CATALOG 2023

LASEROPTIK

Home of high power optics and coatings

Individual coatings unlimited shapes

LASEROPTIK GmbH
Horster Str. 20, 30826 Garbsen, Germany
Phone +49 5131 4597-0, Fax +49 5131 4597-20
E-mail: service@laseroptik.de

eShop and configurator: www.laseroptik.de/loop

www.laseroptik.com

LASEROPTIK at a glance

- Location: Garbsen (Hanover), Germany
- Founded: 1984
- Employees: > 100

- Coating machines: > 40 (18 IBS)
- Techniques: TE, EBE, IAD, IP, MS, IBS, ALD
- ISO 9001:2015 certified
- 24h coating service with LASEROPTIK EXPRESS
- > 1,200 coatings available on LOOP, the **L**ASER**O**PTIK **O**nline **P**ortal

- 180,000 coated optics/year on average

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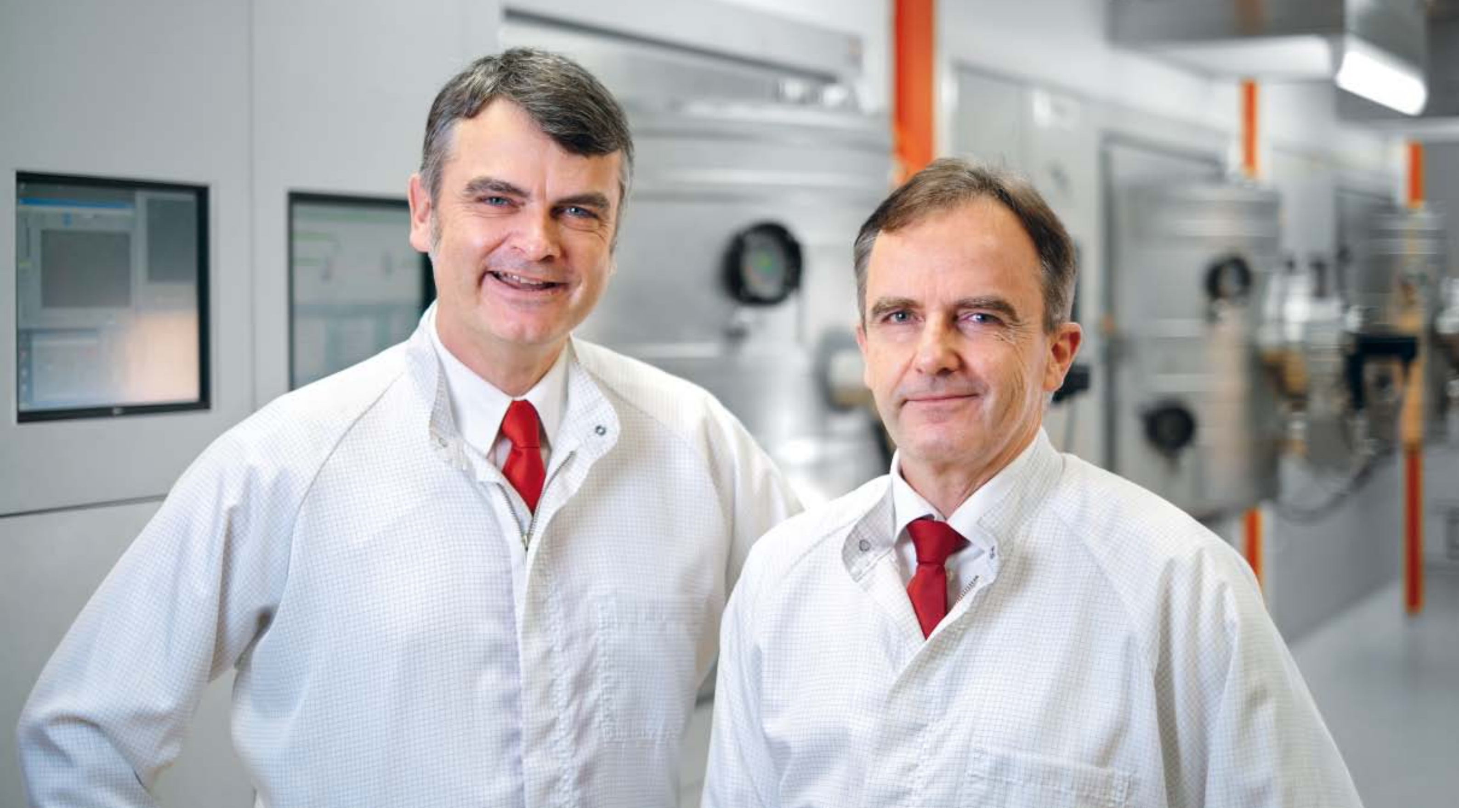


Welcome to the home of high power optics and coatings

LASEROPTIK focusses on the development and production of optical coatings and components for high power laser applications in industry, medicine and research.

With nearly forty years of experience the company is now run by us, as the second generation. LASEROPTIK's number one objective is to help our customers build better lasers by providing excellent coated optics.

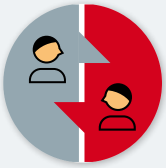
This catalog provides you with broad information about the background of our company, our coatings and substrates, and about what LASEROPTIK is able to do for you in the field of thin film coatings and laser optics.

As these 132 pages cannot give the answer to every question please contact us and we will find a solution to your needs together.

Dr. Wolfgang Ebert

Martin Ebert

Contact



For any matter or request contact our

Service desk

service@laseroptik.de
Tel. +49 5131 4597-0

Coating design – IBS on large optics and dispersive mirrors
Dr. Thomas Willemsen
twillemsen@laseroptik.de
Tel. +49 5131 4597-481

Coating design – IBS on fibers and dispersive mirrors
Tobias Groß
tgross@laseroptik.de
Tel. +49 5131 4597-414

Coating design – MS and spaceborne optics
Martin Ebert
mebert@laseroptik.de
Tel. +49 5131 4597-30

Stock components and coating design
Dr. Christoph Gödeker
cgoedeker@laseroptik.de
Tel. +49 5131 4597-54

LOOP and coating design – AR
Heiko Hänsel
hhaensel@laseroptik.de
Tel. +49 5131 4597-17

Coating design – IAD, IBS
Dr. Michael Kennedy
mkennedy@laseroptik.de
Tel. +49 5131 4597-52

Structured coatings and coating design
Werner Moorhoff
wmoorhoff@laseroptik.de
Tel. +49 5131 4597-12

President
Dr. Wolfgang Ebert
webert@laseroptik.de
Tel. +49 5131 4597-0

Starting a request

For a quotation we need to know at least the following information:

1. Substrates:

- Material, quantity and size ....
- For curved surfaces: radius of curvature and used aperture ....
- Supplied by customer or LASEROPTIK? ....

2. Coating:

- Wavelengths, angle of incidence and polarization ....
- Surface to be coated (both, plane, curved, wedged side?) ....

Helpful information, if available:

3. LIDT:

- Beam radius/ profile ....
- Pulsed: J/cm², repetition-rate and pulse duration ....
- cw: kW per cm beam diameter ....

If not mentioned otherwise we will offer for

- Standard laser power ....
- Normal environmental conditions (use in air at room temperature) ....

4. Your contact data:

- Name
- Name of company
- Department/institute
- Address
- Phone number
- E-mail address

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+49 5131 4597-20
service@laseroptik.de
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Get your substrates and coatings
the easy, secure and fast way!

We keep a stock of standard substrates and a coating machine for customers who need a very fast turnaround. For this we add an EXPRESS surcharge to your invoice.

You can send us your substrates or you can choose from the large LASEROPTIK substrate stock.

The following three options are available:

24 hours

LASEROPTIK EXPRESS 24h:
An EXPRESS 24h time slot starts on any working day at 9 a.m. (CET) and ends at 9 a.m. (CET) on the following working day. At the end of the slot the substrates are ready for shipment. For coating of both sides we need two slots.

1–2 weeks

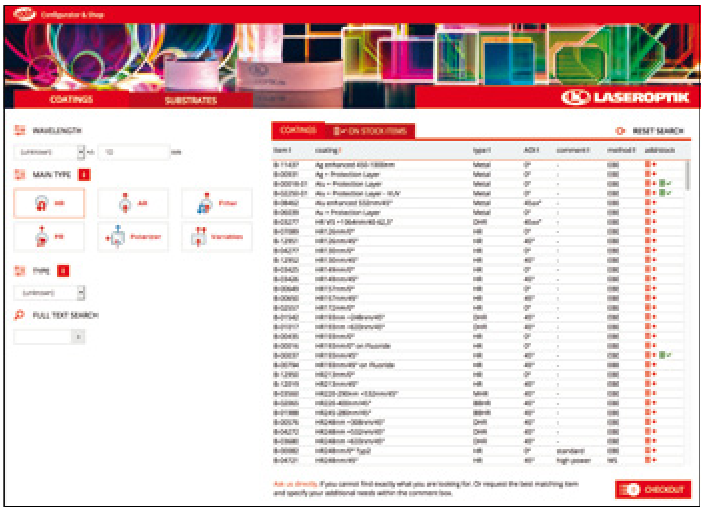
LASEROPTIK EXPRESS SAFE:
EXPRESS SAFE means we will deliver within 1–2 weeks after an order has been confirmed or, in case of customer owned substrates, after receiving the substrates.

3 weeks

LASEROPTIK EXPRESS EXTRA:
Non-standard substrates which cannot be delivered from the LASEROPTIK substrate stock will be manufactured on customer demand.

Due to rapid prototyping capacities we can realize a turn-around time of just 3 weeks, including the coating.

In addition to the EXPRESS coating machine we currently use more than 40 machines partly with sputter technique or ion assistance. Please ask for available time slots.



www.laseroptik.de/loop
Configure and buy your laser optics online!

LOOP is the name of our LASEROPTIK Online Portal. LOOP gives you online access to a selection of more than 1,200 coatings and 390 standard substrates out of our data base stock with 26,000 different coating designs and 12,000 own substrates.

The benefits of LOOP:
- Configurator & shop
- Find coatings (**B**-articles) and substrates (**S**-articles).
- Configure your own optics.
- Send your request online.
- Order stock components online.

1) Choose your coatings — *2) Select substrate or specify your own one* — *Create your own optic or find stock components*

B-*article* — **S**-*article* — **L**-*article*

Find your coating type in the glossary and/or search directly by wavelength. Every coating is specified by a computed curve and tolerances. If available, ready coated stock components are listed below the coating runs.

If you do not find exactly what you are looking for, take the best matching article and specify your additional needs. We will offer you an optimized coating or substrate.


SPECTOR
SOURCERER

Coating guide

Glossary of coating types

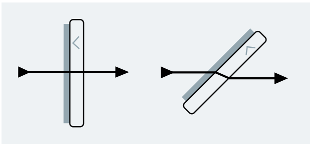
Thin film basics

Production methods

Glossary

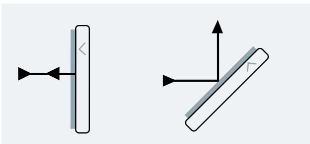
Main types

AR



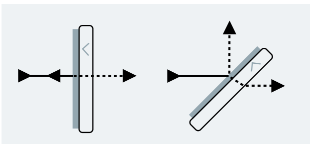
Anti-Reflection Coating *page 9*
Minimizes surface reflection of substrates
for highest transmission, coated on both sides, used as
– window
or, to minimize back side reflection of beam splitters, used as
– rear side coating

HR



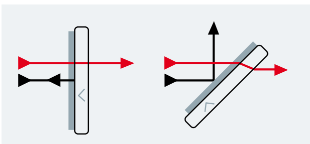
High Reflection Coating *page 9*
for highest reflection, used as
– cavity mirror
– full reflector
– bending mirror
also available as
– metallic mirror

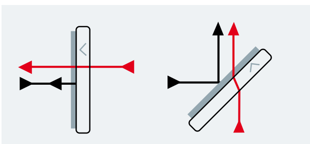
PR



Partial Reflection Coating *page 10*
for splitting or reducing the incoming light, used as
– partial reflector,
– output coupler,
– attenuator,
– beam splitter,
also available as
– non polarizing beam splitter

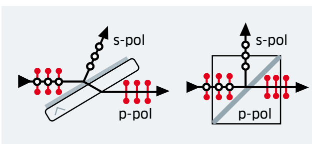
Filter





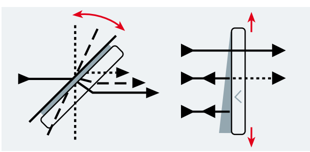
HR / PR + AR Coating *page 10*
Combination of AR and HR or PR coatings for
separating wavelengths, used as
– long / short wave pass
– steep edge filter
– band pass / interference filter
– notch / negative filter
– dichroic filter
– harmonic beam separator
or for combining laser beams, used as
– beam sampler
– combining mirror
– pump mirror

Polarizer

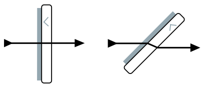


Polarizer *page 11*
Separates the polarizations, coated on plates for
– thin film polarizer (TFP)
also available for
– cube polarizer
– broadband polarizer
works also as
– polarization sampler

Variables



Variable Attenuator *page 11, 48*
Gradient Coating
for changing the transmission/reflection ratio with the angle,
used as
– variable attenuator
or with the beam position used as
– gradient output coupler
– gradient attenuator
– gradient pass filter
– gradient interference filter

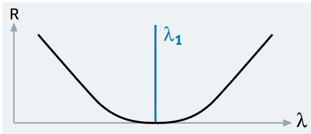


AR Anti-Reflection

Minimizes surface reflection

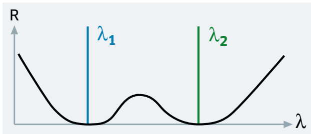
Types

VAR
Single AR Coating
Lowest reflection for one single wavelength or a narrow band



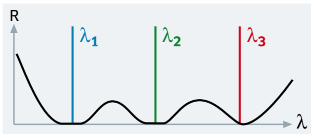
Examples on page 31, 39, 45

DAR
Double AR Coating
Lowest reflection, optimized for two wavelengths



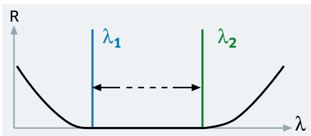
Examples on page 33, 40

TAR
Triple AR Coating
Lowest reflection, optimized for three wavelengths



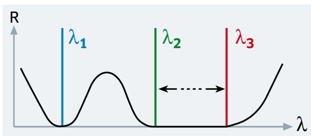
Examples on page 40, 41

BBAR
Broadband AR Coating
Lowest reflection, optimized for a broadband wavelength range



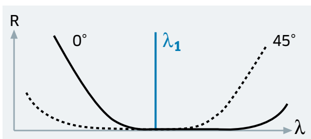
Examples on page 14, 37

MAR
Multiple AR Coating
Combination of AR types

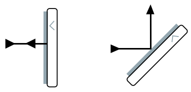


Examples on page 43, 57

WAR
Wide Angle AR Coating
Optimized for a wide angle of incidence (e.g. 0–45°), also available for a broadband wavelength range



Examples on page 35

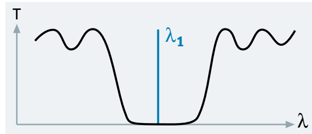


HR High Reflection

Maximizes surface reflection

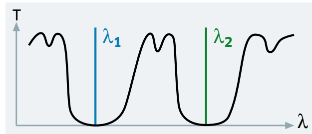
Types

HR
Single HR Coating
Highest reflection for one single wavelength or a narrow band



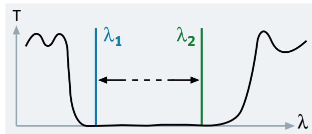
Examples on page 31, 35, 37, 45

DHR
Double HR Coating
Highest reflection, optimized for two wavelengths, also available as HR + adjusting layer



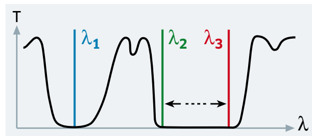
Examples on page 33, 39, 40

BBHR
Broadband HR Coating
Highest reflection, optimized for a broadband wavelength range



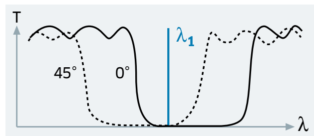
Examples on page 33, 35

MHR
Multiple HR Coating
Combination of HR types



Examples on page 40, 41

WHR
Wide Angle HR Coating
Highest reflection, optimized for a wide angle of incidence (e.g. 0–45°), also available for a broadband wavelength range

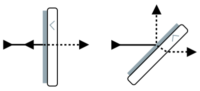


Examples on page 33, 39

METAL
Metal Coatings
Achieve high reflection values over a broad wavelength range. Typical coatings: *Ag, Au, Al*

Examples on page 31, 54, 55

For HR coatings with areas of high transmission see coating type „Filter“ (HR/PR + HT combined), page 10.



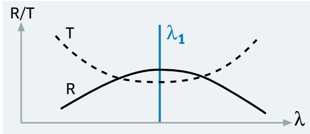
PR Partial Reflection

Splits or reduces incoming light

Types

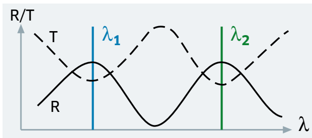
PR with fixed reflection/transmission ratio

PR
Single PR Coating
Constant reflection/transmission for one single wavelength or a narrow band



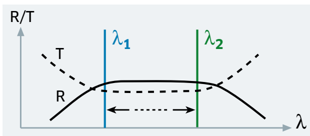
Examples on page 14, 31, 33

DPR
Double PR Coating
Constant reflection/transmission for two wavelengths, ratio can be optimized separately



Examples on page 41

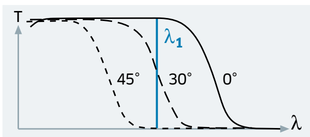
BBPR
Broadband PR Coating
Constant reflection/transmission for a broadband wavelength range



Examples on page 35, 45, 59

PR changes reflection/transmission ratio with AOI

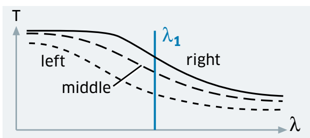
VA
Variable Attenuator
Transmission can be varied continuously by changing the AOI (e.g. 0–45°), also available as Inversely Variable Attenuator (IVA)



Examples on page 33, 43, 48, 49

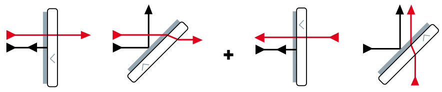
PR changes reflection/transmission ratio with beam position

GOC
Gradient Output Coupler
Transmission can be varied continuously by shifting a rectangular plate across the beam (right-middle-left position)



Examples on page 39, 50, 51

For PR coatings with areas of high transmission see coating type "Filter".

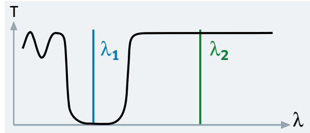


Filter

Separates or combines wavelengths

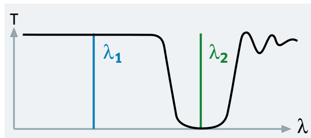
Types

LP
Long Wave Pass Coating
HR for one single wavelength or a narrow band and HT for a longer wavelength or band, also available as Partial Reflector



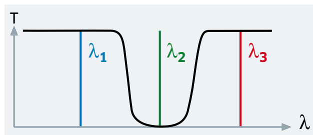
Examples on page 37, 40, 43, 57

SP
Short Wave Pass Coating
HR for one single wavelength or a narrow band and HT for a shorter wavelength or band, also available as Partial Reflector



Examples on page 39, 40, 41, 43

NF
Notch Filter Coating
HR for one single wavelength or a narrow band and HT for a shorter and longer wavelength or band, also available as Partial Reflector

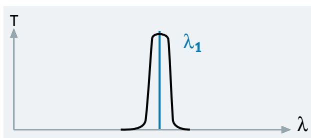


Examples on page 40, 41, 57

MP
Multi Pass Coating
Combination of several HR and HT wavelength areas, also available as Partial Reflector

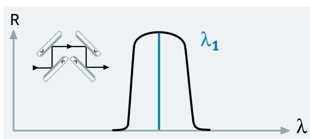
Examples on page 40, 59

BP
Band Pass Coating
Selecting a small wavelength area, sometimes also known as IF (Interference Filter), FWHM of some tens of nm down to < 1 nm, sputtered coating

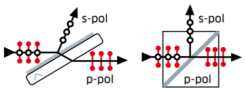


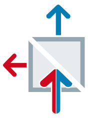
Examples on page 37, 43

REF
Reflection Filter Coating
Scanning and selecting a small wavelength area by tilting 4 reflection filter plates simultaneously. No change in the final beam direction



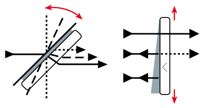
Examples on page 52, 53

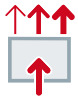




Polarizer

Separates or combines the polarizations





Variables

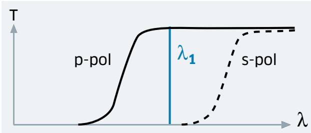
Change transmission/reflection with the angle or the beam position

Types

TFP

Thin Film Polarizer

Separates s- from p-polarized light, effective on a plate with a fixed AOI, available from 45° to 74°, commonly used with Brewster angle

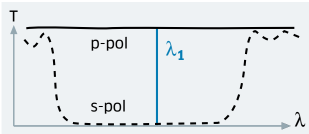


Examples on page 33, 39, 46, 47

CP

Cube Polarizer Coating

Separates s- from p-polarized light, effective inside a cube made out of two prisms, commonly with AOI = 45°

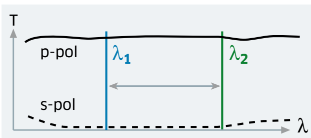


Examples on page 46, 47

BBPOL

Broadband Polarizer

Separates s- from p-polarized light for a broadband range, effective on a plate or inside a cube with a fixed AOI



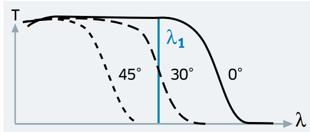
Examples on page 46, 47

Types

VA

Variable Attenuator

Transmission can be varied continuously by changing the AOI (e.g. 0–45°), also available as Inversely Variable Attenuator (IVA)

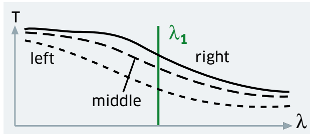


Examples on page 33, 43, 48, 49

GOC

Gradient Output Coupler

Transmission can be varied continuously by shifting a rectangular plate across the beam (right-middle-left position)

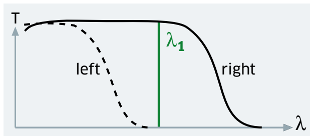


Examples on page 39, 50, 51

GP

Gradient Pass Coating

By shifting a rectangular plate across the beam, the incoming light passes through (right position) or will be blocked (left position), shown as Gradient Short Pass GSP, also available as Gradient Long Pass GLP

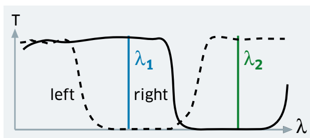


Examples on page 50, 51

GNF

Gradient Notch Filter

By shifting a rectangular plate across the beam, the band around λ_1 passes through (right position) or will be blocked (left position) and reversely for λ_2

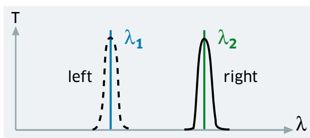


Examples on page 50, 51

GIF

Gradient Interference Filter

By shifting a rectangular plate across the beam (left-right position), various wavelengths can be selected, e.g. for fast external change of multiline noble gas ion lasers



Examples on page 50, 51

Thin film basics

The history of coatings

Dr. Johannes Ebert († 31.07.2019, in loving memory) with an early version of the "Ebert-gun"

A GLANCE INTO THE PAST – WITH A GLIMPSE INTO THE FUTURE

by our founder Dr. Johannes Ebert

The history of modern optical coating starts somewhere in the early part of the last century with the advent of high vacuum technology, one basic necessity for thin film deposition. Credit for the design of the first high vacuum pump (mercury-vapour condensation pump) belongs to Wolfgang Gaede, who filed a German patent application in 1907. Using this technique Robert Wichard Pohl produced thin silver films for Fabry-Perot applications two years later.

In 1934 Gerhard Bauer deposited films of alkali halides and noted their low reflection on quartz substrates. Only one year later Alexander Smakula introduced this discovery into the production at Zeiss-Jena. Bauer recognized that his films were less than perfectly dense, but were sufficient enough for the most optical instruments from camera to photocopier.

However, increased sophistication of optical instruments reinforced the search for high quality optical coatings. In 1985 using an electron microscope Karl H. Guenther could show the columnar structure of evaporated films. Voids running parallel to the columns contribute significantly to the undesirable qualities of the films. When compared to their bulk materials evaporated films are softer, weaker, less dense, and chemically less stable. They show internal stress and absorb more gases and water. Optically they have lower refractive indices, higher extinction coefficients and increased scatter.

Using standard techniques like Thermal Evaporation TE and Electron Beam Evaporation EBE (page 23) cost effective coatings can be made for a broad application range. However, as a result of their microstructure the thin films have a few disadvantages. Some of these problems can be solved by advanced (though more expensive) deposition technologies like the following.

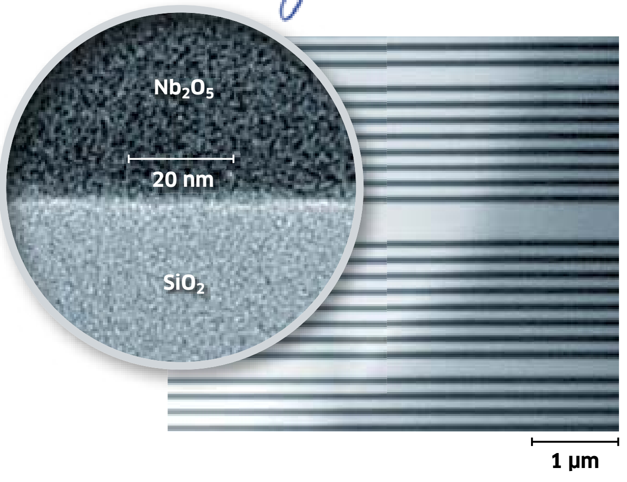
Ion Assisted Deposition IAD (page 24) introduced by the well-known Ebert-gun was a first approach to reduce the porosity of the coatings. But it was suitable for small facilities only. Newer Kaufman-ion sources were able to strike large areas. The drawback of these ion sources is their filament, because tungsten is co-evaporated and the coating thickness is limited by the life time of the filaments. The new ion accelerator of Loeb supported by a gas discharge in magnetic fields was constructed for satellite navigation and was working sufficiently first as an ion source in IAD and later in our IBS plants.

Ion Plating IP (page 25) delivers very hard layers due to high ion impact during deposition, comparable with coatings made by Magnetron Sputtering MS (page 26). Both methods can be used for applications where no porosity and high hardness as protection against particle impact are demanded.

Ion Beam Sputtering IBS (page 27) is a low rate process which gives the highest layer quality: On super-polished surfaces a reflectivity of 99.999% can be realized with absorption and scatter losses lower than 10 ppm. Additionally we developed the IBS method for 2 m long substrates in order to meet the needs of the producers for semiconductors and flat panel displays. Large round optics with a diameter of up to 550 mm can be used as well (page 74).

LASEROPTIK is ready for the future!

Johannes Ebert



TEM (Transmission Electron Microscopy) from an IBS bandpass coating with amorphous structure

Bases of calculation

Light falls from a medium (n_1) onto a thin film (n_2) which is laying on a substrate (n_3). At each interface one part of the light will be reflected and a second transmitted. Every part can be calculated by the Fresnel equations. For the interface n_1/n_2 you get:

For the s-polarization:

$$Rs = \left(\frac{N_1\cos\alpha - N_2\cos\beta}{N_1\cos\alpha + N_2\cos\beta}\right)^2$$

$$Ts = \left(\frac{2N_1\cos\alpha}{N_1\cos\alpha + N_2\cos\beta}\right)^2$$

For the p-polarization:

$$Rp = \left(\frac{N_2\cos\alpha - N_1\cos\beta}{N_2\cos\alpha + N_1\cos\beta}\right)^2$$

$$Tp = \left(\frac{2N_1\cos\alpha}{N_2\cos\alpha + N_1\cos\beta}\right)^2$$

$N_1 = n_1 + ik_1$; $N_2 = n_2 + ik_2$ are the complex indices of refraction, the extinction coefficients k_1 and k_2 relate to absorption.

α is the angle of incidence, β the angle of refraction and can be calculated using Snell's law: $N_1\sin\alpha = N_2\sin\beta$.

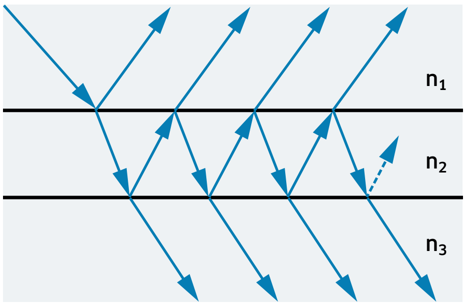
With normal incidence ($\alpha = 0°$) and zero absorption the terms become very simple:

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \quad ; \quad T = \frac{4n_1n_2}{(n_1 + n_2)^2}$$

The same formulas can be used for the interface n_2/n_3.
All reflected parts and the transmitted parts will interfere. The conditions for interference depend on the optical path difference OPD. For the reflected parts: $OPD = 2n_2d\cos\beta$; where d describes the physical thickness of the layer.

The interference for a wavelength λ will be constructive for $OPD = m\lambda$ and destructive for $OPD = (m+½)\,\lambda$; (m = 0, 1, 2, 3, ...)

So, the total reflected and transmitted light can be calculated by the angle of incidence, refractive indices and film thickness.



The reflection with normal incidence becomes zero for a wavelength λ by using a monolayer with an optical thickness of $\lambda/4$ if the medium is air ($n_1 = 1$) and $n_2 = \sqrt{n_3}$. This is the easiest way to produce an anti-reflection coating. For substrates where it is not possible to find a coating material with matching refractive index you need more layers (page 14).

If more than one layer is deposited the described process occurs at every interface between the layers and the total mathematical calculation becomes more difficult but it is still solvable.

The most effective way to get a high reflective coating for the wavelength λ is to stack alternately two different coating materials with an optical layer thickness of $\lambda/4$ each. With an increasing number of layer pairs the reflection will grow up steadily to 100%, only limited by the losses through absorption and scattering, while the transmission falls down to 0% (page 14).

One frequently asked question is: How thick is a coating? To give you an estimation: A normal human hair has a thickness of about 50–100 µm, a dielectric mirror coating HR 1064 nm / 0° has about 5 µm and a single layer AR 248 nm / 0° about 0.05 µm.

On the following pages you will find some more elementary basics of thin film coatings.

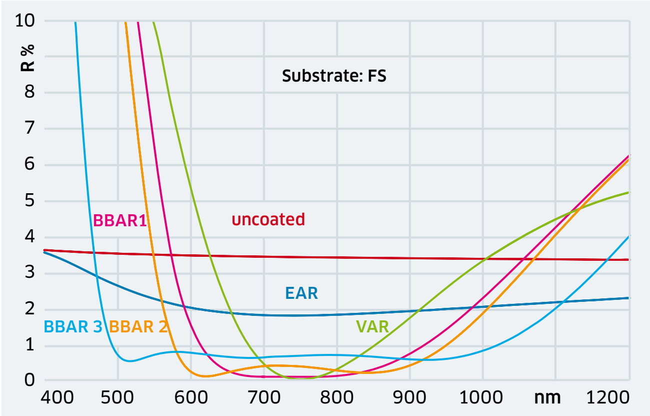
Number of layers

Anti-Reflection coatings (AR)
Number of layers

A simple single layer (EAR) decreases the natural reflection of an uncoated surface, best if the refractive index of the layer is near to the square root of the index of the substrate. For Fused Silica (FS) no coating material can be found which fits perfectly. The best matching material is MgF_2.

By using two layers of different coating materials the reflection can be minimized for one single wavelength (VAR).

Anti-reflection coatings even for broadband areas (BBAR) can be realized through an increased number of layers. The larger the bandwidth the higher the losses in transmission due to the increased reflection.



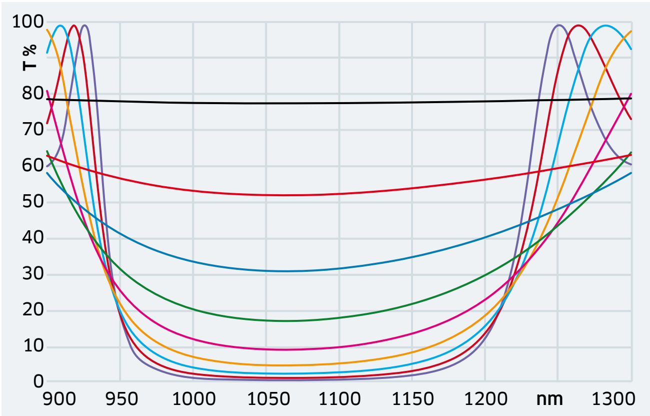
Some different anti-reflection coatings on FS with AOI = 0°

Partial Reflectors (PR)
Number of layers

Most PR coatings are produced by alternatively applying layers of two distinct coating materials with different refractive indices.

By increasing the number of layers the transmission decreases and the reflection increases.

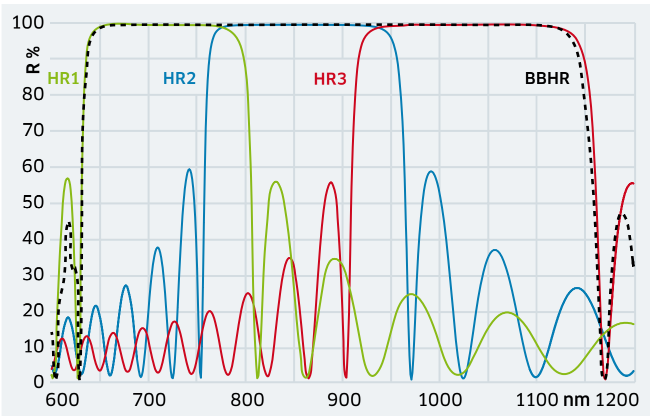
You can achieve any transmission value by changing the thickness of some of the layers.



The transmission curves of different multilayer stacks (number of layers = 1, 3, 5, ... 17) for 1064 nm/0°

High Reflectors (HR)
Number of layers

To reach high reflection over a broad wavelength area you have to increase the number of layers. An easy way to realize broadband HR (BBHR) is to stack single HR systems on each other. The HR system for the most critical wavelength (with the highest laser power and highest reflection) has to be on top.

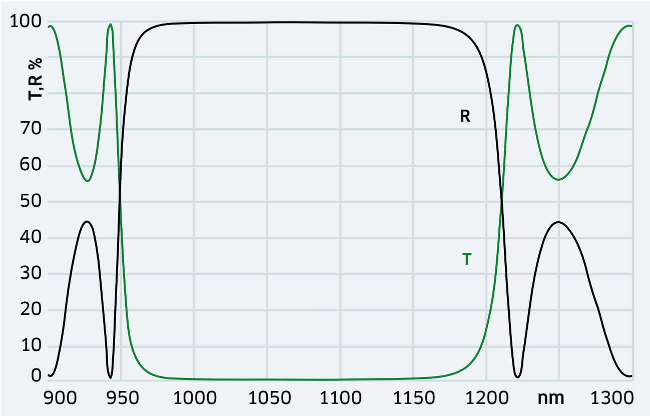


How to create a broadband HR coating HR 650-1120 nm/0° out of three single HR systems

HR standards

R + T = 1 – losses

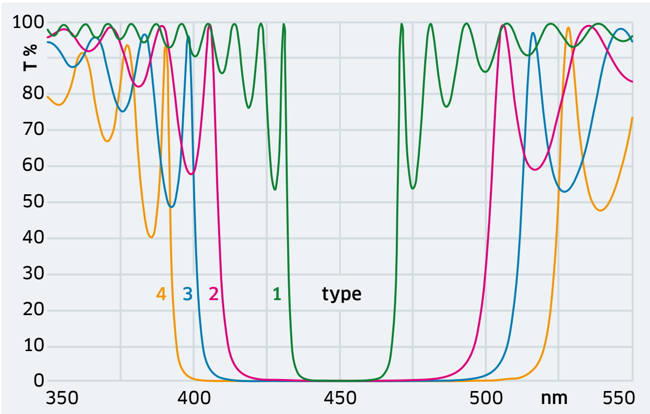
Practically the reflection for coatings with low losses through absorption and scattering is R = 1 – T.
For 1064 nm / 0° a standard EBE-coating has absorption < 20 ppm and scattering < 150 ppm. Lower losses (< 10 ppm) can be achieved with IBS coatings (page 78). For mirrors it is easier to measure the transmission than reflection with standard spectrophotometers. For this reason we normally provide transmission curves for mirrors.



Transmission and reflection of a standard HR 1064 nm / 0°

HR – bandwidth

Different coating material combinations have different bandwidths. Not every combination is suitable for every wavelength or application.

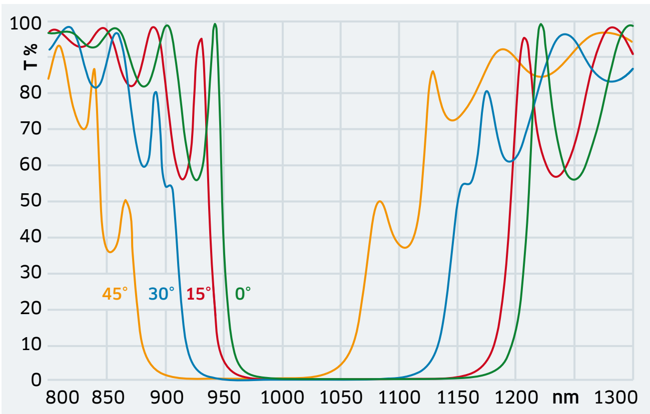


The transmission of four different types of coating material combinations

Wavelength shift with changing AOI

With increasing angle of incidence (AOI) the central wavelength of a dielectric coating shifts to shorter wavelengths.

The example shows a standard HR 1064 nm / 0°.
It shifts about 10% when using AOI = 45° but only less than 1% when using AOI < 13°.

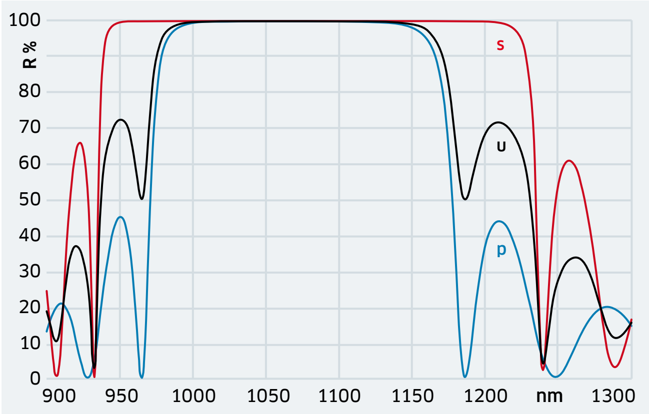


Wavelength shift with changing AOI of a standard HR 1064 nm / 0°

HR – polarization

Dielectric mirrors have a broader reflection band and higher reflection for s-polarized light compared to p-polarized light.

The example shows a standard HR 1064 nm/45° that will achieve:
Rs > 99.9%
Ru > 99.8%
Rp > 99.7%

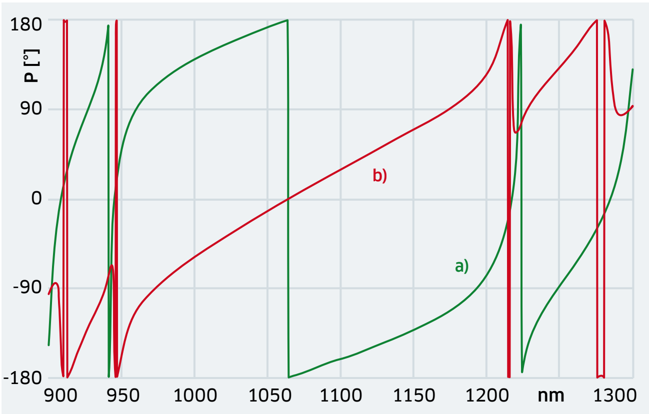


Reflection of a standard HR 1064 nm/45° with different polarizations

HR – phase

In the reflected phase a standard mirror has a shift of 180°. By a simple variation of the top layer thickness the phase falls down to zero.
The example shows the reflected phase of a mirror HR 1064 nm/0°
a) standard design
b) phase optimized

If necessary every coating can be optimized for its phase specification.



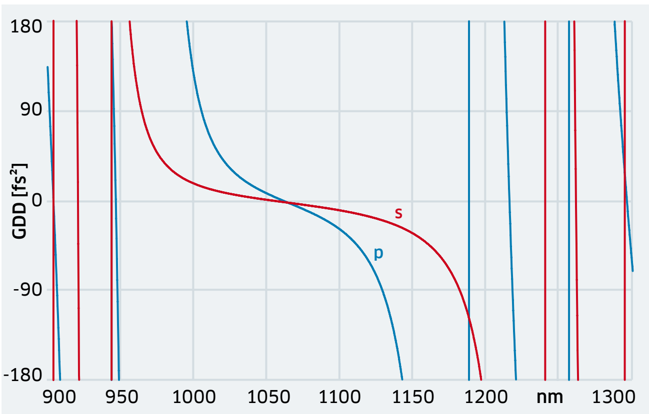
Reflected phase of different coating designs HR 1064 nm/0°

HR – GDD

(Group Delay Dispersion)

Standard mirrors have already a low GDD but only at the center wavelength as shown here for standard mirror HR 1064 nm/45°.

Especially for fs-laser systems the GDD becomes important. LASEROPTIK can supply GDD optimized optics to your specifications.



GDD of a standard mirror HR 1064 nm/45°

For more information see chapter "Dispersive coatings" starting on page 61.

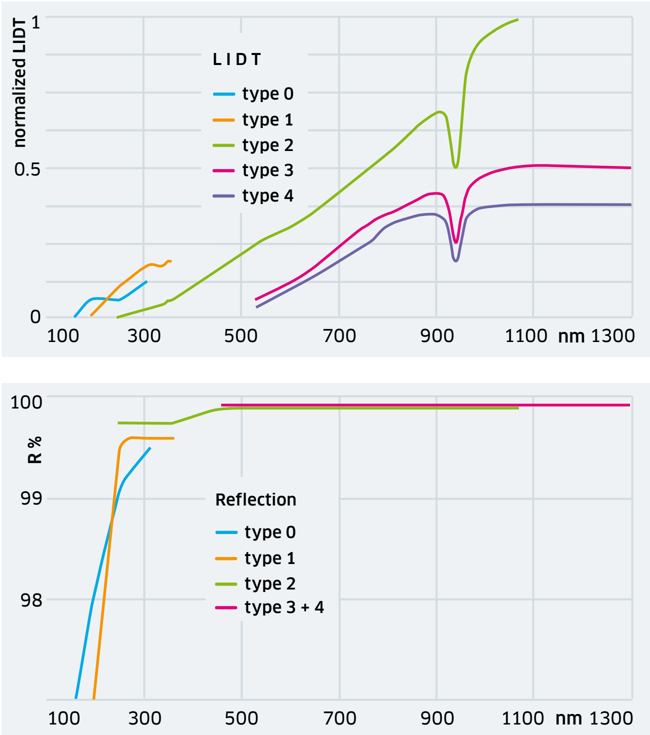
LIDT
(Laser Induced Damage Threshold)

The LIDT of a coating strongly depends on coating materials and production methods.

Normally coatings with the highest LIDT will not have the highest reflection.

The example shows LIDT (pulsed laser) and reflection for different mirror types HR (0°) made with different coating materials (EBE).

The peaks in LIDT result from the water band at 940 nm, can be minimized by using IAD or sputtered coatings.



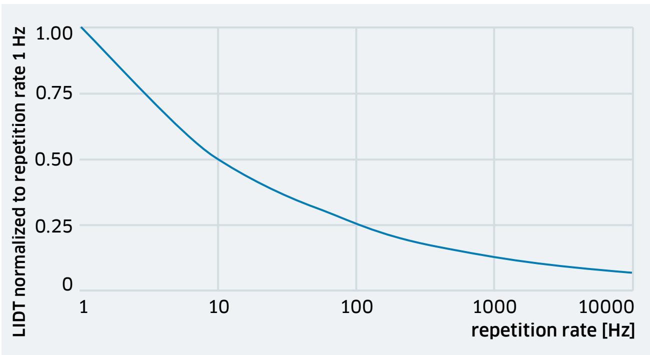
LIDT and reflection shown for different mirror types HR (0°) made with different coating materials (EBE)

The LIDT also depends on the repetition rate and pulse duration τ.

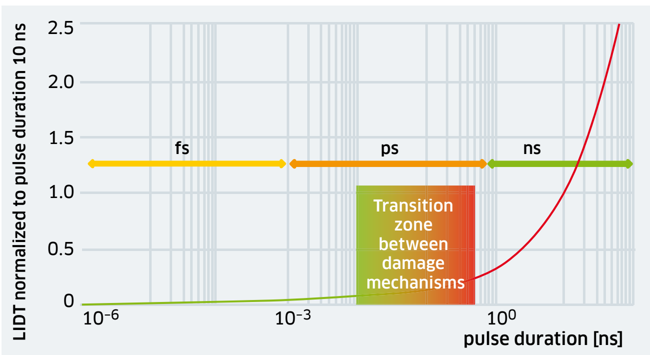
Rules of thumb exist for pulsed laser systems:

1) LIDT $\sim 2^{-\lg \text{(rep-rate)}}$

2) LIDT $\sim \tau^{1/2}$ (τ > 0.1 ns)
LIDT $\sim \tau^{1/3}$ (τ < 20 ps)



Going down from ns-pulses to ps-pulses the damage mechanisms change and the prominent square root rule will not fit anymore.



