# CONTENTS

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# INTRODUCTION TO CONTINUOUS WAVE AND NANOSECOND LASER OPTICS

Most of the lasers which are used in research and industry work either in the continuous wave (cw) mode or with ms, µs ("quasi cw") and ns pulses (Q-switch).
The basis for nearly all optical components for these lasers is the quarter wave stack, i.e. a stack of alternating layers of high and low refractive index having the same optical thickness, sometimes modified to a certain extend to achieve special effects such as regions of high transmission apart from the reflectance band. Also partial reflectors consist mainly of quarter wave stacks which are modified to reach the desired reflectance as exact as possible. Coatings for cw and ns lasers are characterized by:

- Reflectance and transmittance
- Optical losses (straylight and absorption)
- Laser induced damage threshold

Sputtered optical coatings for the VIS and NIR exhibit extremely low straylight and absorption losses (both in the order of some $10^{-5}$ ... $10^{-4}$). This has been confirmed by direct measurements of straylight and absorption as well as by highly accurate reflectivity measurements (e.g. by cavity ring down spectroscopy). The reflectance of HR mirrors or the sum of reflectance and transmittance of partial reflectors produced by magnetron sputtering is well above 99.9%. Evaporated coatings show straylight losses in the order of some $10^{-3}$ in the VIS-NIR region and in the order of some $10^{-3}$ ... $10^{-2}$ in the UV depending on the wavelength and on the materials used. This results in reflectances of 99.5 ... 99.7% in the VIS and NIR while reflectances between 99 ... 99.5% are reached in the UV. Below 200nm the reflectances are lower (R>96% at 193nm, R>92% at 157nm).

Damage in cw and ns laser optics is mainly related to thermal effects such as increased absorption – either intrinsic absorption in the coating materials or absorption by defects – or poor thermal conductivity and low melting temperatures of the coatings. High power coatings require both the controlling of the intrinsic properties of the coating materials and the reduction of defects in the layers.
The determination of the laser induced damage threshold (LIDT) according to the standards ISO 11254-1 (cw-LIDT and 1 on 1-LIDT, i.e. single pulse LIDT), ISO 11254-2 (S on 1, i.e. multiple pulse LIDT) and ISO 11254-3 (LIDT for a certain number of pulses) requires laser systems operating in single modes, precise beam diagnostics as well as online and offline damage detection systems. This is the reason, why only a limited number of measurement systems with only a few types of lasers is available (e.g. for 1064nm at Laserzentrum Hannover). For some of the most prominent laser wavelengths such as e.g. the second harmonic of the Nd:YAG laser (532nm), there´s no measurement system available and no certified LIDT data can be provided.
The 1 on 1-LIDT (i.e. 1 pulse on 1 site of the sample) is not representative for the normal operation conditions. However, these values can be used for comparison of different coatings and for optimization procedures. Moreover, the 1 on 1 values are directly related to the more practical S on 1-LIDT (LIDT for a given number "S" of pulses on the same location of the sample) and can be interpreted as upper limit of the LIDT. Laser systems with high repetition rates (some kHz) require lifetime tests expressed by LIDT values for high numbers of pulses.
The limited number of measurement facilities and the need for lifetime tests for practical applications make it necessary to include also measurements, lifetime tests or cumulative irradiation tests of several customers into this catalog. Please take into account that these values cannot be compared with an LIDT measurement, because the laser parameters given there are those without damage. Moreover, there´s always an uncertainty of these values, especially with respect to the determination of the spot size. Thus, errors in the order of about 30% must be taken into account. Nevertheless, we think that information on parameters of successful operation of our optics will certainly help to decide to use LAYERTEC optics. Sometimes, however, tests at the customers laser system will be necessary. LAYERTEC supports such tests at the customers facility by a considerable discount for the test pieces.

# MIRRORS, OUTPUT COUPLERS AND LENSES

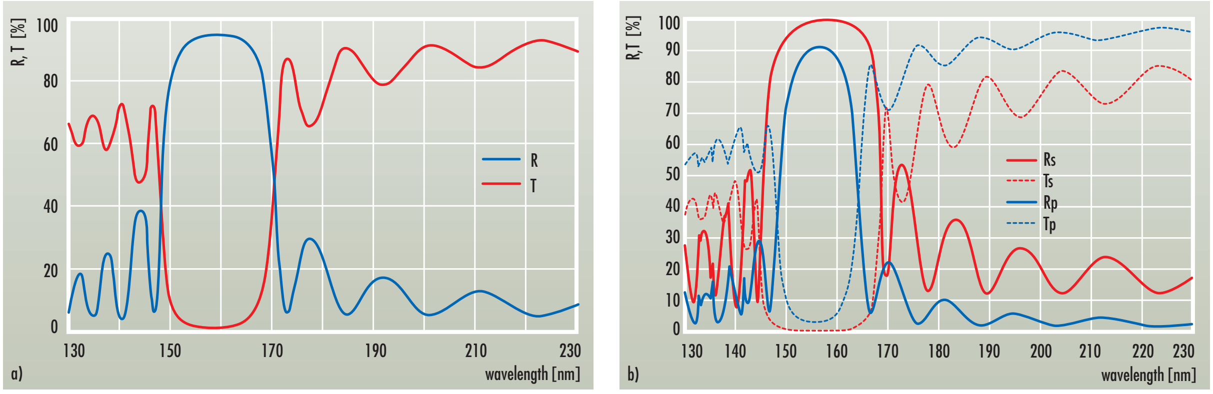


**Figure 1:** Measured reflectance and transmittance spectra of a laser mirror (AOI=0°, a) and a turning mirror (AOI=45°, b) for 157nm

- Laser mirrors: R = 92 ... 95% at AOI = 0°
- Turning mirrors (AOI = 45°) : Rs > 97 %
  Rp > 90 %
  Rr > 92 %
- High quality mirror substrates, windows and lenses of $CaF_2$ (157nm excimer grade quality, SCHOTT-LITHOTEC)
- 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 as beamsplitters and variable attenuators on request

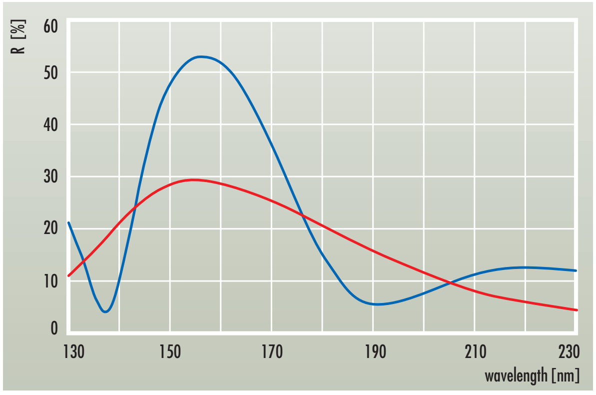


**Figure 2:** Measured reflectance spectra of standard output couplers with R = 50 ± 3% and R=25±2% (rear side uncoated)

# VARIABLE ATTENUATORS

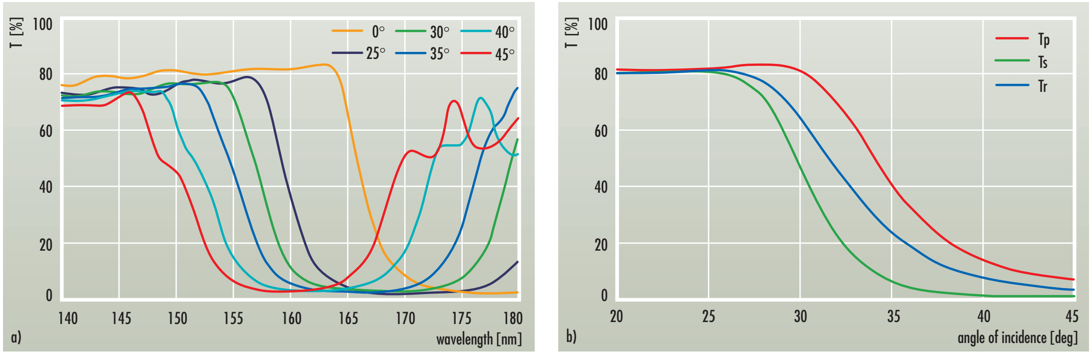


**Figure 3:** Measured transmittance spectra of a variable attenuator at different AOI (a) and transmittance vs. AOI (b); the transmittance varies from T>75% at AOI=0° to T<5% at AOI=45°

# ALUMINUM MIRRORS FOR $F_2$ LASERS

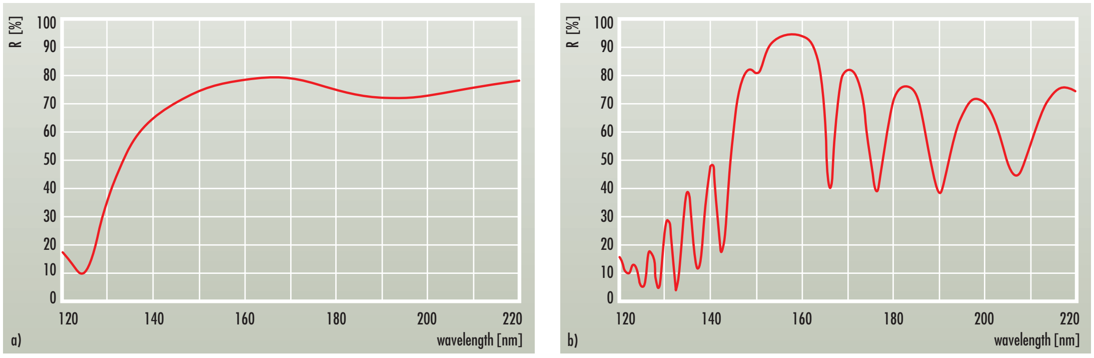


**Figure 4:** Reflectance spectrum of a protected Al mirror (a) and an enhanced Al mirrors for 157nm (b)

Protected Al mirrors (optimized for 157nm): R=74 ... 78%
Dielectrically enhanced Al mirrors: up to R=94% at AOI=0°
For more information on Al mirrors see pages 62–63.

# TECHNICAL DATA OF STANDARD $F_2$ LASER COMPONENTS

| Coating | Spectral performance | Lifetime tests |
|---|---|---|
| HR(0°, 157nm) | R=92 ... 95% | $2x10^8$ – $1x10^9$ pulses* |
| HR(45°, 157nm) | R=90 ... 94% (random pol.) | |
| PR(0°, 157nm) | R=50±3% | $2x10^8$ – $1x10^9$ pulses* |
| PR(0°, 157nm) | R=25±3% | $2x10^8$ – $1x10^9$ pulses* |
| Attenuator | T=67±3% | $5x10^7$ pulses**, no damage |
| Attenuator | T=33±3% | $1x10^8$ pulses***, no damage |
| Beam splitter | T=20±3% | $1x10^8$ pulses***, no damage |
| AR(0°, 157nm) | 0.3 ... 0.7% | |

* Energy density: 25mJ/cm², repetition rate: 800 Hz, pulse duration: 15ns; tested at TUI Laser AG, Germering
** Energy density: 15mJ/cm², rep. rate: 200Hz, pulse duration: 20ns; tested at Institut für Physikalische Hochtechnologie (IPHT) Jena
*** Energy density: 20mJ/cm², rep. rate: 50Hz, pulse duration: 20ns; tested at Institut für Physikalische Hochtechnologie (IPHT) Jena

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## MIRRORS, OUTPUT COUPLERS AND LENSES

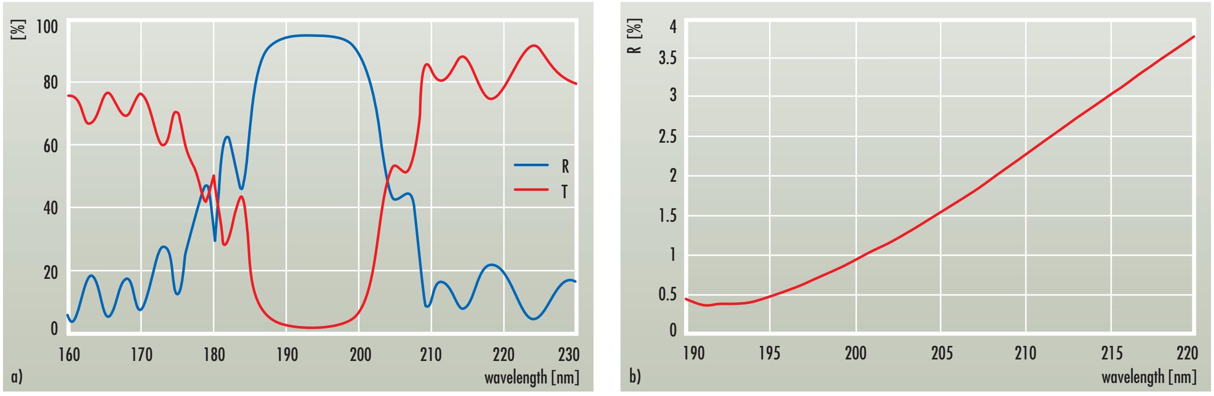


**Figure 1:** Measured reflectance and transmittance spectra of a turning mirror (AOI = 45°) for 193 nm for random polarized light (a) and a $CaF_2$ window coated on both sides with a fluoride AR coating for 193 nm (b)

