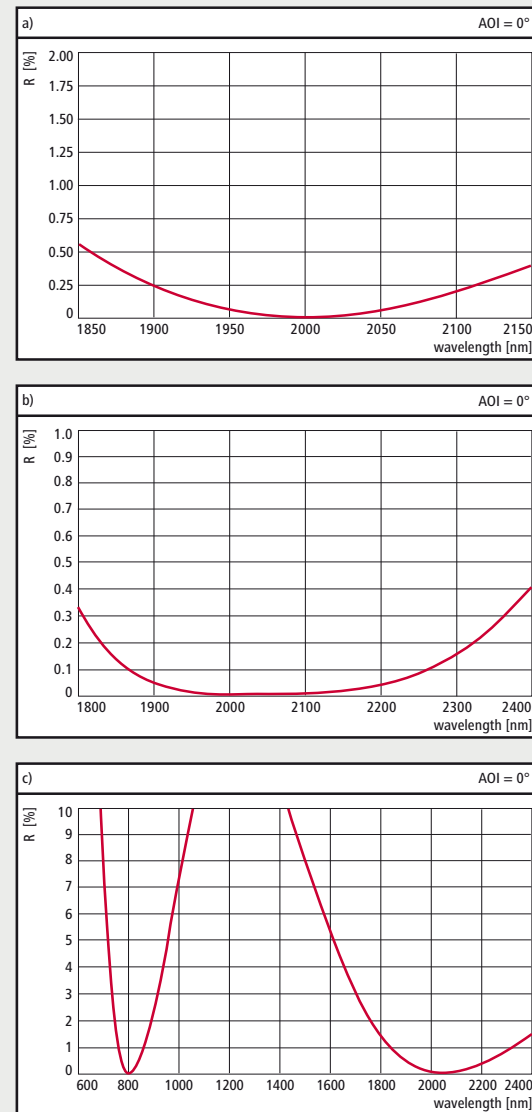


Figure 7: Reflectance spectra of typical antireflection coatings:
a) Single wavelength AR coating for 2010 nm
b) Broadband AR coating 2010 nm - 2100 nm
c) Dual wavelength AR coating for the pump and laser wavelength (808 nm + 2010 nm)

COMPONENTS FOR Er:YAG LASERS AND THE 3 μm REGION

Er:YAG lasers are widely used in medical applications, especially in dermatology, due to the high absorption coefficient of water for 2940 nm radiation. This makes surgical applications easier but is also a challenge for the optical coatings which must be completely free of water. Coatings produced by magnetron sputtering have proved to be ideal for this kind of application.

CAVITY MIRRORS

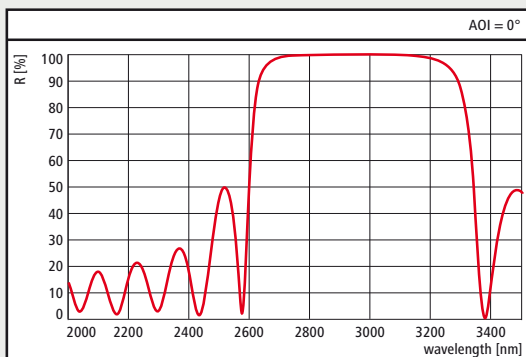


Figure 1: Reflectance spectrum of a HR cavity mirror
HR (0°, 2940 nm) > 99.8 %

PUMP MIRRORS

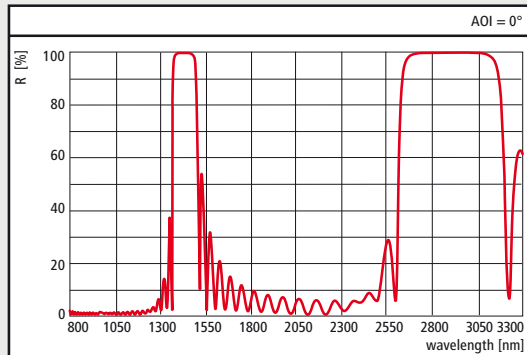


Figure 2: Reflectance spectrum of a HR cavity mirror with a HT region
between 800 nm and 1100 nm

- Reflectance of cavity mirrors and pump mirrors: $R > 99.9\%$ at $\text{AOI} = 0^\circ$.
- Pump mirrors with high transmittance between 800 nm and 1100 nm for pumping with a Nd:YAG laser or a diode laser.