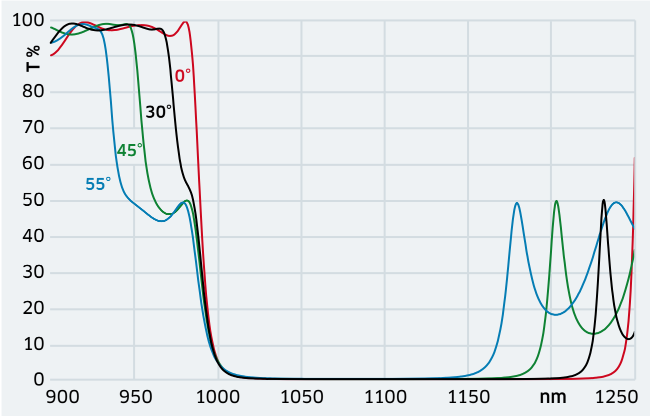
For more information regarding LIDT and its measurement see page 122.

Tips and tricks

Sometimes it is possible to improve the performance of a laser system by changing the setup, such as working inversely with the wavelengths or changing the polarization (if possible). Here are some recommendations.

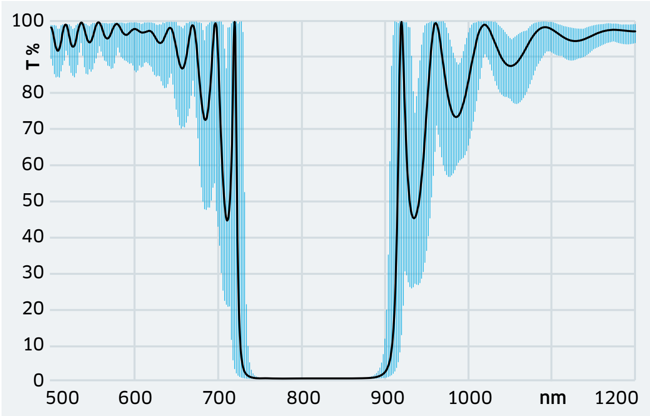
Use a small AOI.

You can achieve the sharpest edge for a filter coating and the broadest HR-range and highest reflection with an angle of incidence AOI = 0°. The example shows four different short pass filters with the same type of design, centered at the same short edge but optimized for different AOIs.



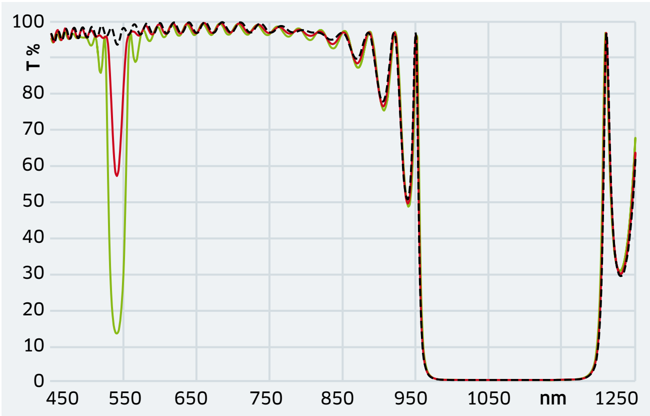
Use the main wavelength in reflection.

Due to the natural variations in refractive index and thickness of each layer in a multi-layer coating normally the tolerances for the HR-range will be much better than for HT-areas. So it is easier to produce high reflection than high transmission. The example shows the margin of error for a standard coating HR 808 nm/0° made by EBE. Note: A higher precision can be achieved by using IAD or sputter techniques.



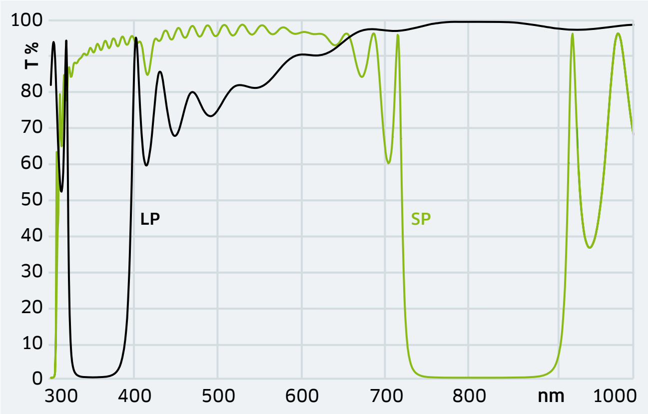
Avoid high transmission around λ/2.

It can be critical to achieve high transmission around half of the center wavelength of a mirror coating. Here a so called λ/2-peak can appear. The depth of this peak varies from 0% to 100% depending on the thickness ratio of the used coating materials (see diagram showing 3 different ratios), angle of incidence, wavelength and condition of the coating machine. With a special coating technique it is possible to minimize this peak.



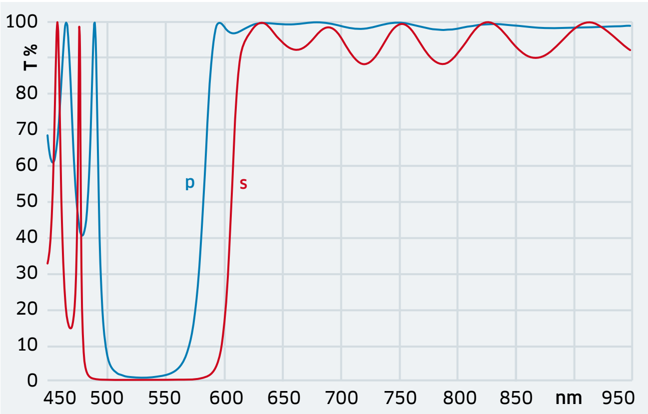
Better use a Long Pass than a Short Pass Filter as …

– the coating will be thinner (and hence probably cheaper).
– potentially you can use coating material with lower absorption and/or higher LIDT.
– you will have no effects from the λ/2-peak.
For example the SP (HT 355 nm HR 808 nm / 0°) will have some absorption at 355 nm, the LP coated with a different material will not.



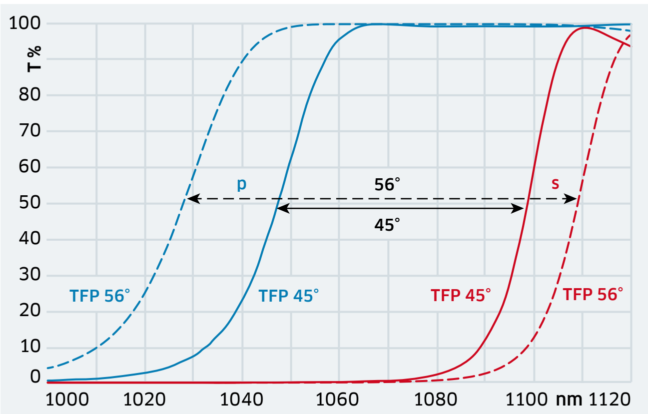
Use HT/AR with p-pol and HR with s-pol.

High transmission can be easier achieved with p- than with s-polarized light and vice versa for high reflection. Normally this rule also applies to AR coatings.
For example see the different polarizations of the shown LP (HR 532 nm / s HT 650–900 nm / p / 45°).



Use a Polarizer with the Brewster angle.

The best extinction ratio for a polarizer can be achieved by using the Brewster angle.
For example, on Fused Silica (against air) choose AOI close to 55.4°.
The often requested Polarizer working with AOI = 45° has a smaller operating range and thus lower tolerances, see illustration right. Additionally you do not need an AR coating on the rear surface as by using the Brewster angle the reflection of an uncoated surface is zero, but Rp ~ 0.6% with AOI = 45° (at 1064 nm, on FS against air).

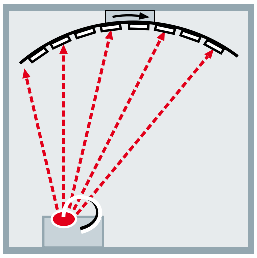


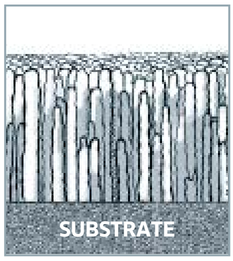
Production methods

Overview coating technologies

Evaporation

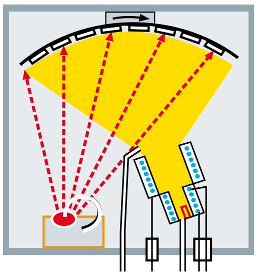
EBE
Electron Beam Evaporation



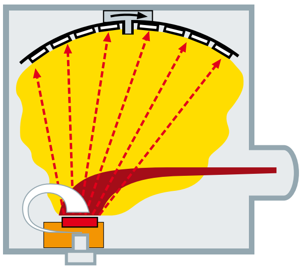


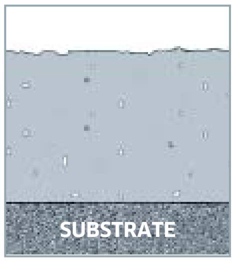
Columnar structure

IAD
Ion Assisted Deposition



IP
Ion Plating

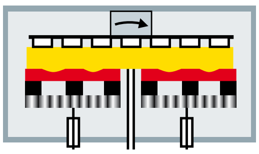




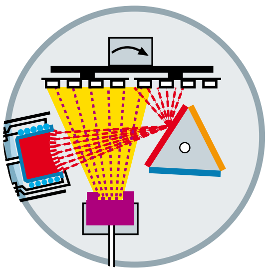
High packing density, some defects/cavities

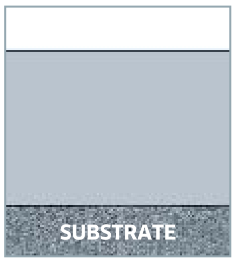
Sputtering

MS
Magnetron Sputtering



IBS
Ion Beam Sputtering

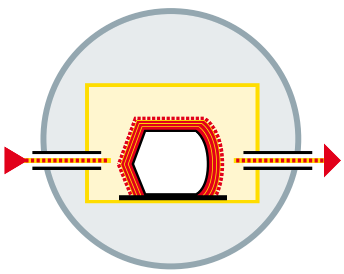


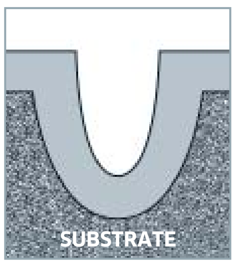


Highest packing density, lowest losses

Chemical

ALD
Atomic Layer Deposition





High packing density, highest film conformality on complex surfaces

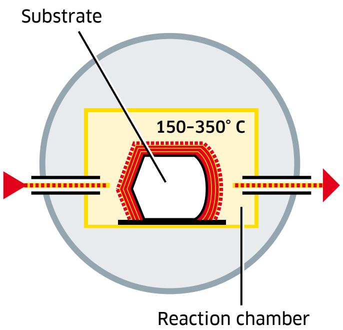
Comparison

Coating technique preferences		EBE	IAD	IP	MS	IBS	ALD
Coating optical properties	high reflection	◐	◐	◐	◐	●	◐
	lowest losses	◐	○	○	○	●	◐
	low absorption	◐ ●	◐	◐	◐	●	◐
	low scattering	◐ ●	◐	◐	○	●	◐
	LIDT pulsed – ns	●	◐	◐	◐	◐	◐
	LIDT pulsed – ps/fs	◐ ●	◐	◐	◐	●	◐
	LIDT cw	◐	◐	◐	●	●	◐
	GDD - chirped mirrors	○ ◐	◐	◐	◐	●	○
	level of difficulty	◐	◐	◐	◐	●	◐
Wavelength areas	VUV	●	○	○	○	○	○
	UV	●	◐ ●	◐	●	◐ ●	●
	VIS	●	●	●	●	●	●
	NIR	●	●	●	●	●	●
	IR	●	●	●	◐	◐ ●	◐
Substrate properties	different substrate materials	●	●	●	●	◐	●
	temperature sensitive substrates	◐	◐	◐	●	●	◐
	length/height of substrates	◐	◐	◐	●	○ ◐	○ ◐
	strongly curved substrates	◐	◐	◐	○ ◐	○ ◐	●
Coating properties	uniformity	◐	◐	◐	◐	●	●
	low stress	◐	●	○	○ ◐	◐ ●	◐
	layer purity	◐	◐	◐	◐	●	◐
	hardness	◐	●	●	●	●	◐
Environmental properties	space	○ ◐	◐	◐	●	●	◐
	harsh environments	◐	●	●	●	●	◐
	temperature changes	◐	●	●	●	●	◐
	vigorous cleaning	◐	●	●	●	●	◐
Efficiency/costs	short coating process time (rate)	●	◐	◐	◐	○ ◐	○
	low price	●	◐	◐	◐	○ ◐	○
	size + quantity of substrates	●	◐	◐	●	◐ ●	○ ◐

● = *specifically suitable* ◐ = *can be used* ○ = *normally unsuitable*

You have to choose the coating technique (and the best coating materials!), that fits best weighting the importance of each criteria.

By discussing your applications and targets with LASEROPTIK we will be able to propose an optimal solution for your substrates and coatings.



Special prisms

ALD Atomic Layer Deposition

Atomic Layer Deposition (ALD) is a special Chemical Vapour Deposition (CVD) technique for innovative and custom-tailored optical applications with extreme film conformality and thickness control at the sub-nano level.

ALD bases on a sequential, self-limiting, layer-by-layer deposition. A solid film is formed by chemical reactions between the gas phase of precursor molecules taking place on the substrate surface, which is typically preheated (150–350 °C) to thermally initiate this reaction.

The film forms sequentially by only one monolayer per cycle. This provides an extreme deposition conformality and thickness control but increases the coating time. The growth is naturally pinhole free and the packing density is close to the bulk material.

Another special feature of ALD is the possibility to coat nearly any 3D-optic (page 72), even with a high aspect ratio or strongly curved surfaces, e.g. special prisms, hemispheres or tubes. All surfaces can be coated at once or can also be protected if needed.

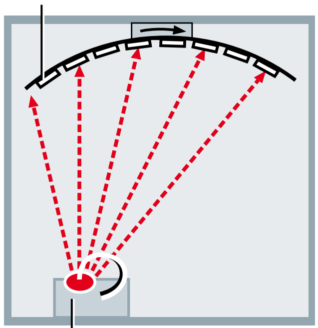
As there is no need to add energy (like using an additional ion source) to achieve a better density, chemical processes such as ALD typically show low internal stress.

Several different reaction chambers are available to support substrate sizes from a few millimeters to 300 mm in all dimensions and can easily be exchanged.

The most common coating materials (SiO_2, Al_2O_3, TiO_2, Ta_2O_5 ...) are available while pure metals or fluorides are still challenging and require some additional development and optimization.

Pros and cons of ALD:

+ *Coating on 3D-optics*
+ *Extreme film conformality*
+ *Excellent microstructure*
+ *Low internal stress*
± *All surfaces coated*
− *Low deposition rate*
− *High production costs*



EBE Electron Beam Evaporation

Electron Beam Evaporation (EBE) is the conventional coating technique. Due to its high evaporation rate the coating time is relatively short. In addition to the large capacity it has a good cost-performance ratio.

Coatings are done in a heated (> 250 °C) high vacuum chamber using electron beam guns. Each gun emits a high-voltage electron beam that is focused into a water cooled rotating crucible, containing the coating material. The beam melts and evaporates the material at temperatures of about 2000 °C.

Rather than generated with an electron gun Thermal Evaporation (TE) can also be achieved with an evaporation boat which is heated by a strong electrical current.

Due to the high vacuum environment the material vapour moves as cloud to the substrates, mounted in a spherical or plano calotte in the top of the chamber.

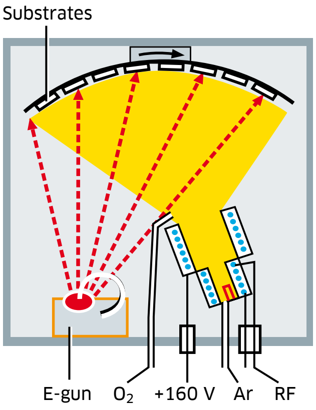
The vapour condenses on the surface of the substrate forming a film with mainly columnar structure. To match surface geometries and to achieve an optimal coating thickness distribution the calotte is being rotated. Optical thickness control is ensured by monochromatic quarter-wave measurement on a witness sample, whereas the physical thickness is detected with a crystal oscillator.

Oxide materials are reactively deposited in an oxygen atmosphere of some 10^{-4} mbar in order to compensate the decomposition during evaporation.

Many different coating materials (metals, metal-oxides or fluorides and sulfides) can be used, so the application range is from DUV to IR. Due to the porous columnar structure EBE coatings show some thermal drift.

Pros and cons of EBE

+ *High deposition rate*
+ *Good cost-performance ratio*
+ *High LIDT*
+ *DUV to IR*
− *Thermal drift*



IAD Ion Assisted Deposition

Ion Assisted Deposition (IAD) is based on a coating system as described before for Electron Beam Evaporation (EBE) but with an additional plasma source. The plasma is directed onto the calotte and provides a bombardment of the growing layer which results in a denser micro structure and therefore eliminates the thermal drift.

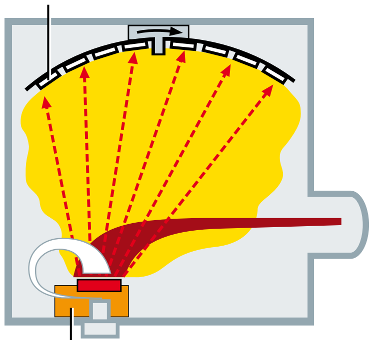
The plasma is generated by a DC-discharge with a RF-heated cathode. Caused by the strong discharge of about 40 amps, the molecules in the vapour are activated and ionized. The reactive argon and oxygen ions hit the substrate with energies up to 150 eV.

IAD still uses the high evaporation rate of EBE what helps to keep the costs down, but it is limited to certain coating materials, for example fluorides cannot be used. By using optimized parameters the internal stress can be minimized. In the VIS/NIR normally the LIDT is close to EBE.

Pros and cons of IAD

+ *Density near to bulk*
+ *No thermal drift*
+ *High deposition rate*
+ *Internal stress can be optimized*

± *VIS / NIR: LIDT close to EBE*



IP Ion Plating

Ion Plating (IP) uses ions to produce dense layers, but in a different way than IAD.

LASEROPTIK works with Reactive Low Voltage Ion Plating (RLVIP) which results in extremely mechanically resistant coatings.

A low voltage electrical arc is ignited from a plasma source directly into the crucible, so the coating material is well ionized. This and the different potentials of the crucible and the calotte lead to high kinetic energy of the particles hitting the substrates. So the growing layer gets a density close to 100%. With this method very high refractive indices can be achieved.

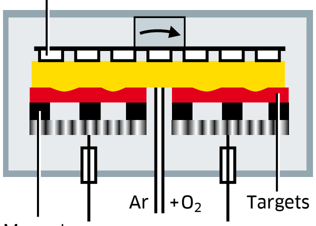
The process gas is argon, for metal-oxides we use additional oxygen as reactive gas.

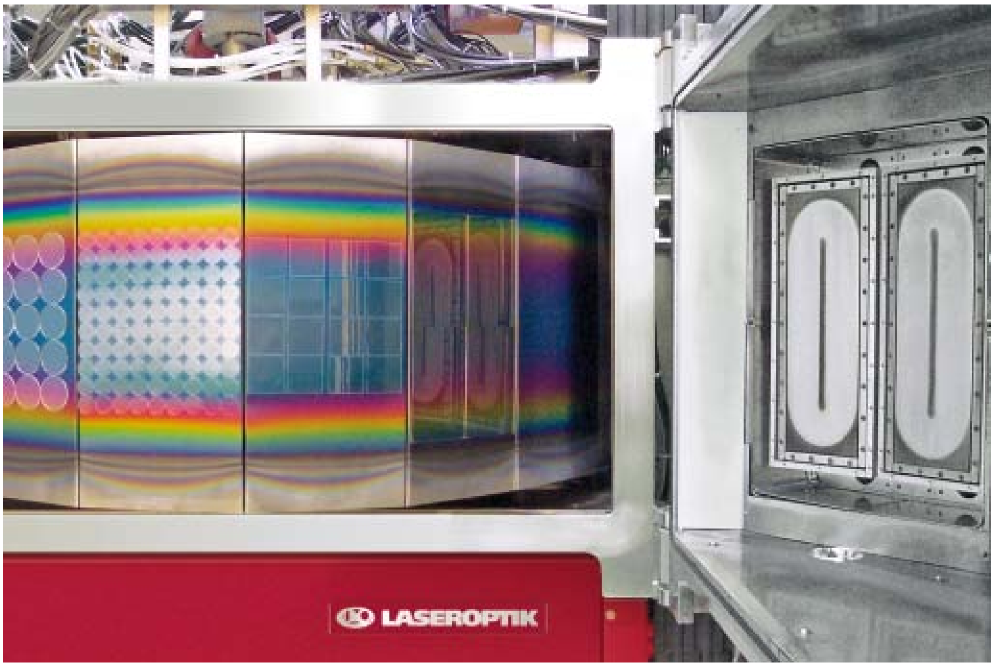
The coatings are extremely hard and do not react on changes in temperature or humidity but they have a high level of stress.

Pros and cons of IP

+ *Extremely mechanically resistant*
+ *High density, high refractive index*
+ *High deposition rate*
− *High stress*

Plasma above IP crucible





MS Magnetron Sputtering

Magnetron Sputtering (MS) uses a magnetron plasma for sputtering a metal layer on the substrates and oxidizing it to a stoichiometric metal-oxide in a microwave plasma afterwards. This technique allows to produce very dense and hard coatings.

In the coating machine a drum with a diameter of 120 cm holds the substrates. It rotates vertically in front of the two magnetrons and microwaves.

A plasma of ionized argon forms in front of the target. The positively charged argon ions are accelerated toward the negatively charged target, where they strike the face of the target and sputter metal atoms on the substrates.

Rotating into the microwave plasma the metal film is oxidized and ready for the next cycle.The coatings are very hard and mechanically resistant and can work in nearly every environment. Specific coatings are space certified by ESA (see page 76).

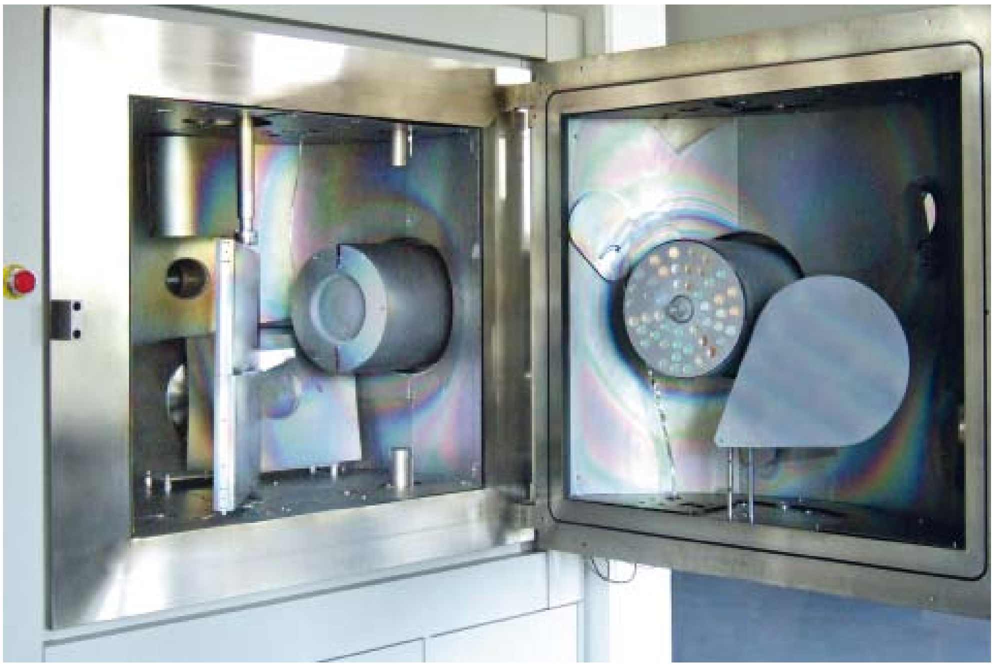
Two different material targets can be used in one configuration. The sputter rates are very stable, so the thickness control is done with high precision simply by time and with an optical monitor as backup. Especially for UV-coatings and cw-applications very high LIDT can be achieved.

As the process works with low temperatures coatings on plastic or other non-glasslike materials (e.g. fiber ends) are possible.

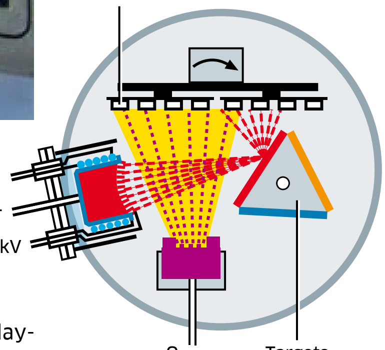
Like all sputter techniques, coatings made by MS may have high stress, depending on the wavelength region and coating materials used.

Pros and cons of MS

+ *Very dense and hard coatings*
+ *Space certified by ESA*
+ *High precision*
+ *High LIDT for UV-coatings and cw*
+ *Low temperature coatings*
− *Compressive stress (case dependent)*



IBS Ion Beam Sputtering



Ion Beam Sputtering (IBS) is the most advanced deposition technology for the most critical demands on laser optics.

IBS works with RF-guns, typically used for satellite propulsion. Argon ions are accelerated by approx. 1.5 kV onto a metal target. Coating material is sputtered off the target and condenses on a vertically rotating substrate fixture. A uniform coating distribution is limited to an area of about 30 cm in diameter for the standard IBS machines.

Our IBS coating plants have been designed with a secondary RF plasma source. It emits oxygen ions directly onto the substrate surfaces in order to receive well-oxidized, non-absorbing oxide layers.

With the accuracy of LASEROPTIK's broadband monitoring systems, fractional parts of a monolayer can be detected. As a result of highest precision in film growth and an amorphous, almost defect free microstructure IBS is considered as the most advanced coating technology in today's thin film industry.

Like magnetron sputtering, IBS is a "cold" process in which the internal temperature does not exceed 150 °C.

The stress can be reduced by compensating layers deposited on the rear surface including additional optical properties, e.g. working as an AR coating.

At LASEROPTIK we actually have 18 machines for special requirements in operation, e.g. high power supermirrors with superior reflectivity (99.99x%) and lowest losses (< 10 ppm), complex filter designs or coatings on crystals. Four of them can work with large optics, so IBS-coatings are available even on substrates up to 2 m in length or Ø550mm (see page 74).

With our GDD measurement setup we also offer dispersive coatings (see page 61).

Pros and cons of IBS

+ *Highest precision, most complex coating designs*
+ *Lowest losses*
+ *Excellent microstructure*
+ *High density*
± *Stress, can be compensated*
− *Low deposition rate*

Coatings

Standard coatings for the most common laser types, sorted by wavelength areas

Polarizers, variables, metal and OPO coatings

Dispersive coatings

Coatings on special substrates

Coatings for special applications or environmental conditions

Every coating type can be optimized

for every
- substrate material
- wavelength
- reflection / transmission value
- angle of incidence
- polarization
- GDD value
- ...

or, alternatively we can create a totally new design for you.

If not mentioned otherwise all values and diagrams are given
- for the standard substrate material used in the described wavelength area (mostly Fused Silica or CaF_2).
- without consideration of the rear surface
- with EBE coating technique for a good cost-performance ratio.

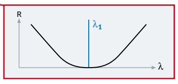
VUV/Excimer 120-179 nm

Coating types

AR

VAR
DAR
TAR
BBAR
MAR
WAR

VAR

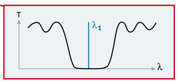


λ[nm]	AR (0°); R <		method	AR (45°); R <		method
157	0.5%	on Fluoride	EBE	0.75%	on Fluoride	EBE
172	0.5%	on Fluoride	EBE	0.75%	on Fluoride	EBE

HR

HR
DHR
BBHR
MHR
WHR
Metal

HR

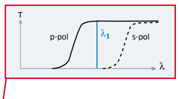


λ[nm]	HR (0°); R >		method	HR (45°); R >		method
126	84%	on Fluoride	EBE	75%	on Fluoride	EBE
130	85%	on Fluoride	EBE	80%	on Fluoride	EBE
149	91%	on Fluoride	EBE	89%	on Fluoride	EBE
157	94% (goal 97%)	on Fluoride	EBE	93% (goal 95%)	on Fluoride	EBE
172	95%	on Fluoride	EBE	94%	on Fluoride	EBE

PR

PR
DPR
BBPR
VA
GOC

TFP

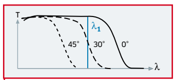


λ[nm]		AOI	method
157	Rp < 0.3%, Rs > 87%	72° on CaF_2	EBE

Filter

LP
SP
NF
MP
BP
REF

VA



λ[nm]	0° → 45°; T =		method
157	75% → 2%	on CaF_2	EBE
	10% → 70%	on CaF_2	EBE

Polarizer

TFP
CP
BBPOL

Variables

VA
GOC
GP
GNF
GIF

LASEROPTIK has longtime experience with coatings in the Vacuum Ultraviolet (VUV) range (120–179 nm), especially for 157 nm including dedicated metrology (see page 120).

The main reason for losses in this spectrum is absorption of water and hydrocarbons. VUV-CaF_2 substrates are used to counter these losses. A surface roughness of RMS < 0.3 nm helps to decrease the losses for all coatings.

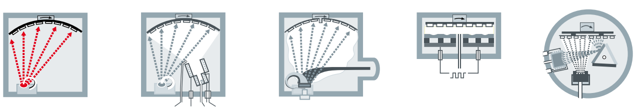
We guarantee LIDT > 400 mJ/cm² with 15 ns pulses for HR 157 nm/0°.

Our mirrors withstand 2.5 billion pulses at 10 mJ/cm² without any detectable degradation as reported from a longterm test. The values for PR and AR coatings will be in the same range.

All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

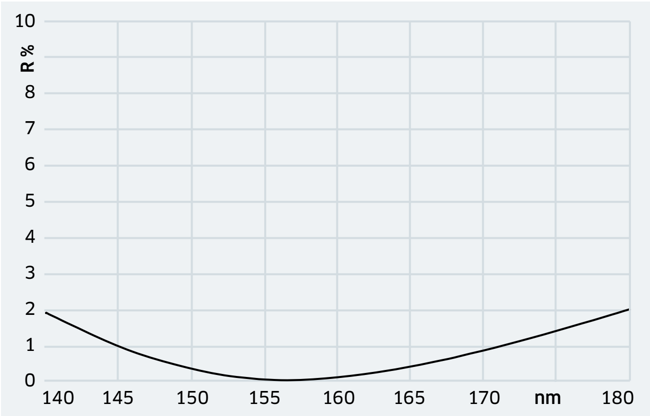
EBE IAD IP MS IBS



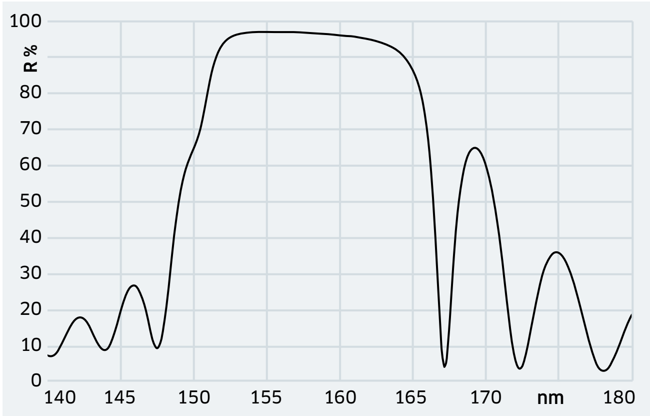
126 | 130 | 149 | 157 | 172 nm

Ar_2 – F_2

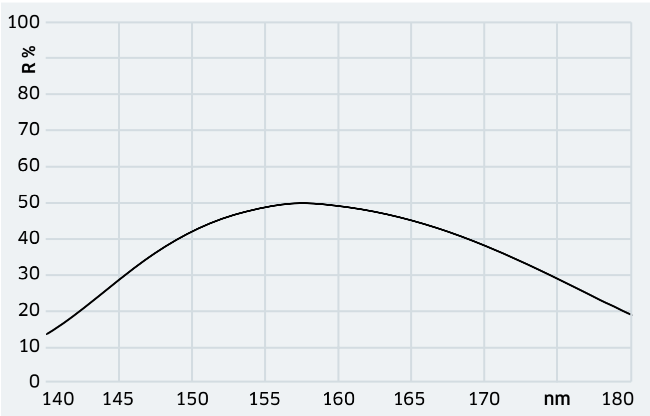
Examples



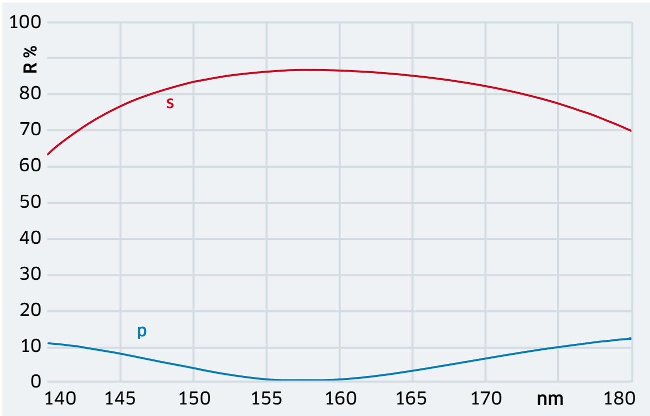
AR 157 nm/0° [B-00768]
157 nm: R < 0.5%



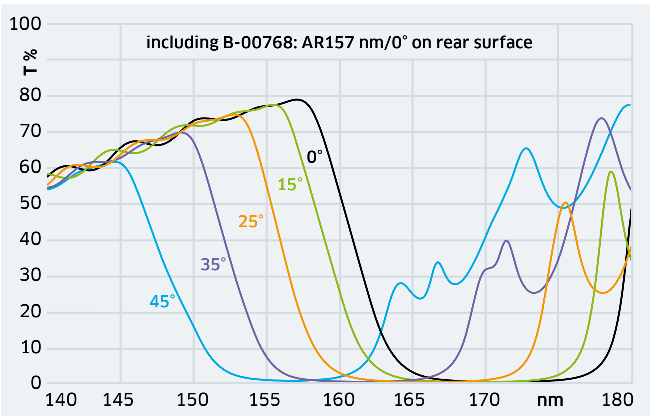
HR 157 nm/0° [B-00649]
157 nm: R > 94% (goal R > 97%)



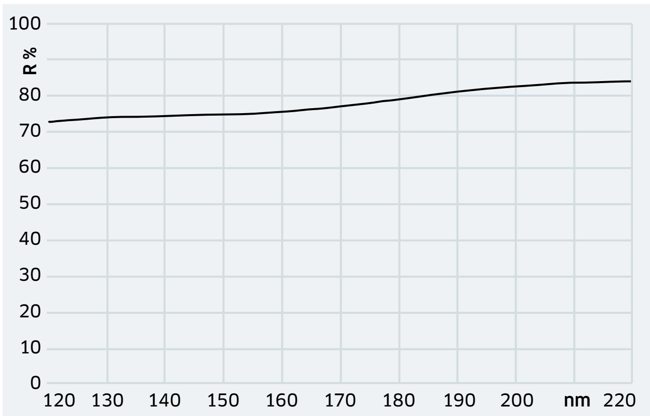
R 50% 157 nm/45° [B-06013]
157 nm: R ±5%



TFP 157 nm/72° [B-01280]
157 nm: Rp < 0.3%, Rs > 87%



VA 157 nm/0–45° T 75–1% [B-11719]
157 nm: 0°: T > 70% (goal T > 75%); 45°: T < 2% (goal T < 1%)



Al + Protection Layer – VUV [B-02250-01]
120–220 nm/0°: R > 65%

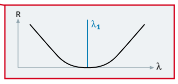
UV/Excimer 180-379 nm

Coating types

AR

VAR
DAR
TAR
BBAR
MAR
WAR

VAR



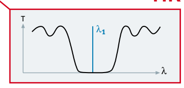
λ[nm]	AR (0°); R <		method	AR (45°); R <		method
193	0.5%		EBE	0.75%		EBE
248	0.25%		EBE	0.75%		EBE
266	0.25%		EBE	0.6%		EBE
355	0.2%		EBE	0.6%		EBE
	0.05-0.1%*	low loss	IBS	0.1-0.6%*	low loss	IBS

* depending on price, substrate size and laser power

HR

HR
DHR
BBHR
MHR
WHR
Metal

HR



λ[nm]	HR (0°); R >		method	HR (45°); R >		method
193	96%		EBE	92% (goal 96%)		EBE
	96% (goal 98%)	on Fluoride	EBE	95%	on Fluoride	EBE
213	98%		EBE	97%		EBE
248	99.5%		EBE	99%		EBE
266	99.5%		EBE	99.5%	standard	EBE
	99.5%		IBS	99.5%	high power	MS
308	99.5%		EBE	99.2%		EBE
	99.7%		IBS	99.7%		IBS
343	99.5%		EBE	99.2%		EBE
351	99.5%		EBE	99.2%		EBE
355	99.5%	high power	MS	99.5%	standard	EBE
	99.9%	low loss	IBS	99.9%	low loss	IBS
				99.5%	high power	MS

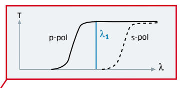
PR

PR
DPR
BBPR
VA
GOC

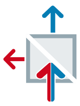
Filter

LP
SP
NF
MP
BP
REF

TFP



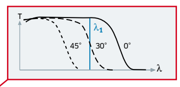
λ[nm]		AOI	method
193	Tp > 80%, Ts < 10%	73°	EBE
248	Tp > 80%, Ts < 2%	Brewster	EBE
266	Tp > 90%, Ts < 2%	Brewster	EBE
355	Tp > 94%, Ts < 2%	Brewster	EBE
	Tp > 96%, Ts < 0.2%	Brewster	IBS



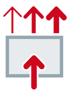
Polarizer

TFP
CP
BBPOL

VA



λ[nm]	0° → 45°; T =		method
193	80% → 10%		EBE
248	90% → 2%	standard	EBE
	95% → 1%	high power	MS
266	92% → 1%	standard	EBE
355	92% → 1%	standard	EBE
	92% → 1%	non-shifting	IAD



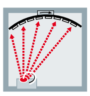
Variables

VA
GOC
GP
GNF
GIF

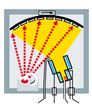
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

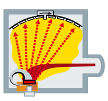
EBE



IAD

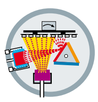


IP



MS

IBS

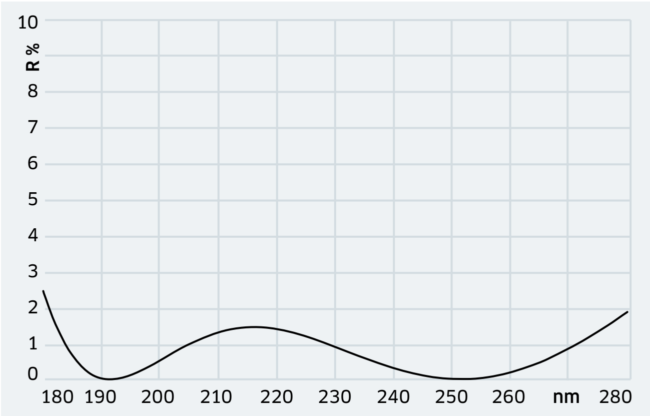


193 | 213 | 248 | 266 | 308 | 325 | 337 | 343 | 351 | 355 | 375 nm

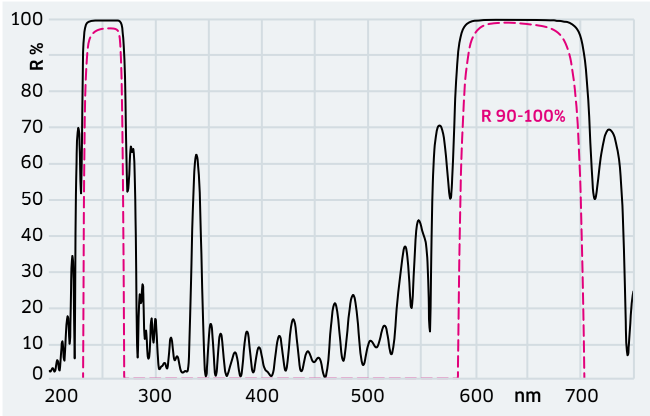
ArF – KrF – XeCl – HeCd – N_2 – XeF – Alexandrite
3rd, 4th, 5th of Nd:YAG/YVO_4 – Yb:YAG

Examples

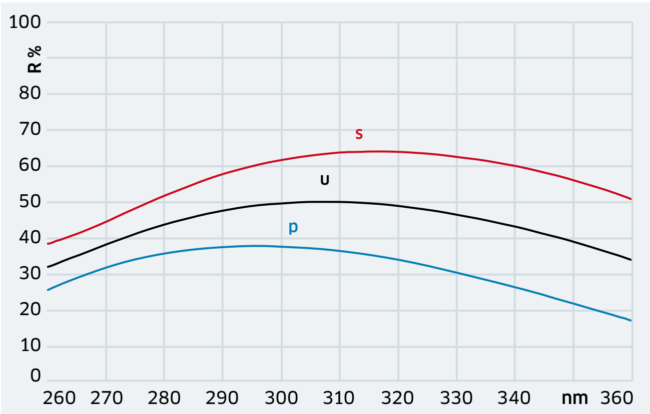
–––– dashed lines show the zoomed curve with the stated magnification



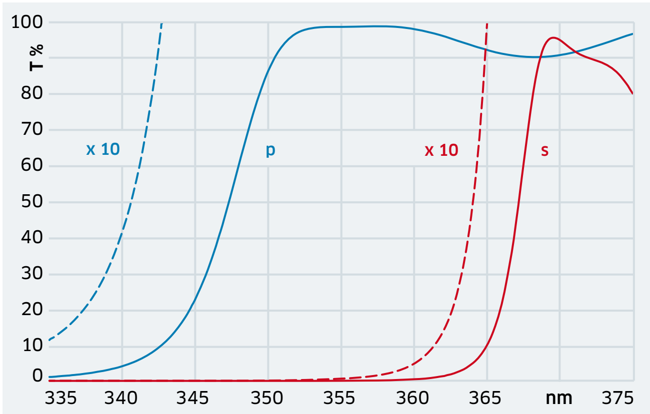
AR 193 nm + 248 nm / 0° [B-00790]
193 nm: R < 0.5%; 248 nm: R < 0.5%



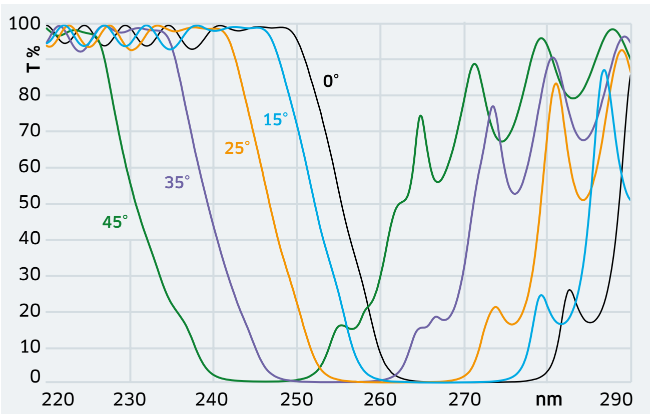
HR 248 nm + 633 nm / 45° [B-03680]
248 nm: R > 99%; 635 nm: R > 98%



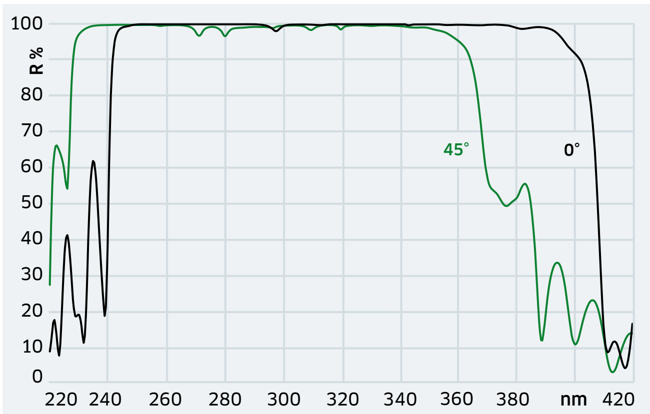
R 50% 308 nm / 45° [B-01937]
308 nm: R ±3%



TFP 355 nm / 55.9° [B-11227]
355 nm: Tp > 96%, Ts < 0.2% (IBS-coating)



VA 248 nm / 0-45° [B-07573]
248 nm: 0° → 45°; T = 95% → 1% (MS-coating)



HR 250-350 nm / 0-45° [B-07720]
250–350 nm: Ravg > 98.5%

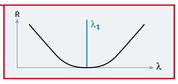
VIS 380-779 nm

Coating types

AR

VAR
DAR
TAR
BBAR
MAR
WAR

VAR



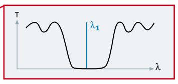
λ[nm]	AR (0°); R <		method	AR (45°); R <		method
532	0.2%		EBE	0.6%		EBE
	0.05-0.1%*	low loss	IBS	0.1-0.6%*	low loss	IBS
633	0.2%		EBE	0.6%		EBE

* depending on price, substrate size and laser power

HR

HR
DHR
BBHR
MHR
WHR
Metal

HR

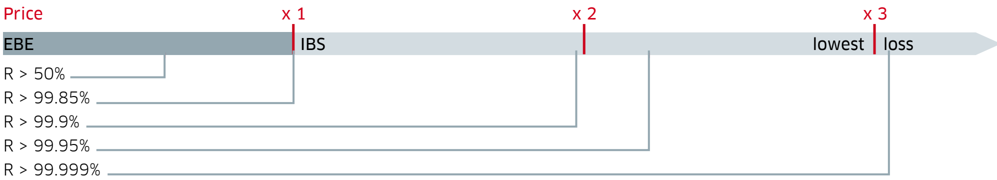


PR

PR
DPR
BBPR
VA
GOC

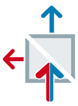
λ[nm]	HR (0°); R >		method	HR (45°); R >		method
405	99.8%		EBE	99.7%		EBE
488	99.85%		EBE	99.8%		EBE
514	99.85%		EBE	99.8%		EBE
515	99.8%	high power	EBE	99.8%	high power	EBE
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
532	99.8%	high power	EBE	99.8%	high power	EBE
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
550	99.85%		EBE	99.8%		EBE
578	99.85%		EBE	99.8%		EBE
633	99.85%		EBE	99.8%		EBE
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
694	99.85%		EBE	99.8%		EBE
760	99.85%		EBE	99.8%		EBE