- All fluoride systems guarantee high reflectivities and high damage thresholds
- PR coatings with tolerances of ± 2% for R = 10 … 30%<br>± 3% for R = 30 … 75%<br>± 2% for R = 75 … 90%<br>and ± 1% for R > 90%
- High quality mirror substrates, windows and lenses of $CaF_2$ (193nm excimer grade, SCHOTT-LITHOTEC) and fused silica
- Development and production of customer specific components such as beamsplitters and variable attenuators on request
- Single wavelength AR coating with residual reflectivities of R < 0.25% at AOI = 0° and R< 0.6% at AOI = 45° (unpolarized light)
- Broadband and multiple wavelength AR coatings

## VARIABLE ATTENUATORS

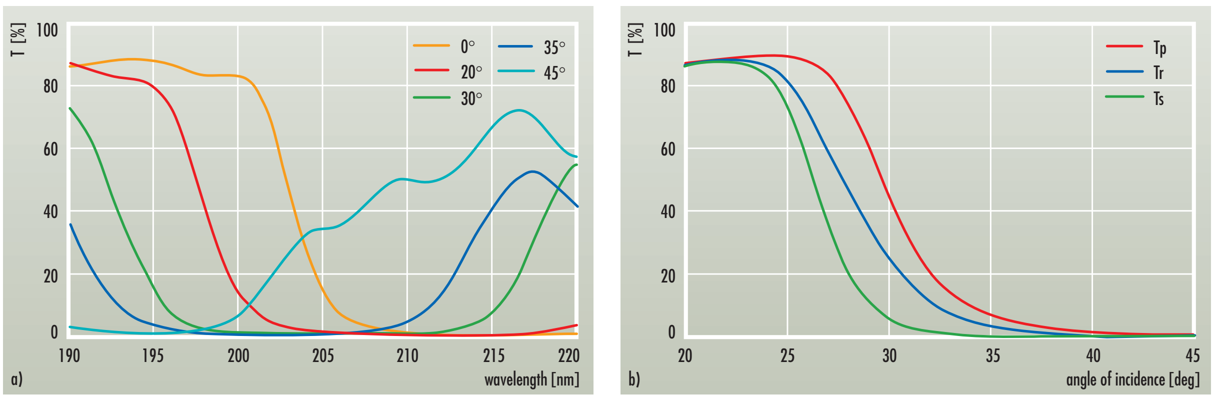


**Figure 2:** Measured transmittance spectra of a variable attenuator at different AOI (a) and transmittance vs. AOI (b); the transmittance varies from T > 88 % at AOI = 0° to T < 2 % at AOI = 45°

# ALUMINUM MIRRORS

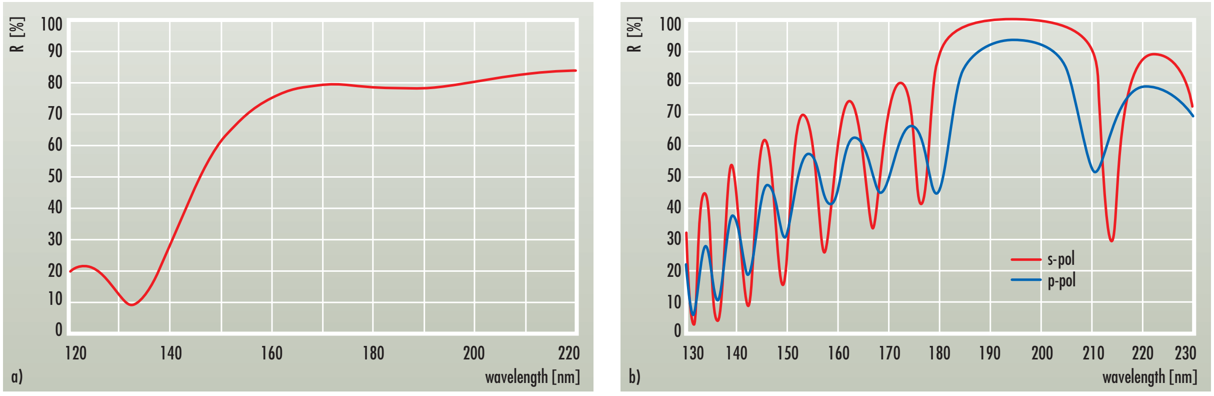


**Figure 3:** Measured reflectance spectra of a protected Al mirror optimized for 193nm (a) and an enhanced Al mirror for 193nm, AOI = 45° (b)

Enhanced aluminum mirrors: Rp > 93%
Rs > 99%
Rr > 96%

For more information on aluminum mirrors see pages 62–63.

# TECHNICAL DATA OF STANDARD ArF LASER COMPONENTS

| Coating / reflectance | Substrate | Damage threshold* | Lifetime test |
|---|---|---|---|
| Fluoride coatings | | | |
| AR (0°, 193 nm) R < 0.25% | $CaF_2$ | 4 – 5 J/cm$^2$ | 2.5x$10^8$ 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$^2$ | 2.5x$10^8$ pulses, no damage** |
| PR (0°, 193 nm) R = 50% | $CaF_2$ | 2 – 3 J/cm$^2$ | 2x$10^8$ pulses, no damage*** |
| HR (0°, 193 nm) R > 96% | $CaF_2$ | 2 – 3 J/cm$^2$ | 2x$10^8$ pulses, no damage ***<br>$10^{10}$ pulses, no damage**** |
| HR (45°, 193 nm) R > 95% (random polarized) | $CaF_2$ | 2 – 3 J/cm$^2$ | |
| Oxide coatings | | | |
| HR (0°, 193 nm) R > 92% | fused silica | <1 J/cm$^2$ | |

* 1000-on-1, 14ns; measurements were performed at Laser Labor Göttingen and at Friedrich-Schiller-Universität Jena
** Energy density: 18mJ/cm², repetition rate: 4 kHz, pulse duration: 30ns; tested at Lambda Physik GmbH Göttingen
*** Energy density: 55mJ/cm², repetition rate 1 kHZ, pulse duration 15ns; tested at TUI Laser AG, Germering
**** Energy density: 27mJ/cm², repetition rate: 4 kHz, pulse duration: 30ns; tested at Lambda Physik AG Göttingen

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# COMPONENTS FOR KrF, XeCl AND XeF LASERS

## STANDARD COMPONENTS

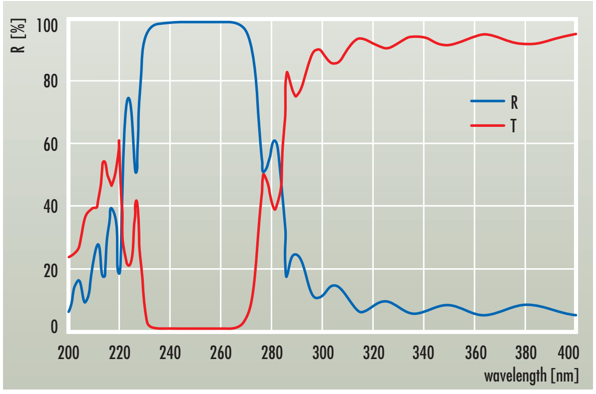
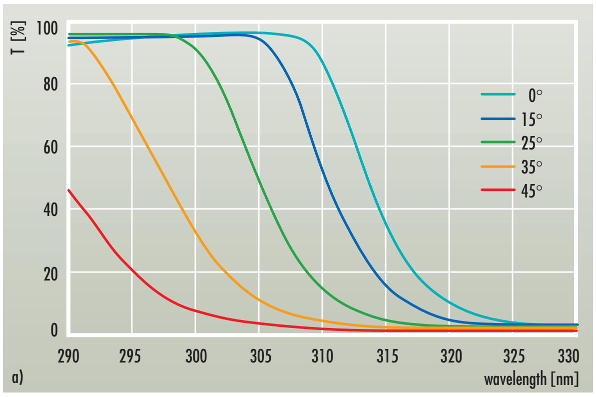



**Figure 1:** Reflectance and transmittance spectra of a 248 nm turning mirror (AOI = 45°) for random polarized light

- Oxide coatings for high mechanical stability and low straylight losses
- Laser mirrors (R > 99 % at 248 nm, R > 99.5 % at 308 nm and 351 nm)
- High quality mirror substrates, windows and lenses of fused silica
- PR coatings with tolerances of ± 2 % for R = 10 ... 30 %<br>± 3 % for R = 30 ... 75 %<br>± 2 % for R = 75 ... 90 %<br>and ± 1 % for R > 90 %
- Development and production of customer specific components



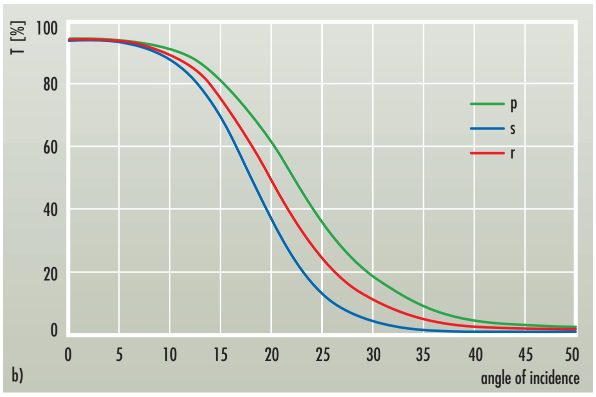




**Figure 2:** Transmittance spectra of a variable attenuator for 308 nm at different AOI (a) and transmittance vs. AOI at 308nm (b); the transmittance varies from T > 85 % at AOI = 0° to T = 2 ± 1 % at AOI = 45° (unpolarized light)

# FLUORINE RESISTANT CAVITY OPTICS

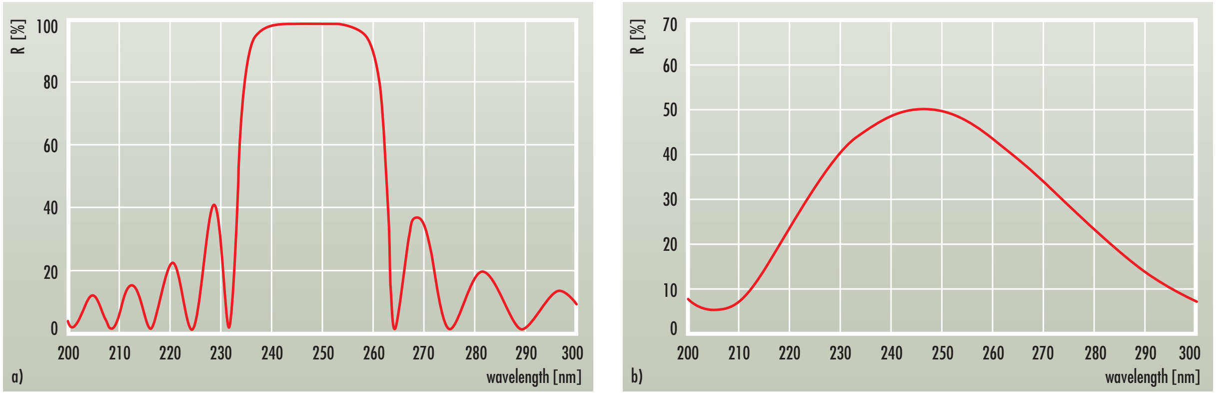



**Figure 3:** Reflectance spectrum of a fluoridic KrF laser mirror (a) and an output coupler with R = 50 ± 3 % (b)

- Fluoride coatings and $CaF_2$ substrates for high stability against fluorine and chlorine
- Laser mirrors (R > 98 % at 248 nm and 308 nm, R > 96 % at 351 nm)
- High quality mirror substrates, windows and lenses of $CaF_2$ (248 nm excimer grade or UV quality, SCHOTT-LITHOTEC)
- PR coatings with tolerances of ± 2 % for R = 10 ... 30 %
  ± 3 % for R = 30 ... 75 %
  and ± 2 % for R = 75 ... > 90 %

# TECHNICAL DATA OF KrF, XeCl AND XeF LASER COMPONENTS

| Coating | Materials | Reflectance | Damage threshold* | Lifetime tests |
|---|---|---|---|---|
| HR (0°, 248 nm) | oxides | > 99 % | 10 J/cm$^2$, 1-on-1, 20 ns<br>5 J/cm$^2$, 1000-on-1 | |
| HR (45°, 248 nm) | oxides | > 99 % (random pol.) | 10 J/cm$^2$, 1-on-1, 20 ns | |
| HR (0°, 248 nm) | fluorides | R > 98 % | | 2 x 10$^8$ pulses** |
| PR (0°, 248 nm) | fluorides | R = 50 ± 3 % | | 2 x 10$^8$ pulses** |
| AR (0°, 248 nm) | fluorides | R < 0.25 % | | 2 x 10$^8$ pulses** |
| HR (0°, 308 nm) | fluorides | R > 98 % | | 2 x 10$^8$ pulses*** |
| HR (0°, 351 nm) | fluorides | R > 96 % | | 2 x 10$^8$ pulses*** |
| PR (0°, 351 nm) | fluorides | R = 25 ± 3 % | | 2 x 10$^8$ pulses*** |

* Measurements were performed at Laser Labor Göttingen and at Friedrich-Schiller Universität Jena
** Energy density: 100 mJ/cm², rep. rate: 100 Hz, pulse duration: 15 ns; tested at TUI Laser AG, Germering
*** Energy density: 55 mJ/cm², rep. rate: 100 Hz, pulse duration: 15 ns; tested at TUI Laser AG, Germering

# COMPONENTS FOR Ti:SAPPHIRE LASERS

On these pages we present optical components for Ti:Sapphire lasers which are operated with ns pulses. These components are not optimized for their phase properties. Optics for fs pulses are introduced on pages 32–43.