TURNING MIRRORS

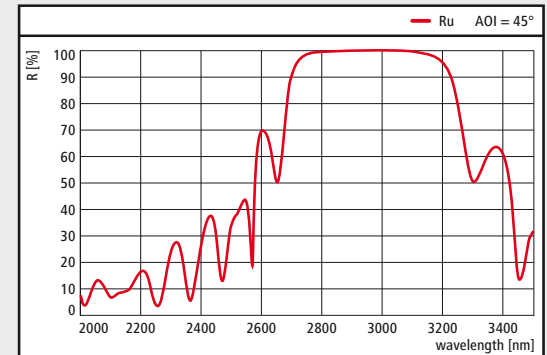


Figure 3: Reflectance spectrum of a turning mirror for unpolarized
light

- Reflectance of turning mirrors: $R > 99.8\%$ at $\text{AOI} = 45^\circ$ for unpolarized light.

LIDT - INFO

400 J / cm², 2940 nm, 400 μs



2940 nm

BEAM COMBINERS AND ALIGNMENT LASER MIRRORS

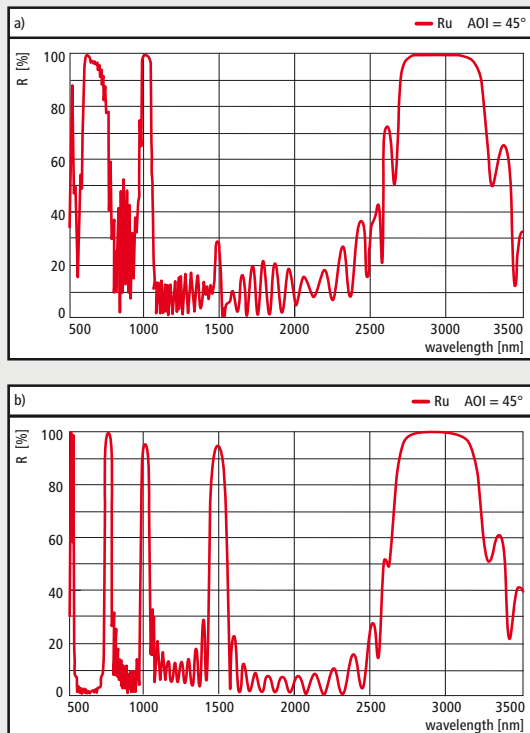


Figure 4: Reflectance spectra of beam steering mirrors
a) Dual wavelength turning mirror
b) Separator/combiner
for 2940 nm and an alignment laser between 630 nm and 655 nm

- Designs for beam splitters and alignment laser mirrors are calculated according to customer specifications.

OUTPUT COUPLERS AND LENSES

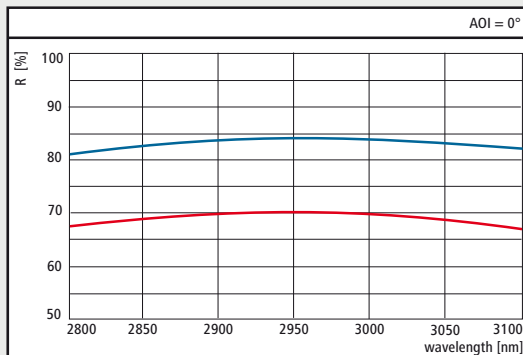


Figure 5: Reflectance spectra of output couplers with
 $R = 70\% \pm 1\%$ and $R = 84\% \pm 1\%$

- Output couplers with precisely adjusted degrees of reflectance (tolerances of $\pm 1\%$ at reflectance values between 70 % and 90 %).