* 99.9xxx% means that we can optimize the reflection/transmission to your needs.
The coating price results from the chosen grade of reflection/difficulty, see estimated multiplier:



Filter

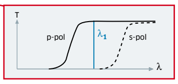
LP
SP
NF
MP
BP
REF



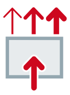
Polarizer

TFP
CP
BBPOL

TFP



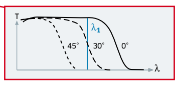
λ[nm]		AOI	method
515	Tp > 90%, Ts < 3%	45°	EBE
	Tp > 99%, Ts < 0.1%	Brewster	IBS
532	Tp > 90%, Ts < 2%	45°	IAD
	Tp > 96%, Ts < 1%	Brewster	IAD
	Tp > 99%, Ts < 0.1%	Brewster	IBS



Variables

VA
GOC
GP
GNF
GIF

VA

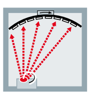


λ[nm]	0°→ 45°; T =		method
532	92% → 1%	standard	EBE
	92% → 1%	non-shifting	IAD

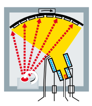
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

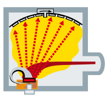
EBE



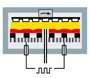
IAD



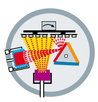
IP



MS



IBS

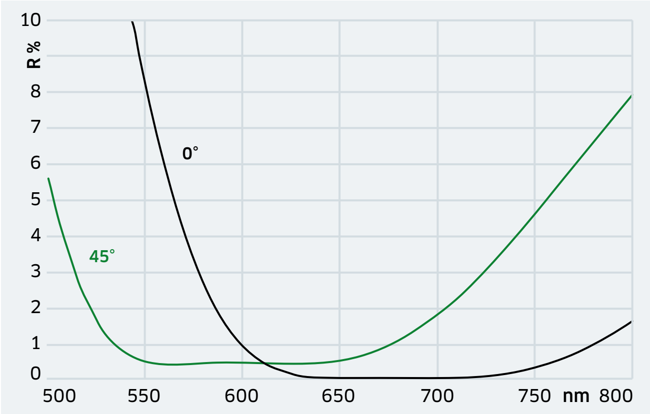


405 | 450 | 476 | 488 | 514 | 515 | 532 | 550 | 578 | 633 | 656 | 671 | 694 | 760 nm

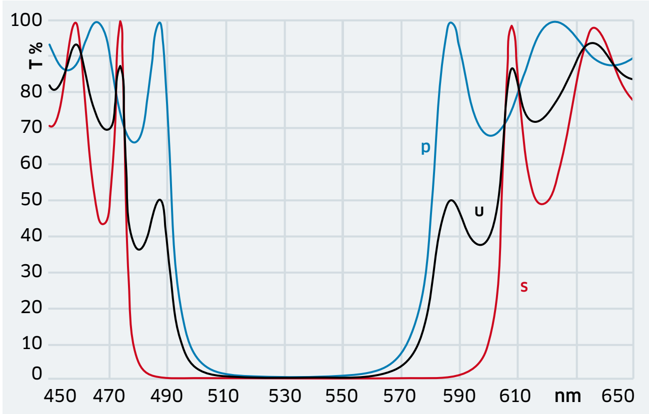
Diode laser – Tm:YLF – Kr⁺ – Ar⁺ – Er:KYW – Copper vapour – HeNe – Ruby – Alexandrite
2[nd] of Nd:YAG/YVO$_4$/YLF – Yb:YAG

Examples

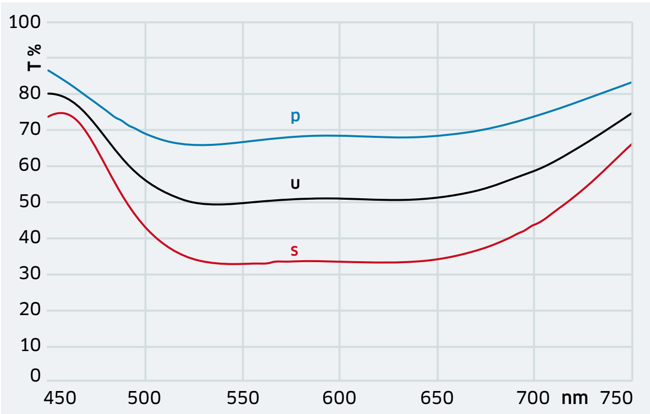
–––– dashed lines show the zoomed curve with the stated magnification



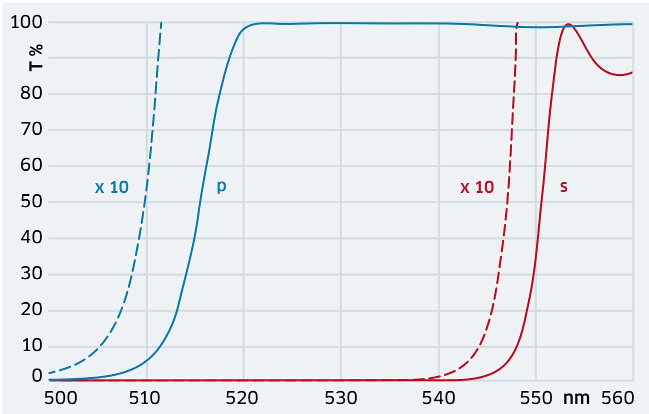
AR 633 nm / 0–45° [B-11397]
633 nm: R < 1%



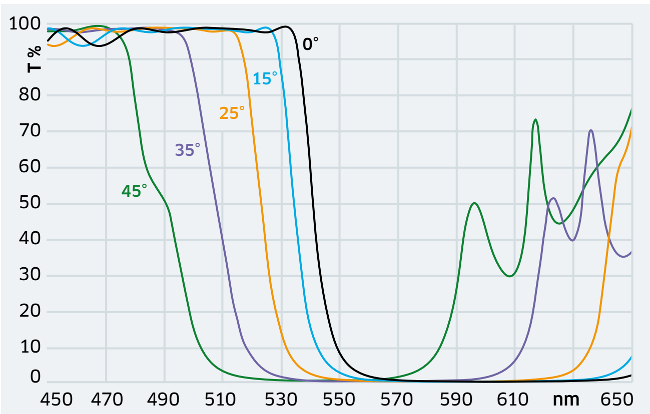
HR 532 nm / 45° [B-00458]
532 nm: Ru > 99.8%



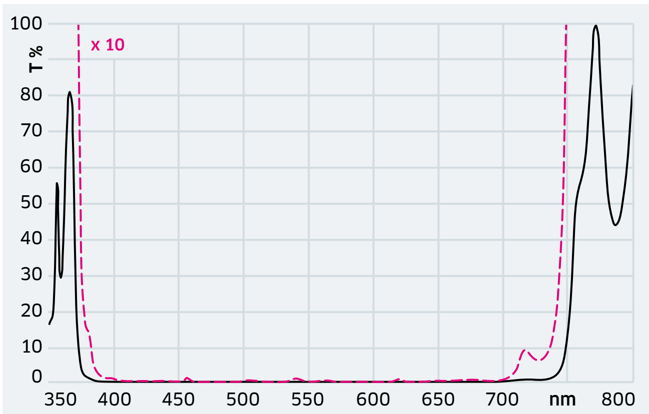
R 50% 532–633 nm / 45° [B-00688]
532–633 nm: Ru ±5% vs. theoretical curve



TFP 532 nm / 55.4° [B-11321]
532 nm: Tp > 99%, Ts < 0.1% (IBS-coating)



VA 532 nm / 0–45° T 92-1% [B-01194]
532 nm: 0° → 45°; T = 92% → 1%



HR 400–700 nm / 0° [B-01845]
400–700 nm: Ravg > 99%

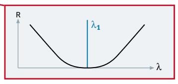
NIR 780-1029 nm

Coating types

AR

VAR
DAR
TAR
BBAR
MAR
WAR

VAR



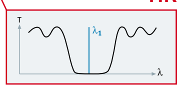
λ[nm]	AR (0°); R <		method	AR (45°); R <		method
780	0.2%		EBE	0.6%		EBE
800	0.2%		EBE	0.6%		EBE
	0.05-0.1%*	low loss	IBS	0.1-0.6%*	low loss	IBS
808	0.2%		EBE	0.6%		EBE
940	0.2%		EBE	0.6%		EBE
	0.05-0.1%*	low loss	IBS	0.1-0.6%*	low loss	IBS

* depending on price, substrate size and laser power

HR

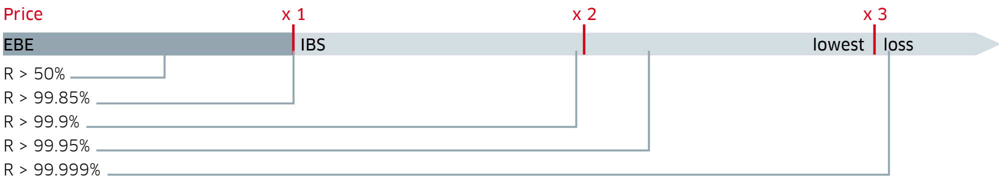
HR
DHR
BBHR
MHR
WHR
Metal

HR



λ[nm]	HR (0°); R >		method	HR (45°); R >		method
780	99.85%		EBE	99.8%		EBE
800	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
808	99.85%		EBE	99.8%		EBE
850	99.85%		EBE	99.8%		EBE
914	99.85%		EBE	99.8%		EBE
940	99.8%	standard	EBE	99.75%	standard	EBE
	99.85%	non-shifting	IAD	99.8%	non-shifting	IAD
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
976	99.85%		EBE	99.8%		EBE
980	99.85%		EBE	99.8%		EBE

* 99.9xxx% means that we can optimize the reflection/transmission to your needs.
The coating price results from the chosen grade of reflection/difficulty, see estimated multiplier:

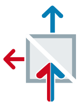


PR

PR
DPR
BBPR
VA
GOC

Filter

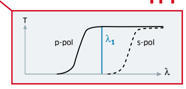
LP
SP
NF
MP
BP
REF



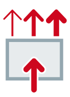
Polarizer

TFP
CP
BBPOL

TFP



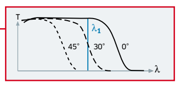
λ[nm]		AOI	method
800	Tp > 99%, Ts < 0.1%	Brewster	IBS
808	Tp > 95%, Ts < 1%	Brewster	EBE
940	Tp > 95%, Ts < 1%	Brewster	IAD



Variables

VA
GOC
GP
GNF
GIF

VA

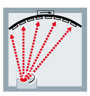


λ[nm]	0°→ 45°; T =		method
808	95% → 1%	non-shifting	IAD
940	95% → 1%	non-shifting	IAD

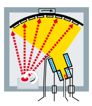
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

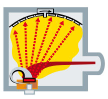
EBE



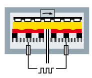
IAD



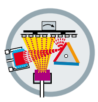
IP



MS



IBS

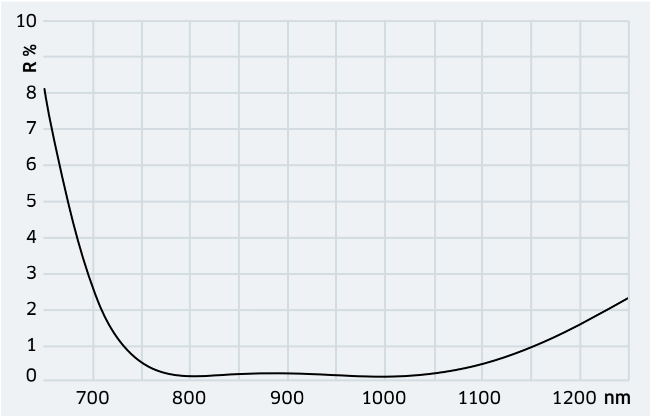


780 | 800 | 808 | 850 | 914 | 940 | 946 | 976 | 980 nm

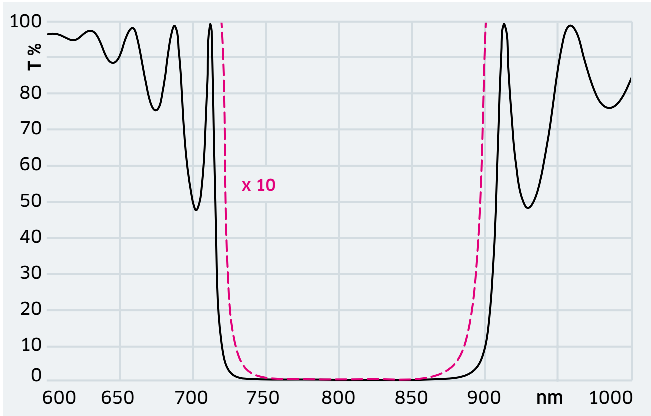
Diode laser – Ti:Sapphire – Er:YLF/YAP – InGaAs diode
weak Nd:YAG/YVO_4

Examples

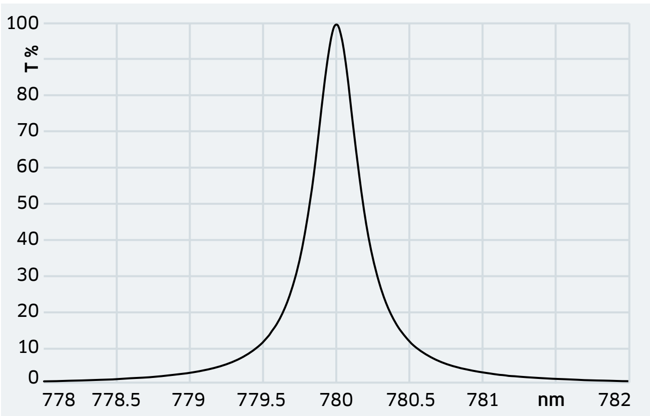
–––– dashed lines show the zoomed curve with the stated magnification



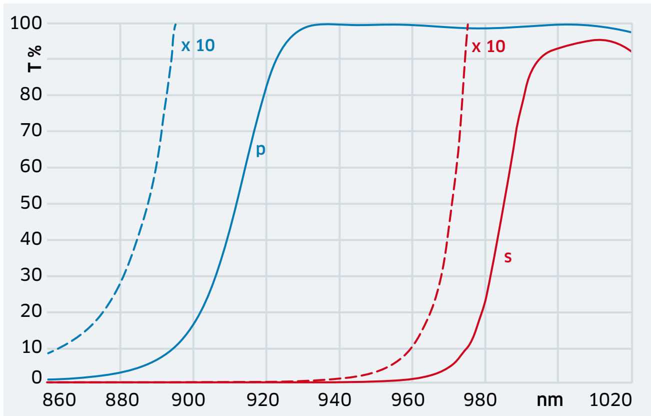
AR 785–1030 nm/0° [B-07312]
785–1030 nm: R < 0.5%



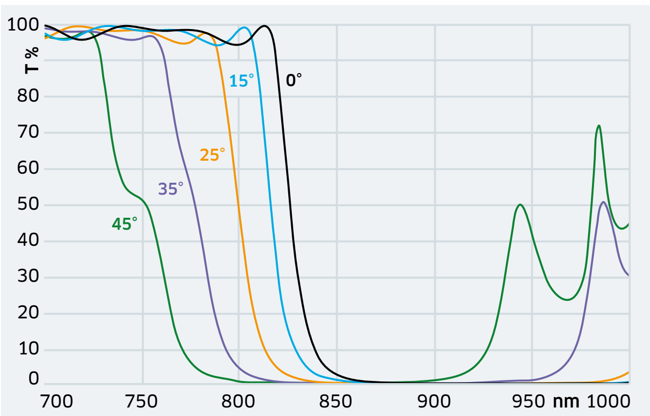
HR 800 nm/0° single stack [B-06166]
800 nm: R > 99.8% single stack (quarter wave layers)



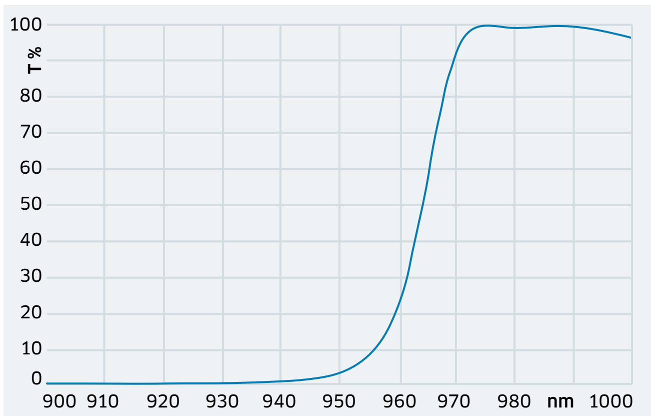
IF 780 nm/6° [B-06650]
780 nm: FWHM 0.37 nm, best effort, angle tuning (IBS-coating)



TFP 940 nm/56° [B-10213-01]
940 nm: Tp > 95%, Ts < 1% (IAD-coating)



VA 808 nm/0–45° T 95–1% [B-01476-01]
808 nm: 0° → 45°; T= 95% → 1% (IAD-coating)



HR 905–945 nm HT 975–985 nm/45° p [B-05178]
905–945 nm: Rp > 95%; 975–985 nm: Rp < 4% (IBS-coating)

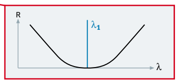
NIR 1030-1064 nm

Coating types

AR

VAR
DAR
TAR
BBAR
MAR
WAR

VAR



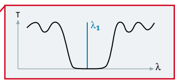
λ[nm]	AR (0°); R <		method	AR (45°); R <		method
1064	0.1%		EBE	0.6%		EBE
	0.05–0.1%*	low loss	IBS	0.1–0.6%*	low loss	IBS

* depending on price, substrate size and laser power

HR

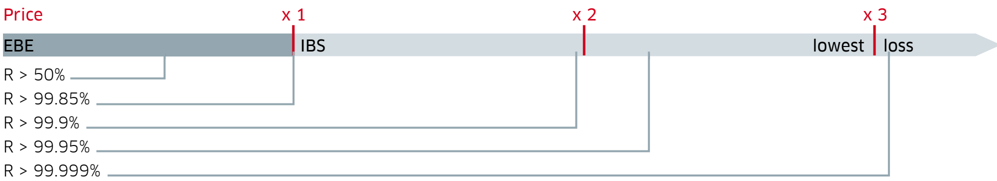
HR
DHR
BBHR
MHR
WHR
Metal

HR



λ[nm]	HR (0°); R >		method	HR (45°); R >		method
1030	99.7%	high power	EBE	99.5%	high power	EBE
	99.85%	standard	EBE	99.8%	standard	EBE
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
1053	99.85%		EBE	99.8%		EBE
1064	99.7%	high power	EBE	99.5%	high power	EBE
	99.9%	standard	EBE	99.8%	standard	EBE
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS

* 99.9xxx% means that we can optimize the reflection/transmission to your needs.
The coating price results from the chosen grade of reflection/difficulty, see estimated multiplier:



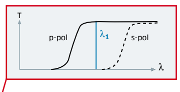
PR

PR
DPR
BBPR
VA
GOC

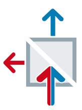
Filter

LP
SP
NF
MP
BP
REF

TFP



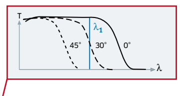
λ[nm]		AOI	method
1064	Tp > 95%, Ts < 5%	45° cube	EBE
	Tp > 99%, Ts < 1%	45°	IBS
	Tp > 95%, Ts < 2%	Brewster	EBE
	Tp > 99%, Ts < 0.1%	Brewster	IBS



Polarizer

TFP
CP
BBPOL

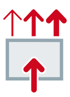
VA



λ[nm]	0°→ 45°; T =		method
1064	95% → 1%		EBE
	95% → 1%	non-shifting	IAD

LIDT for HR 1064 nm / 0° with different methods

method	LIDT – pulsed (10 ns, 1 Hz) energy per effective beam area	LIDT – cw (depending on cooling) power per effective beam diameter
EBE, high power	> 80 J / cm²	> 10 kW / cm
EBE, standard	> 40 J / cm²	> 10 kW / cm
IBS	> 40 J / cm²	> 100 kW / cm



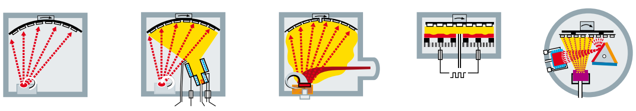
Variables

VA
GOC
GP
GNF
GIF

All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

EBE IAD IP MS IBS

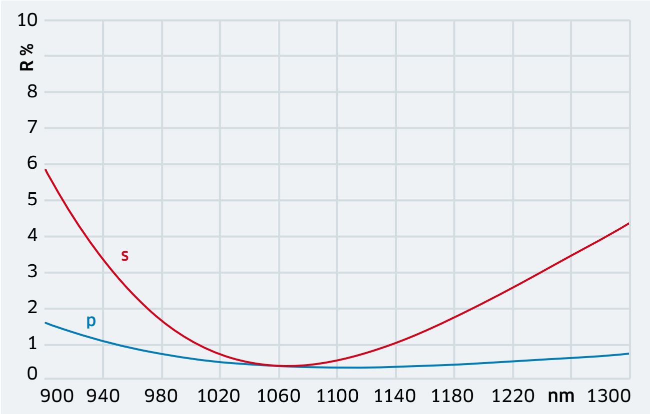


1030 | 1040 | 1047 | 1053 | 1054 | 1064 nm

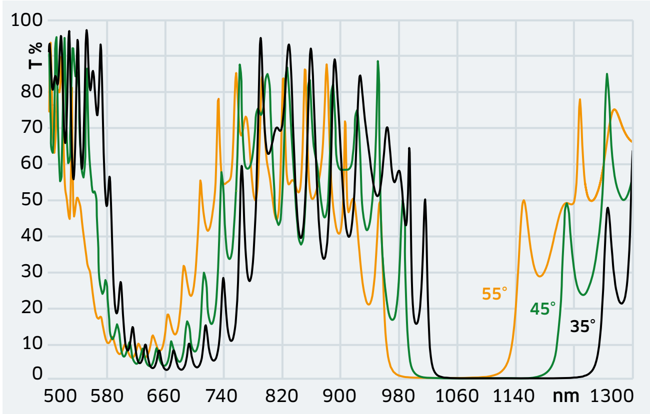
Fibre laser – Yb:YAB/YAG – Nd:glass
Nd:YAG/YVO_4/YLF

Examples

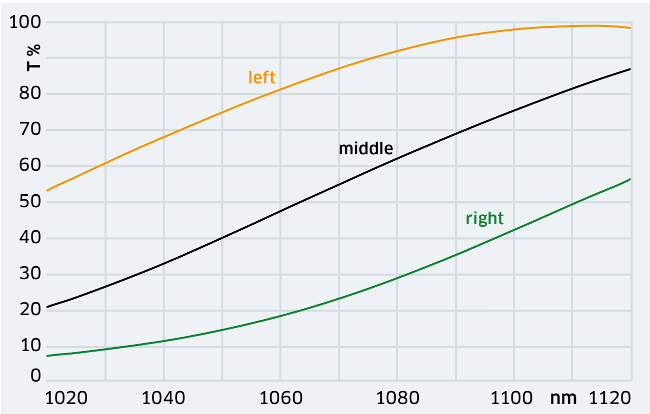
–––– dashed lines show the zoomed curve with the stated magnification



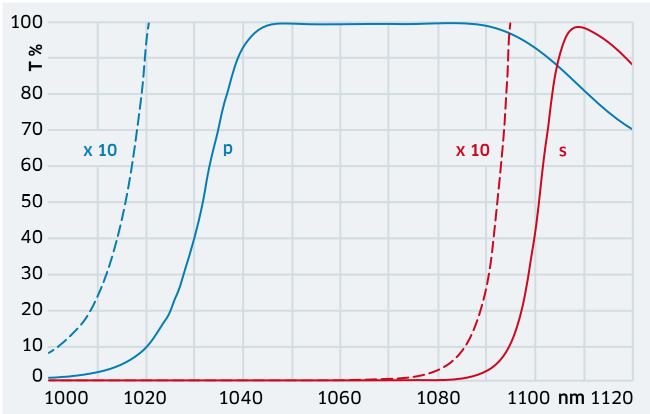
AR 1064 nm / 45° low polarizing [B-07674]
1064 nm: Ru < 0.6%; IRs-Rpl < 0.4%



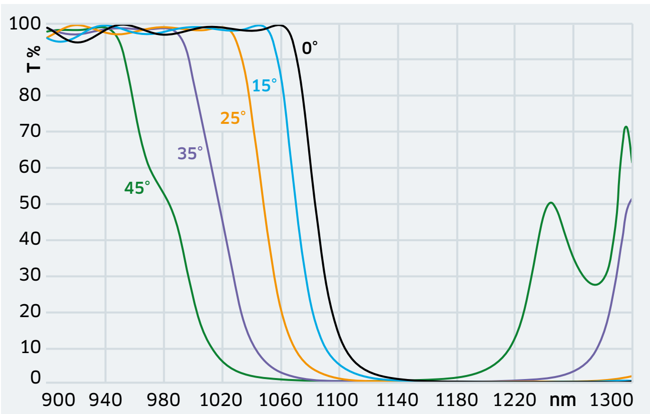
R > 80% 633 nm HR 1064 nm / 45 ±10° Type 3 [B-06544]
633 nm: R > 80%; 1064 nm: Ravg > 99.7%



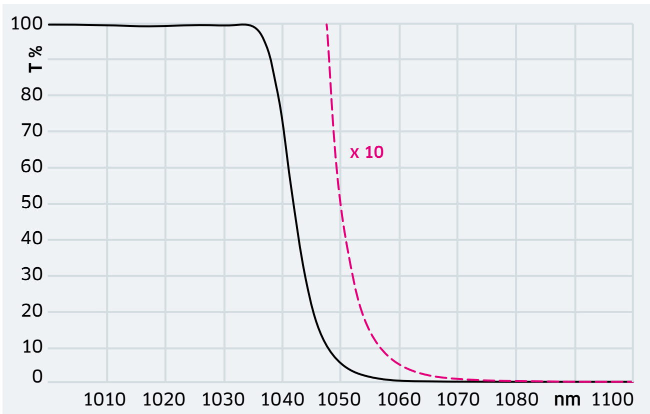
GOC 1064 nm / 0° [B-05981]
1064 nm: T 25–75% min. variation on substrate (IAD-coating);
more details about Gradient Output Coupler GOC on page 50



TFP 1064 nm / 55.4° [B-11324]
1064 nm: Tp > 99%, Ts < 0.1% (IBS-coating)



VA 1064 nm / 0-45° T 95–1% [B-00431-01]
1064 nm: 0° → 45°; T = 95% → 1%

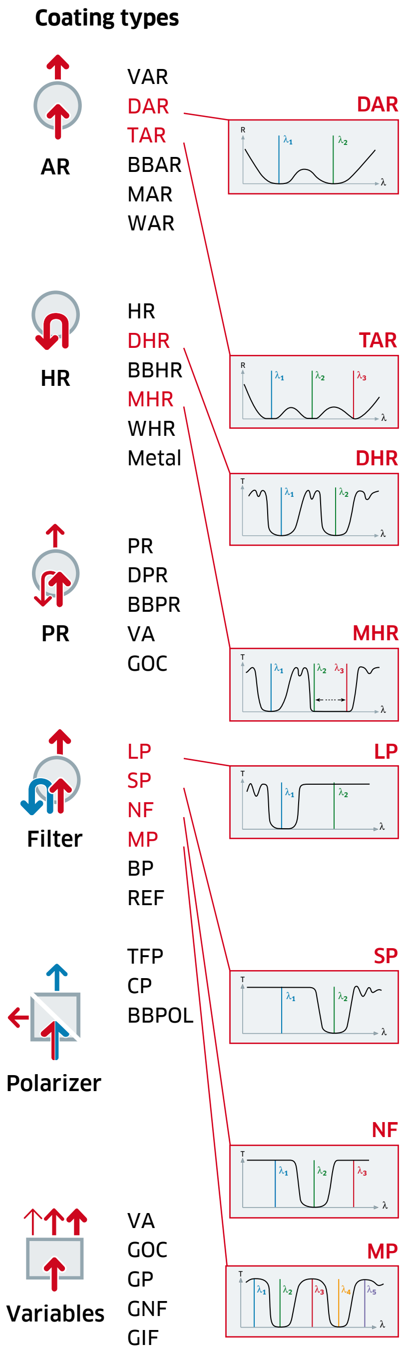


HT 1030 nm HR 1064 nm / 0° [B-06240]
1030 nm: R < 1.3%; 1064 nm: R > 99.4% (IBS-coating)

Find more than 1,200 examples in our LaserOptik Online Portal: www.laseroptik.de/loop

NIR 1030-1064 nm

Combinations of harmonics

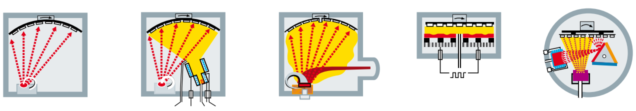


5th harmonic 213 nm	4th harmonic 266 nm	3rd harmonic 355 nm	2nd harmonic 532 nm	1064 nm	AOI	method
R < 1%	R < 0.8%				0°	EBE
	R < 1%	R < 0.5%			0°	EBE
	R < 1%		R < 0.5%		0°	EBE
		R < 0.75%	R < 0.5%		0°	EBE
			R < 0.5%	R < 0.3%	0°	EBE
			R < 0.2%	R < 0.1%	0°	IBS
			R < 1%	R < 0.75%	45°	EBE
	R < 1%	R < 1%		R < 0.5%	0°	EBE
		R < 1%	R < 1%	R < 0.5%	0°	EBE
		R < 0.3%	R < 0.3%	R < 0.3%	0°	IBS
	R > 99%	R > 99.5%			0°	EBE
	R > 99%		R > 99.5%		45°	EBE
		R > 99%	R > 99.5%		45°	EBE
			R > 99.8%	R > 99.8%	0°	EBE
			R > 99.9xx%	R > 99.9xx%	0°	IBS
	R > 98.5%	R > 99%	R > 99.5%		45°	EBE
		R > 99%	R > 99%	R > 99%	0°	EBE
	R > 97%	R > 98%	R > 99%	R > 99.5%	45°	EBE
Rs **> 99%**	Rp < 5%	Rp < 3%	Rp < 3%	Rp < 3%	45°	EBE
	R **> 99.5%**		R < 6%	R < 6%	45°	EBE
		R **> 99.5%**	R < 3%	R < 2%	45°	MS
		Rs **> 99.5%**	Rp < 1%	Rs < 1%	45°	IBS
			R **> 99.8%**	R < 2%	0°	EBE
			Rs **> 99.8%**	Rp < 1%	45°	EBE
	R < 5%	R **> 99.5%**			0°	EBE
	R < 10%		R **> 99.8%**		0°	EBE
		R < 2.5%	R < 2%	R **> 99.9xx%**	0°	IBS
			R < 5%	R **> 99.85%**	0°	EBE
			Rp < 3%	Rs **> 99.5%**	45°	EBE
	R < 8%	R **> 99.5%**	R < 8%	R < 8%	45°	MS
		R < 5%	R **> 99.7%**	R < 5%	0°	EBE
		Rp < 5%	Rs **> 99.7%**	Rp < 5%	45°	EBE
	Rp **> 98%**	Rp **> 98%**	Rs < 5%	Rp < 5%	45°	EBE
		R **> 99%**	R **> 99.5%**	R < 5%	45°	EBE

All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

EBE IAD IP MS IBS

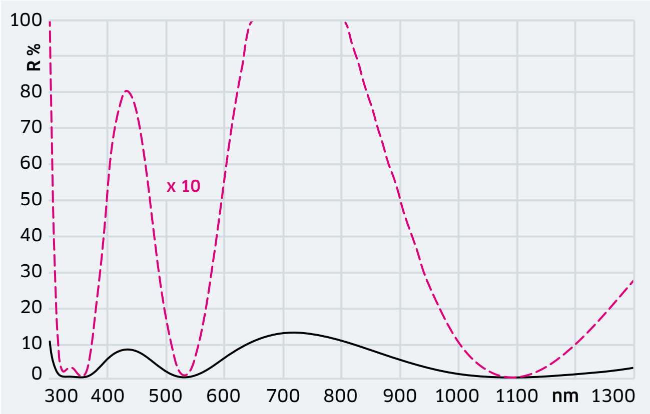


213 | 266 | 355 | 532 | 1064 nm as examples

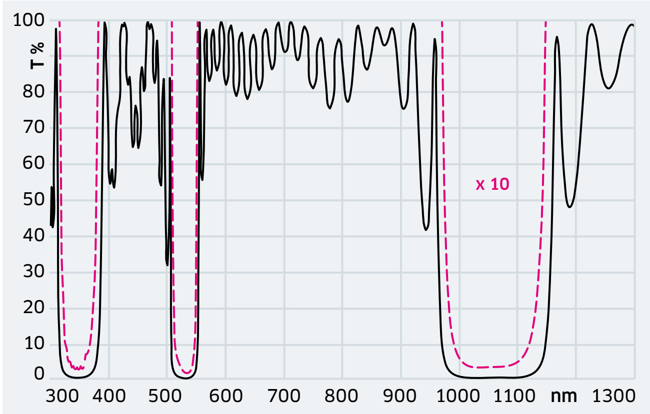
Nd:YAG/YVO_4
can be adapted to all other wavelenghts

Examples

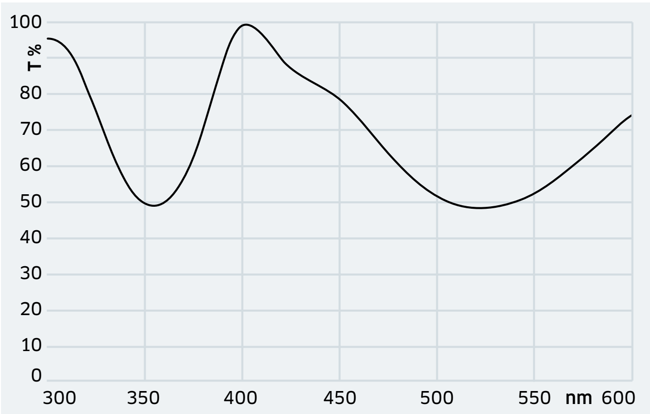
---- dashed lines show the zoomed curve with the stated magnification



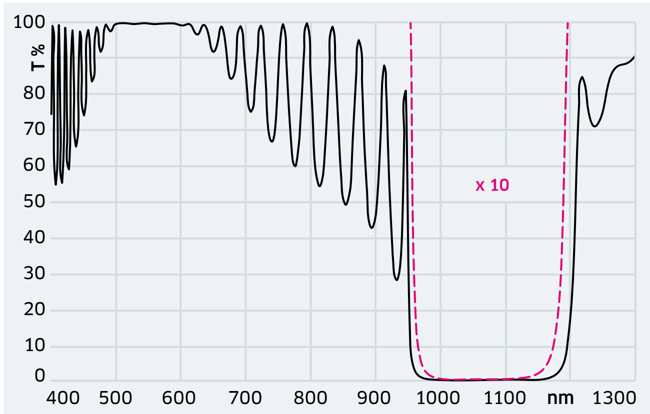
AR 355 nm + 532 nm + 1064 nm/0° [B-00536]
355 nm + 532 nm: R < 1%; 1064 nm: R < 0.5%



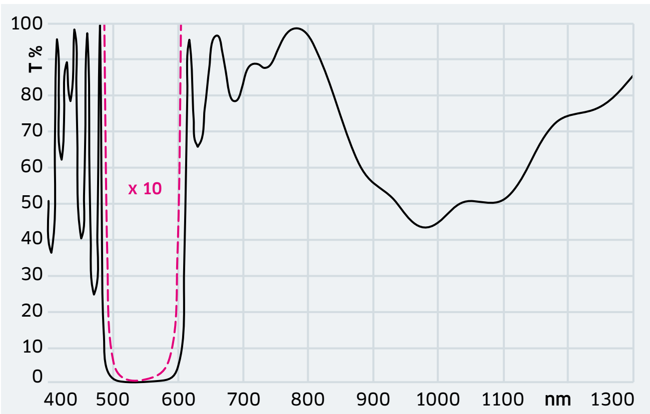
HR 355 nm + 532 nm + 1064 nm/0° Type 2 [B-04212]
355 nm + 532 nm + 1064 nm: R > 99%



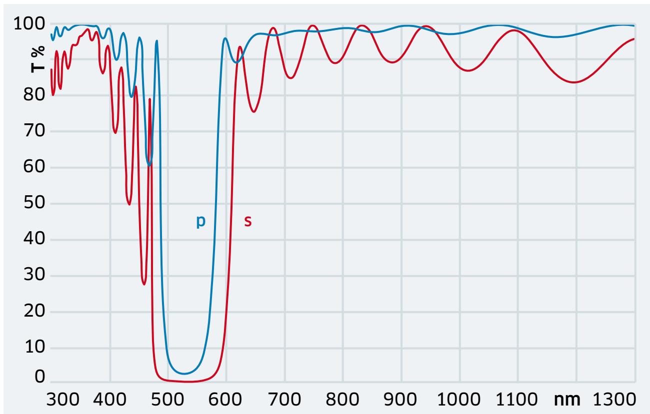
R 50% 355 nm + 532 nm/45° [B-01788]
355 nm + 532 nm: R ±5% vs theoretical curve



HT 532 nm HR 1064 nm/0° [B-00001]
532 nm: R < 5%; 1064 nm: R > 99.85%



HR 532 nm R 50% 1064 nm/0° [B-11735]
532 nm: R > 99.8%; 1064 nm: R ±5% vs theoretical curve



HT 355 nm/p HR 532 nm/s HT 1064 nm/p/45° [B-02977]
355 nm: Rp < 5%; 532 nm: Rs > 99.7%; 1064 nm: Rp < 5%

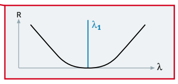
NIR 1065-2500 nm

Coating types


AR

VAR
DAR
TAR
BBAR
MAR
WAR

VAR



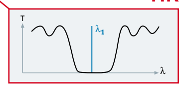
λ[nm]	AR (0°); R <		method	AR (45°); R <		method
1342	0.2%		EBE	0.6%		EBE
1550	0.2%		EBE	0.6%		EBE
	0.05–0.1%*	low loss	IBS	0.1–0.6%*	low loss	IBS
2100	0.25%	non-shifting	IAD	0.75%	non-shifting	IAD
2300	0.25%		EBE	0.75%		EBE

* depending on price, substrate size and laser power


HR

HR
DHR
BBHR
MHR
WHR
Metal

HR

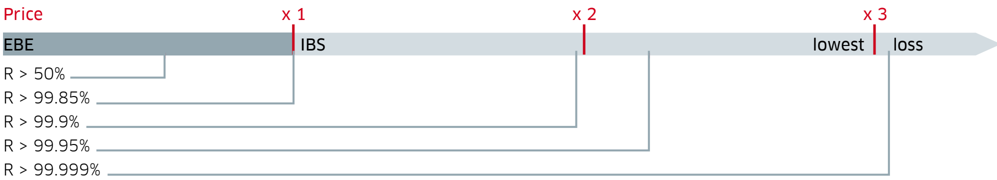



PR

PR
DPR
BBPR
VA
GOC

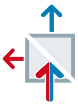
λ[nm]	HR (0°); R >		method	HR (45°); R >		method
1342	99.85%		EBE	99.8%		EBE
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
1535	99.85%		EBE	99.8%		EBE
1540	99.85%		EBE	99.8%		EBE
1550	99.85%		EBE	99.8%		EBE
	99.9xxx%*	low loss	IBS	99.9xxx%*	low loss	IBS
1573	99.85%		EBE	99.8%		EBE
2010	99.8%		EBE	99.7%		EBE
2090	99.8%		EBE	99.7%		EBE
2100	99.8%	standard	EBE	99.7%	standard	EBE
	99.8%	non-shifting	IAD	99.7%	non-shifting	IAD
2300	99.8%		EBE	99.7%		EBE

* 99.9xxx% means that we can optimize the reflection/transmission to your needs.
The coating price results from the chosen grade of reflection/difficulty, see estimated multiplier:



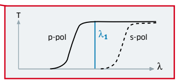

Filter

LP
SP
NF
MP
BP
REF

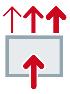

Polarizer

TFP
CP
BBPOL

TFP

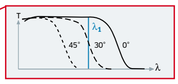


λ[nm]		AOI	method
1342	Tp > 90%, T < 1%	45°	IAD
	Tp > 96%, Ts < 1%	Brewster	IAD
1550	Tp > 98%, Ts < 1%	45°	IBS
2100	Tp > 95%, Ts < 0.5%	Brewster	IAD


Variables

VA
GOC
GP
GNF
GIF

VA

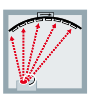


λ [nm]	0°→ 45°; T =	method
1550	95% → 1%	EBE

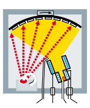
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

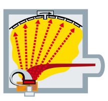
EBE



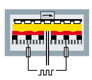
IAD



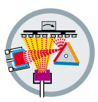
IP



MS



IBS

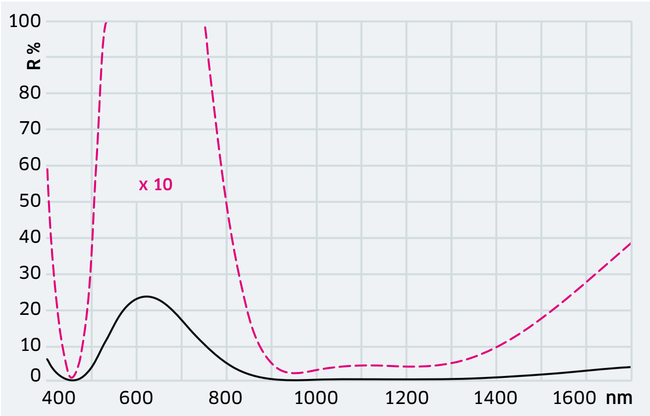


1123 | 1320 | 1342 | 1535 | 1540 | 1550 | 1573 | 2010 | 2090 | 2100 | 2300 nm

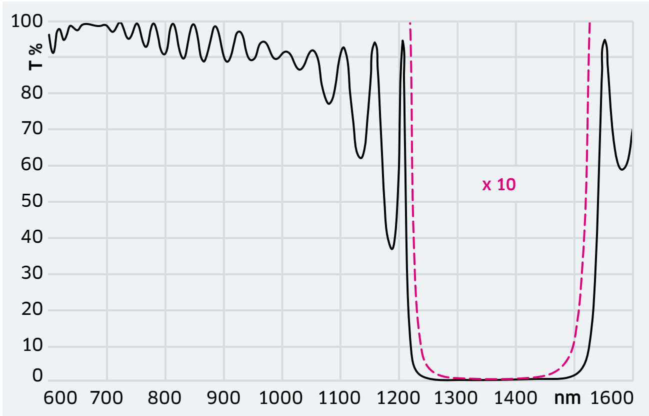
Yb, Er:KGW / KYW / glass – Er:YAG – Q-switched Nd:YVO_4 – Tm, Ho:YAG – YSGG – Tm:YLF
weak Nd:YAG/YVO_4

Examples

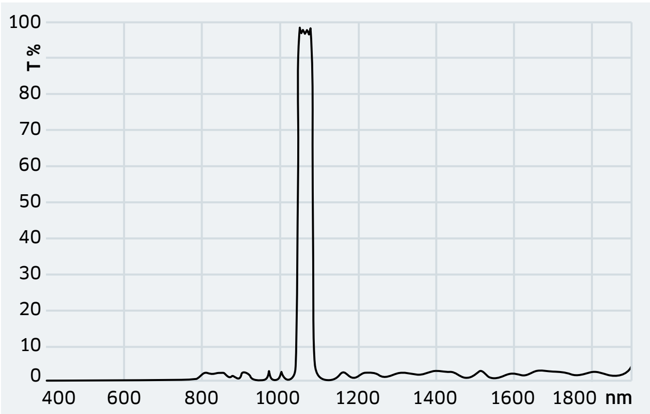
---- dashed lines show the zoomed curve with the stated magnification



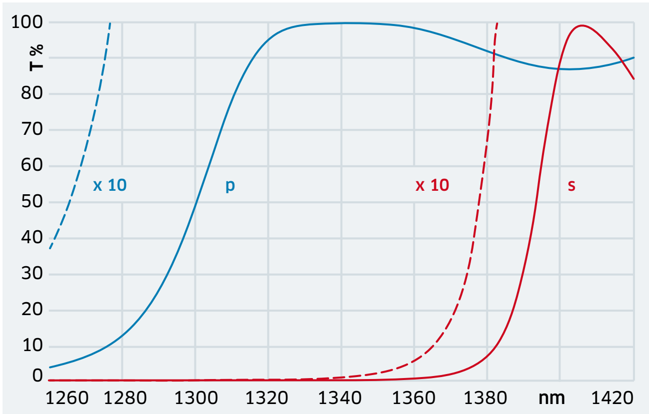
AR 457 nm + 914 nm + 1064 nm + 1320 nm/0° [B-03652]
457 nm + 914 nm: R < 1%; 1064 nm: R < 0.8%; 1320 nm: R < 1%



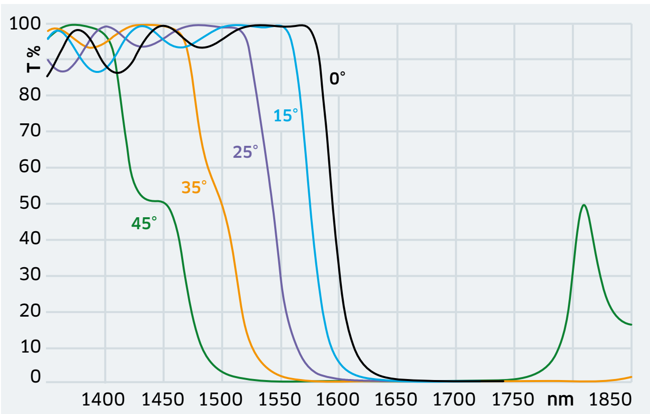
HT 671 nm HR 1342 nm/0° [B-03578]
671 nm: R < 10%; 1342 nm: R > 99.85%



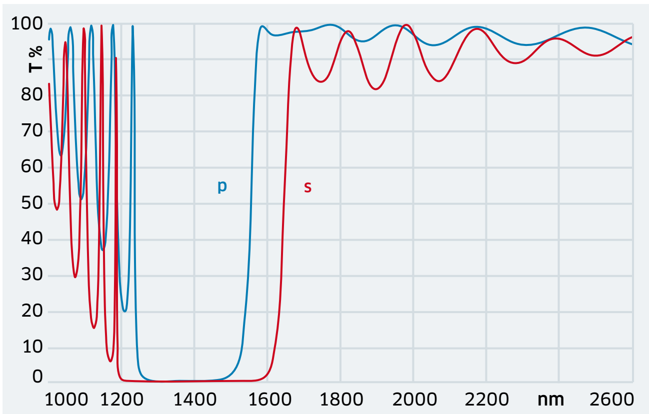
BP 1050–1080 nm/0° on RG 850 incl. AR on rear side [B-05358]
400–1040 nm: Tavg < 2%; 1050–1080 nm: Tavg > 80%
1090–1900 nm: Tavg < 3% (IBS-coating)



TFP 1342 nm/56° [B-07759]
1342 nm: Tp > 96%, Ts < 1% (IAD-coating)



VA 1550 nm/0–45° T 95–1% [B-12535]
1550 nm: 0° → 45°; T = 95% → 1%



HR 1220–1560 nm/s HT 1620–2500 nm/p/45° [B-02997]
1220–1560 nm: Rs > 99%; 1620–2500 nm: Rp < 10%

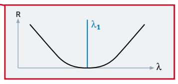
MIR > 2500 nm

Coating types

AR

VAR
DAR
TAR
BBAR
MAR
WAR

VAR



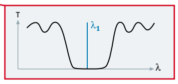
λ[nm]	AR (0°); R <		method	AR (45°); R <		method
2940	0.25%	on CaF_2	EBE	1%	on CaF_2	EBE
	0.05–0.1% *	on Sapphire	IBS	0.1%–0.6% *	on Sapphire	IBS
3300	0.3%	on CaF_2	EBE	1%	on CaF_2	EBE
4000	0.5%	on CaF_2	EBE	1%	on CaF_2	EBE

* depending on price, substrate size and laser power

HR

HR
DHR
BBHR
MHR
WHR
Metal

HR



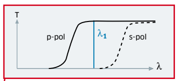
λ[nm]	HR (0°); R >		method	HR (45°); R >		method
2810	99.8%	on CaF_2	EBE	99.7%	on CaF_2	EBE
2940	99.7%	on CaF_2	EBE	99.7%	on CaF_2	EBE
	99.9xx%*	on YAG	IBS	99.9xx%*	on YAG	IBS
3300	99.7%	on CaF_2	EBE	99.7%	on CaF_2	EBE
4000	99.5%	on CaF_2	EBE	99.5%	on CaF_2	EBE

* 99.9xx% means that we can optimize the reflection/transmission to your needs.