## MIRRORS

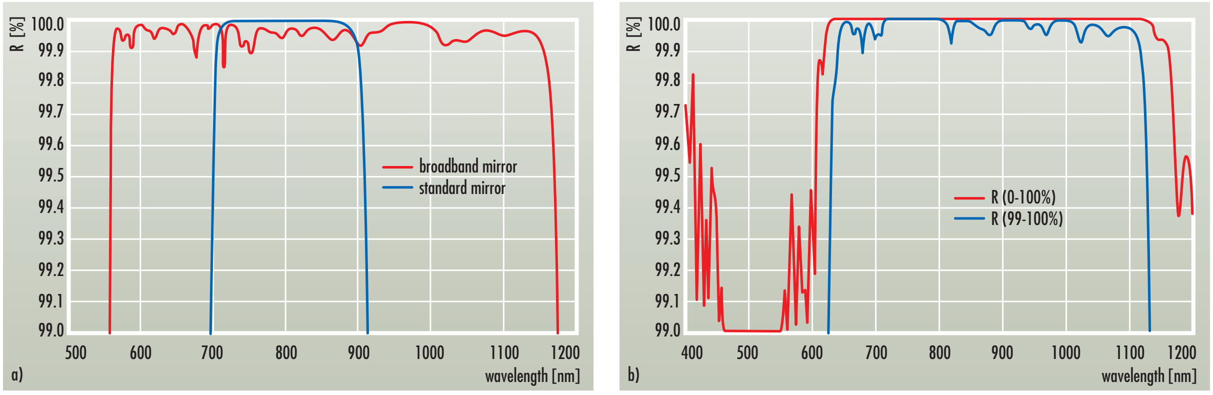



**Figure1:** Reflectance spectra of standard and broadband laser mirrors (a) and of a pump mirror (b)

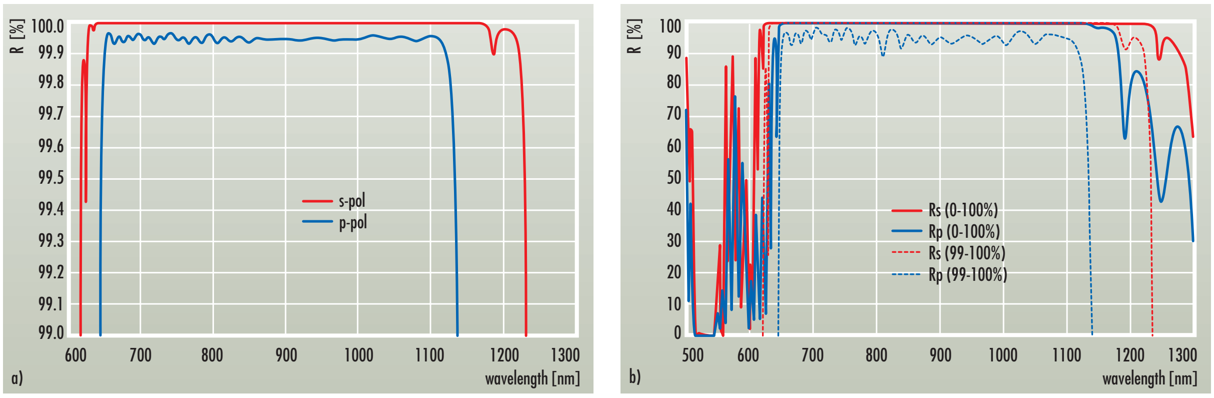



**Figure 2:** Reflectance spectra of a broadband turning mirror (a) and a turning mirror which has a region of high transmittance around 500nm which can be used for the pump light or for a pilot laser

### Special features:

- Very high reflectance of the mirrors (R>99.9% … R>99.98% depending on the design)
- Spectral tolerance: 1% of centre wavelength
- OEM-production:
  Centre wavelength, bandwidth and reflectivity of partial reflectors according to customers specification

# OUTPUT COUPLERS AND BEAMSPLITTERS

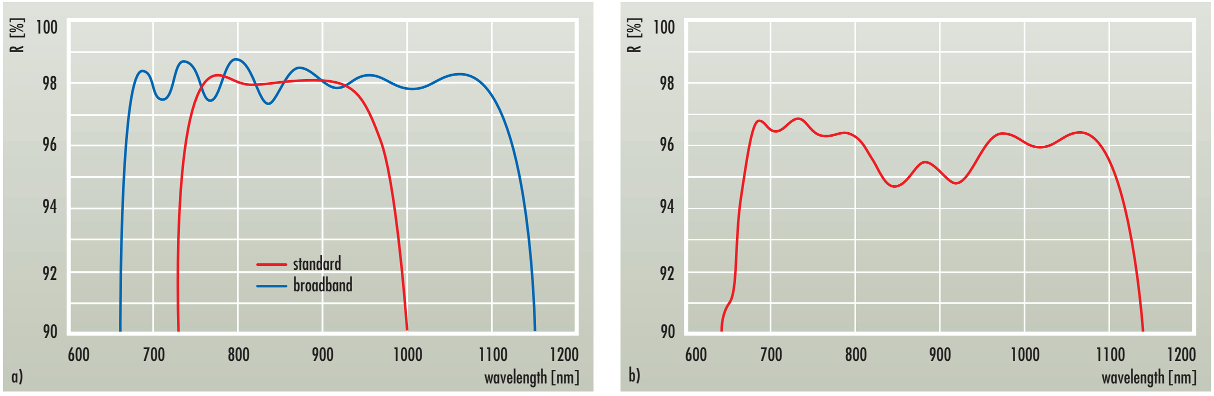



**Figure 3:** Reflectance spectra of a standard and a broadband output coupler (a) and of an output coupler with a special reflectance profile which enables the compansation of the amplification characteristics of the laser (b)

- Tolerances:
  - Standard output couplers (bandwidth: 120 – 150nm):

    | | |
    |---|---|
    | R = 10 … 70% | ± 2.5% |
    | R = 70 … 90% | ± 1.5% |
    | R = 90 … 95% | ± 0.75% |
    | R = 95 … 98% | ± 0.5% |
    | R > 98% | ± 0.25% |

  - Broadband output couplers:

    | | |
    |---|---|
    | R = 10 … 70% | ± 3% |
    | R = 70 … 90% | ± 2% |
    | R = 90 … 95% | ± 1% |
    | R = 95 … 98% | ± 0.5% |

# NARROWBAND FILTERS

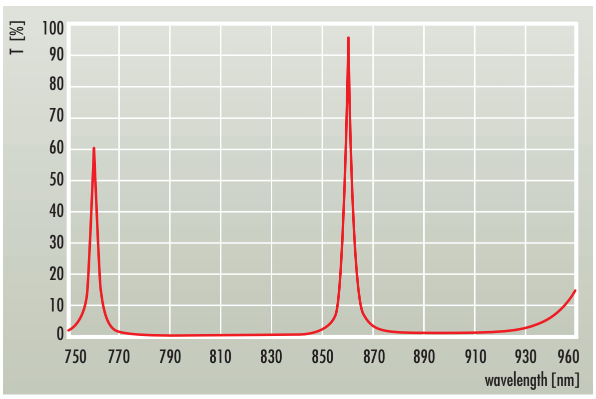



**Figure 4:** Transmittance spectrum of a narrowband filter for 860nm which is used to select one wavelength from the Ti:Sapphire spectrum

These filters are designed for intra cavity use.

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# COMPONENTS FOR DIODE LASERS

Diode lasers are widely used for measurement applications, as pilot lasers, for pumping of solid state lasers and for direct materials processing. Although diode lasers do not require external resonator optics and are mostly coupled to fibres, 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 16–19 and 54–55.

## TURNING MIRRORS

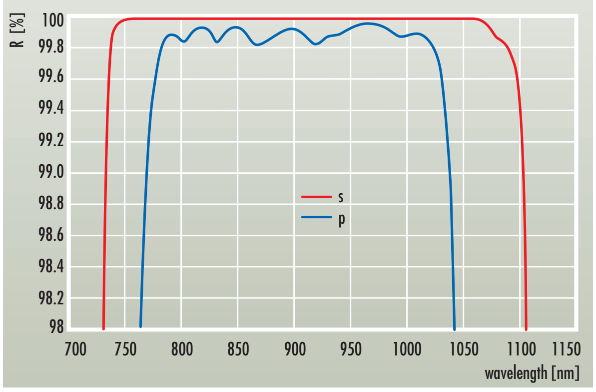



**Figure 1:** Reflectance spectra of a broadband turning mirror which can be used for all diode lasers between 808nm and 980nm (AOI = 45°, s- and p-polarization)

## SCANNING MIRRORS

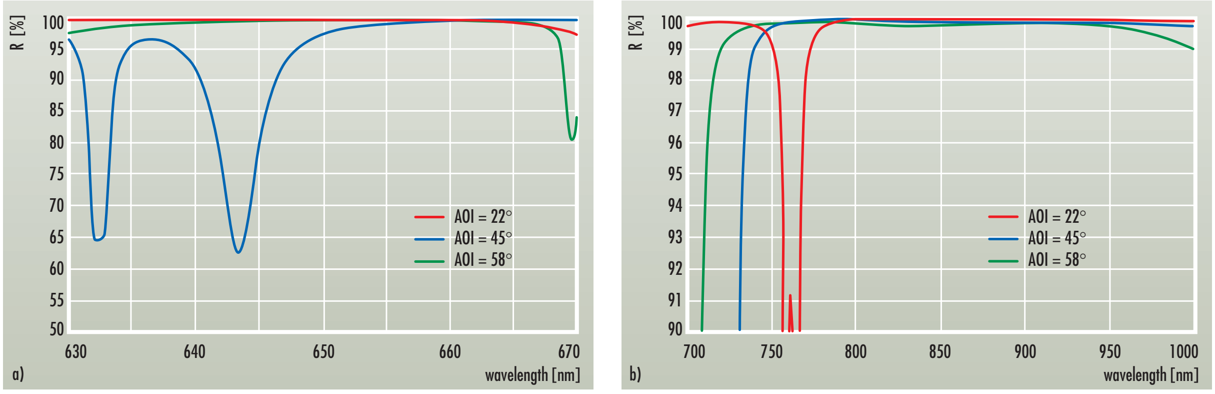



**Figure 2:** Reflectance spectra of a scanning mirror for diode lasers between 805 and 940nm combined with R > 50% between 630 and 670nm (pilot laser):
HR (22°–58°, 805–940 nm) > 99.3% + R (22°–58°, 630– 670nm) > 50%

- Scanning mirrors with other specifications on request
- For more information and examples on scanning mirrors please see pages 15 and 61