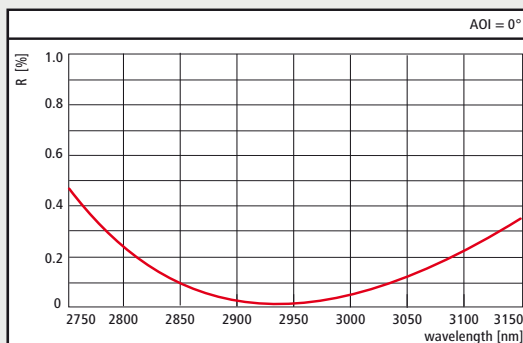


Figure 6: Reflectance spectrum of an antireflection coating for
2.94 μm on sapphire

- AR coatings with residual reflectance of $R < 0.2\%$ on the back side of output couplers as well as on lenses and windows.
- Infrasil®, sapphire and undoped YAG can be used (for substrate materials see pages 20 – 21).

COMPONENTS FOR OTHER LASERS AROUND 3 μm

The strong absorption of water in the wavelength range of 2.6 – 3.4 μm is the fundamental effect which is commonly used for medical laser applications. Between 2.6 μm and 2.8 μm the absorption of water is even stronger than at 2.94 μm (Er:YAG laser) making lasers that work in this wavelength range (e.g. the Er:Cr:YSGG laser) promising candidates for future applications.

However, the strong absorption of water is also the most serious problem with respect to laser damage. Therefore, it is essential to keep the layer system free of water. LAYERTEC uses magnetron sputtering for the production of coatings for the 3 μm region. The high atomic density of sputtered layers, which is close to that of bulk material, suppresses the diffusion of water into the layer systems.

This enables LAYERTEC to offer coatings for the critical 2.6 – 2.8 μm region. As an example, figure 7 shows a dielectric HR mirror centered at 2.8 μm with reflectance $R > 99.7\%$.

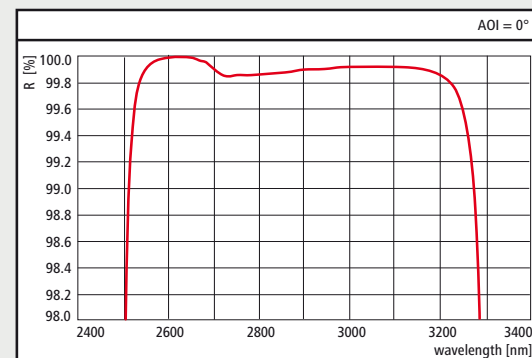


Figure 7: Reflectance spectrum of a HR mirror for 2.8 μm with
 $R > 99.7\%$

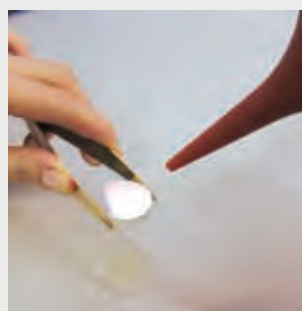
CLEANING OF OPTICAL SURFACES



1

Prerequisites:

- An air blower
- Optical cleaning tissue (e.g. Whatman®)
- Nonslip tweezers (e.g. with cork)
- Spectroscopy grade acetone*



2

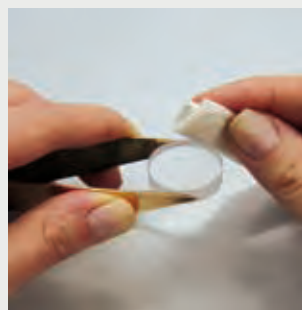
Pre-cleaning:

- Clean hands with soap or use clean gloves (latex, nitrile)
- Blow off dust from all sides of the sample (2)



3

- Moisten tissue with acetone (3)
- Remove coarse dirt from the edge and the chamfer (4)



4

* Compared to alcohol acetone is the better solvent as it significantly reduces the formation of streaks



5

Preparation of the cleaning tissue:

- Fold a new tissue along the long side several times (5, 6)
- Fold across until you have a round edge (7)
- Grab the tissue as shown in (8)



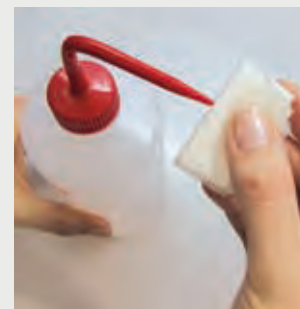
6



7



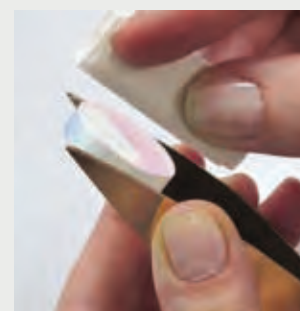
8



9

Cleaning of the optical surface:

- Moisten the tissue with acetone (9)
- A wet tissue will result in streaks
- Hold the sample with tweezers (10)
- Slide the curved tissue from one edge of the sample to the other **once** (10 ... 12)
- The tissue may be turned inside out and used again once
- Repeat steps 9 ... 12 with a new tissue until the sample is clean



10

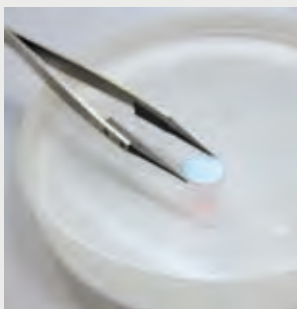


11



12

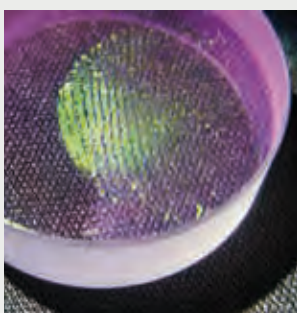
HINTS



13

Small samples:

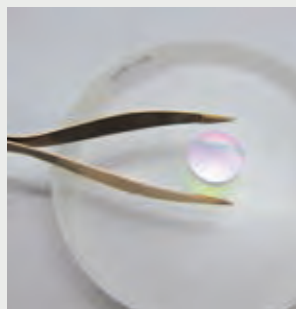
- Put sample onto a concave polished glass support to pick it up easily (13)
- Use special tweezers



14

Fingerprints on sputtered coatings (14):

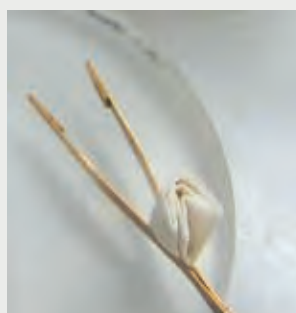
- Moisten the surface by breathing upon it
- Slide (acetone) moistened tissue over the surface as long as the water film is visible
- Exception: Never do this with hygroscopic materials (CaF_2 ...)



15

Storage:

- It works best to store the samples on a polished curved glass support (15)
- Clean the support like an optical surface before use



16

Holding the tissue:

- Use the tweezers to hold the moistened tissue (16)



17

Cleaning of concave surfaces:

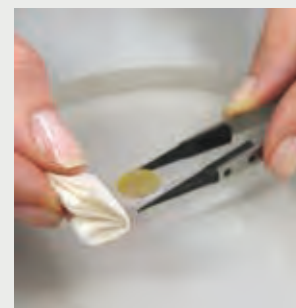
- Use a less often folded tissue that can be slidably bent (17)
- Clean analog to (9) ... (12)
- Use your thumb to gently press the tissue onto the curved surface (18, 19)
- Use tissue only one time
- A concave support helps holding the sample (20)