PR

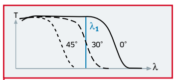
PR
DPR
BBPR
VA
GOC

TFP



λ[nm]		AOI	method
4000	Tp > 95%, Ts < 2%	Brewster	EBE

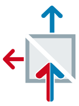
VA



λ[nm]	0°→ 45°; T =		method
2940	90% → 1%	on CaF_2	EBE

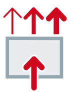
Filter

LP
SP
NF
MP
BP
REF



Polarizer

TFP
CP
BBPOL



Variables

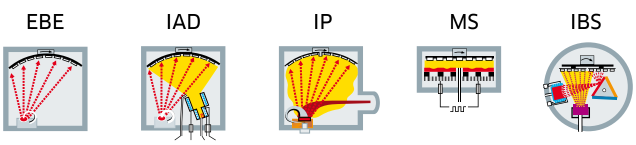
VA
GOC
GP
GNF
GIF

LASEROPTIK has a dedicated EBE coating machine for infrared coatings made with non-radioactive materials. Due to national environmental regulations we do not use ThF_4, but still cover a range of up to λ = 4 µm for reflecting systems and up to λ = 10.6 µm for anti-reflecting systems.

Coatings are applied on various IR substrates such as Ge, ZnSe, Sapphire, CaF_2 and others. Metal coatings are also available for IR applications (see page 54).

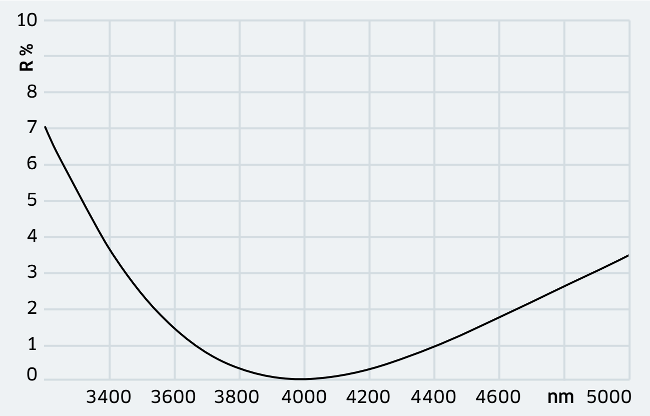
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

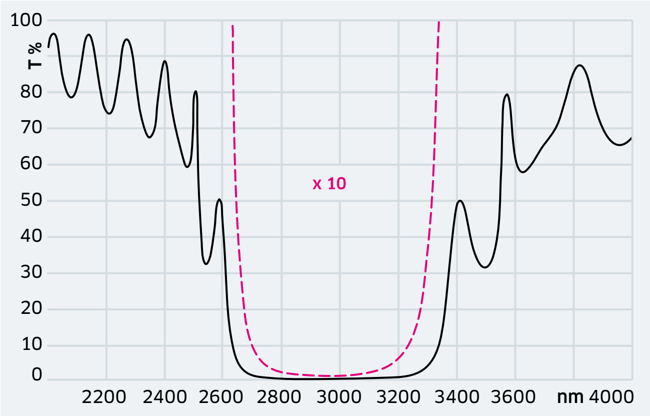


Examples

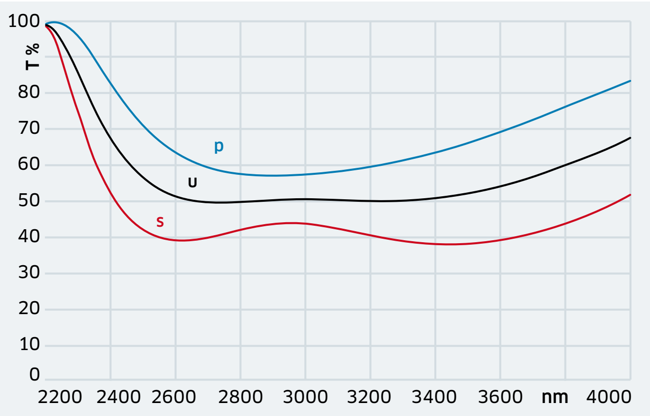
---- dashed lines show the zoomed curve with the stated magnification



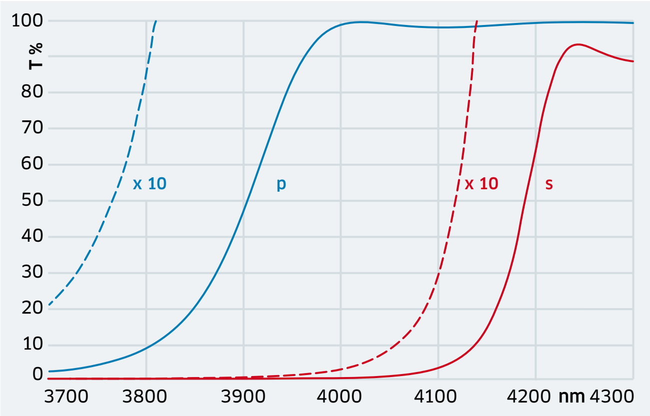
AR 4000 nm / 0° on CaF_2 [B-02246]
4000 nm: R < 0.5%



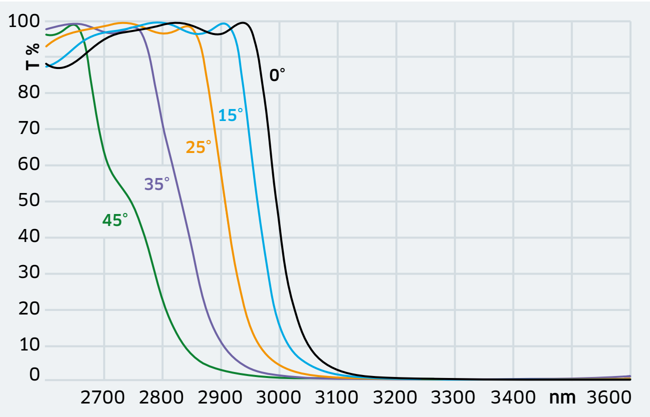
HR 2940 nm / 45° [B-06023]
2940 nm: R > 99.7%



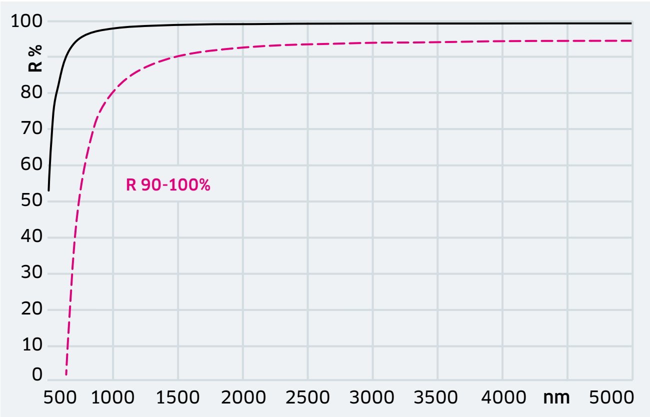
R 50% 2700–3300 nm / 45° [B-04184]
2700–3300 nm: Ru ±5% vs theoretical curve



TFP 4000 nm / 55° on CaF_2 [B-02823]
4000 nm: Tp > 95%, Ts < 2%



VA 2940 nm / 0–45° T 90–1% on CaF_2 [B-03940]
2940 nm: 0° → 45°; T = 90% → 1%



Au + Protection Layer [B-06039]
IR: R > 97%

Polarizer

Thin Film / Cube / Broadband

Coating types

AR: VAR, DAR, TAR, BBAR, MAR, WAR

HR: HR, DHR, BBHR, MHR, WHR, Metal

PR: PR, DPR, BBPR, VA, GOC

Filter: LP, SP, NF, MP, BP, REF

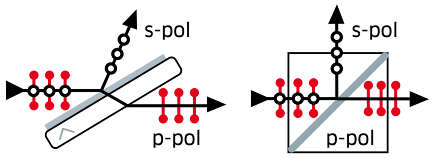
Polarizer: TFP, CP, BBPOL

Variables: VA, GOC, GP, GNF, GIF

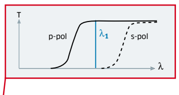
Thin Film Polarizer TFP
Normally is coated on a plate (that does not need to have any birefringence) and uses the strong reflection difference between p- and s-polarized light. Working with the Brewster angle a high extinction ratio can be achieved and no AR on the rear surface is required *(see "tips and tricks", page 19).*

Cube Polarizer CP
Is built out of two 45° prisms with a polarizing coating on one of the hypotenuses. The prisms are cemented or optically contacted after coating, some with an air gap. The output surfaces need an AR at 0°.

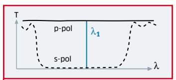
Broadband Polarizer BBPOL
Separates the s- and p-polarized light in a broader range compared to the standard TFP but normally with a lower extinction ratio. It can be made by using a plate coated on both sides and a large angle of incidence (AOI~72°) or a cube (special glass material is required).



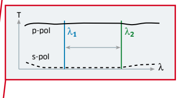
TFP



CP



BBPOL



λ[nm]		AOI	method
157	Rp < 0.3%, Rs > 87%	72° on CaF_2	EBE
193	Tp > 80%, Ts < 10%	73°	EBE
248	Tp > 80%, Ts < 2%	Brewster	EBE
266	Tp > 90%, Ts < 2%	Brewster	EBE
355	Tp > 94%, Ts < 2%	Brewster	EBE
	Tp > 96%, Ts <0.2%	Brewster	IBS
532	Tp > 96%, Ts < 1%	Brewster	IAD
	Tp > 99%, Ts < 0.1%	Brewster	IBS
808	Tp > 95%, Ts < 1%	Brewster	EBE
940	Tp > 95%, Ts < 1%	Brewster	IAD
1064	Tp > 95%, Ts < 5%	45° cube	EBE
	Tp > 99%, Ts < 1%	45°	IBS
	Tp > 95%, Ts < 2%	Brewster	EBE
	Tp > 99%, Ts < 0.1%	Brewster	IBS
1342	Tp > 96%, Ts < 1%	Brewster	IAD
1550	Tp > 98%, Ts < 1%	45°	IBS
2100	Tp > 95%, Ts < 0.5%	Brewster	IAD

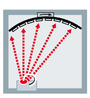
λ[nm]	extinction ratio	AOI	method
1064	Tp/Ts > 990	Brewster	IBS
	Rs/Rp > 200		
	Tp/Ts > 48	Brewster	EBE
	Rs/Rp > 20		

The extinction ratio can be optimized for use in reflection or transmission. The given values refer to the standard TFP made by IBS and the much cheaper EBE. Also other splitting ratios, e.g. Tp/Rs can be optimized.

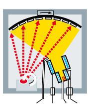
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

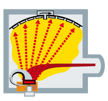
EBE



IAD

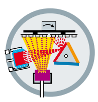


IP



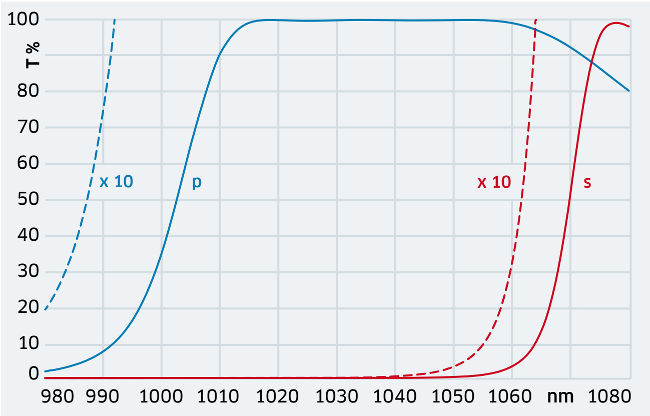
MS

IBS

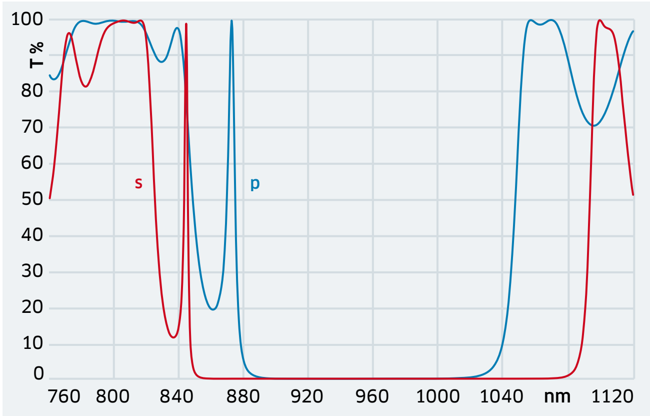


Examples

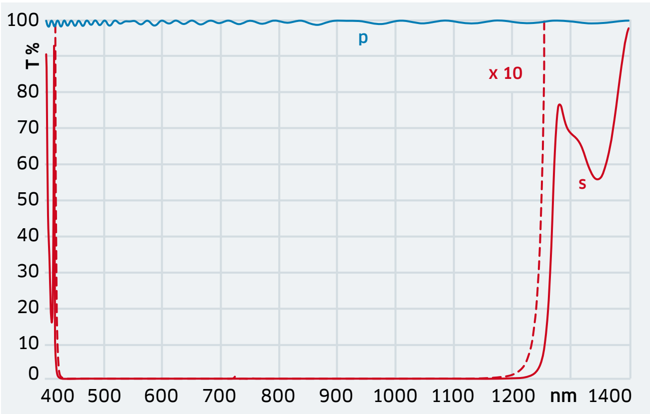
---- dashed lines show the zoomed curve with the stated magnification



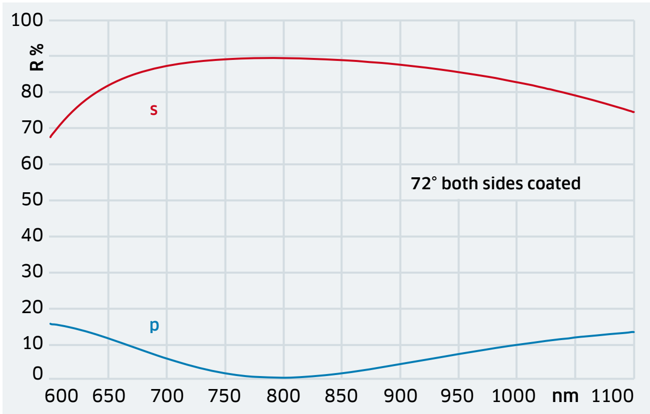
TFP 1022–1038 nm / 55.4° [B-14497]
1022–1038 nm: Tp > 98.5%, Ts < 0.1% (IBS-coating)



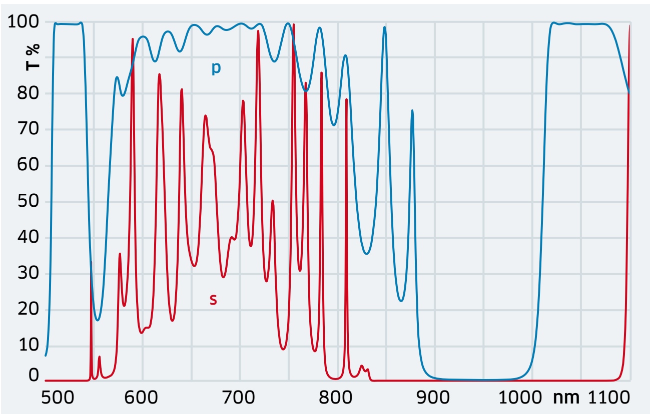
HT 808 nm TFP 1064 nm / 45° [B-11055]
808 nm: Ru < 5%; 1064 nm: Rs > 99.6%, Rp < 5% (IBS-coating)



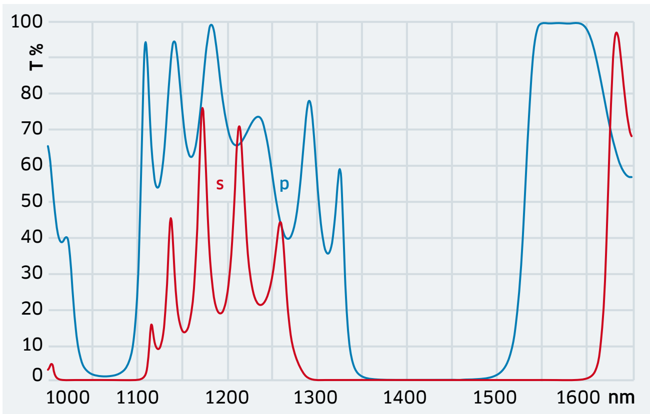
BBPOL 470–1090 nm / 45° S-TiH3-cube [B-06332]
470–1090 nm: extinction ratio > 1000 (IAD-coating)



BBPOL 750–850 nm / 72 ±2° [B-08032]
750–850 nm: 72°: Tp,avg > 97%, Rs > 75%;
70–74°: Tp,avg > 95%, Rs > 75%



TFP 515–532 nm + 1030–1064 nm / 65° [B-13591]
515–532 nm + 1030–1064 nm: Ts < 0.2%, Tp,avg > 98%
(IBS-coating)



HR 1064 nm TFP 1565–1579 nm / 55 ±1° [B-11854-01]
1064 nm: Ru > 99%; 1565–1579 nm: Rs > 99.5%, Tp > 98%;
1572 nm: Tp/Ts ≥ 100 (IBS-coating)

Variables

Variable Attenuators (VA/IVA)

Coating types

AR: VAR, DAR, TAR, BBAR, MAR, WAR

HR: HR, DHR, BBHR, MHR, WHR, Metal

PR: PR, DPR, BBPR, VA, GOC

Filter: LP, SP, NF, MP, BP, REF

Polarizer: TFP, CP, BBPOL

Variables: VA, GOC, GP, GNF, GIF

Variable Attenuators VA
Change transmission by tilting of edge filters, with highest transmission at AOI 0°, mainly produced to work in the range from AOI 0° to 45°.

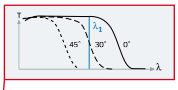
Inversely Variable Attenuators IVA
Work in the same way as VA but have lowest transmission at AOI 0°.

Given tolerances show the minimum tuning range in transmission. Beam displacement can be compensated by using a second plate or two filters simultaneously. For low attenuation we recommend an AR-coated second plate.

LASEROPTIK offers **AVACS** *(Automatic Variable Attenuator Control System)*. The unit is driven by a stepper motor and can be controlled manually or by a computer. The AVACS includes power supply, control display, operation elements, starting routine, limit stop device, computer interface and water cooling.

Additionally a simple housing with manual adjustment can be supplied.

VA

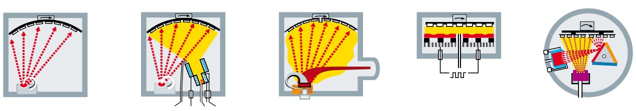


λ[nm]	0° → 45°; T=		method	
157	70% → 2%	on CaF_2	EBE	
	10% → 70%	on CaF_2	EBE	inversely (IVA)
193	80% → 10%		MS	
248	90% → 2%	standard	EBE	
	95% → 1%	high power	MS	
	10% → 95%	high power	MS	inversely (IVA)
266	92% → 1%	standard	EBE	
	95% → 1%	high power	MS	
355	92% → 1%	standard	EBE	
	92% → 1%	non-shifting	IAD	
532	92% → 1%	standard	EBE	
	90% → 1%	non-shifting	IAD	
808	95% → 1%	non-shifting	IAD	
940	95% → 1%	non-shifting	IAD	
1064	95% → 1%		EBE	
	95% → 1%	non-shifting	IAD	
1550	95% → 1%		EBE	
2940	90% → 1%	on CaF_2	EBE	

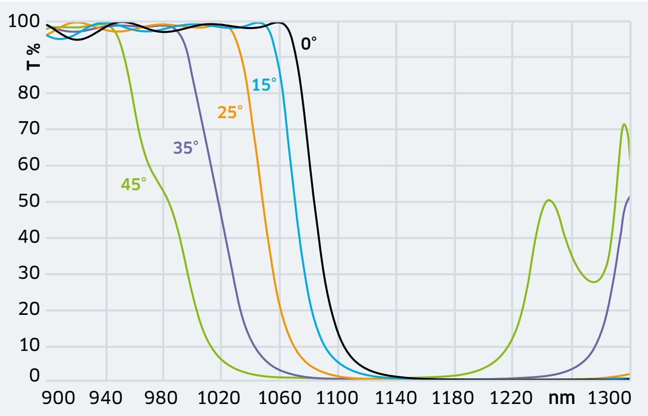
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

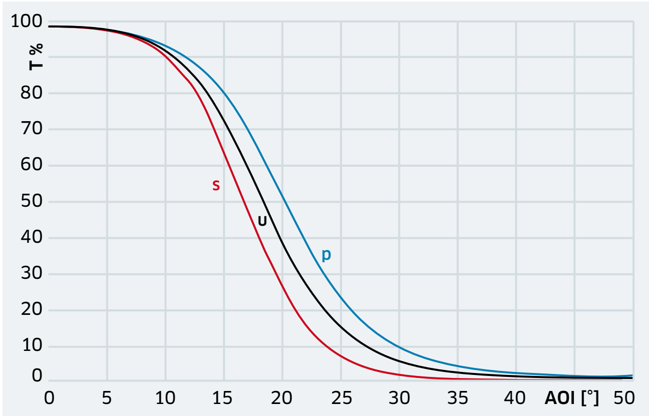
EBE IAD IP MS IBS



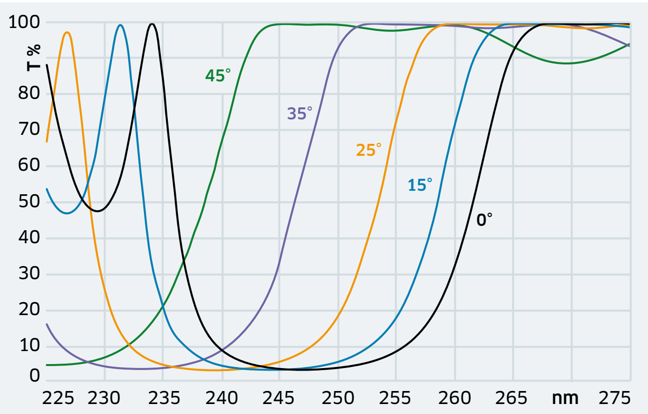
Examples



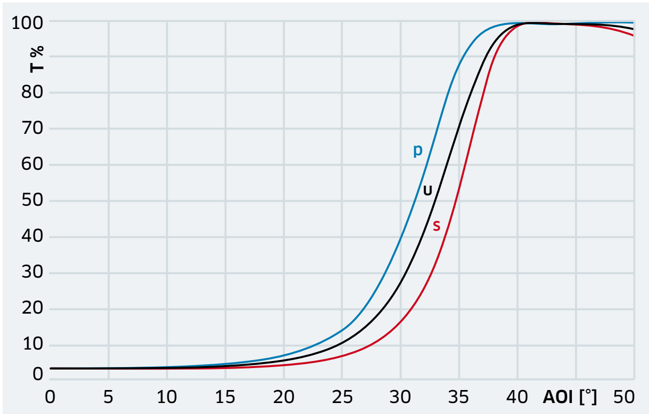
VA 1064 nm / 0–45° T 95–1% [B-00431-01]
1064 nm: 0° → 45°; T = 95% → 1%



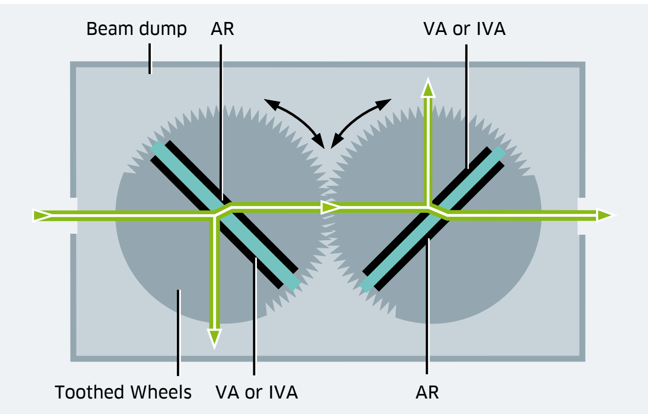
VA 1064 nm / 0–45° T 95–1% [B-00431-01]
Angle resolved transmission at 1064 nm



IVA 248 nm / 15–45° T 10–95% [B-01991]
248 nm: 15° → 45°; T = 10% → 95% (MS-coating)



IVA 248 nm / 15–45° T 10–95% [B-01991]
Angle resolved transmission at 248 nm



Compensated Attenuator
Scheme

AVACS [M-00013]
Automatic Variable Attenuator Control System

Gradient Output Couplers and Filters

Coating types

AR: VAR, DAR, TAR, BBAR, MAR, WAR

HR: HR, DHR, BBHR, MHR, WHR, Metal

PR: PR, DPR, BBPR, VA, GOC

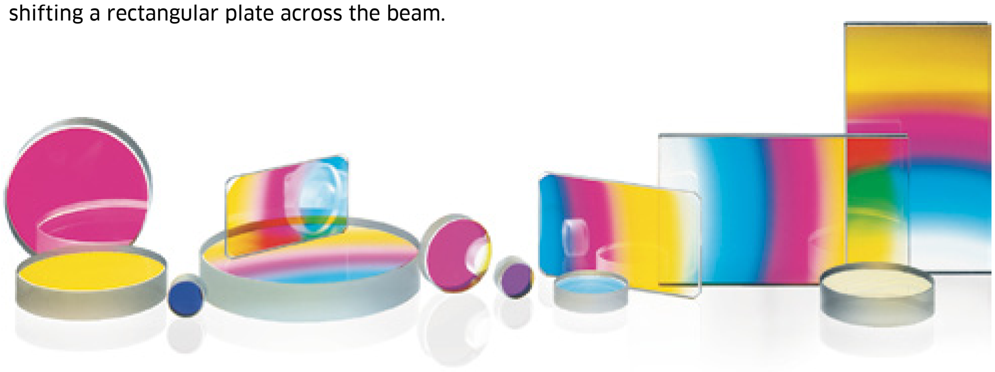
Filter: LP, SP, NF, MP, BP, REF

Polarizer: TFP, CP, BBPOL

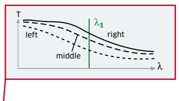
Variables: VA, GOC, GP, GNF, GIF

A special machine setup is required to manufacture gradient optics that allow the central wavelength to change with its position on the substrate. So it is possible to change the optical properties without any beam displacement by shifting a rectangular plate across the beam.

Given tolerances show the minimum variation on a standard substrate 50 x 27 mm if the plate is shifted within about 40 mm (right-middle-left position).



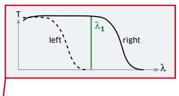
GOC



λ[nm]	right → left T =	method
193	1% → 70%	MS
532	85% → 25%	IAD
1064	25% → 75%	IAD

Gradient Output Coupler GOC
Changes the reflection-transmission-ratio.

GP

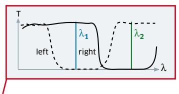


λ[nm]	right → left T =	method	
532	1% → 95%	IAD	GLP
1064	1% → 95%	IAD	GLP
	95% → 1%	IAD	GSP

Gradient Pass Filter GP
The incoming light passes through in one position and will be blocked in the other one, available as long pass GLP and short pass GSP.

If a GLP and GSP are used in combination, the resulting bandwidth can be varied in a large wavelength area.

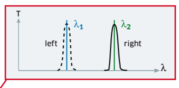
GNF



λ[nm]	right → left T =	method
808–914	1% → 90%	IAD
976–1064	0.5% → 90%	IAD

Gradient Notch Filter GNF
Transmits one wavelength and blocks another one in left position and reversely in right position.

GIF



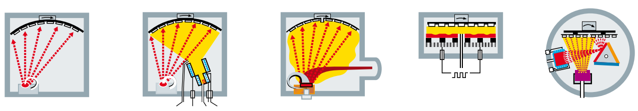
λ[nm]	right → left T =	method
476–514	on request	IAD

Gradient Interference Filter GIF
Gives the opportunity to select various wavelengths, e.g. for fast external change of multiline noble gas ion lasers.

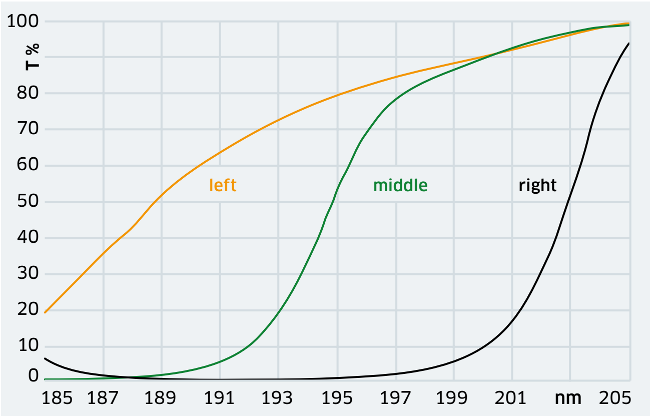
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

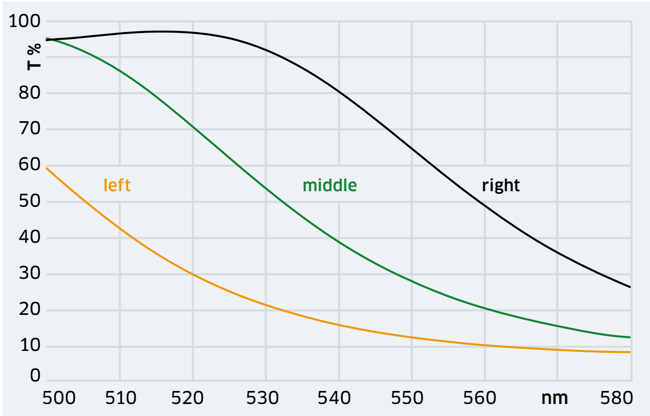
EBE IAD IP MS IBS



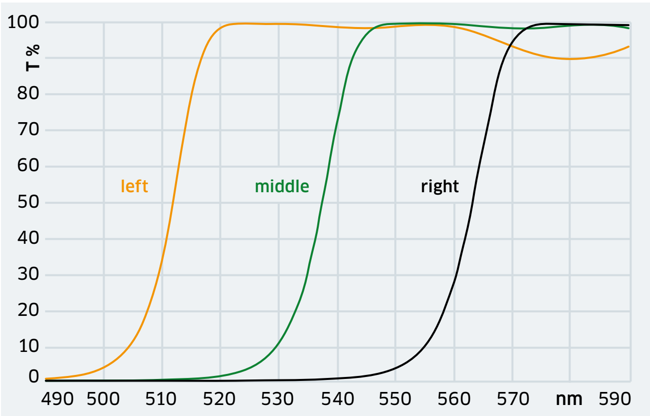
Examples



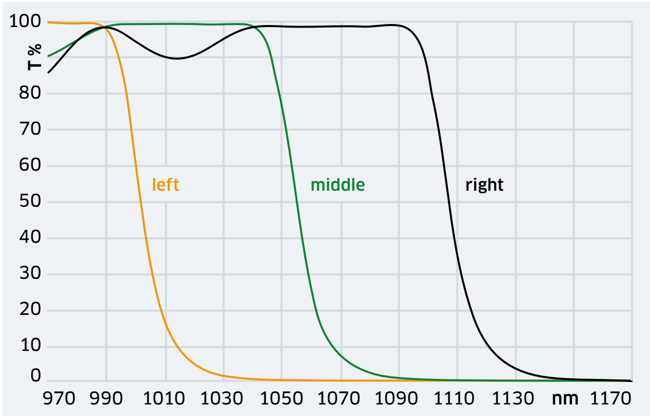
GOC 193 nm / 0° [B-00810]
193 nm: right → left position; T = 1% → 70% (MS-coating)



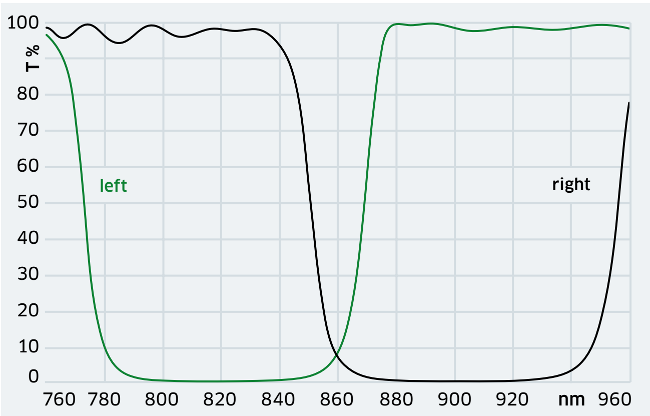
GOC 532 nm / 0° [B-05980]
532 nm: right → left position; T = 85% → 25% (IAD-coating)



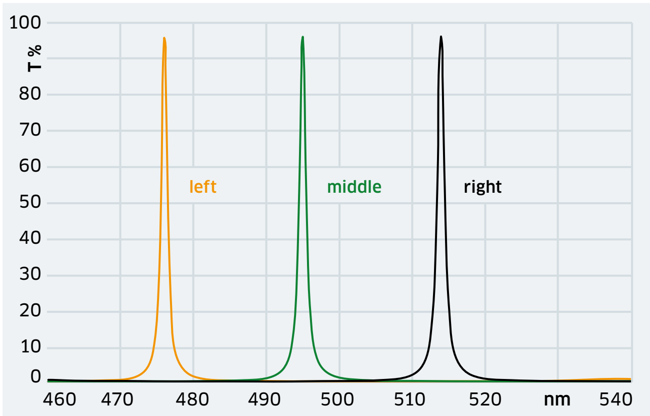
GLP 532 nm / 0° [B-05986]
532 nm: right → left position; T = 1% → 95% (IAD-coating)



GSP 1064 nm / 0° [B-05984]
1064 nm: right → left position; T = 95% → 1% (IAD-coating)



GNF 808–914 nm / 0° [B-05991]
808 nm: right → left position; T = 90% → 1%;
914 nm: right → left position; T = 1% → 90% (IAD-coating)



GIF 476–514 nm / 0° [B-06004]
tolerances on request (IAD-coating)

Reflection Filters

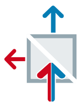
Coating types

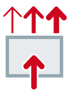

AR
VAR
DAR
TAR
BBAR
MAR
WAR


HR
HR
DHR
BBHR
MHR
WHR
Metal

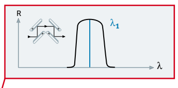

PR
PR
DPR
BBPR
VA
GOC


Filter
LP
SP
NF
MP
BP
REF


Polarizer
TFP
CP
BBPOL


Variables
VA
GOC
GP
GNF
GIF

REF



Reflection Filters REF

Select wavelengths by using 4 filter plates simultaneously. By tilting the plates the transmitted wavelength area can be selected with no change of the final beam direction.

Listed below are scanning range Δλ, half bandwidth HBW and transmission at peak maximum T_{max} of standard REFs.

The manufacturing of variable reflection filters is possible for a spectral range from 140 nm to 2000 nm.

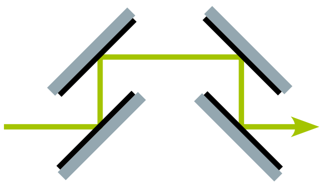
Typically the scanning range is about 15% of the center wavelength, with rejection $<10^{-4}$ from VUV to FIR and damage threshold similar to high power coatings.

Δλ [nm]	HBW [nm]	T_{max}	method	type
180–200	12	80%	EBE	1
235–275	18	90%	EBE	1
	40	95%	EBE	2
290–340	20	95%	EBE	1
340–390	25	98%	MS	1
500–585	30	98%	IAD	1
750–880	60	98%	IAD	1
1000–1150	60	95%	IAD	1

LASEROPTIK offers two different housings to adjust the black filter plates (NG1) between AOI 15° and 60°:

- a manually driven unit, equipped with plates 50 x 50 x 1 mm, and
- a stepper motor driven unit, controlled manually or by PC, with 70 x 50 x 3 mm.

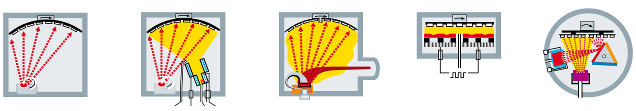
Please ask for more details.



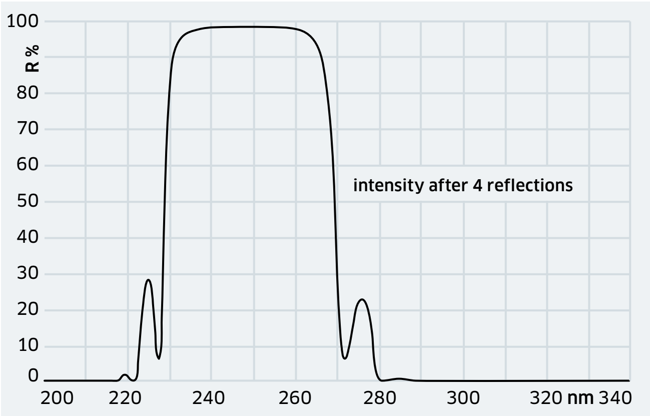
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

EBE IAD IP MS IBS



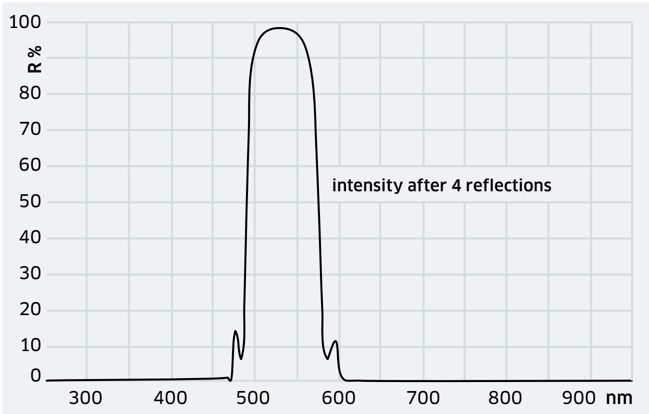
Examples



REF 248 nm / 45° Type 2 [B-01931]
248 nm: R^4 > 95%, compensation of manufacturing tolerance for wavelength by angle tuning necessary

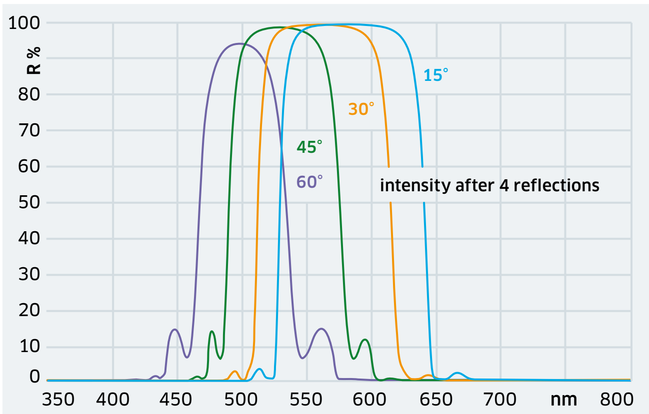
REF 266 nm / 45° Type 2 [B-04555]
266 nm: R^4 > 95%, compensation of manufacturing tolerance for wavelength by angle tuning necessary

REF 355 nm / 45° Type 1 [B-03442]
355 nm: R^4 > 95%, compensation of manufacturing tolerance for wavelength by angle tuning necessary



REF 532 nm / 45° Type 2 [B-06179]
532 nm: R^4 > 98%, compensation of manufacturing tolerance for wavelength by angle tuning necessary

Reflection Filter Housing
motor driven (left) [M-00012] *and manual adjustment* [M-00042]



REF 532 nm / 45° Type 2 [B-06179]
532 nm: R^4 > 98%, compensation of manufacturing tolerance for wavelength by angle tuning necessary

Metal coatings

Coating types

AR: VAR, DAR, TAR, BBAR, MAR, WAR

HR: HR, DHR, BBHR, MHR, WHR, Metal

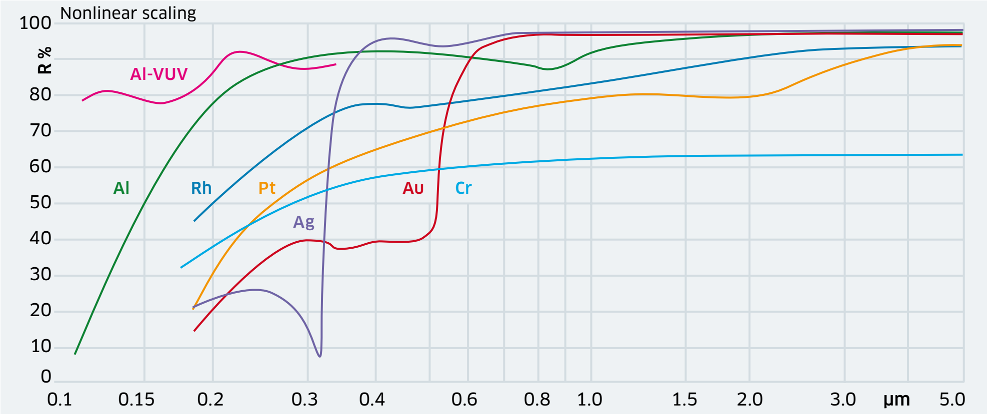
PR: PR, DPR, BBPR, VA, GOC

Filter: LP, SP, NF, MP, BP, REF

Polarizer: TFP, CP, BBPOL

Variables: VA, GOC, GP, GNF, GIF

Metal



Metal coatings have a fair but very broad reflectivity over a certain wavelength range.

LASEROPTIK offers standard mirror coatings such as aluminium, gold or silver, normally with protection layer or even enhanced, i.e. with an additional dielectric coating system.

λ[nm]	Al-VUV R >	Al-VIS-IR R >	Ag R >	Au R >
120	65%			
157	65%			
193	70%			
220	75%			
300	80%	80%		
450		85%	95%	
532		88%	96%	
808		80%	97%	97%
940		87%	97%	97%
1064		92%	97%	97%
1550		92%	97%	98%
2940		92%	97%	97%

Al – Aluminium shows the highest reflectance in the UV. A reflection dip occurs around 850 nm due to phonon absorption.

With a fluoride protection layer Al coatings can be optimized for use in the VUV.

Ag – Silver coatings give the highest reflectivity in the VIS and NIR. As they have low GDD in a broad wavelength area they can be taken as simple and low-priced mirrors for femtosecond lasers.

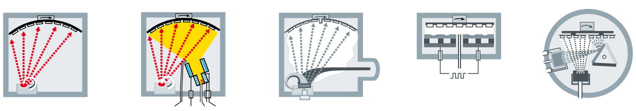
Au – Gold shows poor adhesion to glass and needs a bonding layer of chromium. It is often used in the far IR without a protection layer or as a solderable coating.

Other metal coatings are available too, e.g. chrome, chrome-nickel or platinum.