# CONVENTIONAL STEEP EDGE COMBINERS FOR DIODE LASERS

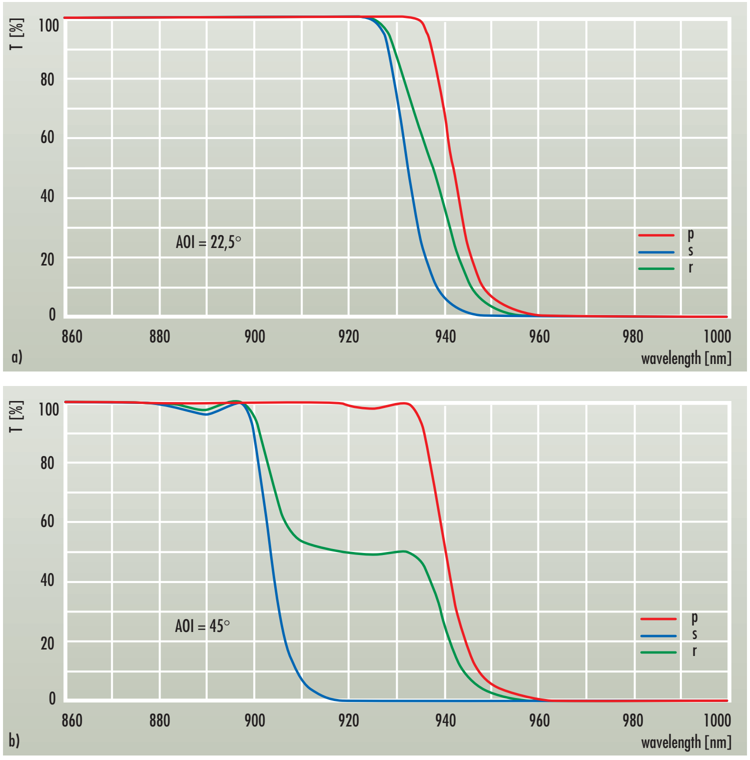



**Figure 3:** Transmittance spectra of a conventional steep edge filter HR (980nm) > 99.9% and HT (915nm) > 95% which is used as combiner for pump laser diodes at 915nm and 980nm; AOI = 22.5° (a) and AOI = 45° (b)

- At AOI = 22.5° the conventional steep edge filter separates 915nm and 980nm for p- and s-polarized and thus also for 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

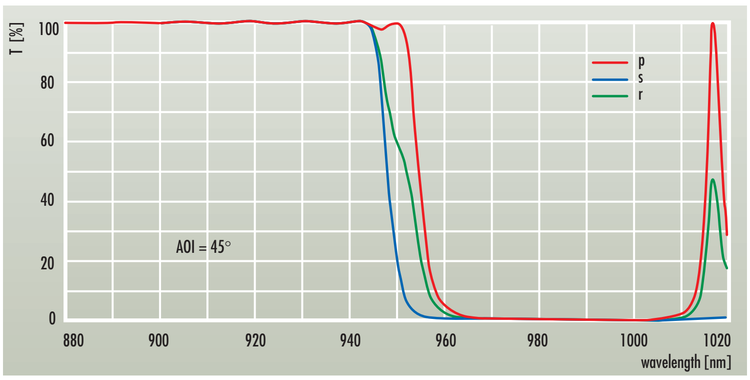


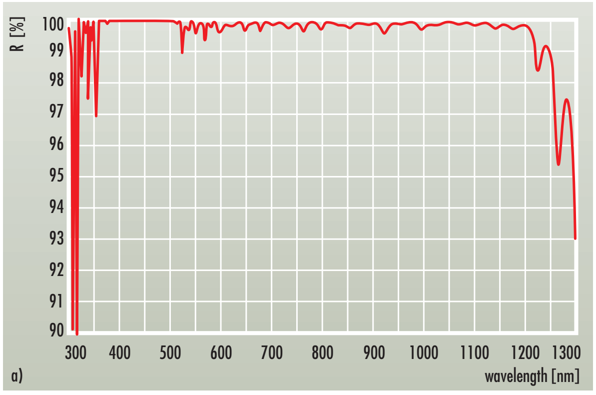

**Figure 4:** Transmittance spectra of a special steep edge filter HRr (980nm) > 99.8% and HTr (940nm) >97% at AOI = 45°.

- 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 show only a spectral distance of about 10 nm.
- Consequently, these filters can be applied as combiners for unpolarized light of 940 nm and 980 nm diodes at AOI = 45°.

# BROADBAND AND SCANNING MIRRORS

Broadband mirrors are widely used to reflect light of lasers emitting in a broad wavelength range such as e.g. Ti:Sapphire or dye lasers. Scanning mirrors are optimized for high reflectance for one wavelength or a certain wavelength region at a wide range of incidence angles.

LAYERTEC produces such mirrors according to customer specifications. Both full dielectric and metal-dielectric coating designs are used. In the following we present some examples which are designed for very broad wavelength regions or extremely wide ranges of incidence angles.



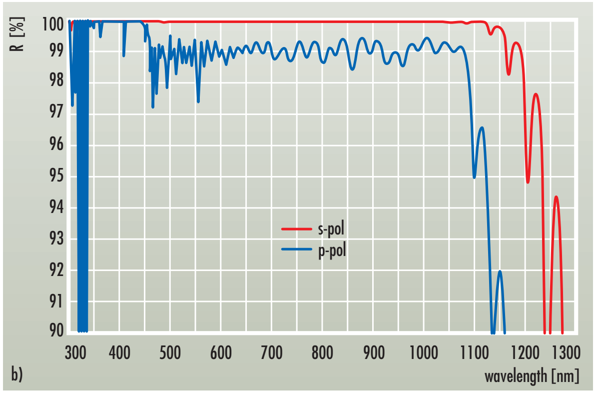




**Figure 1:** Reflectance spectra of an ultra broadband mirror for the NUV, VIS and NIR;
a) R (0°, 360–1200nm) >99 %
b) Rs (45°, 350–1150nm) >99 % + Rp (45°, 350–1050nm) > 97 %

Mirrors of this type cover the whole visible spectrum, the near ultraviolett and considerable parts of the near infrared spectral regions. We recommend these mirrors as universal turning mirrors for nearly all types of laser diodes.

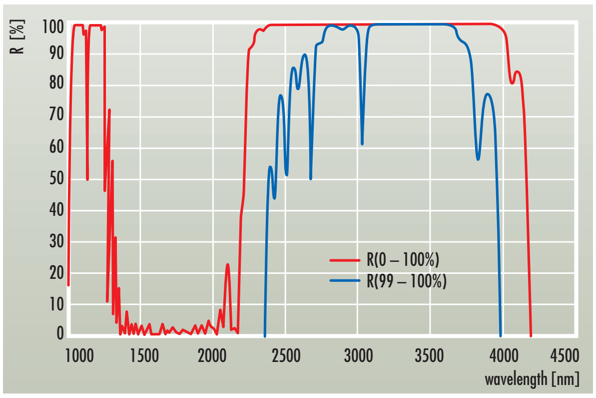



**Figure 2:** Reflectance spectra of a broadband mirror for the NIR: HR (0°, 2300–4000nm) > 99 %

These mirrors are especially useful for reflecting for the idler wavelengths of optical parametrical oscillators. In combination with fused silica as substrate material a wide blocking range from 2300 – 6000nm can be achieved.

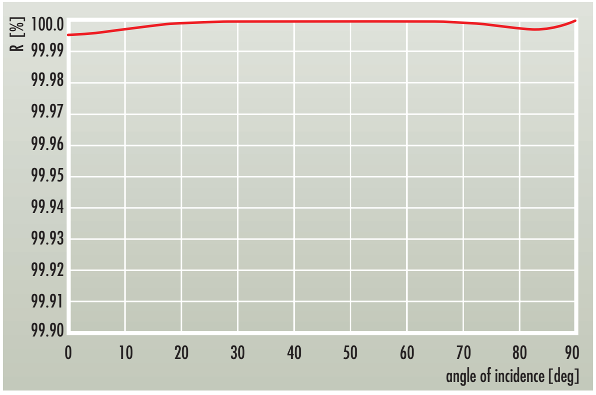



**Figure 3:** Reflectance vs. AOI of a wide angle scanning mirror for polarized Nd:YAG laser radiation: HRs (0°–90°, 1064 nm) > 99.9 %

These mirrors are ideal as scanning mirrors for s-polarized light or to enhance the reflectivity of optical gratings.

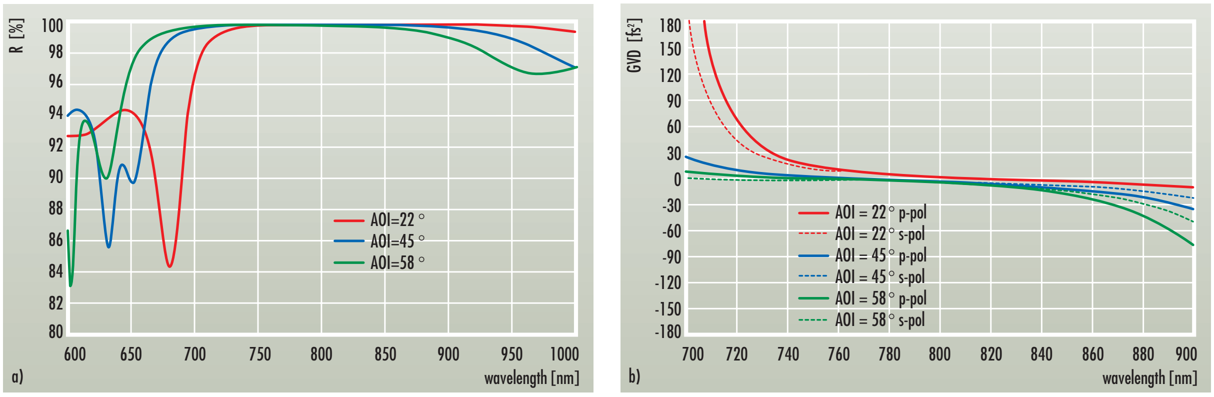



**Figure 4:** Reflectance (a) and GVD (b) spectra of a scanning mirror for femtosecond laser pulses from a Ti:Sapphire laser: HR (22°–58°, 750 – 850 nm) > 99.5 %, GVD < 20 $fs^2$

The broad low GVD wavelength range of these mirrors makes it possible to use them in femtosecond laser applications.

Fore more information or more examples on broadband and scanning mirrors please see pages 10–13 (optics for Ti:Sapphire and diode lasers), 36–40 (femto second laser optics) and 60–61 (silver mirrors).

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# COMPONENTS FOR Yb:YAG; Yb:KGW AND Yb DOPED FIBRE LASERS

Lasers on the basis of Yb doped crystals or fibres have gained increasing importance over the recent years. High power cw lasers were developed on the basis of Yb:YAG as well as with Yb doped fibres. Yb:YAG and Yb:KGW lasers can also be operated as high power ns, ps or fs lasers.