18



19



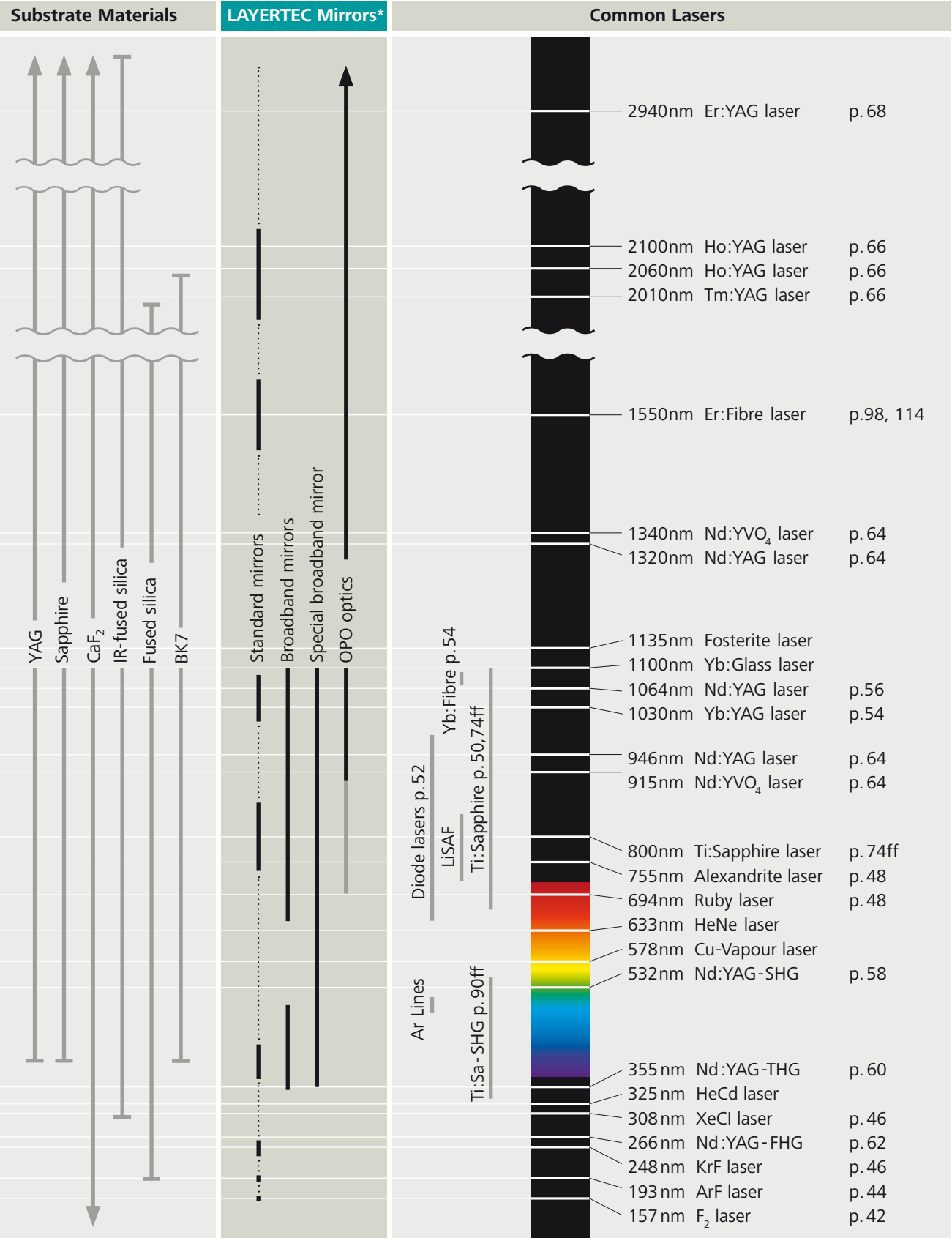
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*Bandwidths of selected LAYERTEC mirrors

Interference Optics

A detailed photograph of a peacock with its tail feathers fanned out. The feathers display a variety of iridescent colors, including deep blues, greens, and oranges, with prominent 'eye' patterns. The peacock's head is turned slightly to the right, showing its blue crest and white stripe around its eye.

The plumage colors of peacock feathers result from interference effects. These effects are also the working principle of optical coatings.

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