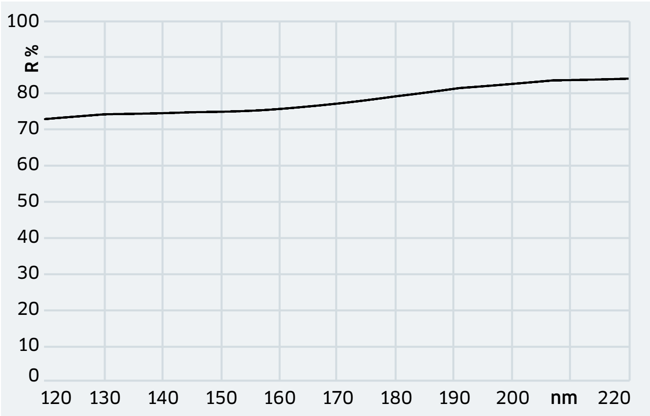
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

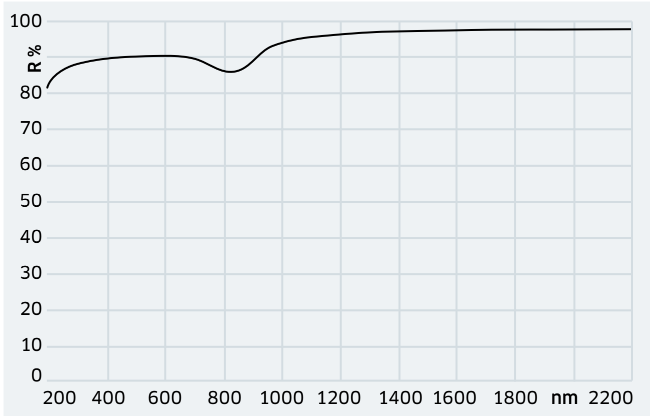
EBE IAD IP MS IBS



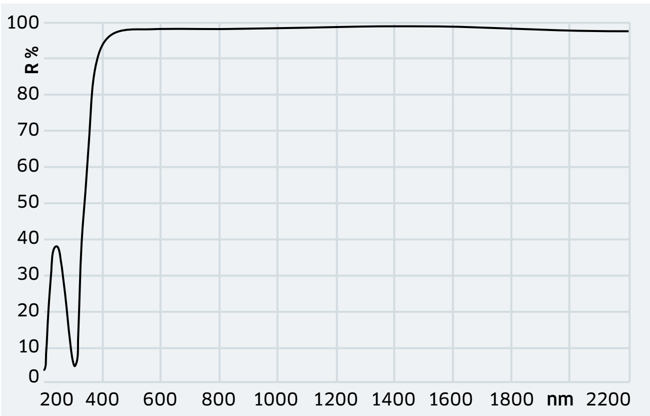
Examples



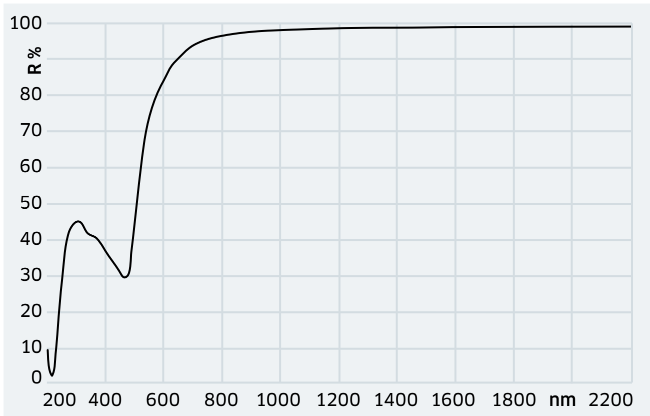
Al + Protection Layer – VUV [B-02250-01]
120–220 nm: R > 65%



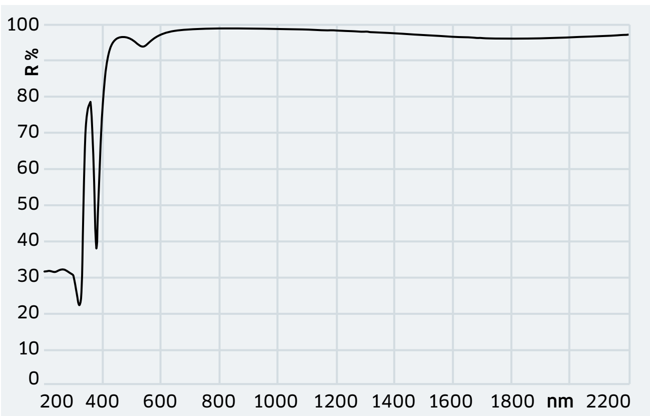
Al + Protection Layer – VIS-IR [B-00018-01]
> 300 nm: R ±3% vs. curve



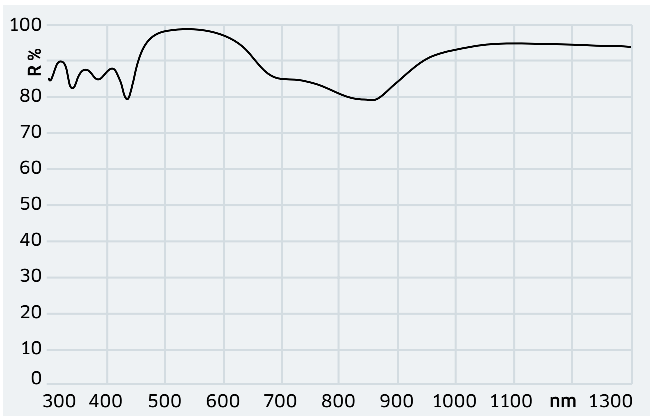
Ag + Protection Layer [B-00931]
450–500 nm: R > 95%; 500–1100 nm: R > 97%



Au + Protection Layer [B-06039]
IR: R > 97%



Ag enhanced HR 650-1350 nm for fs / 45° [B-10662-02]
650–1350 nm: Ravg > 98%



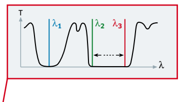
Al enhanced 532 nm / 45° [B-08462]
532 nm: R > 97%

Optical Parametric Oscillators

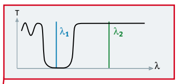
OPO

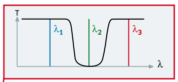
Coating types


AR
VAR
DAR
TAR
BBAR
MAR
WAR

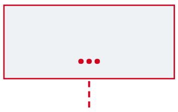



HR
HR
DHR
BBHR
MHR
WHR
Metal

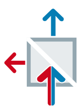


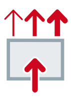



PR
PR
DPR
BBPR
VA
GOC




Filter
LP
SP
NF
MP
BP
REF


Polarizer
TFP
CP
BBPOL


Variables
VA
GOC
GP
GNF
GIF

An Optical Parametric Oscillator (OPO) transforms a pump laser wave with the frequency ω_p into two different waves, called idler and signal, where signal is the one with the higher frequency. The sum of their frequencies (ω_i and ω_s) is equal to the frequency of the pump laser: $\omega_p = \omega_i + \omega_s$

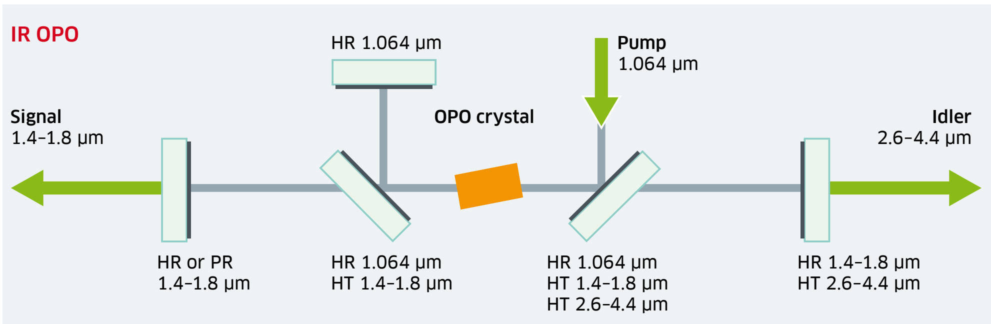
Basically an OPO is a nonlinear crystal working inside an optical resonator where either the idler wave or the signal wave resonates.

By modifying phasematching properties like the orientation or the temperature of the crystal you can change the frequency of the output. Another option is to modify its quasi-phasematching period through a periodical poling. A variation in the optical path length of the resonator can be used for additional finetuning. With an OPO it is possible to achieve wavelengths beyond those of available laser mediums.

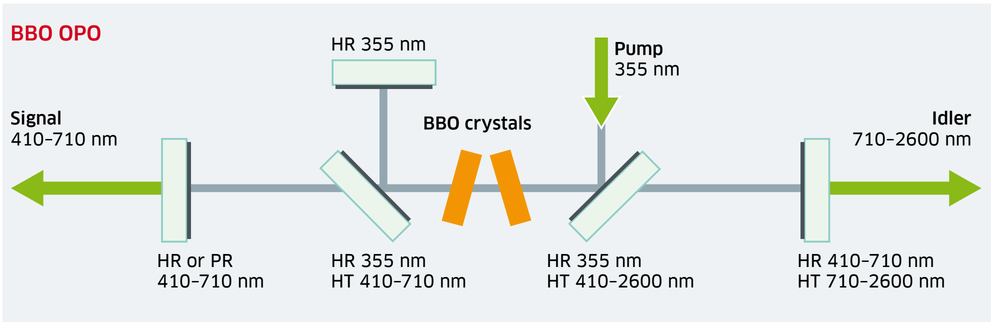
An OPO system uses several different coating types. In the following you can find the diagram for different OPOs. To minimize the losses in intensity every untitled surface has to be coated with a corresponding AR.

Of course there are other possible setups for the featured systems, especially when working with 45°-filters and optimized polarization for the pump, signal and idler wave.

Please find more information regarding OPO coatings with optimized GDD on page 70.

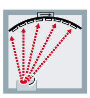
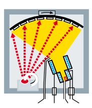
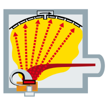
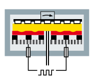
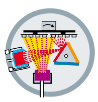


Two examples of an OPO set-up



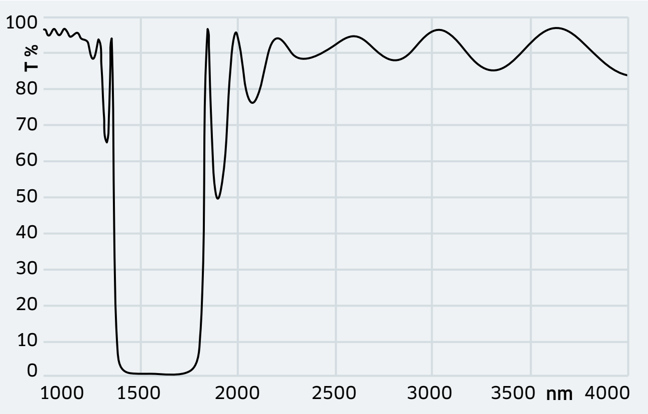
All values are given for standard coatings.
Customized coatings available for all types.

Coating methods available:

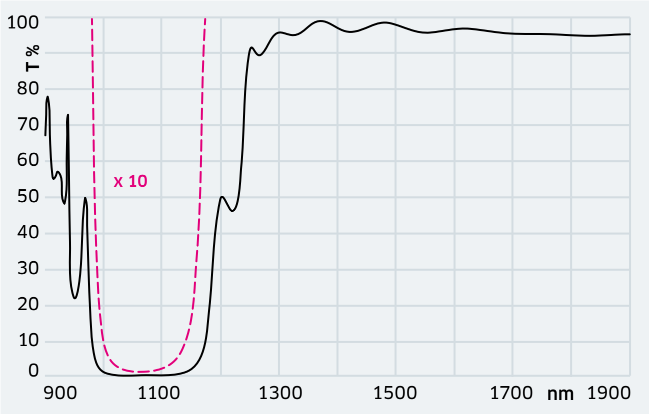
EBE

IAD

IP

MS

IBS


Examples

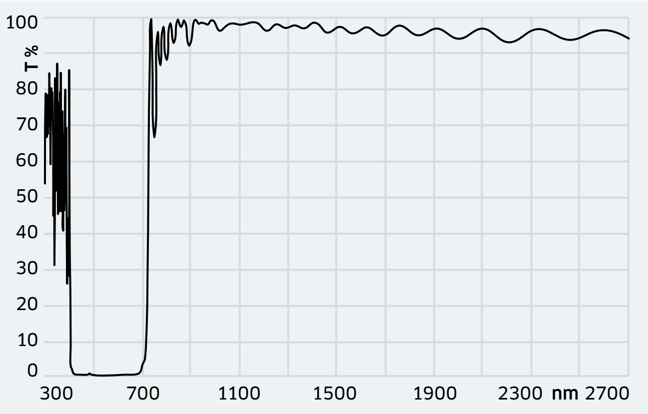
---- *dashed lines show the zoomed curve with the stated magnification*



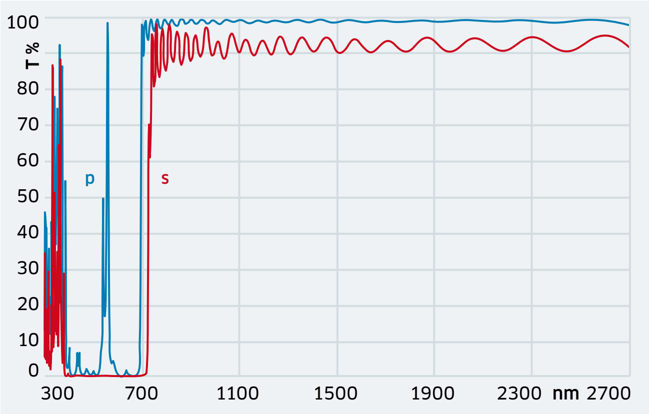
HT 1064 HR 1480–1650 HT 3000–3800 nm/0° CaF_2 [B-05749]
1064 nm: R < 8%; 1480–1650 nm: Ravg > 99.7%; 3000–3800 nm: Ravg < 20%



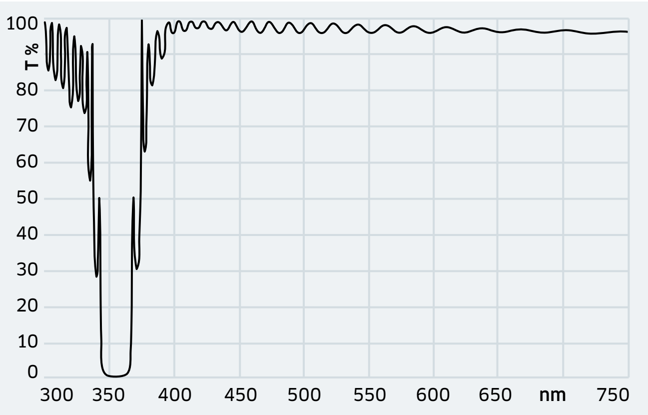
HR 1064 nm HT 1300–1800 nm/45° [B-01392]
1064 nm: R > 99.6%; 1300–1800 nm: R < 10%



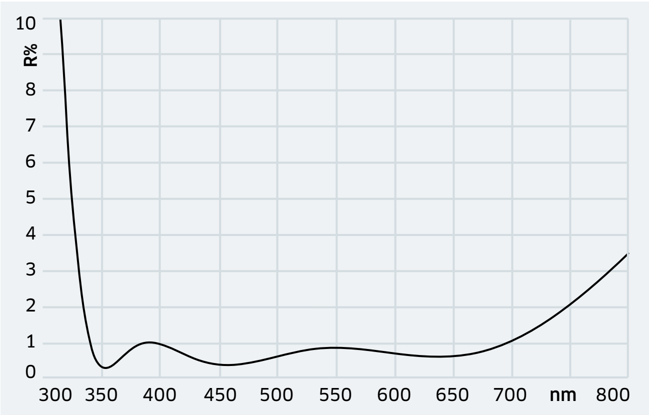
HR 410–700 nm HT 725–2600 nm/0° [B-03084]
410–700 nm: Ravg > 99%; 725–2600 nm: Ravg < 10%



HR 410–710 nm/s HT 710–2650 nm/p/45° [B-05259]
410–710 nm: Rs,avg > 99%; 710–2650 nm: Rp,avg < 2% (IAD-coating)



HR 355 nm HT 400–700 nm/45° [B-11634]
355 nm: R > 99.5%; 400–700 nm: Ravg < 4% (IBS-coating)



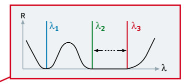
AR 355 nm + 400–700 nm/0° [B-03316]
355 nm: R < 1%; 400–700 nm: Ravg < 1.2%

Multiline coatings

Coating types

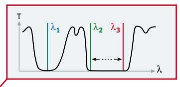

AR

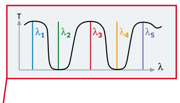
VAR
DAR
TAR
BBAR
MAR
WAR

MAR



HR

HR
DHR
BBHR
MHR
WHR
Metal

MHR


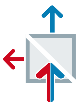
MP



PR

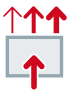
PR
DPR
BBPR
VA
GOC


Filter

LP
SP
NF
MP
BP
REF


Polarizer

TFP
CP
BBPOL


Variables

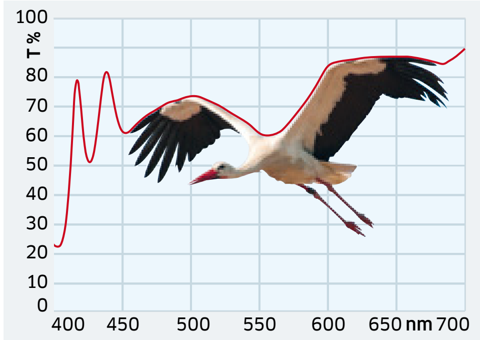
VA
GOC
GP
GNF
GIF

The growing laser market requires more and more complex coatings working simultaneously at many different wavelengths with different optical requirements.

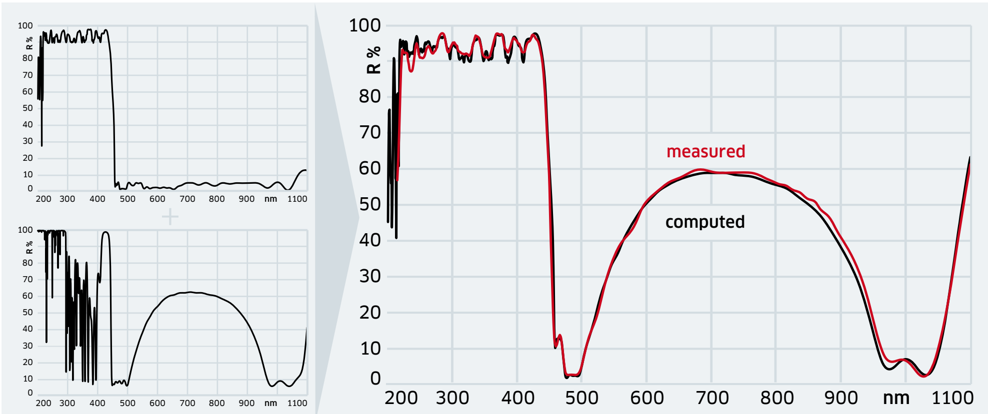
Besides standard multiline coatings described in previous chapters, e.g. Combinations of harmonics (see page 40) and OPO (see page 56), LASER-OPTIK offers customized coatings.

For difficult multiline coatings normally IBS will be the appropriate coating technique of choice as it combines highest precision in film growth and thermal stability.

Besides transmission or reflection of course other optical properties like GD or GDD can be optimized, see the following chapter “Dispersive coatings”.



Even extraordinary wishes can be fulfilled, only the sky is the limit ...

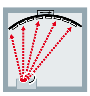
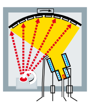
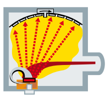
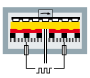
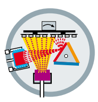


Sometimes it is necessary to use different filter coatings on a pair of substrates or on the front and rear surface of an optic.

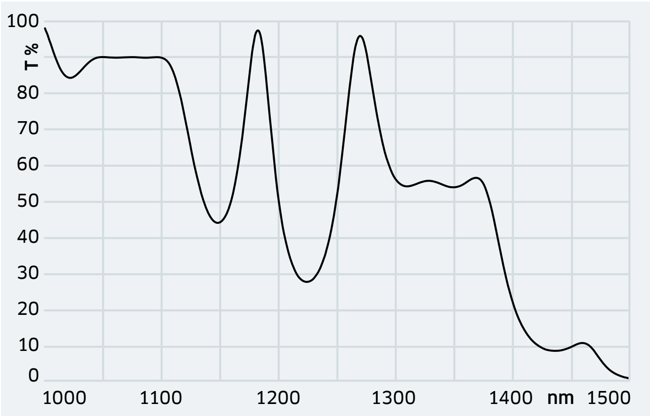
The example above has a broadband long wave pass coated on the front and a gain flattener on the rear surface for superposition of the deuterium and halogen lamp spectra. As shown, the measured reflection (red line) complies with the computed values (black line). This proofs the high precision of the IBS-coating technique.

All values are given for standard coatings.
Customized coatings available for all types.

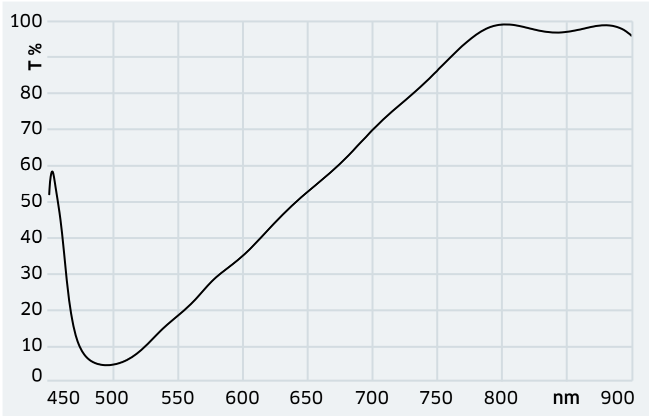
Coating methods available:

EBE

IAD

IP

MS

IBS


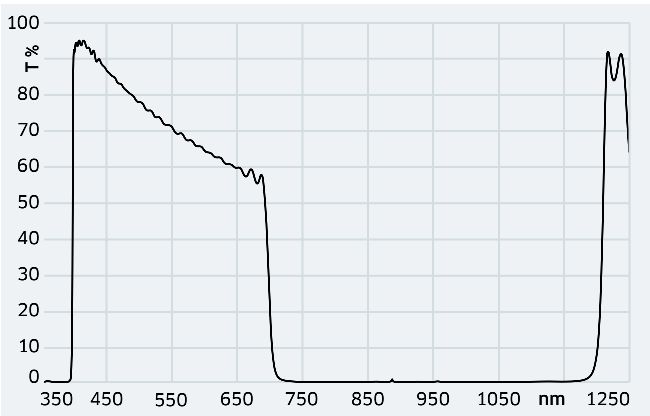
Examples



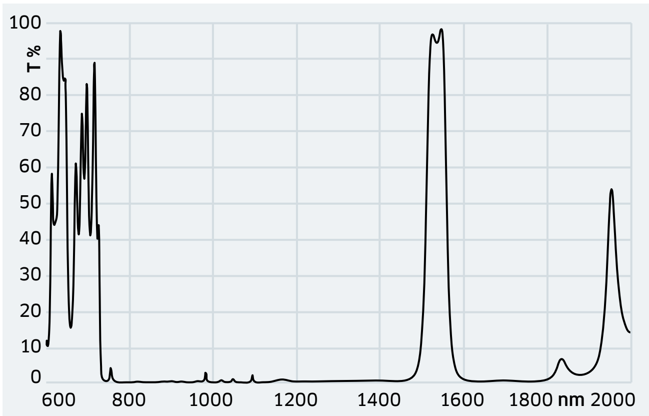
R 10% 1064–1079 nm R 45% 1330 nm R 90% 1440 nm / 0°
[B-10328-01]
1064–1079 nm: R ±2% vs. curve; 1320–1340 nm + 1430–1450 nm: R ±5% vs. curve (IBS-coating)



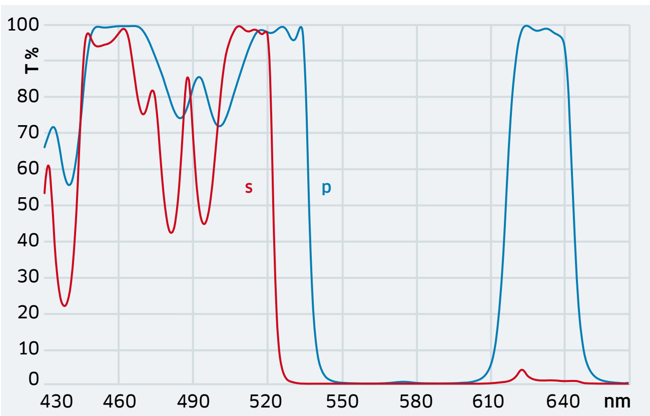
T 5% 500 nm linear to HT 800 nm / 45° [B-14140-01]
500 nm: T ±2%; linear progress with about (avg) ±2% vs. curve; 800 nm: T > 98% (IBS-coating)



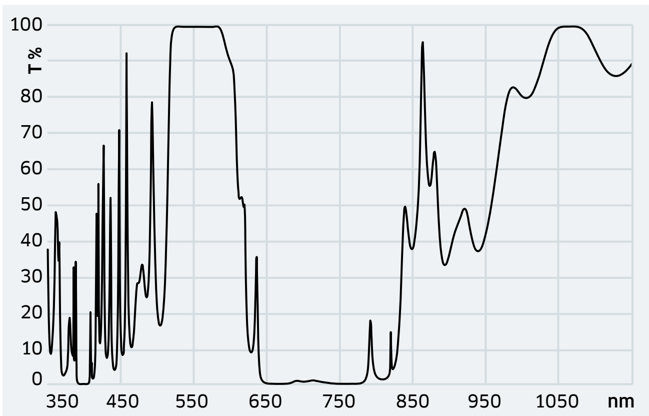
HR 360–390 nm PR 410–680 nm HR 720–1100 nm / 0°
[B-14638]
360–390 nm: T < 1%; 410–680 nm: gain flattening filter; 720–1100 nm: T < 1% (IBS-coating)



HT 630 nm HR 750–1470 nm HT 1535 nm HR 1600–1800 nm / 0°
[B-04390]
633 nm: T > 30%; 750–1470 nm: Tavg < 0.5%; 1535 nm: T > 90%; 1600–1800 nm: Tavg < 1% (IBS-coating)



HT 460 nm + 525 nm HR 532 nm HT 630 nm HR 637 nm / 45°
[B-10107-01]
460 nm: Rp < 2%; 525 nm: Rp < 8%; 532 nm: Rs > 98.5%; 630 nm: Rp < 8%; 637 nm: Rs > 97% (IBS-coating)



HR 399 nm HT 532–578 nm HR 660 + 759 nm HT 1064 nm / 45°
[B-13566]
399 nm: R > 99.5%; 532–578 nm: Ravg < 0.5%; 660 + 759 nm: R > 99.8%; 1064 nm: R < 0.5% (IBS-coating)

Find more than 1,200 examples in our LaserOptik Online Portal: www.laseroptik.de/loop


DANGER

Dispersive coatings

The phase velocity of a light wave travelling through optical materials depends on the wavelength. This phenomenon is called chromatic dispersion.

As a critical requirement for the generation of ultrashort pulses (e.g. in femtosecond lasers) and for controlling the pulse shape, dispersive dielectric optics are needed to compensate the group-delay dispersion (GDD) which is introduced by other components such as the laser crystal.

The GDD is defined as the derivative of the group delay with respect to the angular frequency, or the second-order derivative of the phase.

Of course all dispersive elements inside the resonator have to be taken into account for optimizing the total GDD (see also the Group Velocity Dispersion of standard substrates given on page 98). Otherwise the different delays of various frequency components within a short pulse result in

- pulse broadening
- generation of satellites in the time-domain and
- loss of peak power.

Mirrors may have either low (i.e. close to zero) GDD or a tailored non-zero GDD. As shown in the following sections, there are different types of coating designs. LASEROPTIK offers:

- mirrors with low or optimized GDD
- highly dispersive narrow bandwidth mirrors, so-called GTI mirrors
- chirped mirrors and matched pairs
- octave-spanning broadband chirped mirrors with moderate GDD
- partial reflectors
- coatings used with an OPO

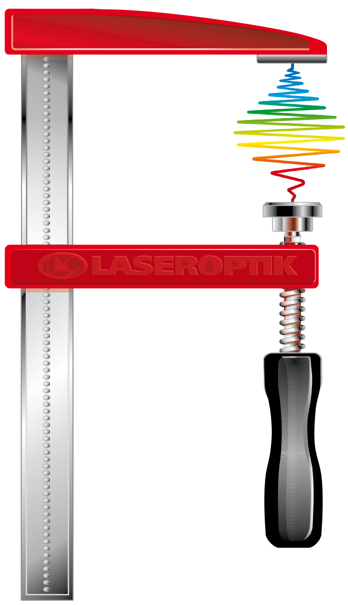
For example, these coatings compensate the dispersion introduced by other components like the laser crystal in a laser cavity. Or they serve as compressors in chirped pulse amplification systems (CPA).

In general, various spectral requirements can be combined with a GDD value as target for coating design and production, e.g. for OPO optics or partial reflectors.

The dispersion management is highly depending on the coating design and a sub-nanometer manufacturing accuracy for GDD optimized optics. At LASEROPTIK, this precision is ensured by the sophisticated method of Ion Beam Sputtering (IBS, see page 27 for details).

With the help of an optical in-situ process control based on the calculated design, the deposition of complex, custom tailored stacks of many (n > 70) nonquarterwave layers is performed. The results are verified ex-situ by in-house GDD measurements and are used for reengineering of the coating design.

LASEROPTIK uses both custom-built and commercial GDD measurement setups ranging from 350 nm to 2400 nm (see measuring methods on page 120), whereas dispersive mirrors can be produced up to 4 µm, optimized and characterized for GDD by retrograde analysis of the coating thickness data.



Keep it ultrashort with our dispersive mirrors for ultrafast applications!

Low GDD mirrors

After having managed to produce short laser pulses, it is necessary to propagate these pulses without disturbing the temporal beam profile. This is the moment where low dispersive beam steering mirrors enter the game.

Often metal mirrors (see page 54) like gold or special enhanced silver mirrors are the most economical solution while having low dispersion.

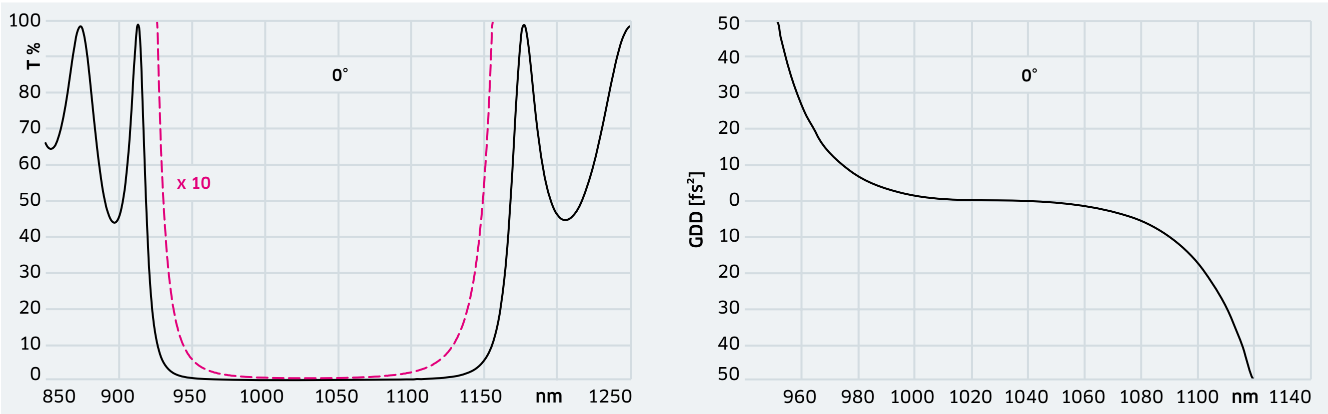
The major drawbacks of these mirrors are limited reflectivity and higher absorption losses, which may cause problems in applications with high average power.

Alternatively dielectric mirrors can be optimized for low GDD. They offer very low losses avoiding thermal problems but normally have a near-zero GDD only for a limited spectral bandwidth. To overcome this, it is possible to make use of the concept of chirped mirror pairs.

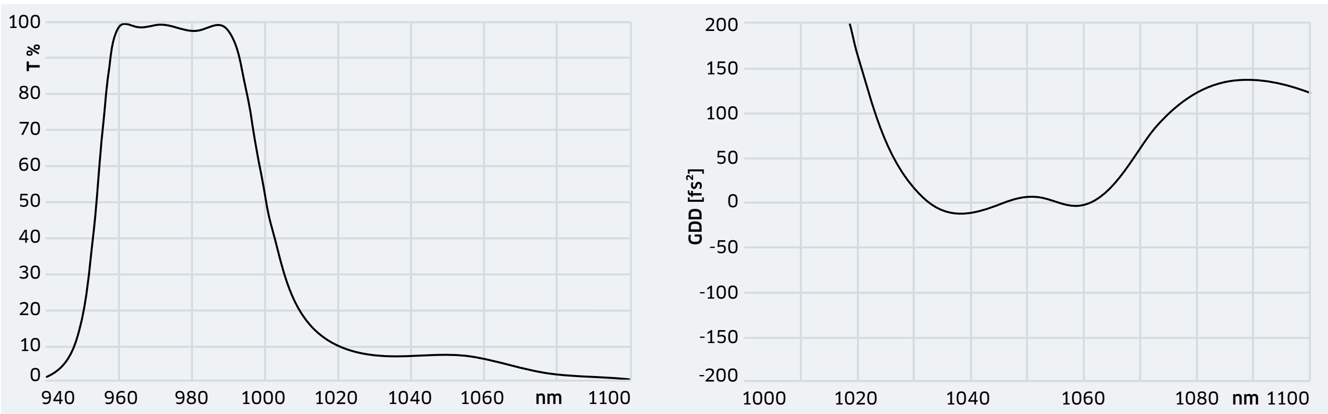
All low GDD coatings can be designed on customer request, see examples:

Examples

---- dashed lines show the zoomed curve with the stated magnification



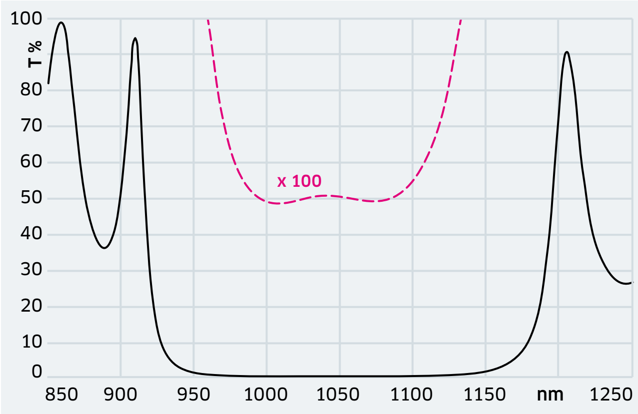
HR 1020–1040 nm /0–10° low GDD [B-11072]
1020–1040 nm: R > 99.9%; |GDD (R)| < 20 fs² (IBS-coating)

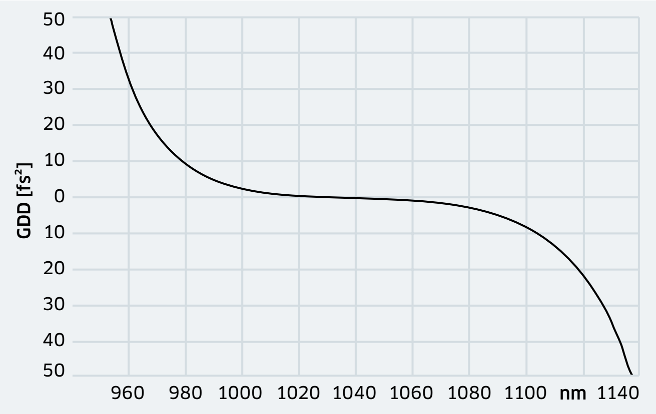


HT 970–982 nm T 7.5% 1035–1055 nm / 0° low GDD [B-11872]
970–982 nm: R < 5%; 1035–1055 nm: R ±1% (IBS-coating)

Examples

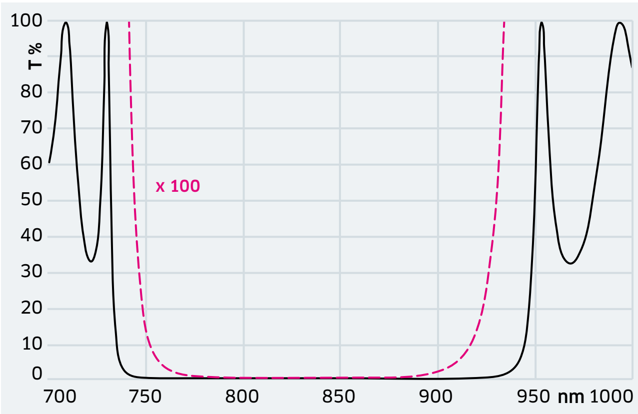
---- dashed lines show the zoomed curve with the stated magnification

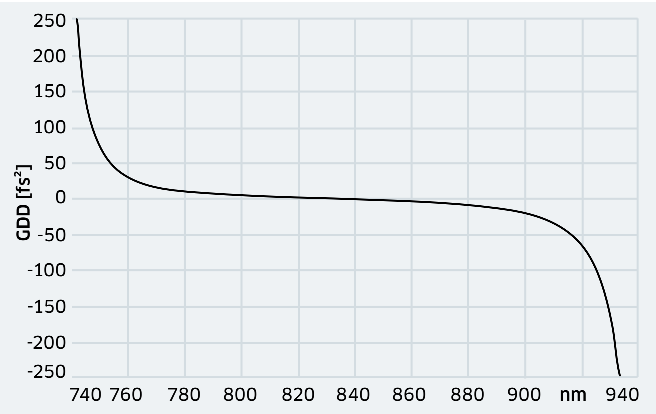




R 99.5% 990–1090 nm / 0° low GDD [B-12042]

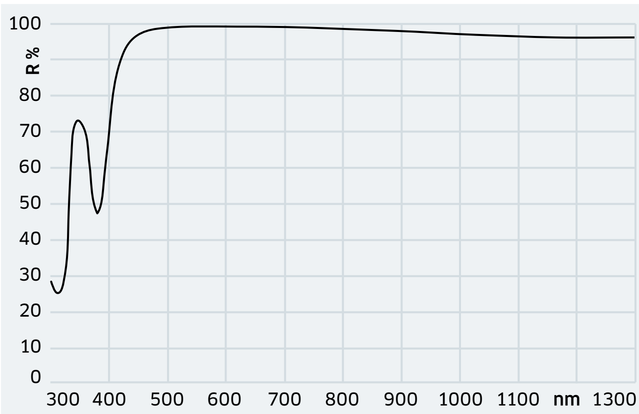
990–1090 nm: T ±0.15%; |GDD (R)| < 10 fs² (IBS-coating)

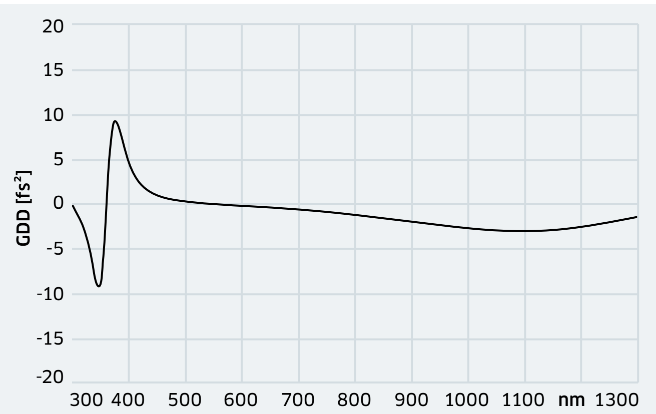




HR 760–910 nm / 45°p low GDD [B-12162]

760–910 nm: Rp > 99.8%; |GDD (Rp)| < 50 fs² (IBS-coating)





Ag enhanced 450–1000 nm [B-11437]

450–1000 nm: R > 90%; Ravg > 97%

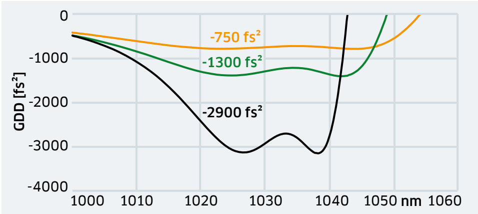
GTI mirrors

GTI mirrors are basically Bragg mirrors with added and precisely adjusted spacer layers in the upper section of the film stack which work like a Gires-Tournois-Interferometer (GTI).

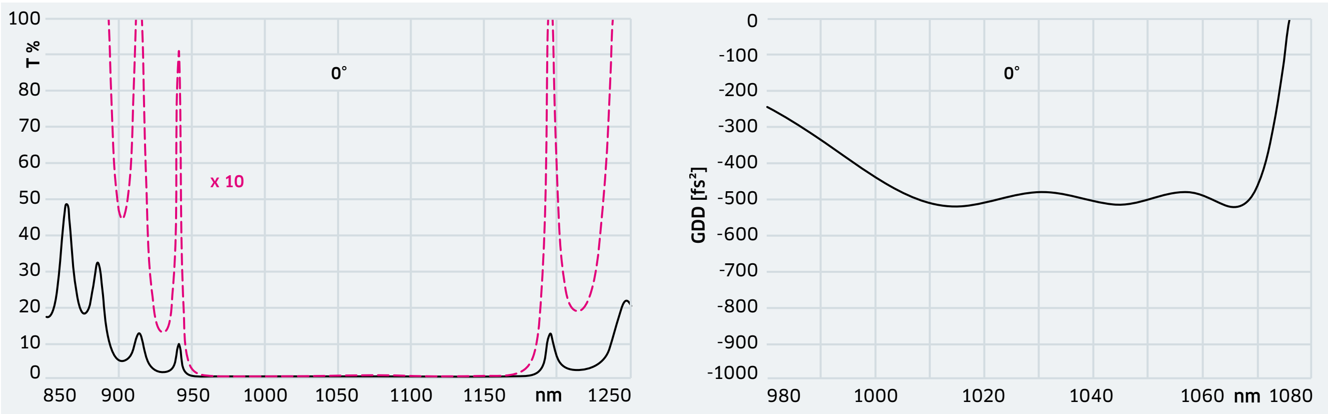
Resonances introduced by the spacer layers can produce very high GDD values but these are limited: The higher the GDD, the smaller the spectral bandwidth (see curves of three different GTI mirrors on the right).

LASEROPTIK offers GTI mirrors with GDD values up to about 5000 fs². Even higher values are possible but will lead to increased optical losses and lower LIDT.

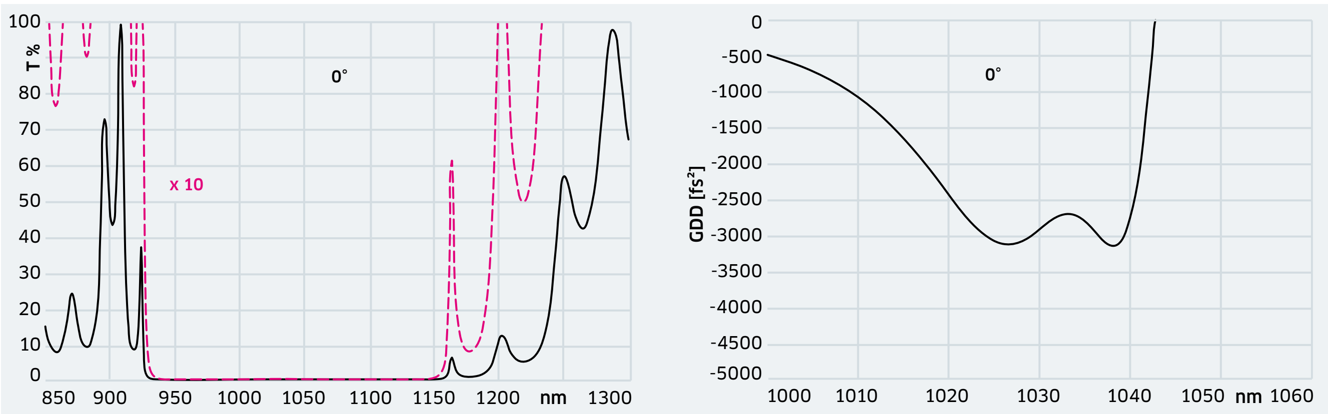
GTI mirrors may be equipped with additional features like a pass band for the pump laser or a tailored transmittance, so they can be used as out-coupling mirrors. A typical application is the dispersion management in Ytterbium based lasers.