## MIRRORS

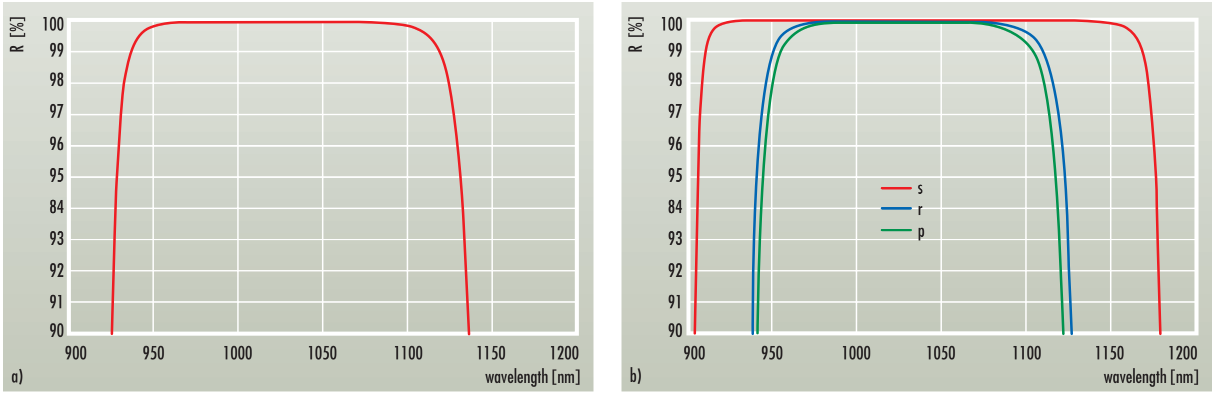


**Figure 1:** Reflectance spectra of a HR cavity mirrors (a) and a HR turning mirror (b)

## SHORT WAVELENGTH PASS FILTERS

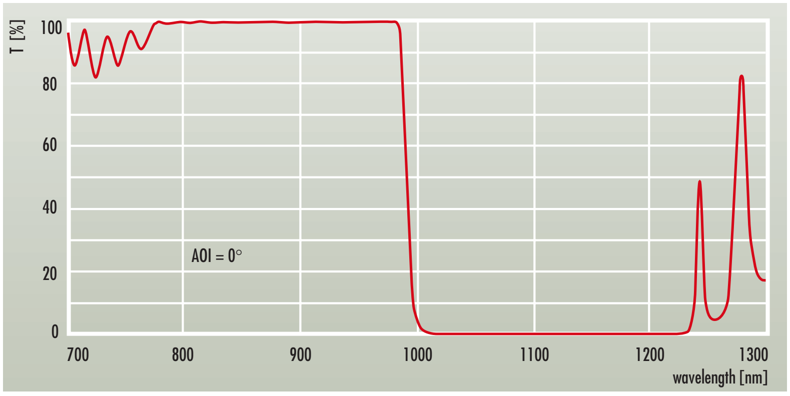


**Figure 2:** Transmittance spectrum of a steep edge short wavelength pass filter with HR (0°, 1030nm) > 99.9% and HT (0°, 808–980nm) > 99.5% (rear side AR coated)

**Special features:**

- Short wavelength pass filter with very steep edge for use as **pump mirror** for solid state lasers on the basis of Yb-doped materials (e.g. Yb:YAG, Yb:KGW, Yb-doped fibers)
- Also useful for Nd-doped and Yb-Nd-co-doped materials
- Transmittance T > 99% at 808nm–980nm, reflectance R > 99.9% at 1020–1200nm, i.e. transition from the high transmittance range to the high reflectance range within 4% of the laser wavelength
- Superior laser damage thresholds (100 MW/cm² cw at 1064nm*)
- Thermally and climatically stable

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

# LONG WAVELENGTH PASS FILTERS

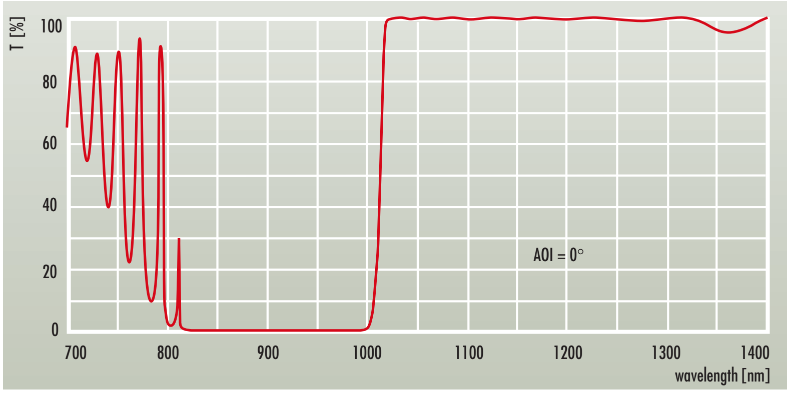


**Figure 3:** Transmittance spectrum of a steep edge long wavelength pass filter with HR (0°, 915 – 980nm) > 99.8 % and HT (0°, 1030 – 1200nm) > 97 % for use as output mirror of a fibre laser (rear side AR coated)

# OUTPUT MIRRORS FOR YTTERBIUM DOPED SOLID STATE LASERS

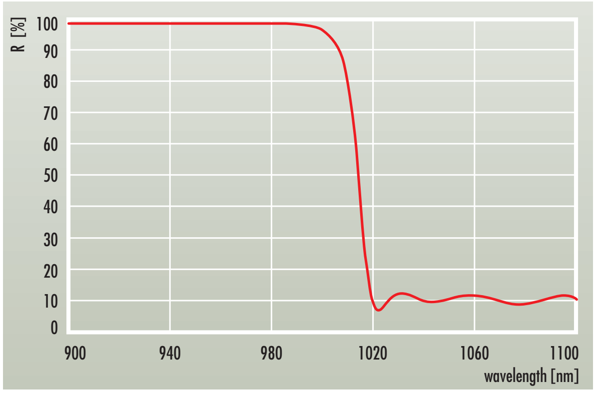


**Figure 4:** Reflectance spectrum of an output mirror for a fibre laser which blocks the diode radiation at 980nm and has a partial reflectivity R = 10 % for 1030 – 1100nm

Steep edge of a long wavelength pass filter combined with a defined partial reflectance in the wavelength range of the laser radiation

For GTI mirrors in the 1030nm wavelength range see page 50.

# MIRRORS AND PARTIAL REFLECTORS

- HR cavity and turning mirrors with R > 99.9 % at AOI = 0° and at AOI = 45° for s- and p-polarized light
- Spectral bandwidth of about 70nm, 1-on1-LIDT > 50MW/cm² (cw) and > 50J/cm² (10ns)

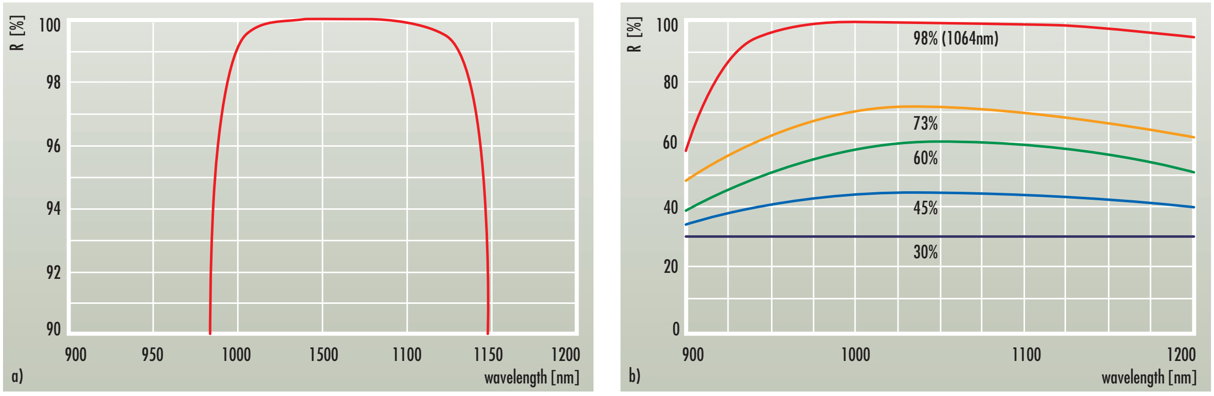


**Figure 1:** Reflectance spectra of a high power cavity mirror (a) and of output couplers with different degrees of reflectivity (b)

Beam splitters and output couplers with precisely adjusted degree of reflectivity:

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

- Pump mirrors (HR (1064nm) > 99.9 % + R (808nm) < 2 %)
- Beam splitters, beam combiners and scanning mirrors
- Optics for the harmonics of the Nd:YAG / Nd:YVO$_4$ laser are presented on pages 20 – 21

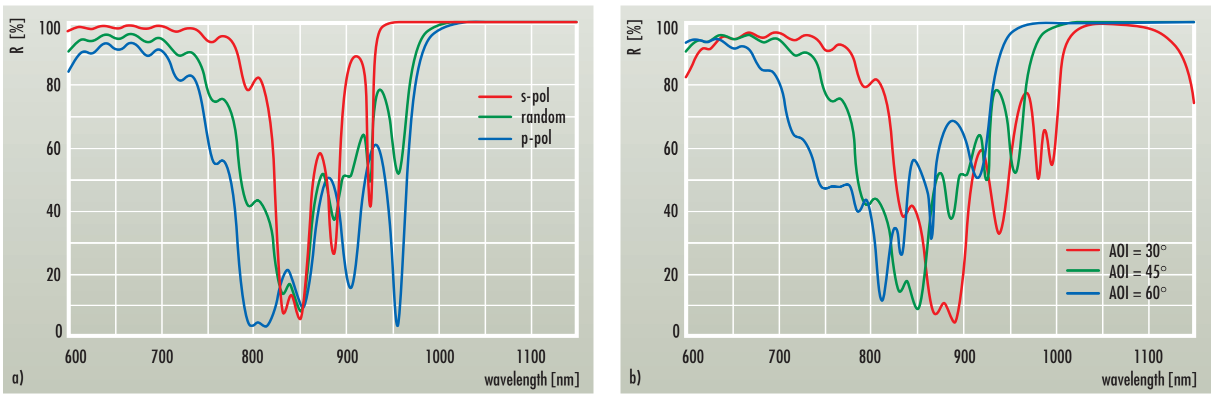


**Figure 2:** Reflectance spectra of a pilot mirror HR (1064 nm) + PR (630 – 670 nm) for s-, p- and random polarization at AOI = 45° (a) and for random polarization at different AOI (for use as scanning mirror) (b)

## THIN FILM POLARIZERS

- Separation of the s- and p-polarized component of the light (s-polarized light is reflected and p-polarized light is transmitted)
- TFPs can be produced for AOI > 40°, but polarization is most efficient and appears in a broad wavelength range if AOI ≈ 55° (Brewster angle) is used
- Typical polarization ratio Rs/Rp: standard: > 10000 (AOI = 45° or 55°)
  high power TFP: > 500 (AOI = 55°)
- High laser damage thresholds (useful for intra cavity applications)

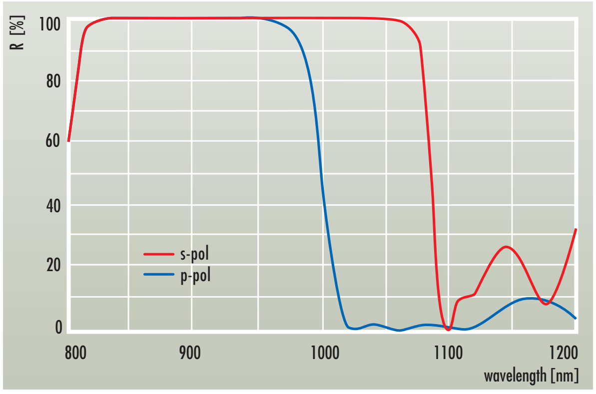


**Figure 3:** Reflectance spectra of a standard TFP for AOI = 55° (Brewster angle) for s- and p-polarized light

## NONPOLARIZING BEAM SPLITTERS

- Beamsplitters with $R_s \sim R_p$ ($|R_s - R_p| < 1.5\%$) for AOI = 45° and different degrees of reflectivity
- Most common types : $R_{s,p} = 66 \pm 1\%$
  $R_{s,p} = 50 \pm 2\%$
  $R_{s,p} = 33 \pm 3\%$
- All nonpolarizing beamsplitters with rear side AR ($R_s \sim R_p \leq 0.6\%$)

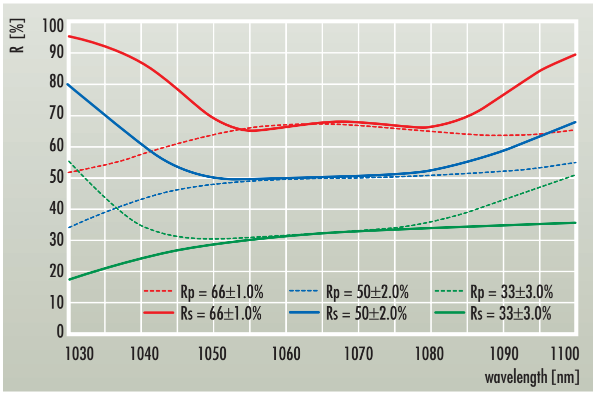


**Figure 4:** Reflectance spectra of 3 types of nonpolarizing beam splitters (AOI = 45°)

Ernst-Abbe-Weg 1, D-99441 Mellingen, Germany, e-mail: info@layertec.de
Phone 49 (0)3 64 53 / 7 44-0, Fax 49 (0)3 64 53 / 7 44-40, www.layertec.de

# COMPONENTS FOR THE HARMONICS OF Nd:YAG AND Nd:$YVO_4$ LASERS

The harmonics of Nd:YAG and Nd:$YVO_4$ lasers are widely used for materials processing as well as for measurement applications. On these pages we introduce dual wavelength mirrors and separators, but also cavity optics for compact diode pumped lasers of different configurations. All designs are calculated according to customers specification.

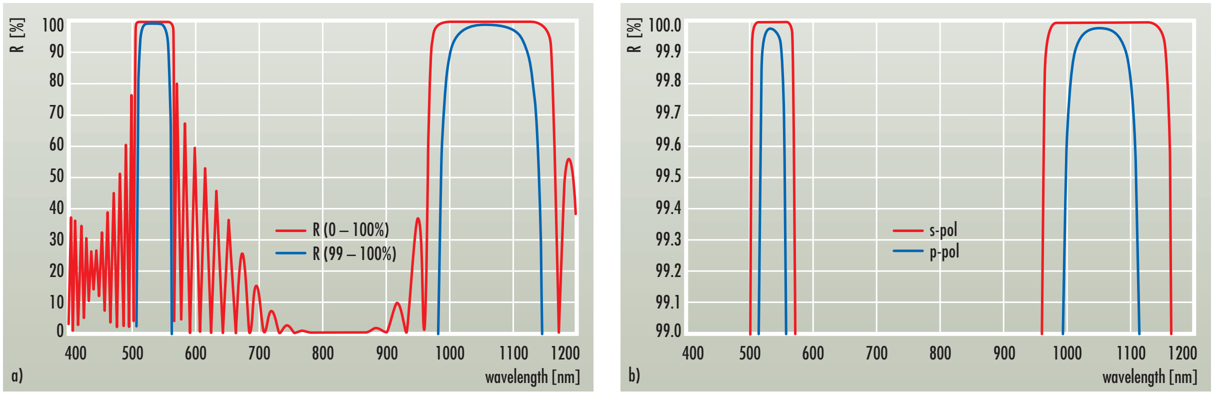


**Figure 1:** Reflectance spectra of a dual wavelength cavity mirror with high transmittance for the pump wavelength (808nm) (a) and a dual wavelength turning mirror (b)

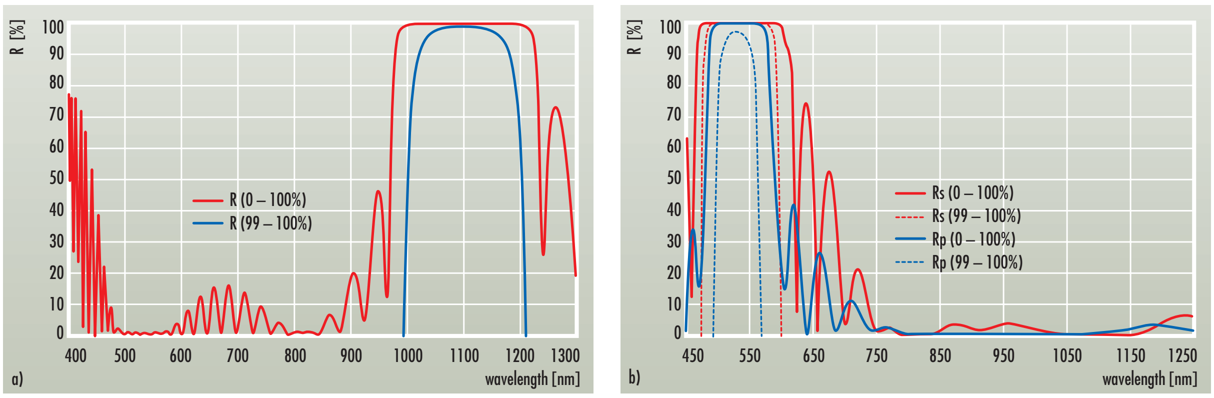


**Figure 2:** Reflectance spectra of separators for the second harmonic from the ground wavelength:
(a): HR(0°, 1064nm) > 99.9% + R(0°, 532 + 808nm) < 3%
(b) HRs + p(45°, 532nm) > 99.9% + Rs + p(45°, 808 + 1064nm) < 2%

Please do not hesitate to contact us for separators with other angles of incidence.

# SEPARATORS FOR THE HIGHER HARMONICS OF THE 1064nm RADIATION

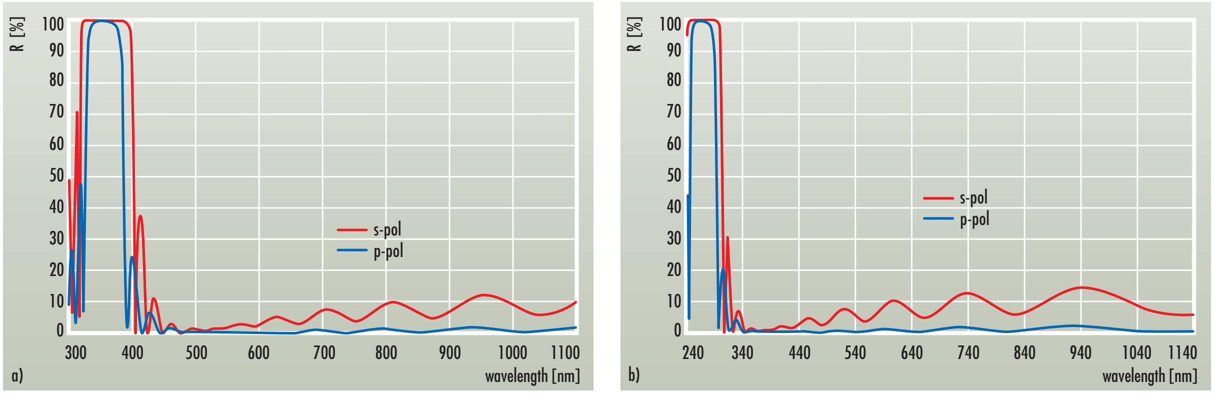


**Figure 3:** Reflectance spectra of separators for the third (a) and the fourth harmonic (b) from the second harmonic and the ground wavelength.

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

| Separator type | Centre wavelength | Reflectance at centre wavelength [%] | | Reflectance at the corresponding longer Nd:YAG wavelengths [%] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 266nm | | 355nm | | 532nm | | 1064nm | |
| | | Rs | Rp | Rs | Rp | Rs | Rp | Rs | Rp | Rs | Rp |
| 3rd harmonic | 355nm | >99.7 | >99 | | | | | <5 | <2 | <10 | <2 |
| 4th harmonic | 266nm | >99.7 | >99 | | | <5 | <2 | <10 | <2 | <10 | <2 |
| 5th harmonic | 213nm* | >97 | >93 | <5 | <2 | <10 | <2 | <10 | <2 | <10 | <2 |

**Table 1:** Common specifications of separators for the harmonics in the UV
* Fluoridic coating on $CaF_2$

# COATINGS ON NONLINEAR OPTICAL CRYSTALS

Nonlinear optical crystals are the key elements for frequency conversion. LAYERTEC offers a variety of coatings on crystals like KTP or LBO.

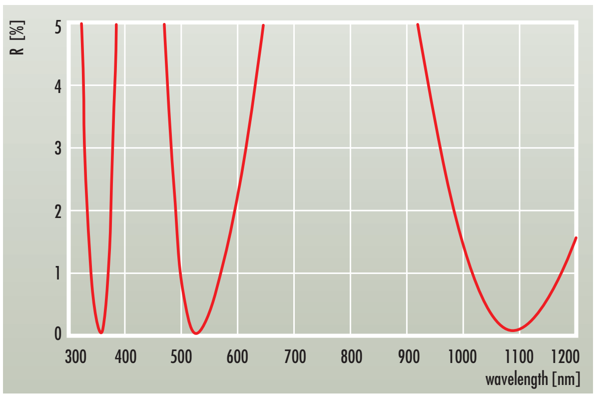


**Figure 4:** Reflectance spectrum of a triple antireflection coating on LBO for 355nm, 532nm and 1064nm.

For more information on coatings on crystals see pages 58–59.

# COMPONENTS FOR OTHER Nd:YAG OR Nd:$YVO_4$ WAVELENGTHS

Neodymium doped crystals show laser transitions at different wavelengths. Table 1 gives an overview about the laser wavelengths of the most common Nd doped materials Nd:YAG and Nd:$YVO_4$.

| Nd:YAG | | Nd:$YVO_4$ | |
|---|---|---|---|
| Laser lines | Second harmonic | Laser lines | Second harmonic |
| 946 nm | 473 nm | 915 nm | 457 nm |
| 1064 nm | 532 nm | 1064 nm | 532 nm |
| 1123 nm | 561 nm | | |
| 1319 nm | 659 nm | 1340 nm | 670 nm |

**Table 1:** Laser lines and corresponding wavelengths of the second harmonic of Nd:YAG and Nd:$YVO_4$

As can be seen, a variety of laser lines in the VIS and NIR can be obtained from these crystals. This is used to build compact diode pumped solid stated 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 1064nm line. Efficient laser radiation at the other wavelengths it is only possible by suppressing this line. LAYERTEC offers a variety of laser mirrors for this application.

Compact laser designs include also the pump diode (808nm) and a unit for the second harmonic generation. This is the reason, why coatings for Nd:YAG or Nd:$YVO_4$ wavelengths apart from 1064nm mostly show several spectral regions of high transmission as well as of high reflection. In the following, we present some examples of such coatings. All coatings are designed according to customers specifications because the specifications depend on the laser design. All examples on these pages are for Nd:YAG wavelengths. Coatings for Nd:$YVO_4$ can be designed and produced as well.

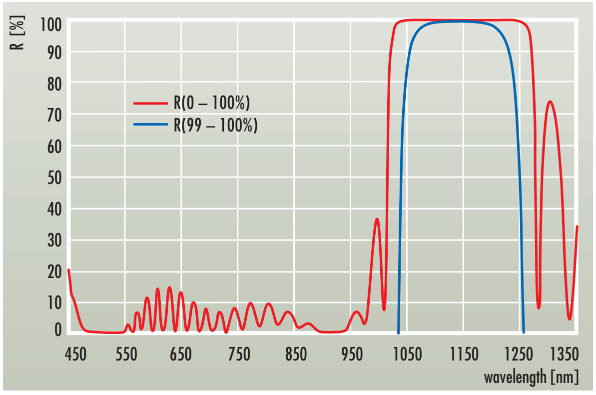


**Figure 1:** Reflectance spectrum of a dichroic mirror:
HR(0°,1064+1123nm) > 99.9% + R(0°, 480–545 + 914–940nm) < 2%

# COMPONENTS FOR OTHER Nd:YAG OR Nd:$YVO_4$ WAVELENGTHS

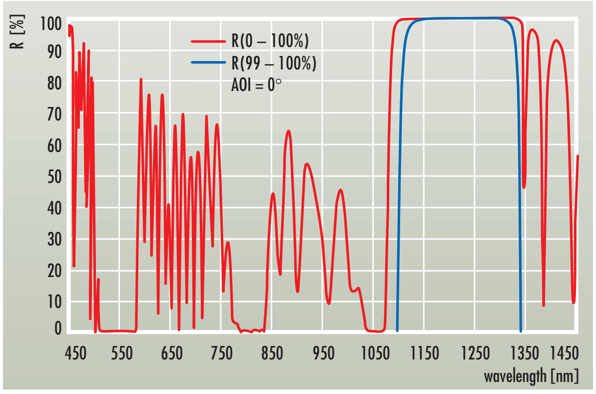


**Figure 2:** Reflectance spectrum of a dichroic mirror with high transmission for the pump wavelength which supresses also the 1064nm line:
HR (0°, 1123nm) > 99.9% + R (0°, 561nm) < 2% + R (0°, 808nm) < 10% + R (0°, 1064nm) < 50%

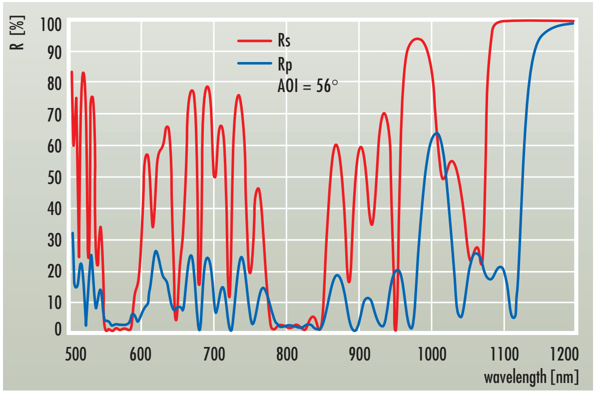


**Figure 3:** Reflectance spectra of a thin film polarizer with high transmission for the pump wavelength and the second harmonic which supresses also the 1064nm line:
HRs (56°, 1123nm) > 99.9% + Rp (56°, 1123nm) < 50% + Rs+p (56°, 561 + 808nm) < 10% + Rs+p (56°, 1064nm) < 50%