Examples *---- dashed lines show the zoomed curve with the stated magnification*



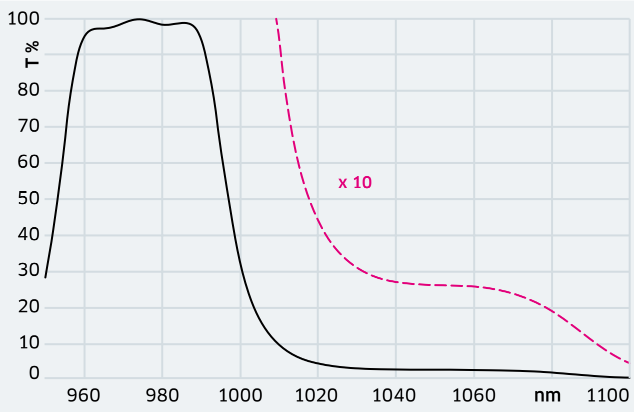
HR 1010–1060 nm / 0–10° GDD –500 fs² [B-12654]
1010–1060 nm: R > 99.9%, GDD ±150 fs² (IBS-coating)

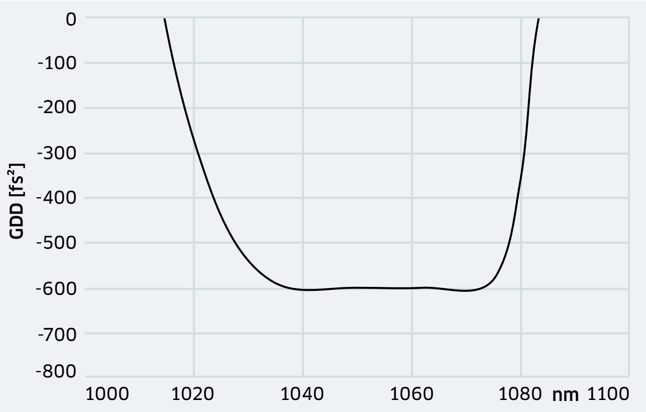


HR 1030 nm / 0–5° GDD –2900 fs² [B-08609]
1030 nm: R > 99.95%, GDD (R) ±500 fs² (IBS-coating)

Examples

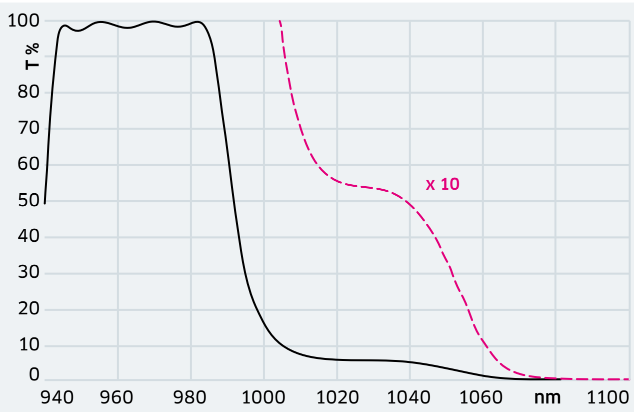
---- dashed lines show the zoomed curve with the stated magnification

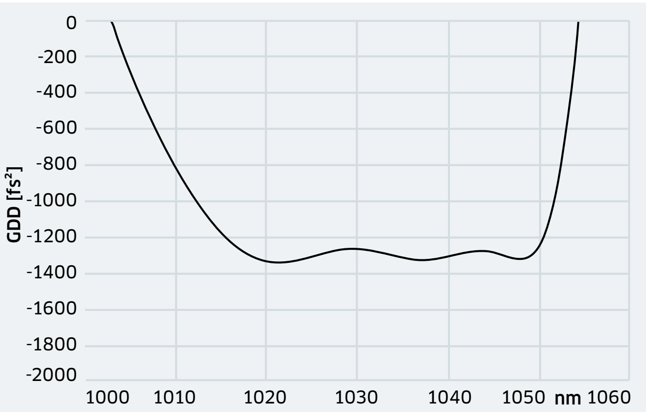




HT 980 nm T 2.6% 1055 nm / 0° GDD –600 fs² [B-11395]

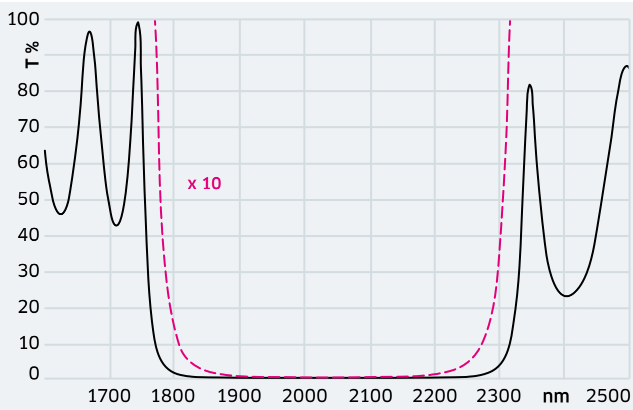
980 nm: T > 95%; 1055 nm ±8 nm: R ±0.25%, GDD ±60 fs² (IBS-coating)

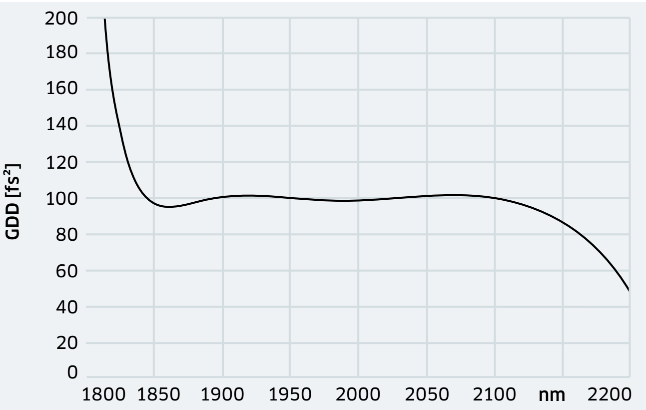




HT 976 nm T 5% 1030 nm / 0° GDD –1300 fs² [B-12655]

976 nm: T > 95%; 1030 nm: T ±1%, GDD ±250 fs² (IBS-coating)





HR 1900–2100 nm / 0° GDD +100 fs² [B-12656]

1900–2100 nm: R > 99.9%, GDD ±15 fs² (IBS-coating)

Chirped mirrors and matched pairs

One can think of a chirped mirror as a Bragg mirror where the thickness of the layers slowly increases or decreases from bottom to top, so that the different “colours” are reflected at different depths resulting in different group delays which gives a non-zero GDD.

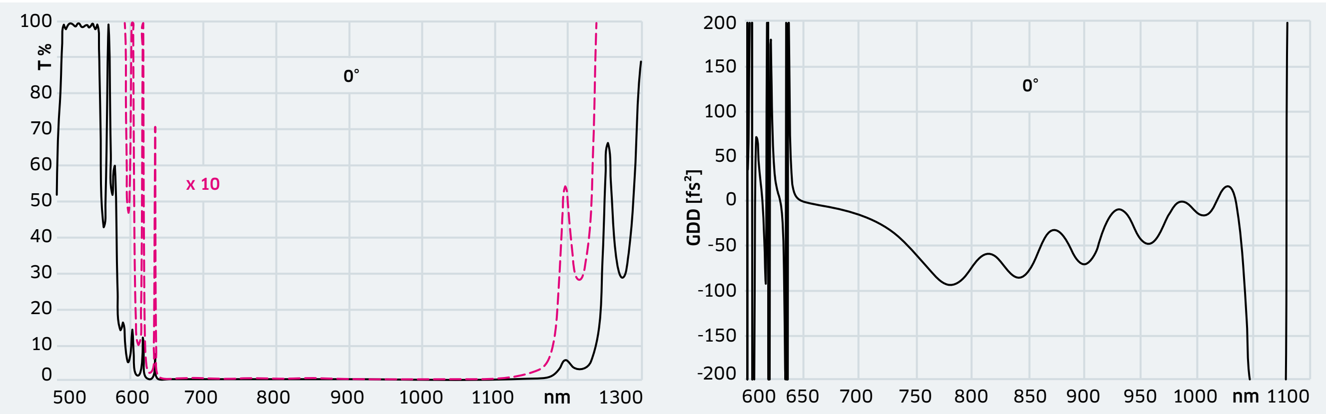
There are unavoidable residual GDD oscillations of such mirrors. If necessary they can be suppressed for example by using chirped mirror pairs where the oscillations of two different mirrors cancel each other out.

It is possible to produce chirped mirrors spanning more than one optical octave and having extra features like a high transmission pumping pass band.

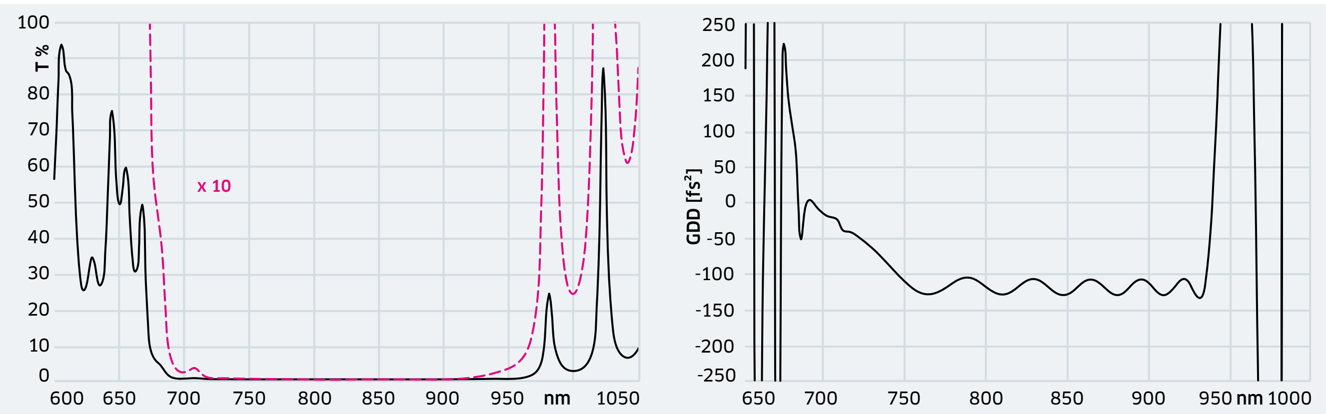
LASEROPTIK’s cooperation with leading research institutes in the field of ultrashort lasers and frequency combs helps to generate new results about the producibility of complex GDD coatings of which some findings are published.*

* Chia, S.-H., Cirmi, G., Fang, S., Rossi, G. M., Mücke, O. D., Kärtner, F. X., Two-octave-spanning dispersion-controlled precision optics for sub-optical-cycle waveform synthesizers, in: Optica, Vol. 1 (2014), Iss. 5, pp. 315–322

Examples *–––– dashed lines show the zoomed curve with the stated magnification*



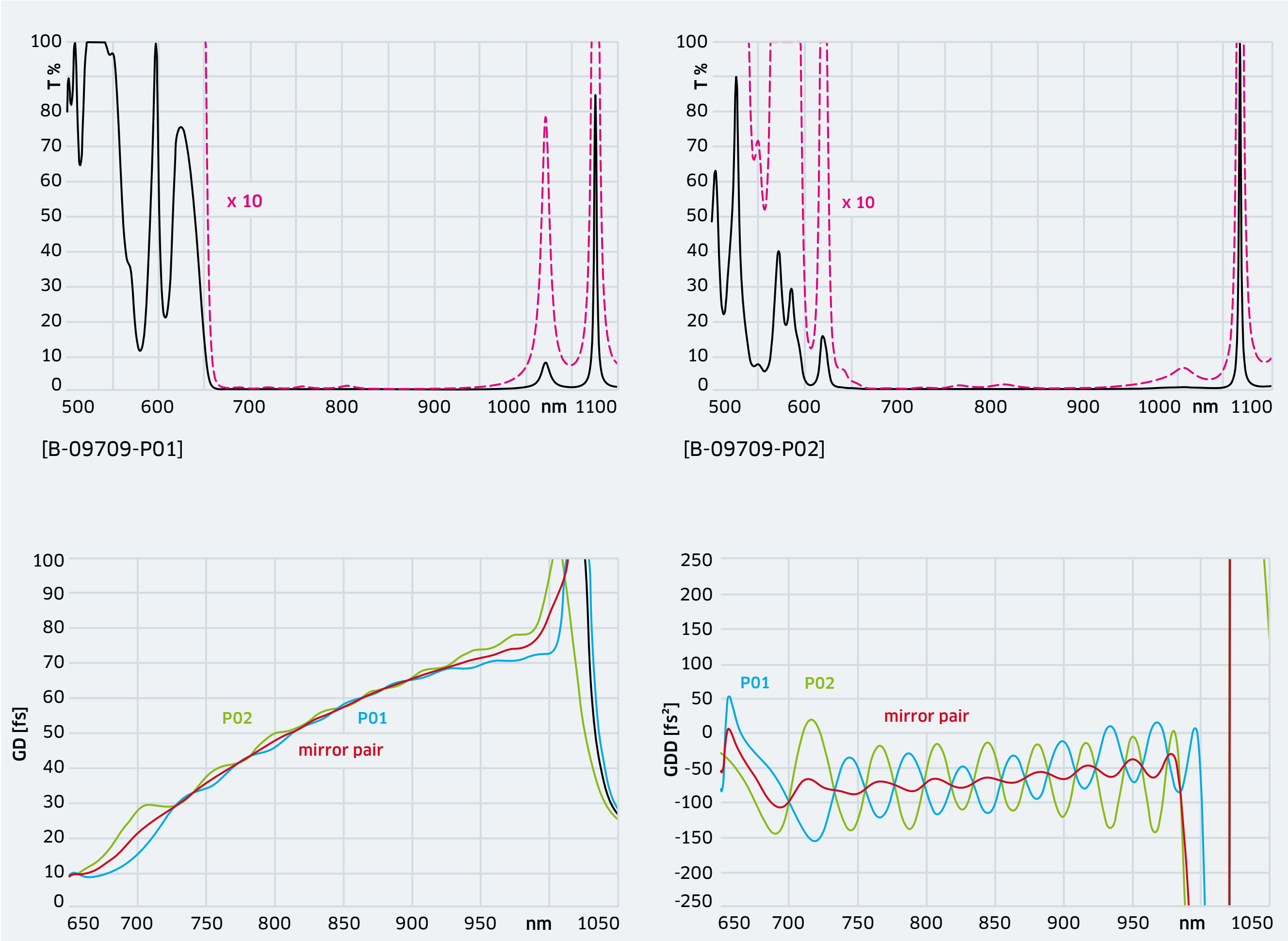
HT 532 nm HR 650–1100 nm / 0–15° GDD opt. [B-10888]
532 nm: T > 95%; 650–1100 nm: R > 99.9%; 780–1010 nm: GDD (R) = -88 → 0 fs² ±50 fs² (IBS-coating)



HR 730–930 nm / 7° p GDD –125 fs² [B-12658]
730–930 nm: Ravg > 99.9%, GDD ±40 fs² vs. theoretical curve (IBS-coating)

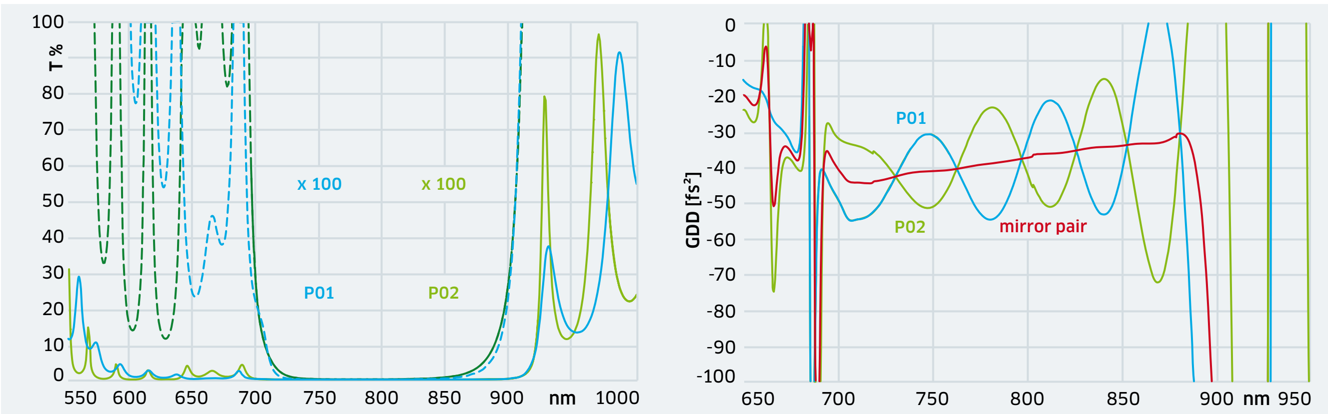
Two examples for chirped mirror pairs

–––– dashed lines show the zoomed curve with the stated magnification



HT 532 nm HR 675–975 nm / 7° p GDD opt. [B-09709-P01+02]

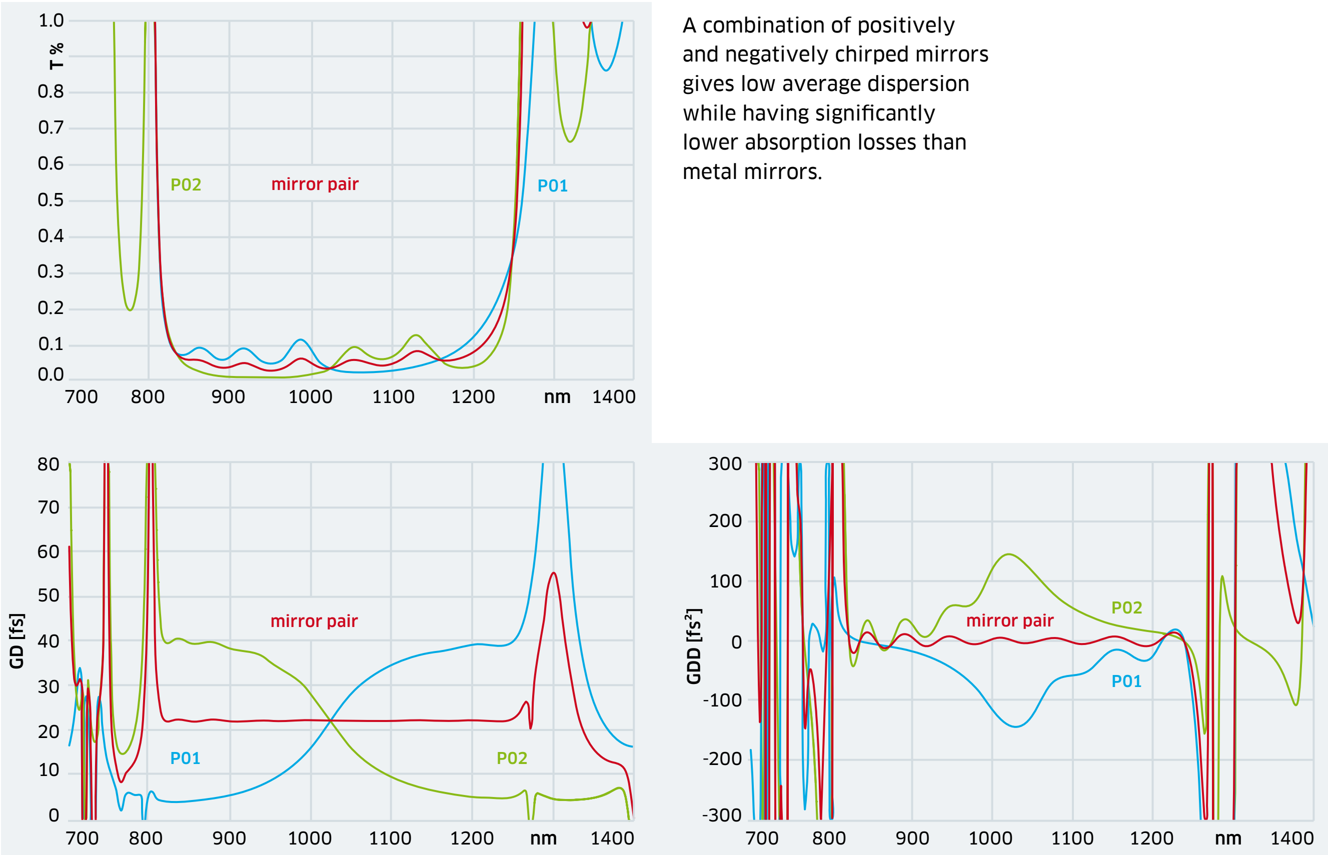
target specifications for a mirror pair, best effort (IBS-coating):
532 nm: T > 98%; 675–975 nm: Rp > 99.9%, GD (R)-ripple < 2 fs



HR 700–900 nm / 7° s GDD opt. [B-09813-P01+02]

700–900 nm: Ravg > 99.9%; 710–860 nm: GDD ±10 fs² (IBS-coating)

Example for chirped mirror pairs with combination of positive and negative GDD



A combination of positively and negatively chirped mirrors gives low average dispersion while having significantly lower absorption losses than metal mirrors.

HR 830–1230 nm / 45° s GDD opt. [B-12544-P01+02]

830–1230 nm: R > 99.8%, GD = const ±3 fs, GDD = 0 ±30 fs² (IBS-coating)

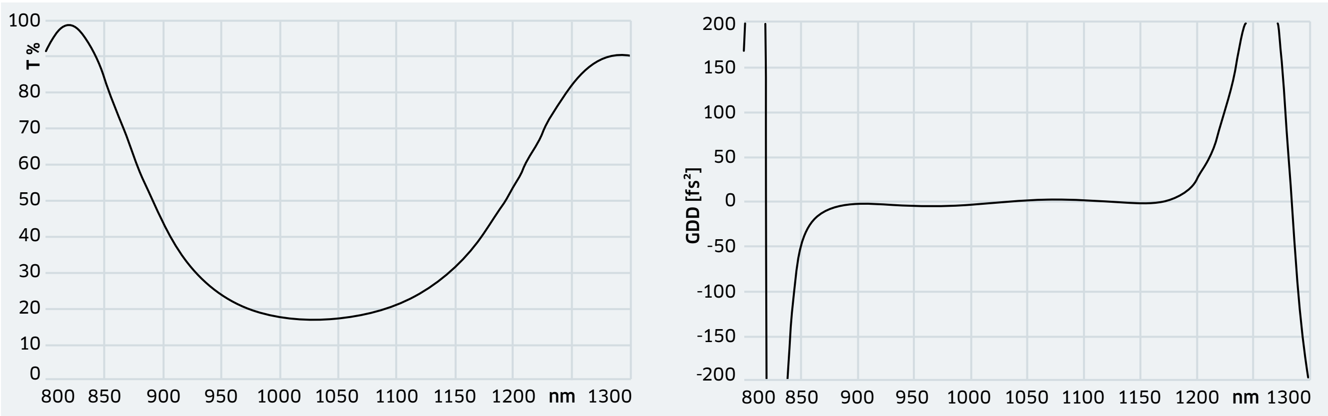
Chirping by nature: House cricket (lat. Acheta domesticus)

Partial Reflectors

In the Ti:Sapphire range and other bands, tightly toleranced partial reflectors are needed to split the beams or to couple out a certain proportion while keeping the GDD under control.

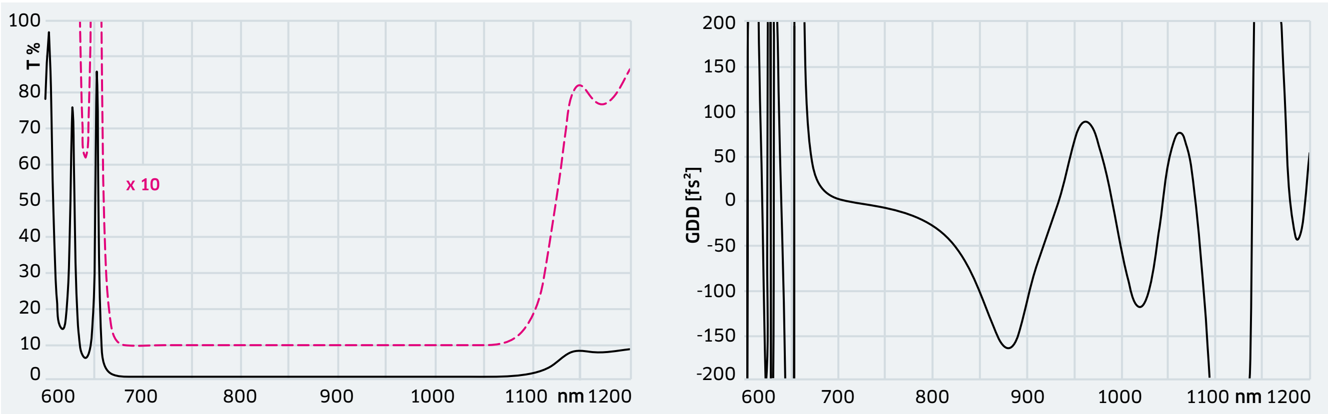
Examples

–––– dashed lines show the zoomed curve with the stated magnification



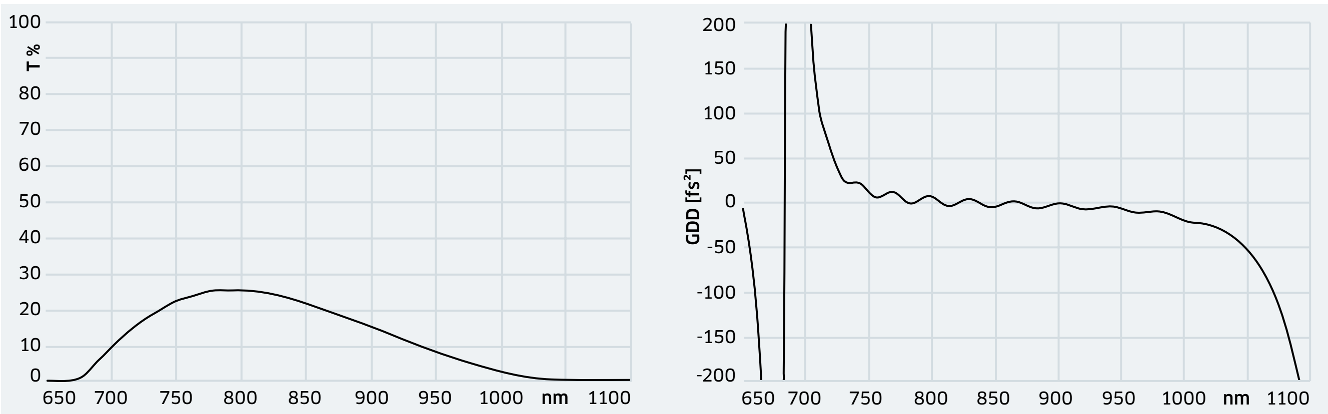
R 83% 1020–1040 nm / 0° low GDD [B-11074]

1020–1040 nm: R ±0.5% vs. curve; |GDD (R)| < 20 fs² (IBS-coating)



R 99% 690–1050 nm / 20° p low GDD [B-11214]

690–1050 nm: R ±0.25% (goal ±0.1%) vs. curve (IBS-coating)



T 1–25% 680–1010 nm / 0° low GDD [B-11263]

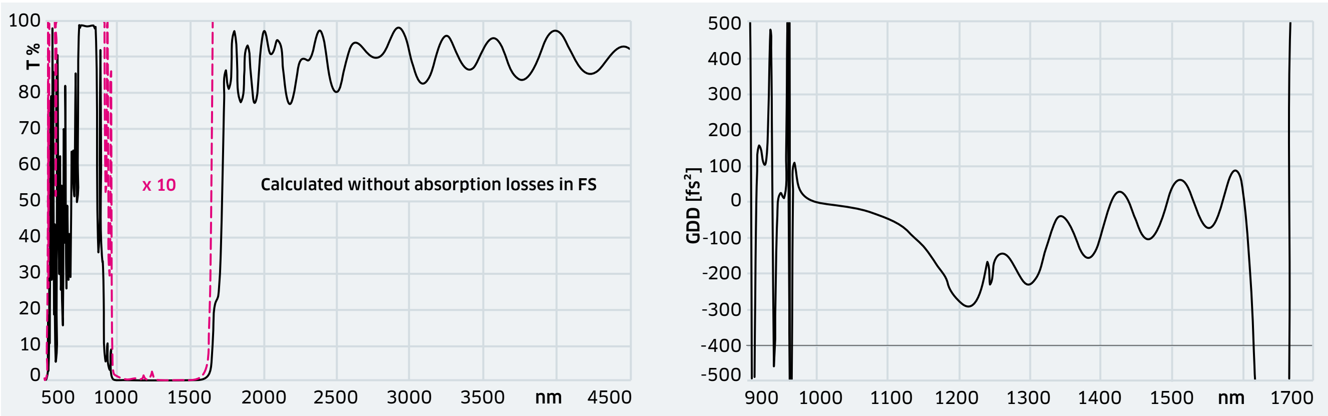
Tolerance for transmission: ±0.2% absolute or ±10% of target value (IBS-coating)

OPO coatings

Optical Parametric Oscillators (OPO) also convert radiation of femtosecond lasers and allow tunable lasing in other wavelength ranges (see page 56). This conversion introduces more optical components into the total system and consequently more GDD that has to be managed. The diagrams demonstrate some examples of GDD optimized OPO coatings.

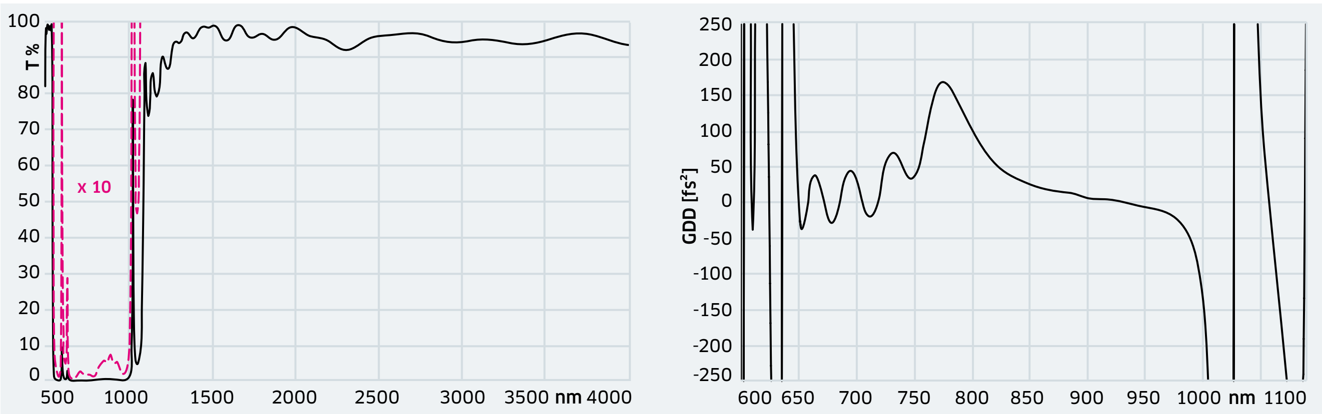
Examples

–––– dashed lines show the zoomed curve with the stated magnification



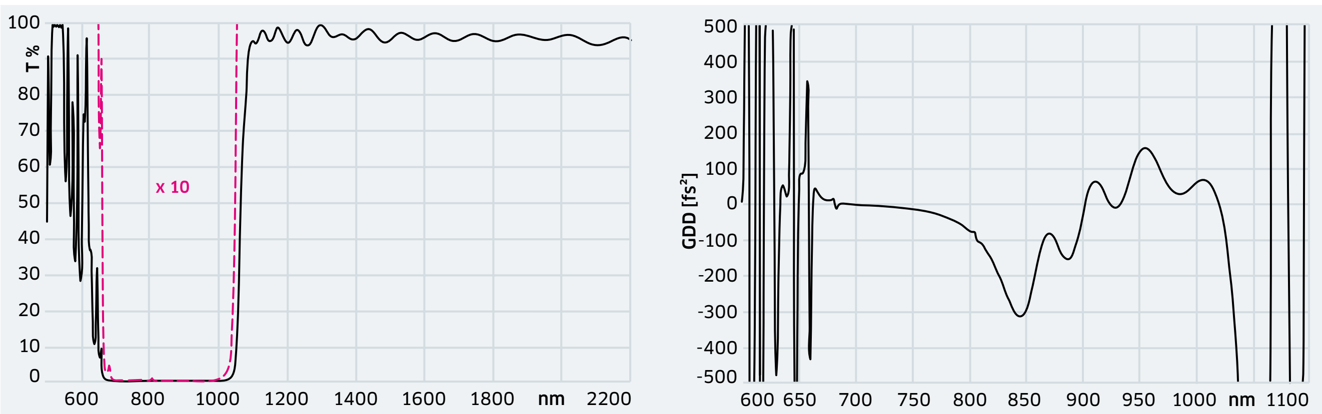
HT 750–850 nm HR 980–1620 nm HT 1750–4500 nm / 4° GDD opt. [B-11613]

750–850 nm: Tp > 96%; 980–1620 nm: Rs,avg > 99.8%; 1750–4500 nm: Tp,avg > 80% (IBS-coating)



HT 515–532 nm HR 650–1000 nm HT 1100–4000 nm / 0° GDD opt. on YAG [B-07321]

best effort (IBS-coating)



HT 532 nm HR 700–1000 nm HT 1100–2100 nm / 0° low GDD [B-11546]

532 nm: R < 5%; 700–1000 nm: R > 99.9%; 1100–2100 nm: T > 90% (IBS-coating)

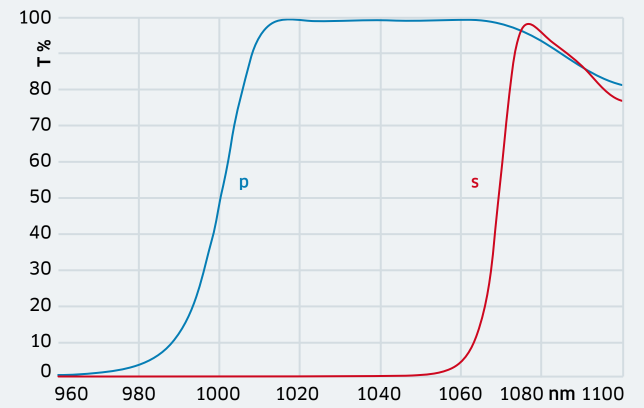
Others

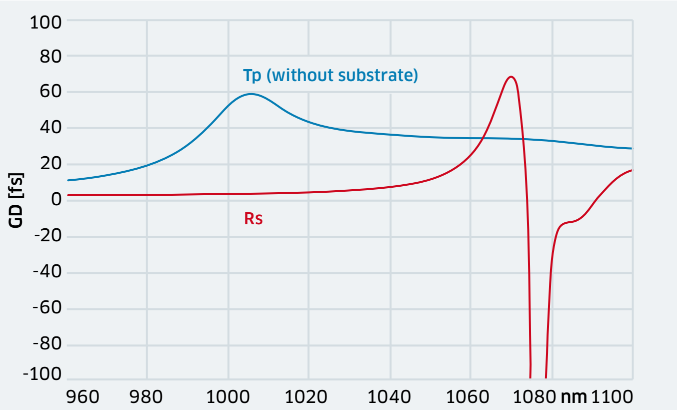
While all the coatings shown before are specifically designed for dispersion control there usually is the need for more kinds of optical filters.

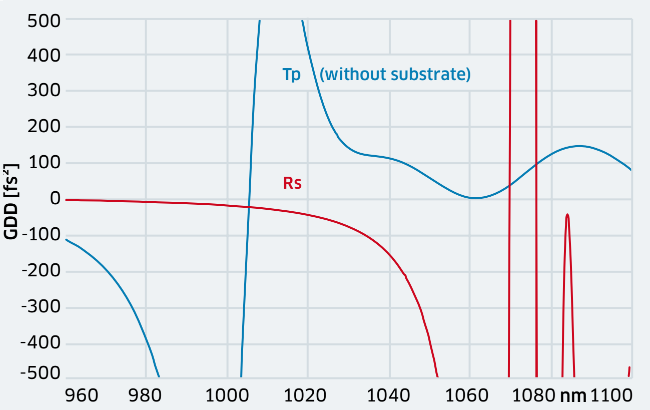
When working with femtosecond laser pulses it is important to know at least their dispersion. On request, we are able to provide dispersion information even for our coatings which are not optimized in this regard.

The example shows a thin film polarizer (TFP) at 1030 nm with GDD tolerances for the reflected and transmitted wavelength.

Examples







TFP 1030 nm / 55.4° [B-06289]
1030 nm: Rs > 99.98%, Tp > 99%

Coatings on special substrates

LASEROPTIK has long-term experience in coating on almost every type of substrate. Besides standard glasses and crystals like Fused Silica, CaF_2, MgF_2, other common types e.g. crown glass or flint glass made by SCHOTT, CORNING, HOYA, NIKON or OHARA, we offer optimized coating designs and techniques, substrate handling and coating fixtures especially for the following items:

Please note:

For an effective and fast overview, all coatings in this catalog or in our **L**aser**O**ptik **O**nline **P**ortal **LOOP** are given for standard substrate materials (mostly Fused Silica or CaF_2).

For quotations for coatings on special substrates we have to know:

- refractive index
- allowed maximum temperature
- thermal expansion coefficient
- size

Every coating design and process can be adapted to each substrate type. Please choose the best matching coating and ask us for a quotation with an optimized one.

Coated ball lens

Crystals, wafers and metals

LASEROPTIK has approved coating processes in place including pre- and after-treatment for a broad variety of laser and non-linear crystals e. g. common materials like BBO, BiBO, COB, CTA, KDP, KGW, KTA, KTP, KYW, LBO, $LiNbO_3$, Ruby, RTA, RTP, Spinell, TGG, YAB, YAG, YAP, YLF, YVO_4, Sapphire, diamond and many others. Dedicated rimless fixtures are developed and built in our workshop. Coatings for wafers and similar materials (e. g. Ge, Si, SiC, GaAs) are also available.

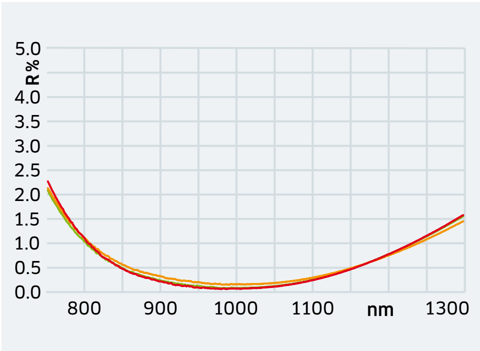
LASEROPTIK offers a selection of coatings on metals like Fe, Cu, Al. All processes are optimized for best optical performance and highest adhesion.

3D-optics

Geometrically challenging substrates such as ball lenses, tubes, domes, special prisms, gratings, nozzles and many more items cannot be coated by common coating techniques because shadowing effects and thickness non-uniformity will occur here.

With ALD (Atomic Layer Deposition, see page 22) LASEROPTIK can offer highly conformal multilayer coatings on complex 3D-substrates.

Typically, anti-reflection coatings are offered in the range from UV towards 1550 nm. HR coatings are more suitable for UV applications due to economic coating thickness limitations. In addition, protective and passivating coatings are offered on a variety of materials.



Measured reflection of an ALD coated ball lens (AR 980-1064 nm / 13° on H-K9L) at three random positions

Further reading:

Weiss, T. and Ebert, W. (2017): Atomic Layer Deposition for Coating of Complex 3D Optics. Optik & Photonik, 12: 42–45.

Fibers

Naked or fully confectioned fibers can be coated in holders that are individually manufactured in the workshop in-house. In a rather “cold” process like Ion Beam Sputtering (IBS) or Magnetron Sputtering (MS) the coating of fibers is done, e.g. to achieve the evidently lowest reflectivities for AR.

For MS some meters of fibers can be hidden in the spaciouse drum or elsewhere behind the exposed surface. Even lower temperatures can be realised with IBS. Adapted fixturing is available for a wide range of fiber optics.

Glass cells

Glass cells / cuvettes have to be coated on up to five sides. They require specially designed substrate holders and optimized coatings.

With the experience of almost 40 years, LASEROPTIK developed a technique to achieve a maximum clear aperture and reliable fixtures.

UHV windows

For coatings on UHV windows LASEROPTIK developed approved tooling as well as pre- and after-treatment processes. Standard holders for the most common sizes from CF16 up to CF160 are available.

The coating process will be adapted to the allowed maximum temperature and thermal gradient. Because of technical limitations UHV windows normally can only be coated with EBE technique.

The usual shadow-effects from the metal-flange will be reduced as far as technically possible in order to coat the maximum of the optical surface. Our experiences show that a coating will work in an area of about Ø 9 mm for CF16, Ø 29 mm for CF40 and Ø 57 mm for CF63 and will not be centred exactly in the middle.

Please note:

For an effective and fast overview all coatings in this catalog or in our **L**aser**O**ptik **O**nline **P**ortal **LOOP** are given for standard substrate materials (mostly Fused Silica or CaF_2).

For quotations for coatings on glass cells or UHV windows we have to know:

- allowed maximum temperature
- glass material (mostly Fused Silica, Kodial or Sapphire)
- size

Every AR coating can be adapted to each substrate type. Please choose the best matching coating and ask us for a quotation with an optimized one.

Standard UHV windows: CF40, CF63, CF100

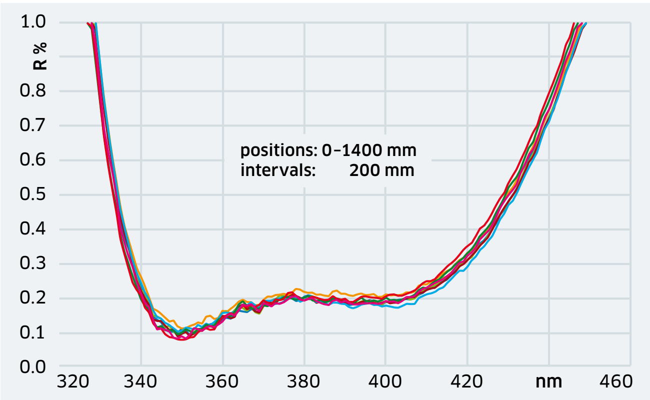
Large optics

LASEROPTIK uses dedicated equipment for dielectric coatings on large optics up to 2 m in length (long axis for rectangular shapes) or 550 mm in diameter with a superior spectral uniformity over the complete surface and high LIDT values. Approved automated ultrasonic and manual cleaning procedures guarantee an optimum cleanliness even on these large scale geometries. The possible sizes are listed in the table below.

coating technique	rectangular long axis	short axis*	round Ø
IBS	2000 mm	250 mm	550 mm
IAD	940 mm	80 mm	350 mm
EBE	940 mm	80 mm	500 mm

* at the given maximum of the long axis, can be larger with a shorter long axis.

The uniformity of the coatings is a critical factor for applications in industrial lasers, e.g. for laser beam expansion and delivery systems. Coating design, inner architecture of the machine and in-situ process control help to reduce gradient effects to a minimum. The uniformity can also be adapted to the radii of curvature, for example with cylindrical lenses.



Uniformity of an IBS coating on a large optic (BBAR 342–412 nm/0°)

Long shapes

For long bar-shaped substrates, plane or curved, LASEROPTIK can coat laser mirrors that are amongst the largest in the world (up to 2000 mm in length) by using IBS. This method (see page 27) is commonly known for producing the highest quality thin films, but just on small areas. However, by redefining an advanced substrate motion, an unique approach for long optics was found and has been patented. Currently two custom-built machines are working to offer this unique process.

A variance in central wavelength of below ±1% can be achieved for optics up to 2000 mm in length. The 8 measured curves on the left show the excellent uniformity on a large optic (long axis > 1300 mm) which is coated with an IBS broadband AR.

Further reading:

Within an ELI Beamline project LASEROPTIK coated large area ultrafast mirrors. Reflectivity, uniformity, GDD, LIDT and flatness have been proven and the results are shown in the following article.

Thomas Willemsen, Uddhab Chaulagain, Irena Havlíčková, Stefan Borneis, Wolfgang Ebert, Henrik Ehlers, Melanie Gauch, Tobias Groß, Daniel Kramer, Tomáš Laštovička, Jaroslav Nejdl, Bedřich Rus, Konrad Schrader, Tomas Tolenis, František Vaněk, Praveen K. Velpula, and Stefan Weber: Large area ion beam sputtered dielectric ultrafast mirrors for petawatt laser beamlines, Opt. Express 30, 6129-6141 (2022)

"Maxima", the patented IBS coating machine for large optics (long shapes)

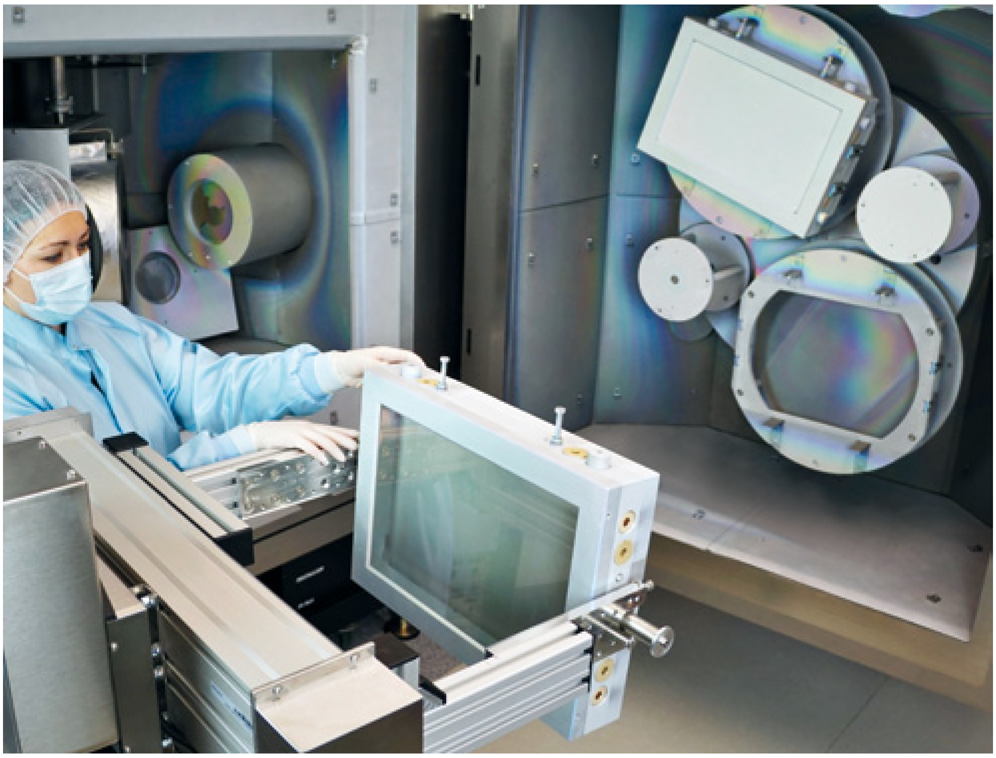
Round shapes

As with long substrates, round optics can be coated by IAD and EBE if the coating requirements are standard. When it comes to complex coating designs and superior spectral performance, IBS coatings offer adequate solutions. LASEROPTIK has commercial coating systems for substrates up to Ø 400 mm and custom-built machines for up to Ø 550 mm in operation, or adequately for rectangular shapes fitting onto the carrier planet.

These specialized machines also allow the use of three or more coating materials, which is important for advanced thin-film design strategies aiming at the highest LIDT. This capability is crucial for very high energy laser research, also known as petawatt and laser fusion projects. Another common use of large round optics is gravitational wave research. The detector's sensitivity is dependent on the end mirrors' perfection, i.e. the total losses and Brownian noise have to be reduced to a minimum. IBS is well suited to this task as its low loss coatings are approved by gyroscope applications (see page 78).