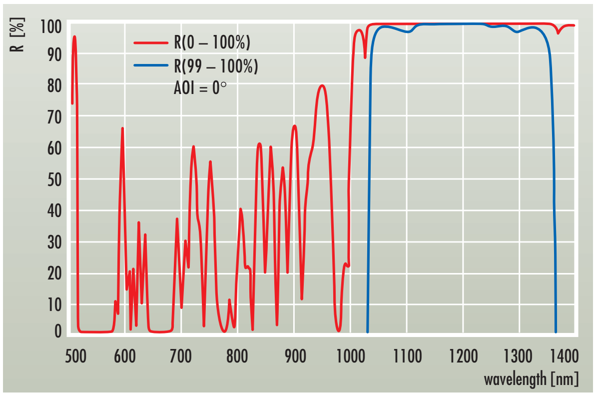


**Figure 4:** Reflectance spectrum of a dichroic mirror with high reflectance for the NIR wavelengths and high transmittance for the corresponding second harmonic wavelengths:
HR (0°, 1064 + 1123 + 1319nm) > 99.9% + R (0°, 532–561 + 659nm) < 2%

# COMPONENTS FOR Ho:YAG AND Tm:YAG LASERS

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

## MIRRORS

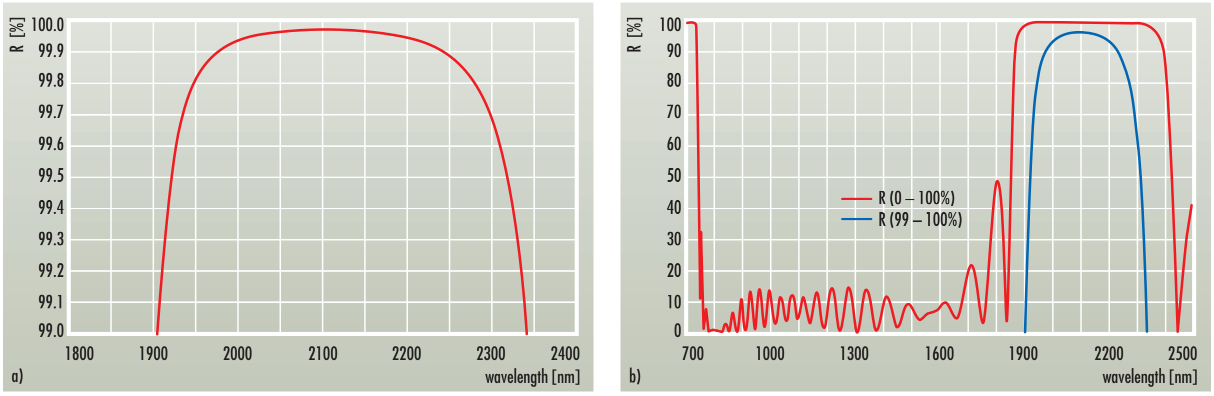


**Figure 1:** Reflectance spectra of a cavity mirror (a) and a pump mirror (b) which has a region of high transmittance around 808nm.

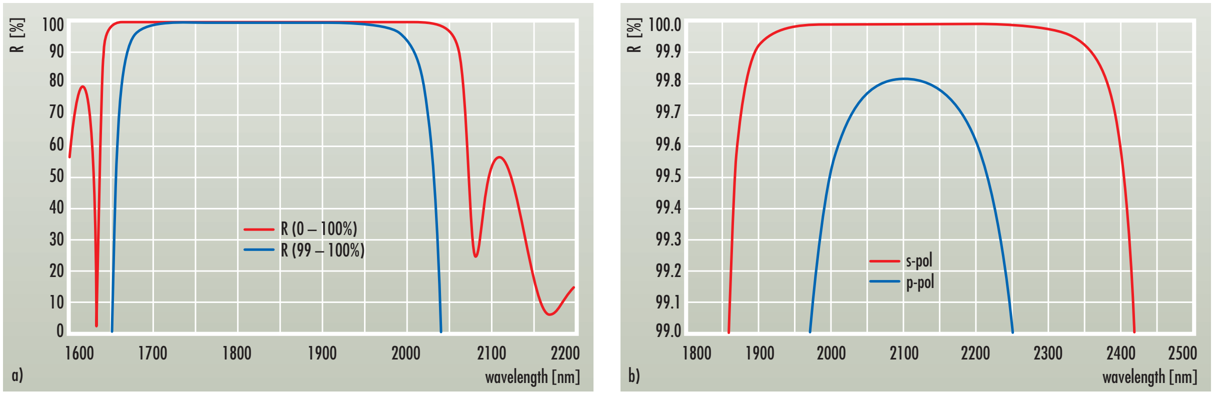


**Figure 2:** Reflectance spectra of a cavity mirror for 2010nm which supresses the 2100nm line (a) and a turning mirror for 2100nm (b)

- HR cavity, pump and turning mirrors with R > 99.9% at AOI = 0° and at AOI = 45° for s-polarization, R > 99.8 % at AOI = 45° for p-polarized light
- High laser induced damage thresholds

# OUTPUT COUPLERS AND BEAMSPLITTERS

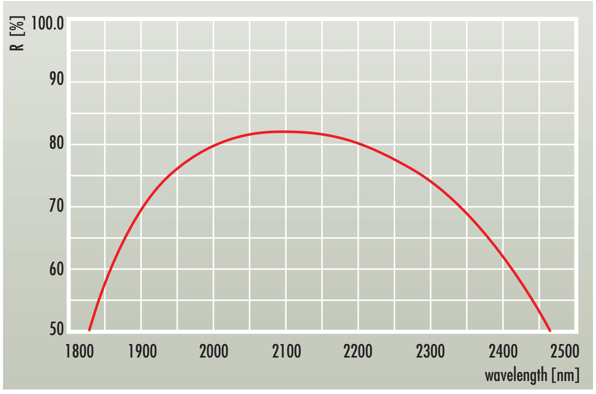


**Figure 3:** Reflectance spectrum of an output coupler with R = 82 % at 2100nm

Beam splitters and output couplers with precisely adjusted degree of reflectivity:

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

# SPECIAL COMPONENTS

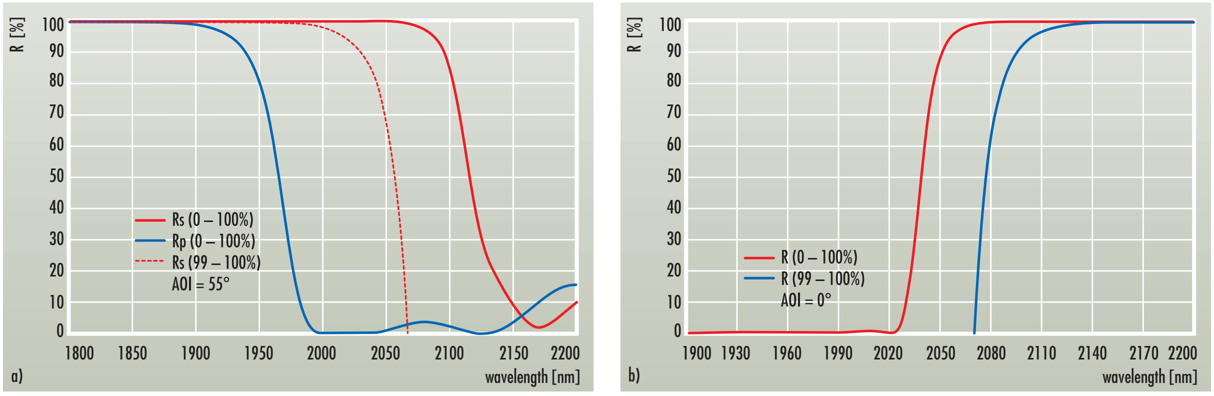


**Figure 4:** Reflectance spectra of a thin film polarizer for 2010nm (Rs > 99.8 %, Rp < 2 %, AOI = 55°) (a) and a steep edge filter for the separation of the 2010nm and 2100nm lines (b)

Thin film polarizers:

- Separation of the s- and p-polarized component of the light (s-polarized light is reflected and p-polarized light is transmitted)
- TFPs can be produced for AOI > 40°, but polarization is most efficient and appears in a broad wavelength range if AOI ≈ 55° (Brewster angle) is used

# COMPONENTS FOR Er:YAG LASERS

- HR cavity and turning mirrors
- Reflectivity: R > 99.9 % at AOI = 0°, R > 99.8 % at AOI = 45° for random polarized light
- High damage thresholds (400 J/cm² at 400 µs)
- Pump mirrors with high transmittance between 800 nm and 1100 nm for pumping with a Nd:YAG laser or a diode laser

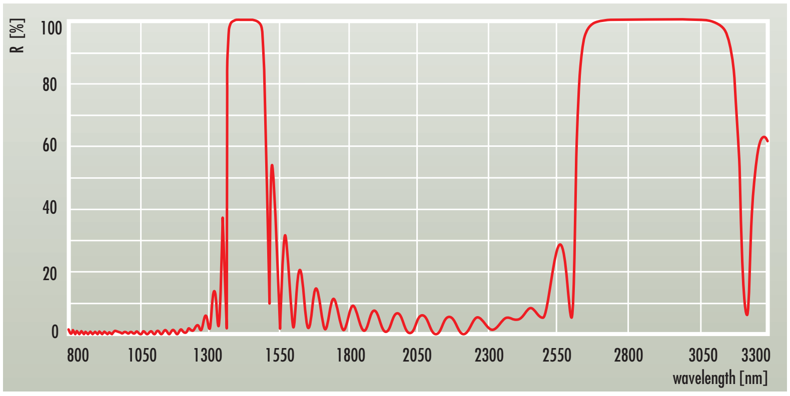


**Figure 1:** Reflectance spectrum of a HR cavity mirror with a HT region between 800 nm and 1100 nm

- Dual wavelength turning mirrors (e.g. HRr (45°, 2940 nm) > 99.5 % + Rr (45°, 630–655 nm) > 95 %)
- Beam splitters and beam combiners, e.g. HR (45°, 2940 nm) > 99% + HT (45°, 630–655 nm) > 80 %
- These components allow to use a He-Ne laser or a diode laser between 635 nm–655 nm for the alignment of the optical system.

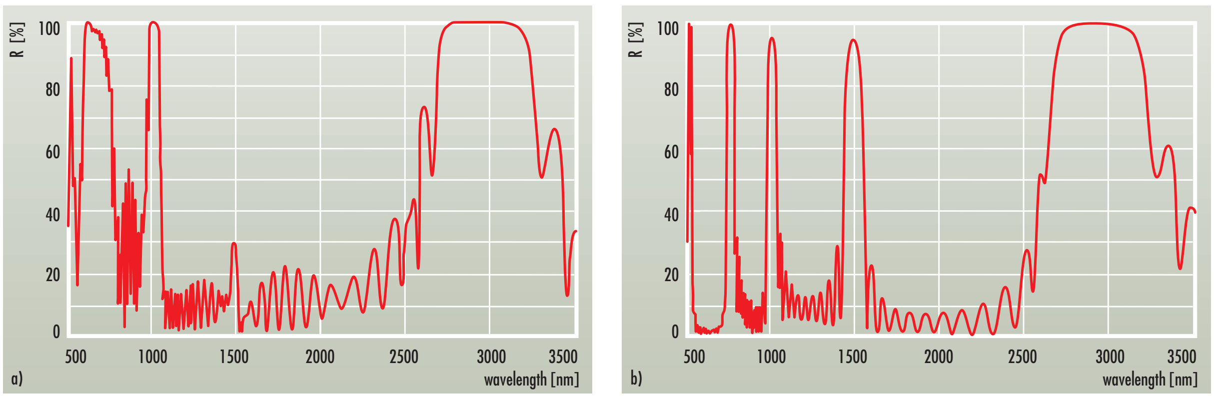


**Figure 2:** Reflectance spectra of a dual wavelength turning mirror (a) and a separator/combiner (b) for 2940 nm and a pilot laser between 630 nm and 655nm

# COMPONENTS FOR Er:YAG LASERS AND THE 3 µm REGION

## OUTPUT COUPLERS AND LENSES

- Output couplers with precisely adjusted degree of reflectivity (tolerances of ±1% at reflectivities between 70% and 90%)
- AR coatings with residual reflectivities R < 0.2% on the rear side of output couplers as well as on lenses and windows made of sapphire, undoped YAG, $CaF_2$ or Infrasil®
  (for substrate materials see pages 68–69)

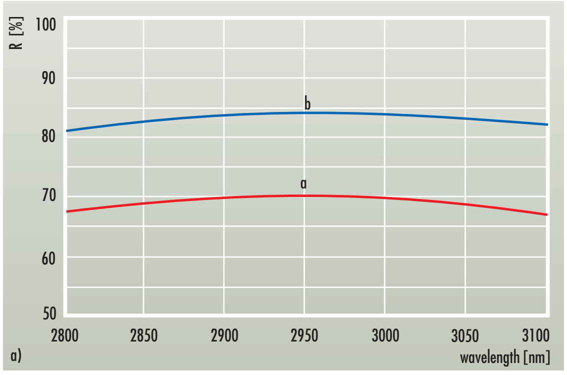


**Figure 3:** Reflectance spectra of output couplers with R=70% (a) and R=84% (b)

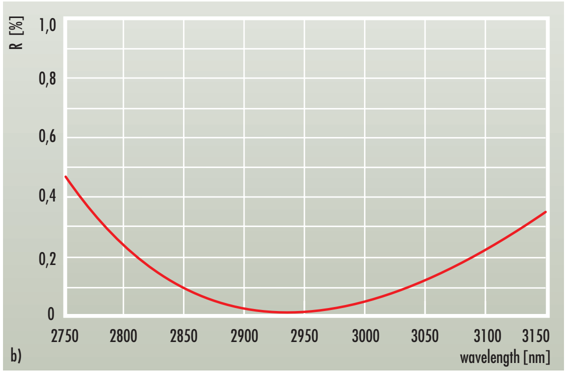


**Figure 4:** Reflectance spectrum of an AR-coating for 2,94 µm on sapphire

## COMPONENTS FOR OTHER LASERS AROUND 3µm

The fundamental effect which is especially used for the medical application of lasers emitting light between 2.6–3.4µm is the strong absorption of water in this wavelength range. Between 2.6µm and 2.8µm the absorption of water is still stronger than at 2.94µm (Er:YAG laser) which makes lasers working 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 3µm 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 also coatings for the critical 2.6–2.8µm region. Figure 5 shows as example a HR mirror centered at 2.8µm with a reflectivity R > 99.7%.