Tailored environment of separate cleanrooms with a dedicated inspection metrology, optic cleaning and annealing solutions was built to support this innovative equipment. It is part of a department that specializes in working with large round and rectangular optics, addressing the highest demands for LIDT, low losses and spectral performance.

A space-resolved quality inspection is performed on the whole dimension to check for surface defects and spectral properties, including interferometric inspection. Large optics are held in custom-built lifting and handling tools for inspection, transportation and fixing in the coating machine.



"Teresa", the largest IBS machine, suitable for substrates up to Ø 550 mm

Coatings for special applications

Spaceborne/airborne optics

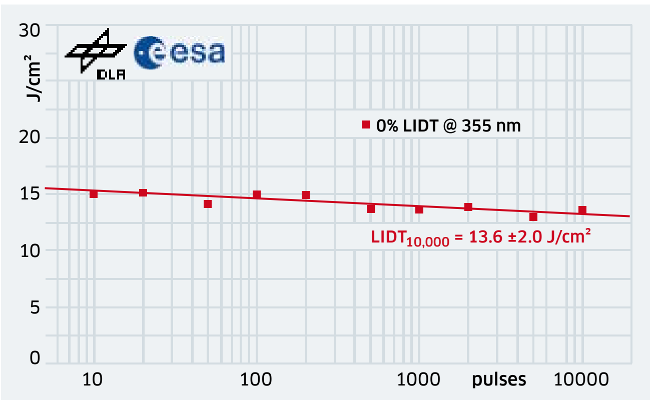
Operating a laser system under high-vacuum conditions in space requires environmentally robust coatings and optics.

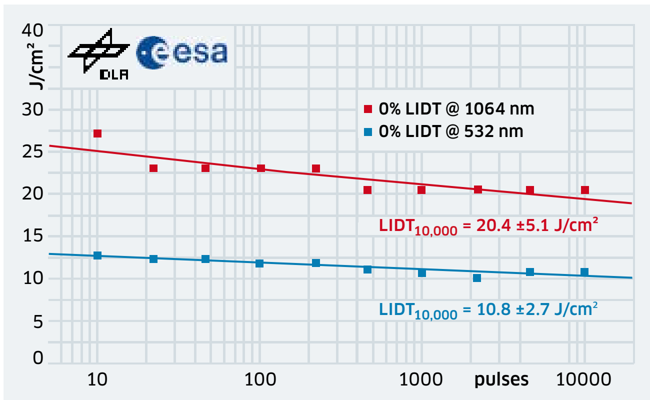
The key risk factors for failure are laser-induced contamination and coating degradation. You have to exclude increasing absorption, coating destruction or delamination due to cosmic, solar or laser radiation before sending out flight optics.[1)]

In various projects[2)] for DLR, ESA and NASA or their industry partners, LASEROPTIK has developed coatings and optics for laser applications in space or airborne environments and proven their functionality and durability.

MS and IBS coatings withstand extreme temperature ranges and working conditions required for airborne laser optics. Additionally, we test the resistancy of specific coatings against gamma and neutron radiation for use in space. Environmental testing can be done by LASEROPTIK or one of our partner institutes.

As part of the extensive qualification program, laser optics and coatings underwent several LIDT tests with simulated space conditions. DLR and LZH[3)] performed for example damage tests under vacuum conditions. See below for the results for an UV space laser HR 355 nm/s HT 532 nm/p + 1064 nm/s/45° with an AR on the rear surface, measured in vacuum:





Technical data: LIDT with 10,000 on 1 LIDT, vacuum 2 x 10^{-6} mbar, repetition rate 100 Hz. Pulse duration: 3 ns (355 nm); 6.5 ns (532 nm); 12 ns (1064 nm)
Beam diameter: 160 µm (355 nm); 280 µm (532 nm); 310 µm (1064 nm)

References and further reading:

1) Wernham, D. (2011): Optical coatings in space, in: Proc. SPIE 8168, Advances in Optical Thin Films IV, 81680F (04. Oct. 2011).

2) Cosentino, A.; Selex Galileo S.p.A., Rome, Italy; D'Ottavi, A.; Sapia, A.; Suetta, E.: Spaceborne lasers development for ALADIN and ATLID instruments, Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International

3) Riede, W.; Allenspacher, P.; Lammers, M.; Wernham, D., Ciapponi, A.; Heese, C.; Jensen, L.; Maedebach, H.; Ristau, D. (2013): From ground to space: How to increase the confidence level in your flight optics, in: 45rd Annual Laser Damage Symposium on Optical Materials for High Power Lasers, 8885. SPIE Laser Damage, 22.–25. Sep. 2013, Boulder, USA.

With Aeolus, ESA's satellite for observing global wind currents, groundbreaking space technologies and observation techniques have been put into operation.

The satellite houses one of the most innovative instruments ever launched into space: Aladin. This device incorporates revolutionary laser technology that generates short pulses in the UV range to accurately measure wind motion around the globe, which is a completely novel method.

With each orbit over the poles, the satellite crosses the day/night line for a short time. This means maximum stress in temperature change for all components.

After a long search, coatings from LASEROPTIK proved to be optimal for meeting these extreme conditions and ensuring the continuous operation of Aeolus and Aladin.

Extremely low loss laser optics

So-called supermirrors in ring laser gyroscope assemblies or certain scientific applications require coated optics with extremely low losses (i.e. absorption and scattering).
These mirrors also have a maximum reflectivity with R > 99.998% and total losses < 10 ppm.

LASEROPTIK uses modified IBS machines that are capable to produce coatings on super-polished substrates. The cleanliness of the machines and environment is maintained in dedicated cleanrooms, where also the extensive substrate pre- and aftertreatment takes place.

Measurement devices such as white light profilometers and high resolution microscopes (up to x 1000) for the inspection procedures are in place. A custom built cavity ring-down setup allows to determine the reflection with a precision of up to four decimal places and to quantify the losses.

The total back scattering (TSB, as referred to in ISO 13696) of a supermirror at 633 nm taken from LASEROPTIK's current production has been measured at the Fraunhofer Institute for Applied Optics and Precision Engineering in Jena and achieved a value of TSB = 1.1 ppm. The typical absorption and residual transmission of together < 15 ppm is equivalent to a reflectivity of at least 99.998%. For longer wavelengths even 99.999% has been achieved which is very close to the perfect laser mirror with R = 100%.

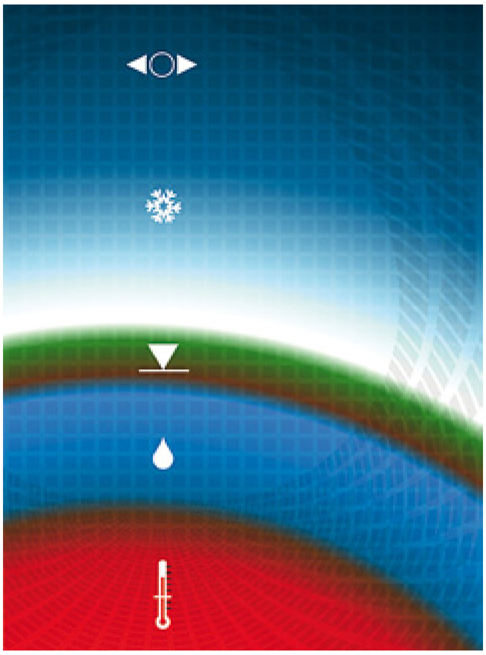
The results have been confirmed by LASEROPTIK's in-house cavity ring-down setup and scatter measurement. The use of super-polished substrates with a surface roughness RMS < 0.1 nm is essential for the values mentioned above. An overview of available standard substrates with a superior polishing quality is given on page 109. Their quality is inspected with a white light profilometer. Some measured values are given in the table on the left.

	Scatter TSB	Absorption	Reflection CRD
HR 532 nm/0°	4.9 ppm [1] (int. ARS)	10.2 ppm [2]	> 99.997% [2] (T~5 ppm)
HR 633 nm/0°	1.1 ppm [1]		> 99.998% (T~5 ppm)
HR 1064 nm/0°	(< 1 ppm) [3]	< 2 ppm [4]	> 99.999% (T~5 ppm)
HR 2940 nm/0°	24 ±12 ppm [6]		99.994% [5] (T=36 ppm)

1) Measured at IOF Jena; 2) Measured at LZH; 3) Calculated from surface roughness;
4) Measured at ILT Aachen; 5) measured by customer; 6) 1-R-T

A view into a cleanroom

Typical gyro mirrors



Natural environmental influences:
radiation – cold – pressure – humidity – heat

Coatings for harsh environments

As described in the section 'spaceborne / airborne optics', IAD and sputtered coatings (IBS and MS) withstand hostile working conditions, such as extreme temperature ranges or high humidity.

Magnetron sputtered coatings also have been successfully tested in customer projects as being resistant to several gases, acids and other fluids.

Optimizing flatness

Stress in thin films may cause a slightly deformed surface, concave if the stress is tensile, convex if it is compressive. The easiest way to avoid deformation is to use thicker substrates but often this is not possible.

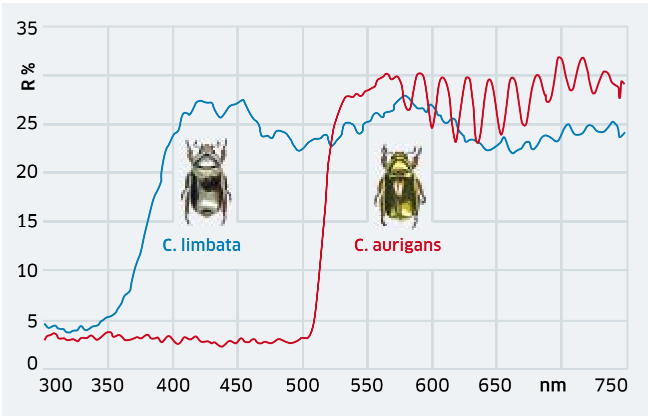
LASEROPTIK has approved coating processes in place that help to reduce stress in the coating and to avoid unwanted (a)spherical effects for substrates with extraordinary flatness requirements.

Additionally, the stress can be reduced significantly by optimizing the coating design. Taking the Stoney equation into account, the number and thickness of the layers can be adapted to the size and elastic properties of the substrate. But this may lead to a higher total film thickness and reduced spectral performance. For optimizing coating processes LASEROPTIK has a dedicated machine with an optional in-situ stress measurement.

If it is not possible to achieve the desired flatness with the chosen coating technique or design there are two further options but some more effort is required: A specially designed coating on the rear surface can compensate the stress of the main coating. This rear side coating can also be optimized for extra features like a high transmission pass band.

The most extensive way for stress compensation is to use pre-curved substrates. They have to be manufactured with a curvature adapted exactly to the computed stress of the coating, so standard substrates cannot be used anymore.

Coatings by mother nature



Steep natural edge filter / partial reflector on dorsal elytra of Chrysina limbata and Chrysina aurigans [1)]

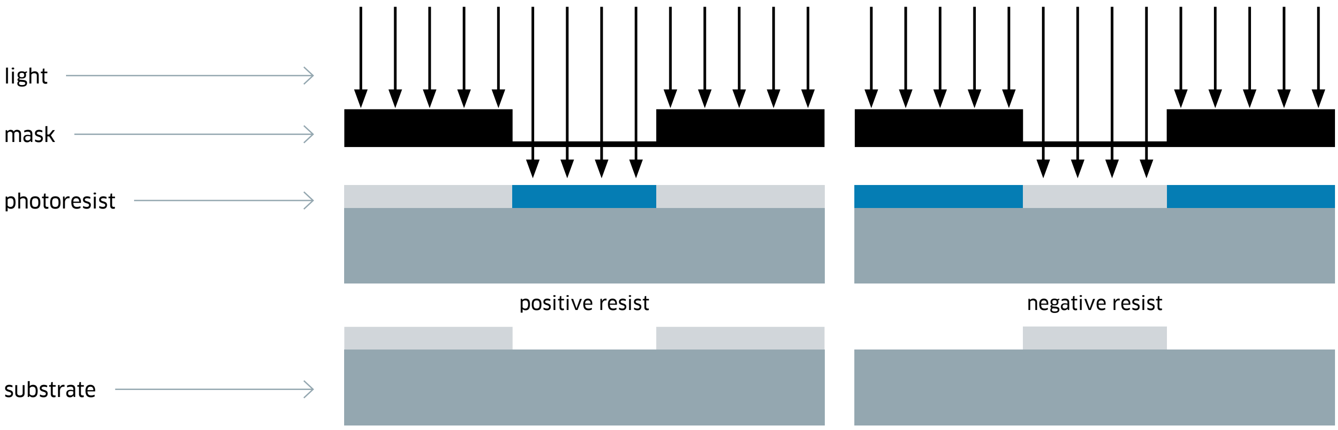
1) Campos-Fernández, C. et al., Optical Materials Express, Vol. 1, Iss. 1, pp. 85–100 (2011)

Structured coatings

How is it possible to arrange several optical filters on one substrate in order to enable miniaturized sensors? Or to deposit a high reflective mirror on a small and well-defined area in the middle of a substrate? This can be done by the combination of structuring and coating.

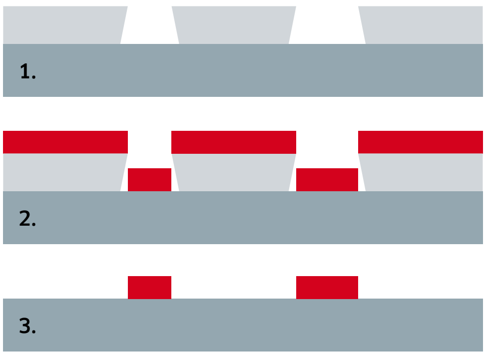
In the simplest case a metal mask is used. This is attached to the substrate before deposition and covers the areas which have to remain uncoated. But this can be used only for limited applications: Various shapes like covering a closed area in the middle of a substrate cannot be realized with a metal mask. Additionally, due to shadowing effects at the edges of the mask a transition zone between coated and uncoated areas occurs, so the achievable structure size is limited. Therefore, LASEROPTIK combines high quality custom coatings with photolithography in order to meet the requirements especially of the sensor and lighting technology.

The basic principle of photolithography is the creation of a structured surface by means of light shining through a mask onto a light-sensitive photoresist. Depending on the resist's type the exposed areas become soluble (positive resist) or insoluble (negative resist) in a liquid chemical solvent called developer. After removing the soluble areas you receive a structured resist which can be used as a mask for further processes, e.g. etching or lift-off.



Principle of the two different types of resists

To pattern our coatings we use a process called lift-off. A negative resist is applied onto an uncoated or regular coated substrate. Then it is structured as described above. Depending on the exposure time the edges of the resist do not have a rectangular but an undercut shape (1).



Lift-off process using a negative resist

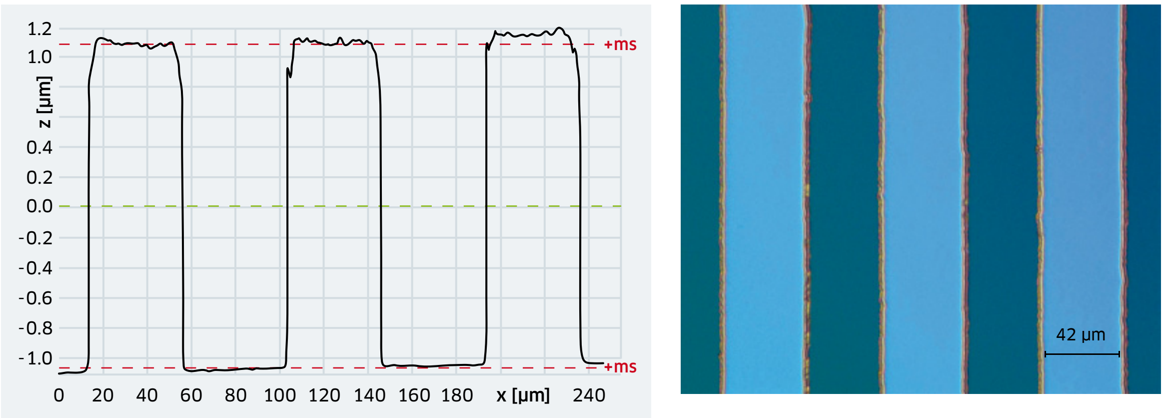
In the next step the desired coating is deposited on top. Because of the structured resist layer the coated areas are directly on the substrate or on the resist (2).

Finally a liquid chemical solvent dissolves the resist whereby the coating above is removed (lifted off), too and the structure of the mask is transferred positively to the coating (3).

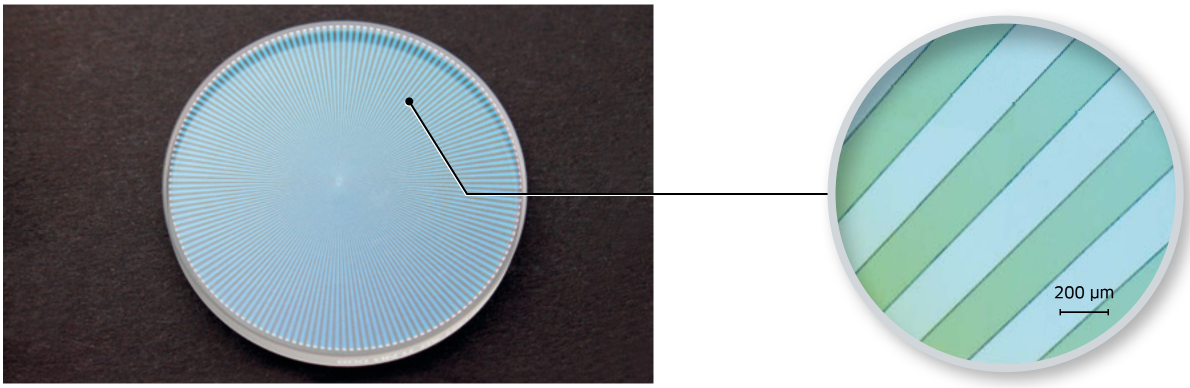
For a successful lift-off you have to ensure that the coating areas on the resist disconnect with the ones on the substrate, so the solvent can penetrate into the resist layer. To achieve this its thickness has to be larger than the coating layer. Additionally, it is helpful to create the greatest possible undercut profile in the resist structure by using an optimized exposure and developing time.

With our equipment we are currently able to process round substrates with a maximum diameter of 150 mm and rectangular substrates with a maximum length/width of 100 mm. Only sputtered coatings can be used.

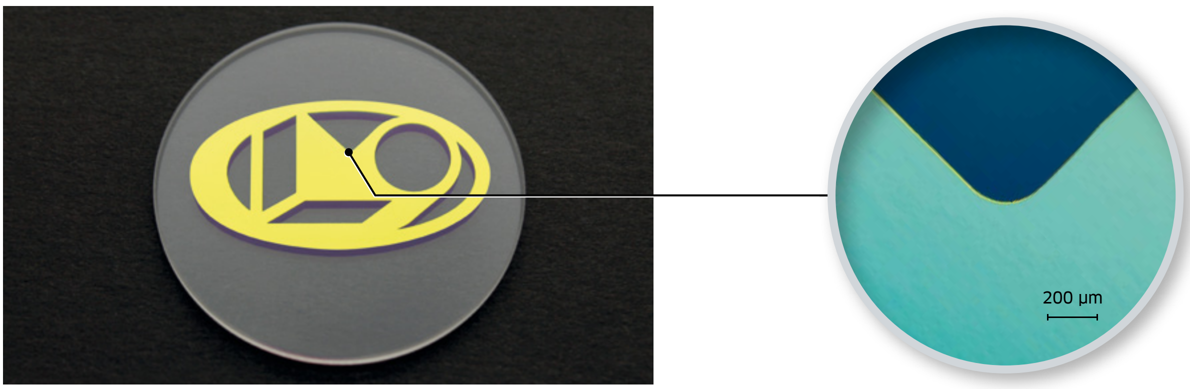
Due to the precise process of photolithography structures with sharp edges and very small widths (down to 25 µm) can be achieved. To give you an impression three examples are shown below. The measurements/pictures are done by Leica DCM 3D (courtesy of LNQE, Leibniz University Hanover) or our Zeiss Axio Imager.



Sharp edged structures with a width and gap of about 42 µm



Radial structure on a Ø 50 mm substrate with 314 lines



Our logo on a Ø 50 mm substrate, showing the shape's accuracy

Substrates

Production

Tolerances

Characteristics and transmission curves

Group Velocity Dispersion (GVD)

Reflection of an uncoated surface

Stock substrates

Production of substrates

Raw glass

Pre-cut in rough shape

- from a melt (Fused Silica) or a crystal boule (CaF_2, Sapphire)
- made at glass companies like Schott, Heraeus, Ohara, Corning
- a stock of common glass types from different suppliers is available for quick turnaround

Cutting

Cut into blanks

- by diamond-studded blades
- for round optics: edge grinding or CNC milling into round and plano blanks
- for curved optics: pre-manufacture radius by CNC processing
- the alternative to processed blanks are preformed moulded blanks

Chamfering edges

Chamfer sharp edges by grinding or milling

- prevents handling damages and gives a cleaner appearance
- done in an early stage to avoid damaging during later ones

Grinding

Approach the dimensional tolerances

- after fine grinding the substrate still is intransparent, but already has precise dimensions
- quality aspects like parallelism, radius or surface figure are already being monitored throughout the process
- CNC combines several grinding steps in one machining center

Polishing

Polish to our standard P4

- using pitch as carrier for the polishing agent leads to a very good surface quality
- using a polishing foil can reduce process time and costs significantly and can get to similar results
- polishing for super-polished optics (roughness RMS < 0.1 nm) can take twice as long
- CNC can help in all stages to handle larger quantities and to reduce processing times and cost

Cleaning

Clean off processing residues

- using multi-frequency ultrasonic and various baths with different chemical add-ons
- details about automatic ultrasonic and manual cleaning on *page 116*

Inspection

Inspect for all given specifications

- tolerances see next pages
- measuring methods see *page 118*

Tolerances for substrates

LASEROPTIK has a wide selection of sizes and materials in stock but can also provide nearly every custom optic manufactured to your individual needs.

For a quotation we need to know at least the following information:
- material
- quantity and size
- for curved surfaces: radii of curvature
- used aperture

If we do not get any other information we will choose standard quality properties and standard tolerances.

Please note: the quality of the substrate has to be chosen with the specifications of the coating in mind. For example low loss mirrors need to have substrate surfaces with a low micro-roughness. You can of course use super-polished optics for a standard mirror, but that might be a waste of money. Our standard polishing quality is P4.

It is common to accept tolerances for substrate size but also for variations of surface form and surface imperfections. Nevertheless some applications require more precise specifications.

In the next columns you can find a description of how to specify substrates according to DIN ISO 10110.

CODE NUMBER 0

Material imperfections: Stress birefringence (DIN ISO 10110-2)
- specified as 0/A
- where A is the maximum allowable stress birefringence in nanometers per centimeter of optical path length, e.g. 0/5

CODE NUMBER 1

Material imperfections: Bubbles and inclusions (DIN ISO 10110-3)
- specified as 1/N x A
- where N is the number of bubbles and inclusions with a maximum allowable size A, e.g. 1/3 x 0.010

CODE NUMBER 2

Material imperfections: Inhomogeneity and striae (DIN ISO 10110-4)
- specified as 2/A; B
- where A denotes the inhomogeneity class and B denotes the striae class, e.g. 2/5; 5

Please note:

We often see specifications like:

flatness < λ/10 @ 632.8 nm

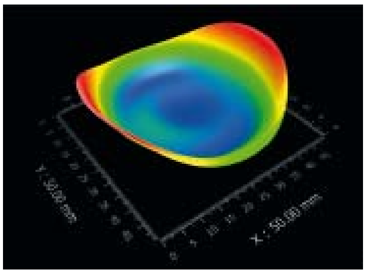
Nonetheless this is a commonly used phrase, we recommend using the more precise DIN ISO-term instead.

The Hg e-line (= 546.07 nm) is the standard wavelength for flatness tolerances in the DIN ISO 10110-5.

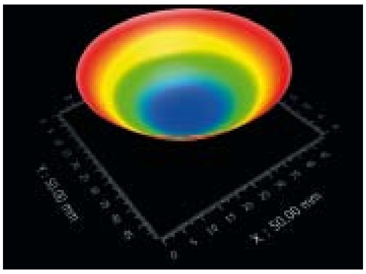
CODE NUMBER 3

Surface form tolerances (DIN ISO 10110-5)

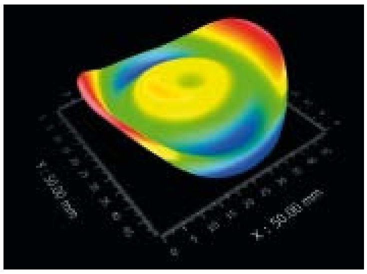
- specified as 3/A (B/C)
- where A is the maximum permissible power deviation (≈ peak to valley (PV) of the best-fit-sphere), B is the maximum permissible PV of the resulting surface after subtracting the best-fit-sphere (= irregularity) and C is the maximum permissible PV of the best fit asphericity of the irregularity (= rotationally invariant irregularity).
  Therefore C is a subset from B.
- please see DIN ISO 14999 for more detailed information.



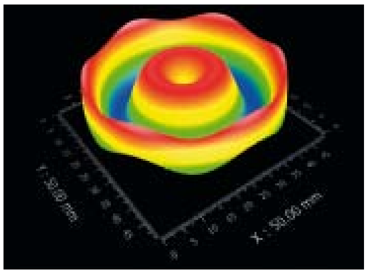
Original surface



Best-fit-sphere



Irregularity (B)



Rotationally invariant irregularity (C)

Usually, the values are tolerated in fringes, but nanometers are possible as well.

fringes	nanometer
2	546.07 nm
1	273.04 nm
0.5	136.52 nm
0.4	126.60 nm
0.2	54.61 nm
0.1	27.30 nm

Example

3/0.5 (0.2/0.1) = **3/**136.5 nm (54.6 nm/27.3 nm)

Commonly the surface form tolerance is stated as flatness and can roughly be converted into values of the measuring wavelength λ, as shown in the table. Please note that the achievable flatness strongly depends on the diameter-thickness-ratio of the substrate.

3/0.1 (0,1)	3/0.2 (0.2)	3/0.5 (0.5)	3/1 (1)	3/2 (2)
λ/20	λ/10	λ/4	λ/2	λ

CODE NUMBER 4

Centering tolerances (DIN ISO 10110-6)

- specified as 4/σ
- where σ denotes the maximum permissible wedge angle by spherical surfaces, e.g. 4/3'

CODE NUMBER 5

Surface imperfection tolerances (DIN ISO 10110-7)

- specified as 5/N x A
- where N is the number of allowed surface imperfections with maximum size A, e.g. 5/3 x 0.025
- other codes represent additional errors: C stands for coating imperfections, L for scratches with any length and E for chips
- a possible complete nomenclature would be 5/3 x 0.025; C3 x 0.025; L1 x 0.001; E 0.2
- please see DIN ISO 14997 for more detailed information

CODE NUMBER 6

Laser irradiation damage threshold (DIN ISO 10110-17)

- specified as 6/
- For more information regarding the LIDT see page 122.

CODE NUMBER 13

Wavefront deformation tolerance (DIN ISO 10110-14)

- specified as 13/A (B/C)
- where A is the maximum permissible sagitta deviation (single pass), B is the maximum permissible irregularity (single pass) and C is the maximum permissible rotationally invariant irregularity (single pass), e.g. 13/0.2 (0.2/0.1)
- compare with the additional information given for 3/A (B/C)
- please see DIN ISO 14999 for more detailed information.

The above explanations of DIN ISO 10110 are simplified. For more information please see the complete text of DIN ISO 10110.

Another way to specify substrates is to use the MIL-norms. A comparison between MIL and DIN ISO is very difficult and reveals that the DIN ISO 10110 provides finer levels for decisions.

For the standard surface quality of our substrates we can give you the values listed in the table:

Please contact us, if you require higher quality standards.

clear aperture up to Ø	according to DIN ISO 10110-7 surface imperfections	accordi ng to MIL-0-13830A Scratch/Dig[1)]
12.7 mm	5/3 x 0.025; L1 x 0.001	10 / 5
25 mm	5/3 x 0.025; L1 x 0.001	10 / 5
50 mm	5/3 x 0.025; L1 x 0.001	10 / 5
75 mm	5/3 x 0.040; L1 x 0.001	20 / 10
100 mm	5/3 x 0.063; L2 x 0.001	20 / 10

1) Please note: The scratch/dig information in accordance with MIL-13830 shall apply for a maximum inspection area of Ø 20 mm.

For special customer-owned substrates (e.g. crystals) we additionally need to know the following properties:

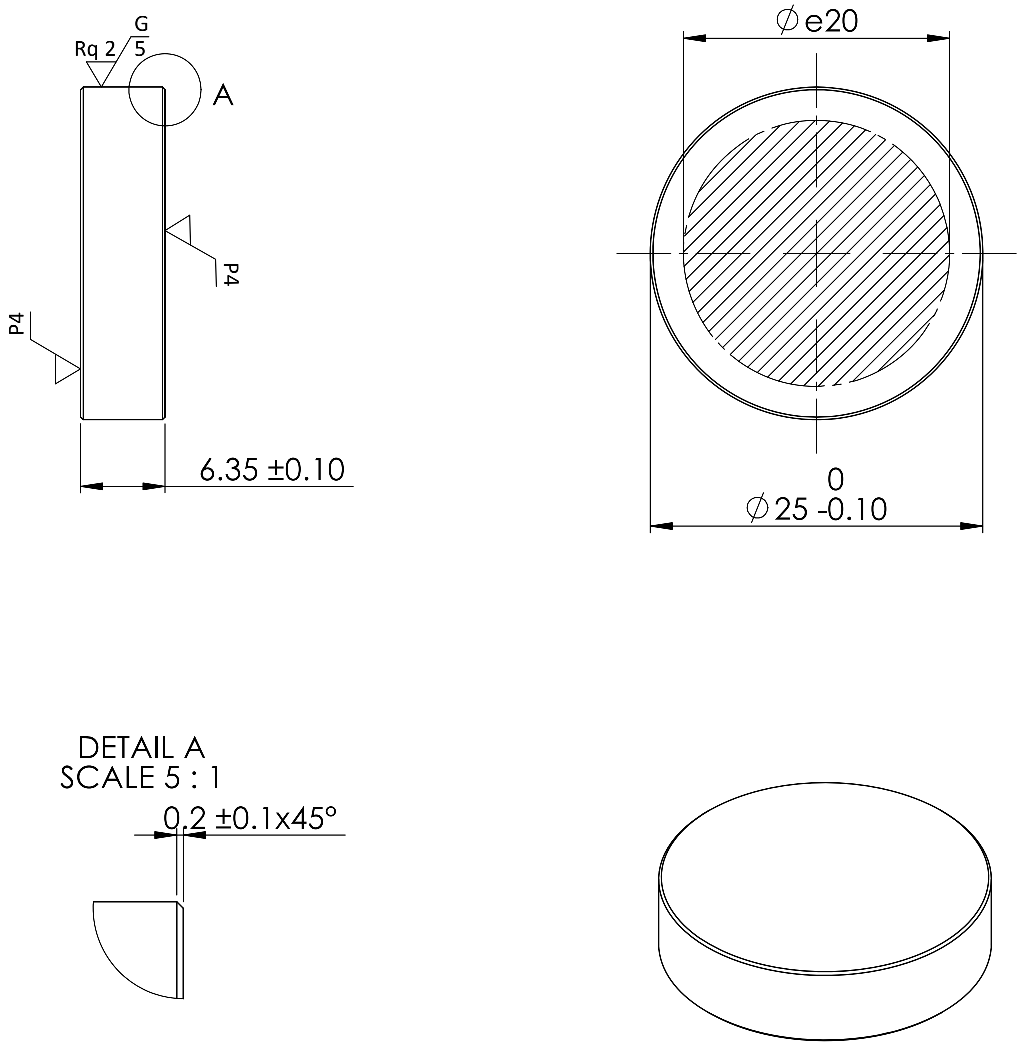
- maximum temperature we can use while coating
- thermal expansion coefficient
- refractive index
- incompatibility e.g. with certain cleaning solvents

LASEROPTIK has decades of experiences in coating on all kind of substrates and a large data base, but we gratefully accept any additional information about the characteristics of your substrates.

For choosing the correct substrate size it might be useful to think about the possible aperture and about the holders used for the coating process:

- If not described otherwise we use holders with rims (normally covering about 2% of the diameter, minimum 0.5 mm) which will remain uncoated.
- If the coating has to be rimless, small defects caused by the clamp holder and overspray can occur on the sides of the substrates.

We do have over 16,000 substrate holders available and can work with nearly all sizes. Of course we will find a special holder system for your substrates if necessary.



Wedge angle between optical surfaces: ≤5'

Left Surface		Material		Right Surface	
		Fused Silica FS-LO-U			
R	∞			**R**	∞
Clear aperture	80%			**Clear aperture**	80%
Chamfer	0.2 ±0.1x45°	**nd**	1.4585 ±0.0005	**Chamfer**	0.2 ±0.1x45°
3/	0.2(0.2)	**vd**	67.8 ±0.5%	**3/**	0.2(0.2)
4/	-	**0/**	5	**4/**	-
5/	3x0.025	**1/**	3x0.010	**5/**	3x0.025
		2/	5; 5		

Specifications: DIN ISO 10110 All dimensions are mm unless otherwise specified

Title:	Substrate Ø25x6.35mm	**Material No.:**	**Scale:** 2:1
Document No.:	S-00010	**Sheet No.:**	**Format:** A4

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Created by:	Arnold, M.								
Changed by:									

LASEROPTIK

LASEROPTIK GmbH
Horster Straße 20, 30826 Garbsen, Germany
Tel. +49 5131 4597-0, Fax -20, www.laseroptik.com

Data sheet for the standards of specification for our uncoated substrate S-00010 according to DIN ISO 10110

Standard substrates

Characteristics and transmission curves

Overview of the characteristics of the most common substrates

	useable transmission range				refractive index		thermal expansion coefficient
	VUV	UV-NIR	MIR	[nm]	n_d 588 nm	n 2940 nm	$\alpha_{20\text{-}300°C}$ [10^{-6}/°C]
Borofloat®		x		350-2000	1.471	–	3.3
CaF_2	x	x	x	130-8000	1.434	1.418	18.9
Duran®		x		350-2000	1.473	–	3.3
FS-UV		x		180-2000	1.458	–	0.55
FS-IR		x	x	250-3500	1.458	1.421	0.55
Ge			x	2000-12000	–	4.053	6.1
$LiNbO_3$ 1)		x	x	380-4500	2.3	2.162	2 to 14
MgF_2 1)	x	x	x	120-6000	1.377	1.364	8.5 to 14
N-BaK2®		x		350-1800	1.54	–	9.1
N-BK7®		x		350-2000	1.517	–	7.1
N-SF11®		x		380-2500	1.785	–	6.8
N-SF6®		x		380-2500	1.805	–	9
PYREX® (Corning 7740)		x		400-2200	1.474	–	3.3
Quartz (crystal) 1)		x		200-2300	1.544	1.501	7.8 to 14.2
S-PHM52		x		420-1800	1.618	–	12
S-TIH53		x		550-1800	1.847	–	10.4
Sapphire 1)		x	x	220-5000	1.768	1.713	5 to 7
Si			x	1250-12000	–	3.437	4.2
ULE® (Corning 7972)		x		400-2000	1.483	–	< 0.1
YAG 2)		x	x	300-4000	1.837	1.787	7
Zerodur®		x		550-2500	1.542	–	< 0.1
ZnSe		x	x	550-20000	2.624	2.438	7.6

Reference values, with no guarantee

1) birefringent, all values refer to the ordinary ray
2) undoped

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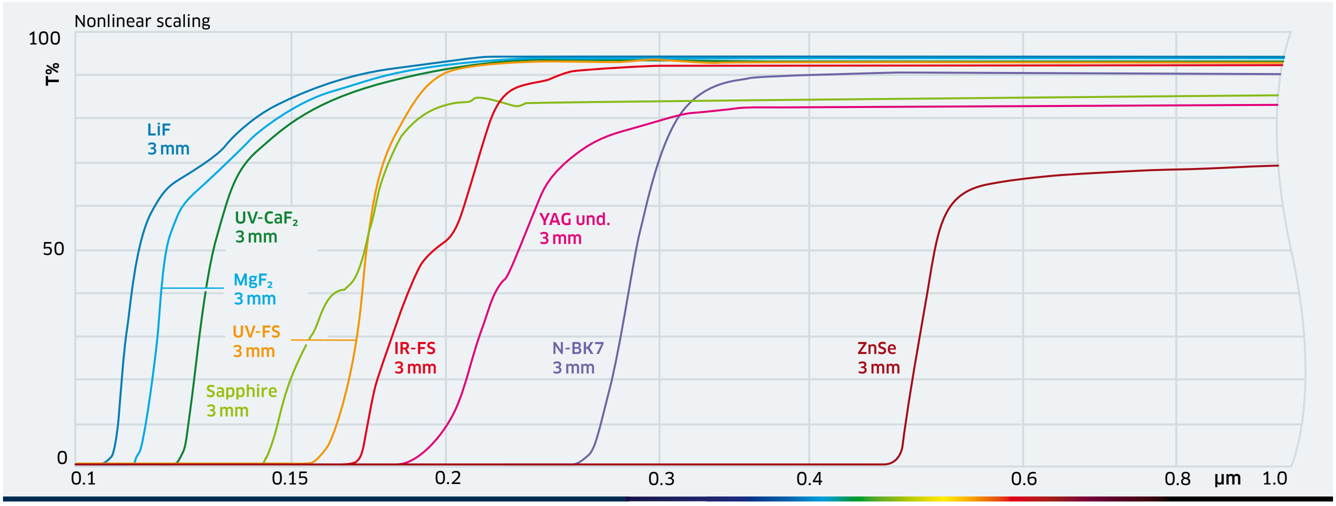
Duran Group GmbH
Heraeus Holding GmbH
j-fiber GmbH
Nikon Corporation
Ohara Corporation
Schott AG

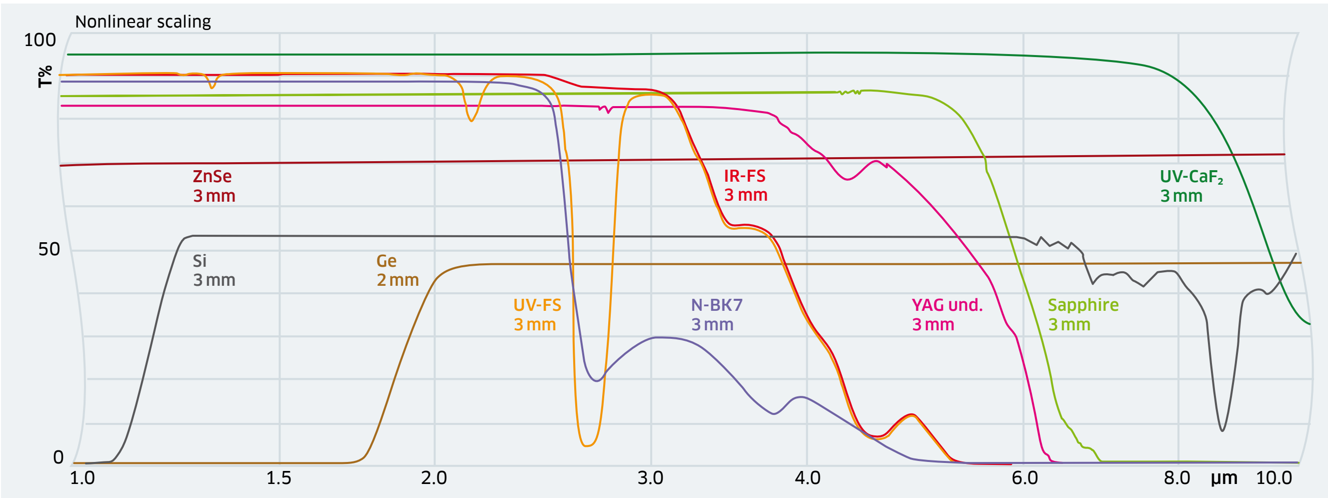
Please note:

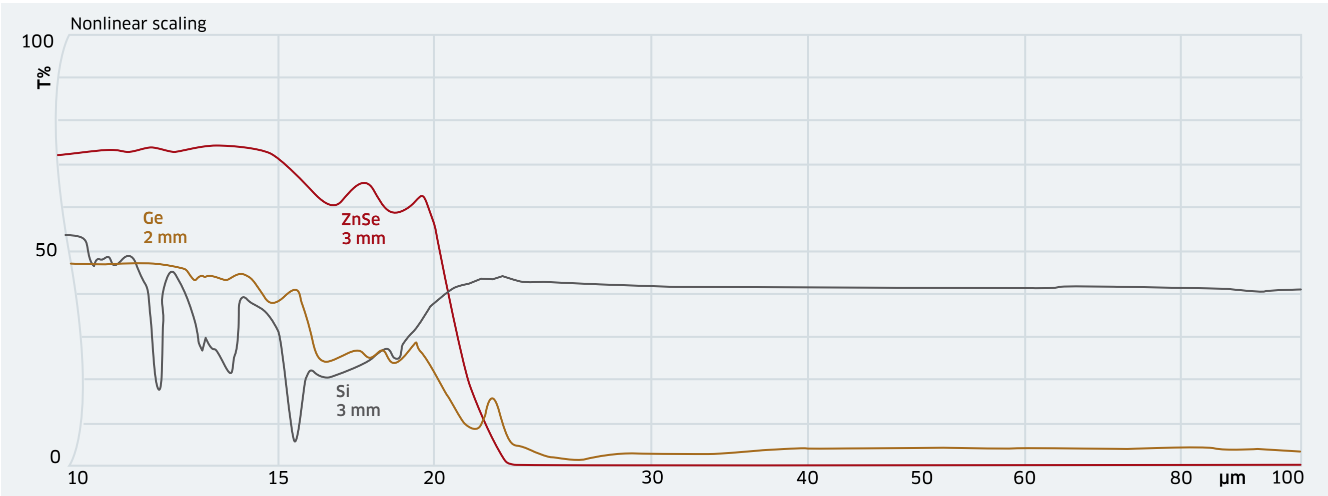
LASEROPTIK has a wide selection of sizes and materials in stock. We also can provide nearly every custom optic, manufactured according to your specific needs. Using standard substrates can help to hold down the total cost and lead time.

> **Please note:**
>
> *The curves below show external transmission and include the fresnel reflection losses of the polished surfaces. With high quality antireflection coatings these losses can be eliminated for selected wavelength ranges.*

Transmission curves of optical glasses and crystals

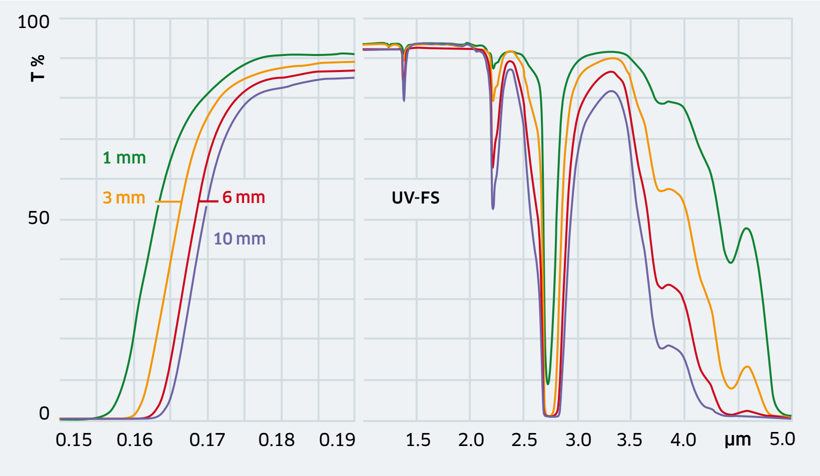






Most customers' needs can be met with two standard materials: FS-UV and FS-IR.

Fused Silica-UV



Transmission curve of UV Fused Silica

(amorphous silicon dioxide) is produced synthetically from high purity silicon by flame hydrolysis. It differs by its high UV-transmittance from natural Fused Silica, molten from crystalline quartz. UV-FS offers:

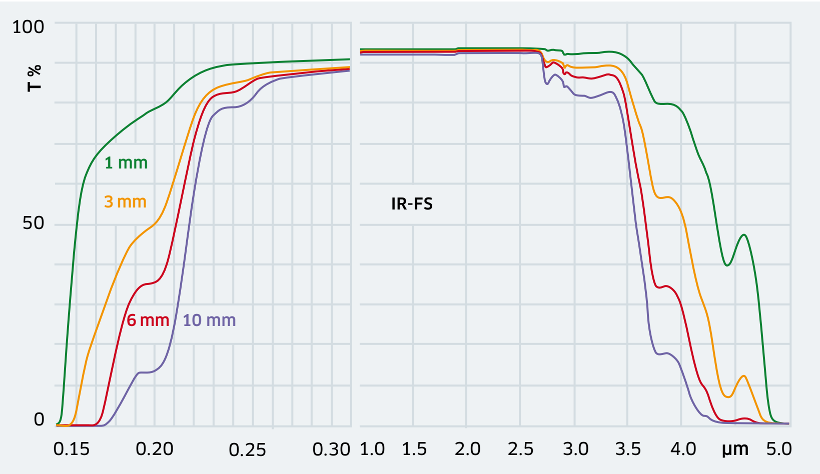
- broad transmission range
- low thermal expansion coefficient, providing high thermal stability and resistance to thermal shocks
- thermal operating range up to 800 °C
- great hardness and resistance against scratches
- very high resistance to radiation darkening
- absence of bubbles and impurities

Even it is called UV-FS normally it is the standard substrate material for a use in UV, VIS and NIR.

There is a wide range of different substrate materials available, varying in homogeneity, grades of laser induced fluorescence and content of bubbles, inclusions and OH. LASEROPTIK often uses SQ0, SQ1 (former Q0, Q1, Q2), Suprasil® 1/2, Corning 7980® or NIFS-U®.

In the UV-range we recommend to use optimized materials like SQ0/SQ1 E-193 or E-248 for lowest losses. Other materials can be supplied as well.