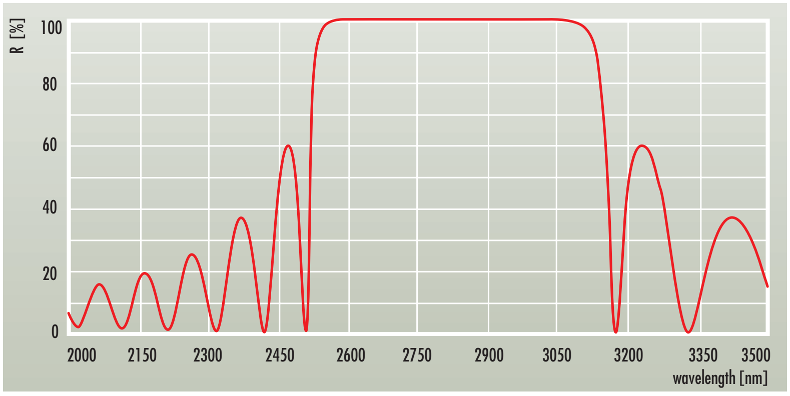


**Figure 5:** Reflectance spectrum of a HR mirror for 2.8 µm with R > 99.7%

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# OPTICS FOR OPTICAL OSCILLATORS (OPOs)

Mirrors for OPOs are optimized for a good separation of the pump laser, signal and idler wavelengths as well as for a broad reflectance band of the signal wavelengths and a wide range of high transmittance for the idler wavelengths. Moreover, all optics show smooth group delay (GD) and group velocity dispersion (GVD) spectra. Thus, wide tuning ranges for the signal and the idler wavelengths can be achieved. Broadband output couplers are also available. Centre wavelength and tuning range can be adjusted according to customers specifications.

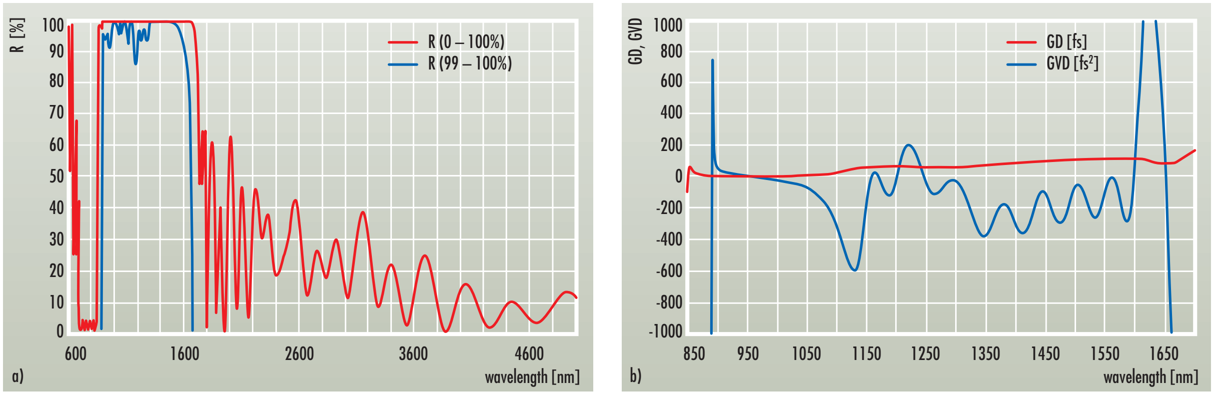


**Figure 1:** Reflectance (a), GD and GVD (b) spectra of an OPO incoupling mirror

This type of mirrors separates the pump and signal wavelengths while supressing the idler wavelength: R (0°, 700 – 850 nm < 10 %) + HR (0°, 900 – 1600 nm) > 99.8 % + R (0°, 1800 – 5000 nm) < 60 %

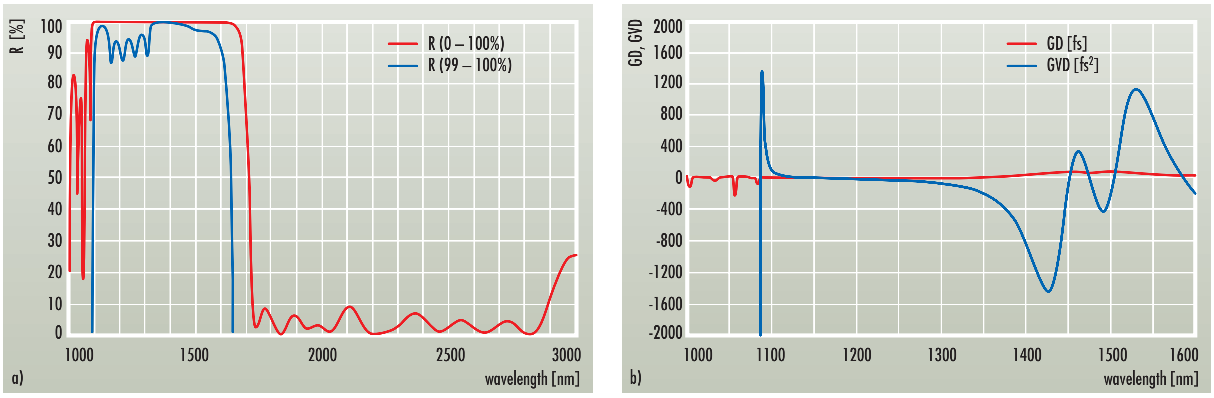


**Figure 2:** Reflectance (a), GD and GVD (b) spectra of a separator for the signal and idler wavelengths

- Edge filters separating signal and idler wavelengths can be used as broadband outcoupling mirrors for the idler: HR (0°, 1100 – 1600 nm) > 99.8 % + R (0°, 1730 – 2900 nm) < 10 %

- We recommend undoped YAG or sapphire as substrate material if high transmission for the idler wavelengths is required (see also page 69 for transmission curves).

- These filters can also be provided with a band of high reflectance or high transmittance for the pump wavelength.

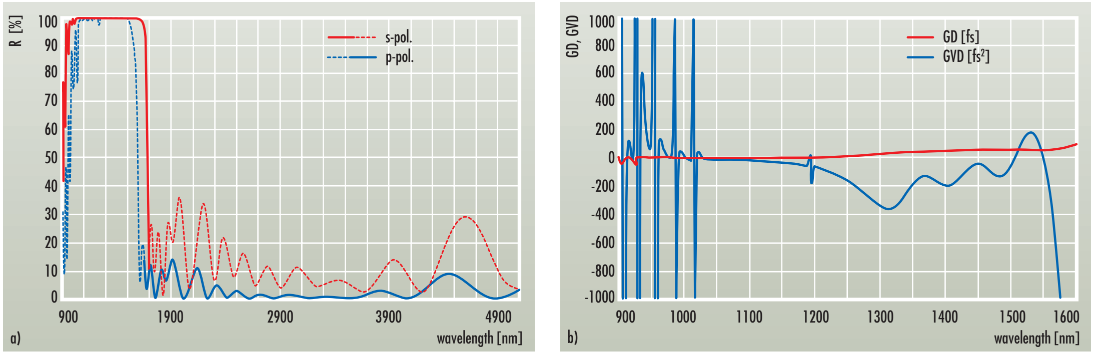


**Figure 3:** Reflectance (a), GD and GVD (b) spectra (reflected beam) of a separator for signal and idler working at AOI = 45°

A very small distance between the signal and idler wavelengths is achieved if the signal beam is s-polarized while the idler is p-polarized: HRs (45°, 1030–1560 nm) > 99.9 % + Rp (45°, 1650–5000 nm) < 15 %

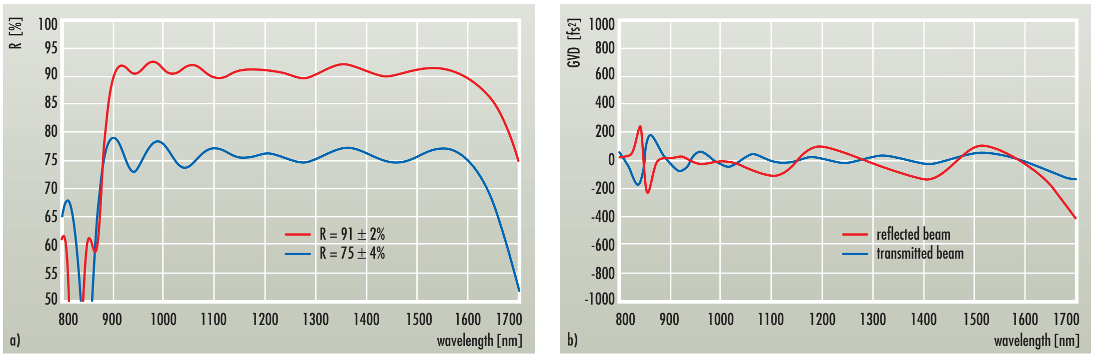


**Figure 4:** Reflectance (a) and GVD (b) spectra of different broadband output couplers for the signal wavelengths

Please note the smooth GVD spectra. The GVD spectra shown are calculated for the 75% output coupler, but the spectra for other reflectivities are very similar.

# COATINGS ON NONLINEAR OPTICAL CRYSTALS

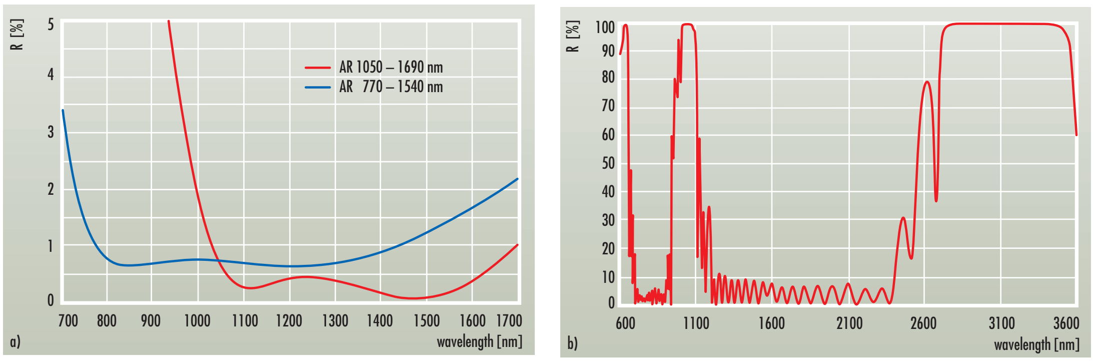


**Figure 5:** Reflectance spectra of different broadband AR coatings (a) and of a double reflector with two regions of high transmittance (b) on lithium niobate

(a): AR (0°, 770–1540 nm) < 1.5 %; AR (0°, 1050–1690 nm) < 1 %
(b): HR (0°, 1010–1075 + 2750–3450 nm) > 99.8 % + R (0°, 700–900 + 1200–2400 nm) < 10 %
All AR coatings according to customers specifications.