Fused Silica-IR

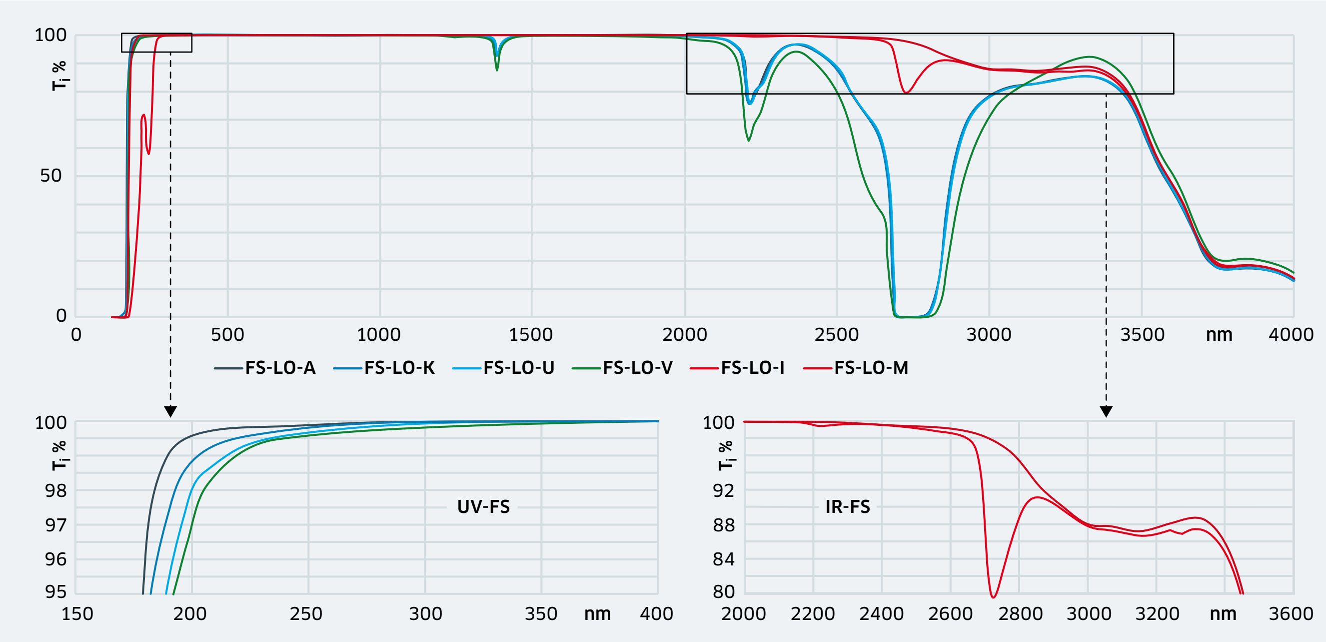


Transmission curve of IR Fused Silica

IR absorption of FS is caused by OH-chemical bond content, most relevant at wavelengths near the water absorption band at 2.7 µm but also critical at 940 nm. Reduction in OH can be assured by melting high quality quartz or special manufacturing techniques, but mostly at the sacrifice of UV transmittance.

A common material is Infrasil®. For high power applications, especially in the range of the OH-waterbands we recommend a material with lowest OH-content, like Corning 7979®, Suprasil® 300 or Suprasil® 3001/3002.

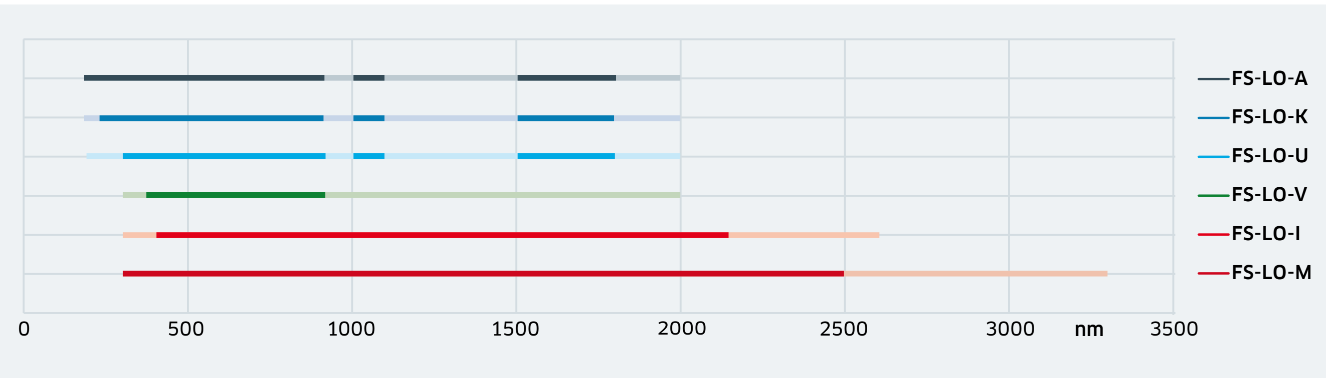
Overview of the Fused Silica classes used by LASEROPTIK



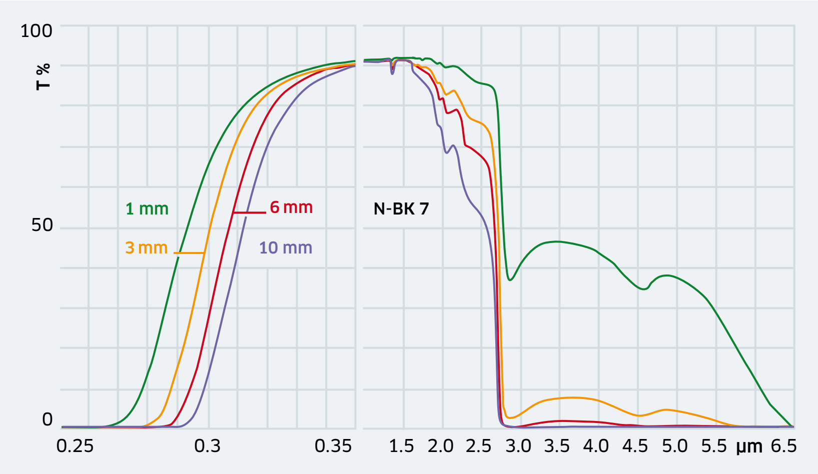
Typical internal transmittance T_i [%] of the FS-LO classes, 10 mm thickness

FS-LO class	main wavelength [nm]	OH-absorption 920–1000 nm	best performance in transmission [nm]	typical materials	
FS-LO-A	185–2000	x	185–1100 + 1500–1800	SQ0/1-E193; Suprasil® 1/2 ArF	can be used as FS-LO-K
FS-LO-K	185–2000	x	225–1100 + 1500–1800	SQ0/1-E248; Suprasil® 1/2 KrF	can be used as FS-LO-U
FS-LO-U	190–2000	x	300–1100 + 1500–1800	SQ0/1; Suprasil® 1/2	can be used as FS-LO-V
FS-LO-V	300–2000	x	370–1000	Corning 7980®-0F	
FS-LO-I	300–2600		400–2150	Infrasil® 301/302	
FS-LO-M	300–3300		300–2500	Corning 7979®-0F; Suprasil® 3001/3002	export control necessary

Classification of the FS types



Useable transmission ranges of the FS-LO classes



Transmission curve of N-BK7®

N-BK7®

is a frequently used optical glass, a chemically stable borosilicate crown glass, molten in ceramic vessels to be free of Platinum impurities. Normally N-BK7® has a more instable polishing and is softer than FS, so the surface can be damaged easier. Unfortunately often defects will only become visible after the cleaning process.

Additionally N-BK7® has higher losses through higher absorption and scattering and therefore cannot be used for high power applications.

These are the reasons why LASEROPTIK recommends using Fused Silica instead and offers N-BK7® or equivalent substrates only on request.

Low expansion glasses

If applications require low thermal expansion and FS will be too expensive, commonly the following materials are used: Borofloat®, Duran®, Pyrex® (Corning 7740). Glass materials with a thermal expansion coefficient lower than FS and close to zero are for example ULE® (Corning 7972) or Zerodur® .

But all glasses have a limited transmission range (see table on page 90).

Glasses with special refractive index

LASEROPTIK can supply all sizes of nearly all common substrate materials, like all types of flint glass or crown glass. For these normally we use optical glasses from Schott, Ohara or Hoya. On customer request we can of course also work with the material of other manufacturers. We can for example provide a refractive index between n_d = 1.487 (S-FSL5) and n_d = 2.00 (S-LAH 79).

Optical filter glasses

We can also supply and/or coat on optical filter glass (mainly from Schott), which works as natural filter, for example as band-, long- or short-pass filter. A number of different colorants and concentrations can be provided on request.

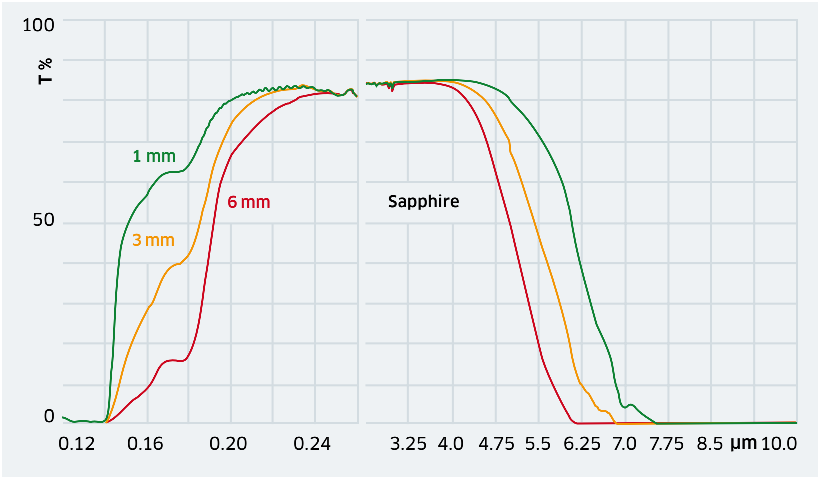
Sapphire (crystalline Al_2O_3)

is free of absorption in the range 240 nm – 4 µm. Optical components generally have c-cut (0001-orientation).

It stands out by strength, hardness, chemical and thermal stability and is often used as high pressure and high temperature window material and for viewports.

Compared to Fused Silica it has 20 times higher heat conductivity. In addition it is insoluble in most common acids.

LASEROPTIK offers ultrahard coatings that parallel the material hardness and allow best environmental durability.

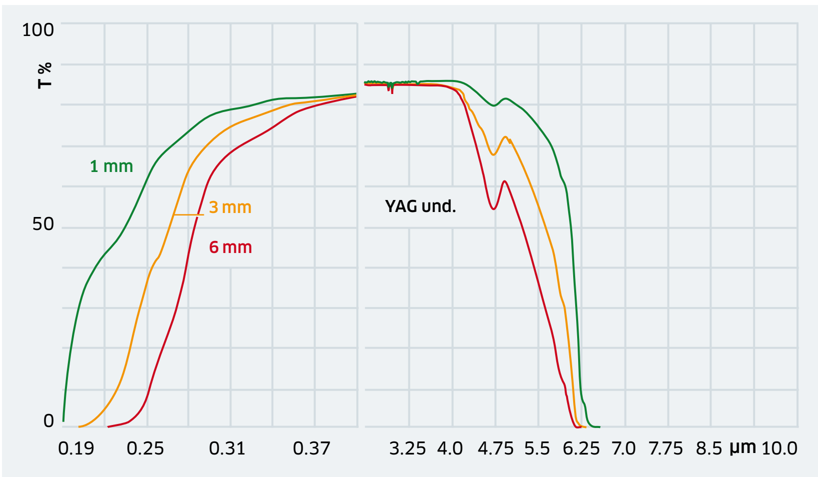


Transmission curve of Sapphire (cryst. Al_2O_3)

YAG undoped

Yttrium Aluminium Garnet ($Y_3Al_5O_{12}$) has nearly the same IR transmission as Sapphire, but is not birefringent and has a high optical homogeneity.

It is pulled from the melt in the same manner as the Nd:YAG rods by Czochralski method, which produces high quality crystalline boules without any inclusions and bubbles. Due to a special thermal treatment, the YAG material has a minimum of internal stress.



Transmission curve of YAG undoped

Fluorides

Fluorides have a very broad transmission range from VUV to FIR. They must be chosen especially if the coating materials will also be fluorides, like often used in the VUV/UV or in the MIR/ FIR. The main materials are MgF_2 and CaF_2.

MgF_2 is the fluoride with the highest resistance to degradation by atmospheric moisture, also at higher temperatures. Its hardness, ruggedness and resistance to mechanical and thermal shock is advantageous for laser windows.

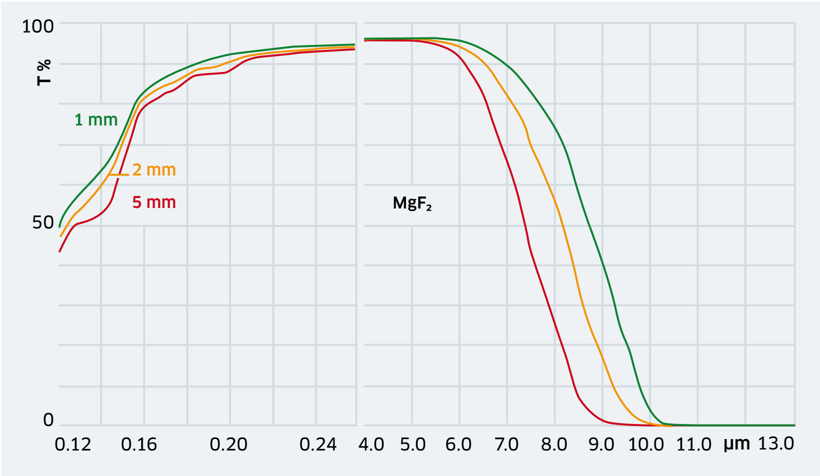
MgF_2 has a low birefringence. The windows are fabricated with the optical axis as symmetry axis, minimizing the birefringence effect (c-cut).

LASEROPTIK's MgF_2 substrates are very resistant to F-center formation due to their low O_2-contamination, which is also expressed by the high VUV transmission.

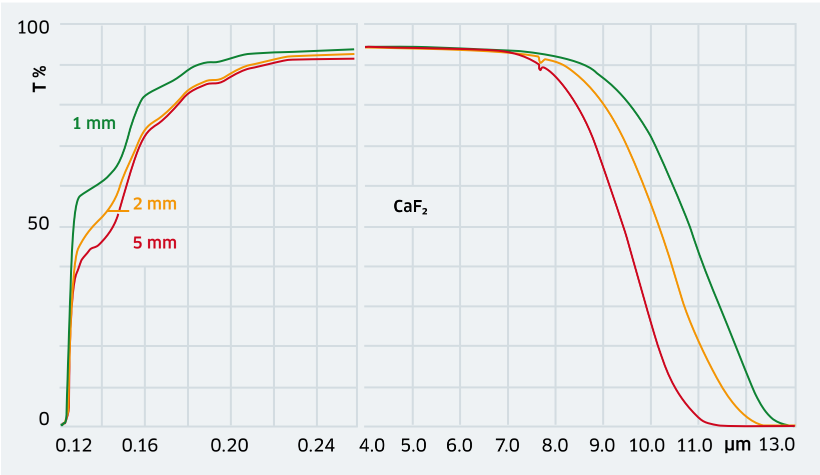
CaF_2 is used as window as well as substrate material. Compared to MgF_2 it has an isotropic structure, lower hardness and it is sensitive to thermal shocks. If CaF_2 windows are protected from humidity, they can be used for several years in the laboratory. CaF_2 begins to soften at 600 °C, the reaction with atmospheric moisture will take place above this temperature.

Especially in the VUV/UV-range we recommend to use optimized materials for lowest losses like 157 nm- or 193 nm-grade.

The curves on the left show the transmission of the standard UV-grade.



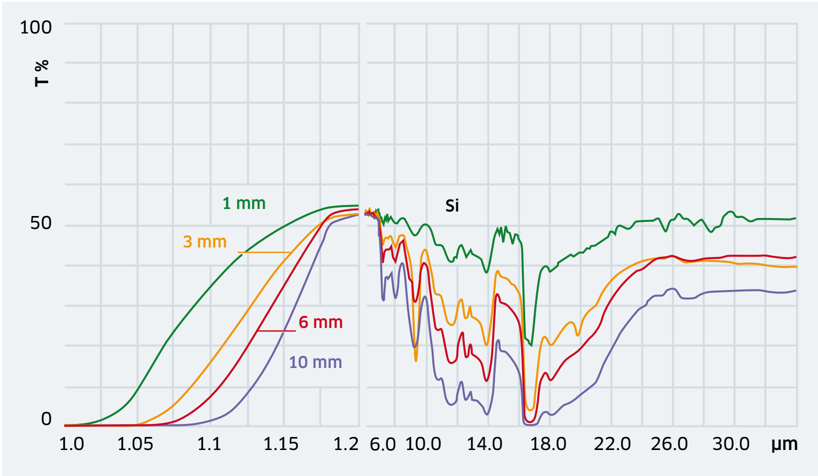
Transmission curve of Magnesium Fluoride



Transmission curve of Calcium Fluoride

Si (Silicium)

is often chosen as a substrate material for high power mirrors, making use of its high thermal conductivity. But it can be used for windows in the whole FIR range up to some 100 µm.

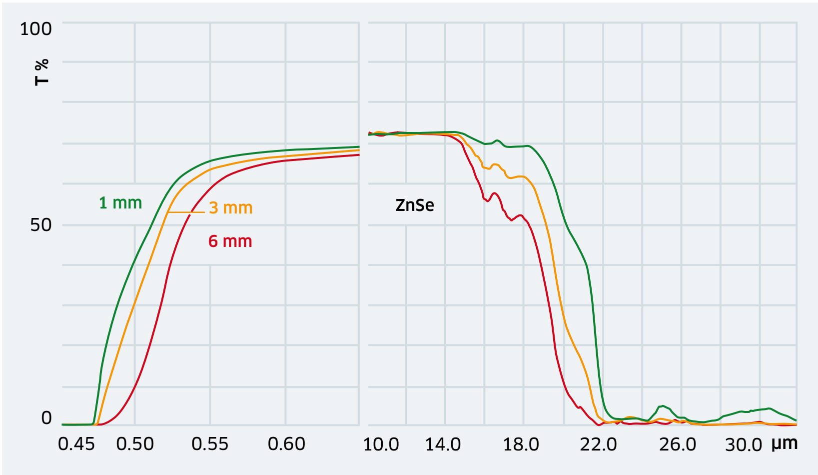


Transmission curve of Silicium

ZnSe (Zinc Selenide)

is a standard material for use in CO_2 lasers as windows, beamsplitters, output couplers or focussing lenses. Because of its broad transmission range, its low absorption and scatter, ZnSe is a standard material for use from 500 nm up to 22 µm. ZnSe is nonhygroscopic, chemically stable unless treated with strong acids, and has a very high damage threshold.

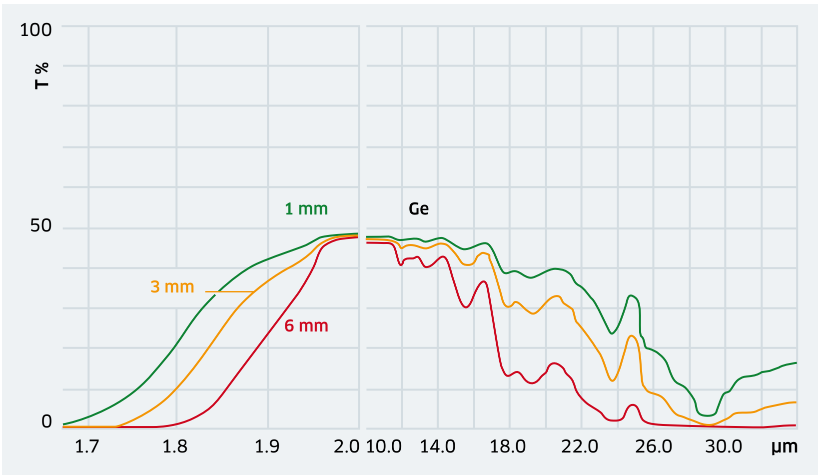
LASEROPTIK offers a large selection of AR, reflecting and beamsplitter coatings on ZnSe.



Transmission curve of Zinc Selenide

Ge (Germanium)

is commonly used in imaging systems and instruments in the 2–12 µm range. Ge is utilized as a substrate for lenses, windows and output couplers for low power cw as well as pulsed CO_2-lasers. It is also a popular choice as a substrate for a variety of infrared filters. Ge is nontoxic and nonhygroscopic, has good thermal conductivity and excellent hardness.



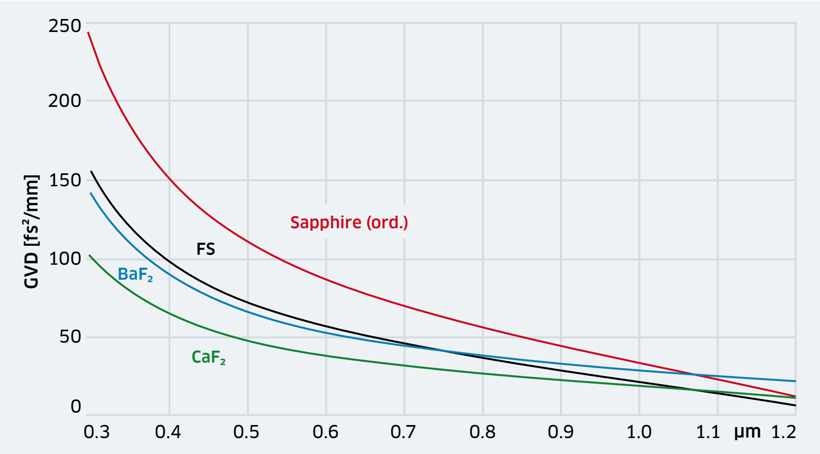
Transmission curve of Germanium

Group Velocity Dispersion (GVD) of standard substrates

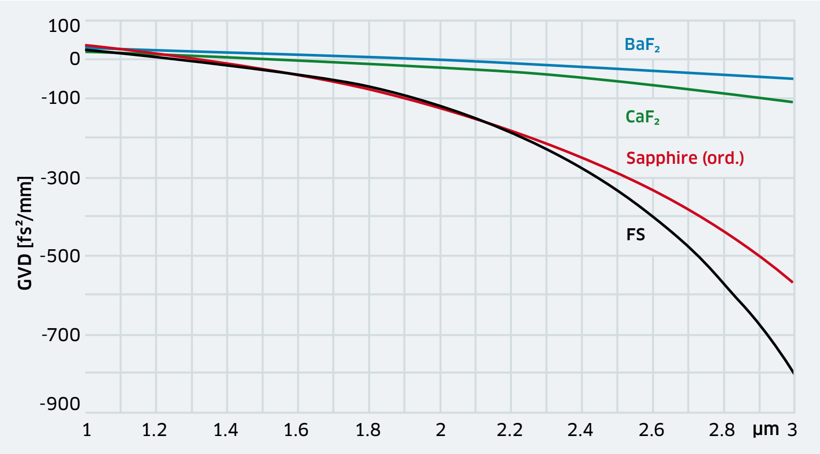
For special applications the dispersion of the substrates becomes important.

The two diagrams show the dispersion curves of four common substrate materials:

For coatings with optimized dispersion properties see chapter “Dispersive coatings”, starting on page 61.



Dispersion of plane substrates, AOI 0°



Dispersion of plane substrates, AOI 0°

Reflection of an uncoated surface

The reflection of an uncoated surface decreases the transmission of an optic. So windows and lenses used in transmission need an anti-reflecting coating on both sides.

Optics with a filter coating on the front surface need an AR on the rear surface as well which is often forgotten in customer's requests.

The example, right, shows the reflection of an uncoated surface depending on the refractive index of the substrate.

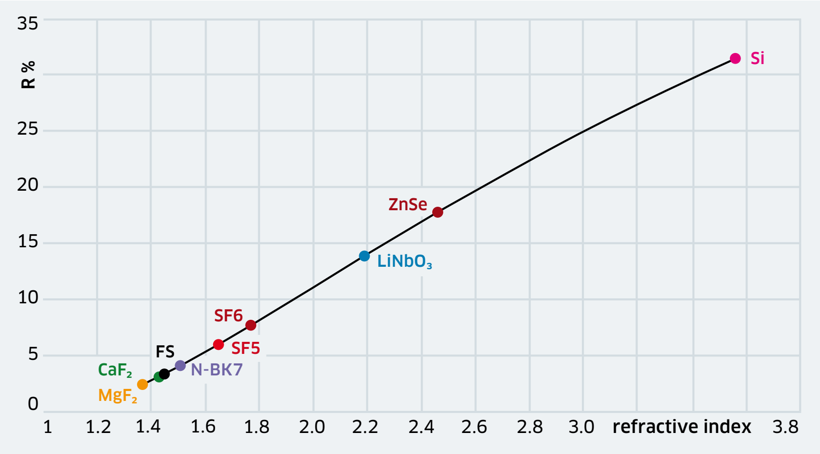
The values are calculated from the Fresnel equations with an angle of incidence AOI = 0° and against air, so the reflection becomes:

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

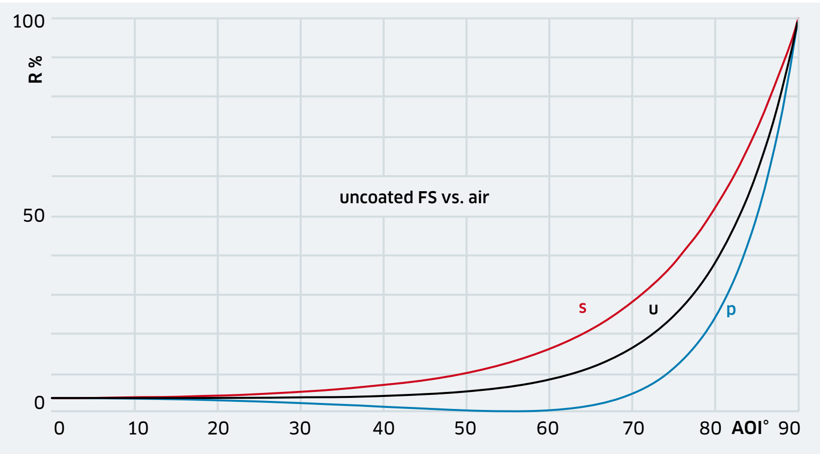
The values for the given materials refer to a wavelength of 1064 nm.

The impact of polarization changes with the angle of incidence. The diagram shows the reflection for different polarizations depending on the AOI for Fused Silica against air at 1064 nm.

Please notice that working with p-polarized light and the Brewster angle (arctan(n), for FS AOI = 55.4°) the reflection falls down to zero and no antireflective coating will be necessary. This effect is used for TFP rear surfaces.



Reflection of an uncoated surface



Reflection of an uncoated surface

Stock substrates

LASEROPTIK stocks substrates for coatings in the wavelength range from 120 nm to 50 µm. Only the highest grade materials are used in the production of the components.

Nevertheless most optics are custom made at unique requirements and drawings. So please feel free to send your individual specifications.

All substrates are manufactured at high quality specifications in order to keep critical optical properties as scattering, absorption or beam deviation at a minimum. Besides flatness and roughness, the surface imperfections are another critical parameter.

Listed on the following pages LASEROPTIK stocks a selection of UV- and IR-transmitting substrates for fast delivery. A brief characterization of the substrates is given for every type.

Most orders of our customers can be met with FS-UV and FS-IR. For these we offer a large number of plane and curved substrates.

In our standard sizes we can offer Fluorides as MgF_2 and CaF_2. For CaF_2 we offer four different qualities (VUV-grade for 157 nm, UV-grade for 193 nm or 248 nm and VIS-IR quality).

For applications with an absorption free range up to 4 µm, Sapphire or undoped YAG is recommended. Both materials are very hard and withstand temperatures up to 1.000 °C as well as high pressure.

ZnSe is a standard material for use from 500 nm up to 22 µm, because of its broad transmission range, its low absorption and scatter.

Material refractive indices

Refractive index for each stock substrate material, listed for different wavelengths.

λ (nm)	MgF_2 ord. ray	CaF_2	FS	Sapphire ord. ray	YAG undoped	ZnSe
157	1.468	1.558	1.661	–	–	–
193	1.428	1.502	1.561	1.927	–	–
248	1.403	1.468	1.509	1.847	–	–
266	1.399	1.462	1.500	1.833	–	–
308	1.392	1.453	1.486	1.811	–	–
337	1.389	1.448	1.479	1.801	–	–
355	1.387	1.446	1.476	1.796	2.020	–
450	1.381	1.439	1.466	1.779	1.855	–
488	1.379	1.437	1.463	1.777	1.847	2.775
514	1.378	1.436	1.462	1.773	1.844	2.715
532	1.378	1.435	1.461	1.772	1.842	2.687
588	**1.377**	**1.434**	**1.458**	**1.768**	**1.837**	**2.624**
633	1.376	1.433	1.457	1.766	1.833	2.591
800	1.374	1.431	1.453	1.761	1.824	2.524
1064	1.372	1.429	1.450	1.755	1.818	2.482
1320	1.371	1.427	1.447	1.750	1.812	2.465
1540	1.370	1.426	1.444	1.747	1.810	2.456
2100	1.368	1.424	1.437	1.735	1.802	2.445
2940	**1.364**	**1.418**	**1.421**	**1.713**	**1.787**	**2.438**
4000	1.351	1.410	1.389	1.675	1.760	2.433

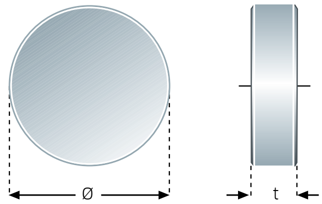
Reference values, with no guarantee

Plane windows

Diameter Ø mm	Thickness t mm	Flatness λ (633 nm)	Surface imp. tol.	UV-FS Article-No.	Stock	IR-FS Article-No.	Stock
3	2	λ/10	5/3 x 0.025	S-00265	✓	S-00945	
6	2	λ/10	5/3 x 0.025	S-00909	✓	S-00402	✓
6.35	4	λ/10	5/3 x 0.025	S-00910	✓	S-00946	
8	2	λ/10	5/3 x 0.025	S-00350	✓	S-00947	
10	0.5	λ/2	5/3 x 0.040	S-00614		S-00948	
10	1	λ/4	5/3 x 0.025	S-00911	✓	S-00949	
10	2	λ/10	5/3 x 0.025	S-00912		S-00950	
10	5	λ/10	5/3 x 0.025	S-00609	✓	S-00951	✓
12.7	2	λ/10	5/3 x 0.025	S-00264	✓	S-00952	
12.7	3	λ/10	5/3 x 0.025	S-00323	✓	S-00401	✓
12.7	5	λ/10	5/3 x 0.025	S-00913	✓	S-00953	
12.7	6.35	λ/10	5/3 x 0.025	S-00018	✓ +	S-00027	✓
15	6.35	λ/10	5/3 x 0.025	S-00914		S-00954	
19	3	λ/10	5/3 x 0.025	S-00915	✓	S-00955	
19	4.5	λ/10	5/3 x 0.025	S-00295	✓	S-00956	
19	6.35	λ/10	5/3 x 0.025	S-00163	✓	S-00957	
20	2	λ/4	5/3 x 0.025	S-00644	✓	S-00958	
20	5	λ/10	5/3 x 0.025	S-00916	✓	S-00959	
22.4	5	λ/10	5/3 x 0.025	S-00917	✓	S-00960	
25	0.5	λ	5/3 x 0.040	S-00600	✓	S-00961	
25	1	λ/2	5/3 x 0.025	S-00617	✓	S-00962	
25	2	λ/4	5/3 x 0.025	S-00499	✓	S-00500	
25	3	λ/4	5/3 x 0.025	S-00028	✓	S-00501	✓
25	5	λ/10	5/3 x 0.025	S-00321	✓	S-00964	
25	6.35	λ/10	5/3 x 0.025	S-00010	✓ +	S-00025	✓
25.4	6.35	λ/10	5/3 x 0.025	S-00035	✓	S-00965	
25	9.5	λ/10	5/3 x 0.025	S-00409	✓	S-00966	
30	2	λ/4	5/3 x 0.025	S-00918	✓	S-00967	
30	6	λ/10	5/3 x 0.025	S-00919	✓	S-00968	
30	8	λ/10	5/3 x 0.025	S-00920		S-00969	
38	3	λ/4	5/3 x 0.025	S-00502	✓	S-00972	
38	5	λ/4	5/3 x 0.025	S-00922	✓	S-00973	
38	6.35	λ/10	5/3 x 0.025	S-00923	✓	S-00974	
38	9.5	λ/10	5/3 x 0.025	S-00924	✓	S-00975	
40	5	λ/10	5/3 x 0.025	S-00925	✓	S-00397	
45	2	λ/2	5/3 x 0.025	S-00926	✓	S-00976	
45	6.5	λ/10	5/3 x 0.025	S-00927	✓	S-00977	
50	1	λ	5/3 x 0.040	S-00734	✓	S-01115	
50	2	λ/2	5/3 x 0.040	S-00735	✓	S-00979	
50	3	λ/4	5/3 x 0.040	S-00237	✓	S-01116	
50	6.35	λ/10	5/3 x 0.040	S-00248	✓	S-00980	
50	9.5	λ/10	5/3 x 0.040	S-00021	✓	S-00981	
50	12.5	λ/10	5/3 x 0.040	S-00928	✓	S-00982	
60	9.5	λ/10	5/3 x 0.040	S-00929	✓	S-00983	
75	12.5	λ/10	5/3 x 0.063	S-00165	✓	S-00984	
80	12.5	λ/10	5/3 x 0.063	S-00930	✓	S-00985	
100	15	λ/10	5/3 x 0.063	S-00931	✓	S-00986	

✓ available from stock

+ also available with a superior polishing quality for lowest loss applications, see page 108



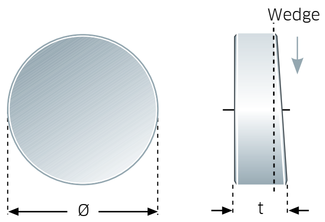
Tolerances

Diameter Ø:	+0.0/-0.1 mm
Thickness t:	±0.1 mm
Parallelism/Wedge:	< 5 min. of arc
Chamfer:	0.1-0.3 mm x 45°
Clear aperture:	> 80%

Surface imperfection tolerance: acc. to DIN ISO 10110-7

Other sizes and materials available on request.

Wedged windows 30’



Tolerances

Diameter Ø:	+0.0/−0.1 mm
Thickness t:	±0.1 mm
Parallelism/Wedge:	±5 min. of arc
Chamfer:	0.1–0.3 mm x 45°
Clear aperture:	> 80%

Surface imperfection tolerance:
acc. to DIN ISO 10110-7

Diam. Ø mm	Thickn. t mm	Wedge	Flatness λ (633 nm)	Surface imp.tol.	UV-FS Article-No.	Stock	IR-FS Article-No.	Stock
6	2	30’	λ/10	5/3 x 0.040	S-00987	✔		
12.7	3	30’	λ/10	5/3 x 0.040	S-00481	✔		
12.7	6.35	30’	λ/10	5/3 x 0.040	S-00015	✔	S-00992	✔
25	3	30’	λ/4	5/3 x 0.040	S-00012	✔		
25	6.35	30’	λ/10	5/3 x 0.040	S-00009	✔	S-00254	✔
38	6.35	30’	λ/10	5/3 x 0.040	S-00988	✔		
38	9.5	30’	λ/10	5/3 x 0.040	S-00989	✔		
50	6.35	30’	λ/10	5/3 x 0.040	S-00990	✔		
50	9.5	30’	λ/10	5/3 x 0.040	S-00991	✔		

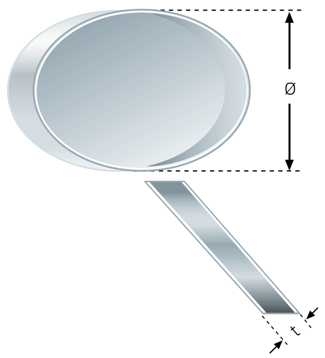
✔ available from stock

Large wedges 1°, 2°, 3°

Diam. Ø mm	Thickn. t mm	Wedge	Flatness λ (633 nm)	Surface imp.tol.	UV-FS Article-No.	Stock	IR-FS Article-No.	Stock
25	6.35	1°	λ/10	5/3 x 0.040	S-00031	✔		
25	6.35	2°	λ/10	5/3 x 0.040	S-00032	✔	S-01722	
25	6.35	3°	λ/10	5/3 x 0.040	S-01124	✔		
50	9.5	1°	λ/10	5/3 x 0.040	S-00993	✔		
50	9.5	2°	λ/10	5/3 x 0.040	S-00994	✔		

✔ available from stock

Elliptical windows 45° cut



Tolerances

Diameter Ø:	+0.0/−0.1 mm
Thickness t:	±0.1 mm
Parallelism/Wedge:	< 5 min. of arc
Chamfer:	0.1–0.3 mm x 45°
Clear aperture:	> 80%

Surface imperfection tolerance:
acc. to DIN ISO 10110-7

Elliptical windows, used as bending mirrors, deviate a beam at 90° and have an optimum cross section for circular beams. They are ideal for folded optical systems where dimensions or weight must be minimized.

Elliptical windows can be easily mounted in protection tubes. They are polished on both sides and can also be used as beam splitter substrates.

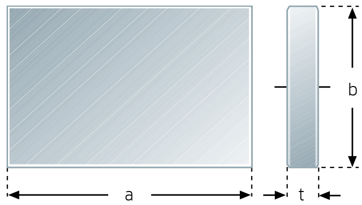
Diam. Ø mm	Thickness t mm	Flatness λ (633 nm)	Surface imp.tol.	UV-FS Article-No.	Stock
10	3	λ/10	5/3 x 0.025	S-01049	
12.7	5	λ/10	5/3 x 0.025	S-01050	✔
15	3	λ/10	5/3 x 0.025	S-01051	
25	3	λ/4	5/3 x 0.025	S-01052	✔
30	3	λ/4	5/3 x 0.025	S-01053	
38	5	λ/10	5/3 x 0.025	S-01054	✔
50	5	λ/4	5/3 x 0.040	S-00311	✔
75	8	λ/4	5/3 x 0.063	S-00410	✔

✔ available from stock

Rectangular windows

Length a mm	Width b mm	Thickness t mm	Flatness λ (633 nm)	Surface imp.tol.	UV-FS Article-No.	Stock
25	15	1.5	λ/4	5/3 x 0.040	S-01019	✓
25	15	3	λ/4	5/3 x 0.040	S-01020	✓
30	20	3	λ/4	5/3 x 0.040	S-01021	
35	25	3	λ/4	5/3 x 0.040	S-01022	✓
45	30	5	λ/10	5/3 x 0.040	S-01023	
50	27	1.5	2λ	5/3 x 0.040	S-00016	✓
50	27	3	λ/4	5/3 x 0.040	S-00171	✓
60	35	2	2λ	5/3 x 0.040	S-00017 *	✓
60	35	4	λ/4	5/3 x 0.040	S-00309	✓
60	35	5	λ/10	5/3 x 0.040	S-00867	✓
75	50	5	λ/4	5/3 x 0.040	S-00415	✓
105	75	8	λ/4	5/3 x 0.063	S-01024	
120	80	8	λ/4	5/3 x 0.063	S-00412	✓
150	100	8	λ/4	5/3 x 0.063	S-01025	

✓ available from stock



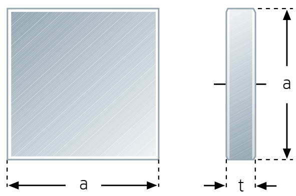
Tolerances

Length / width: +0.0/−0.1 mm (a < 105 mm)
+0.0/−0.2 mm (a ≥ 105 mm)
Thickness t: ±0.1 mm (t < 8 mm)
±0.2 mm (t ≥ 8 mm)
* +0.0/−0.2 mm for S-00017
Parallelism/Wedge: < 5 min. of arc
Chamfer: 0.1–0.3 mm x 45° (a < 105 mm)
0.4–0.6 mm x 45° (a ≥ 105 mm)
Clear aperture: > 80%
Surface imperfection tolerance:
acc. to DIN ISO 10110-7

Square windows

Length a mm	Width a mm	Thickness t mm	Flatness λ (633 nm)	Surface imp.tol.	UV-FS Article-No.	Stock
10	10	2	λ/10	5/3 x 0.025	S-00798	✓
12.7	12.7	3	λ/10	5/3 x 0.025	S-00173	✓
20	20	6	λ/10	5/3 x 0.025	S-01035	✓
25.4	25.4	6.35	λ/10	5/3 x 0.025	S-00859	✓
50	50	5	λ/4	5/3 x 0.040	S-01036	

✓ available from stock

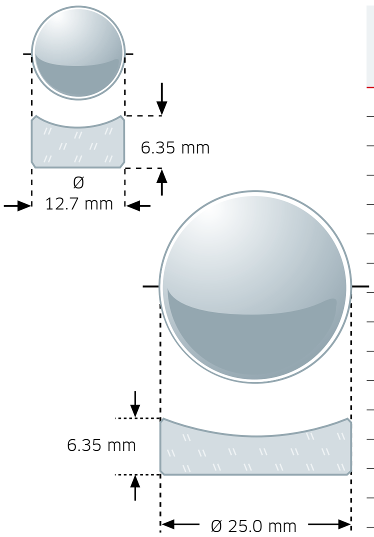


Tolerances

Length / width: +0.0/−0.1 mm
Thickness t: ±0.1 mm
Parallelism/Wedge: < 5 min. of arc
Chamfer: 0.1–0.3 mm x 45°
Clear aperture: > 80%
Surface imperfection tolerance:
acc. to DIN ISO 10110-7

Other sizes and materials available on request.

Plano-concave substrates



Radius	UV-FS Ø 12.7 x 6.35 mm Article-No.	Stock	UV-FS Ø 25 x 6.35 mm Article-No.	Stock
-10 mm	S-00126	✔	–	
-15 mm	S-00127	✔	–	
-18 mm	S-01061	✔	–	
-20 mm	S-00807	✔	–	
-25 mm	S-00128	✔	S-00069	✔
-30 mm	S-00513	✔ +	S-01078	✔
-38 mm	S-00554	✔	S-01079	✔
-50 mm	S-00129	✔ +	S-00070	✔
-75 mm	S-00130	✔	S-00207	✔
-100 mm	S-00131	✔ +	S-00071	✔
-150 mm	S-00132	✔ +	S-00044	✔
-200 mm	S-00133	✔ +	S-00072	✔
-250 mm	S-00134	✔ +	S-00073	✔
-300 mm	S-00135	✔ +	S-00074	✔ +
-350 mm	S-01062	✔	S-00075	✔
-400 mm	S-00136	✔ +	S-00076	✔ +
-500 mm	S-00137	✔ +	S-00077	✔ +
-600 mm	S-00864	✔	S-00041	✔
-750 mm	S-00138	✔	S-00061	✔
-1 m	S-00139	✔ +	S-00062	✔ +
-1.5 m	S-00140	✔	S-00063	✔ +
-2 m	S-00141	✔ +	S-00065	✔
-3 m	S-00142	✔	S-00064	✔
-4 m	S-01063	✔	S-00066	✔
-5 m	S-00143	✔	S-00067	✔
-6 m	S-01064	✔	S-00509	✔
-10 m	S-00144	✔	S-00068	✔
-15 m	S-01065	✔	S-01080	✔
-20 m	S-00860	✔	S-00745	✔

✔ available from stock

+ also available with a superior polishing quality for lowest loss applications, see page 108

Tolerances

Diameter Ø: +0.0/-0.1 mm
Thickness t: ±0.1 mm
Radius of curvature: ±1%
Centering/Wedge: < 5 min. of arc
Chamfer: 0.1–0.3 mm x 45°
Clear aperture: > 80%
Surface imperfection tolerance: 5/3 x 0.025

Our plano-concave substrates are polished on both sides and can be used ...

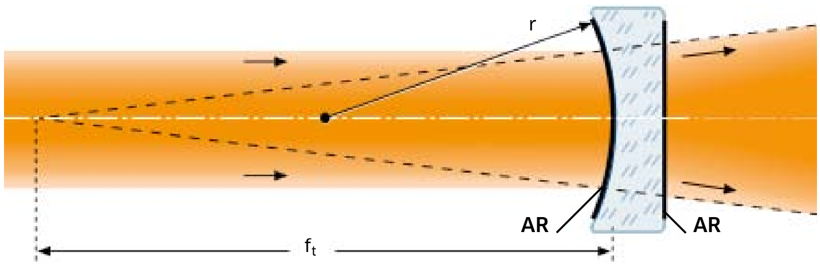
... in *transmission as diverging lenses* with the focal length

$$f_t = \frac{r}{(n-1)} \approx 2r$$

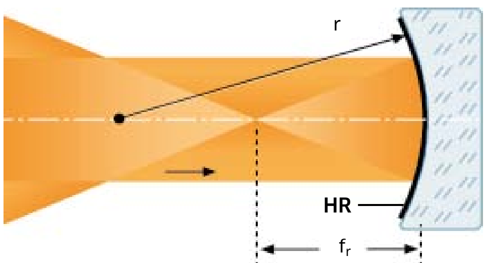
... with a *reflecting coating as focussing mirrors* with the focal length

$$f_r = \frac{r}{2}$$

Plano-concave lens



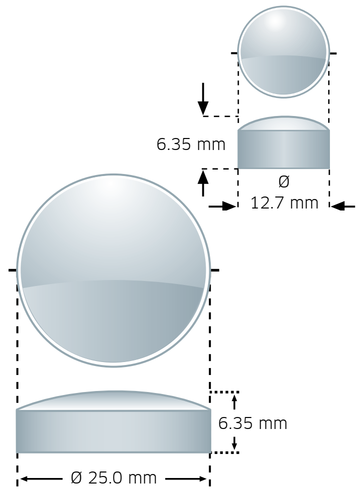
Plano-concave reflector



Plano-convex substrates

Radius	UV-FS Ø 12.7 x 6.35 mm Article-No.	Stock	UV-FS Ø 25 x 6.35 mm Article-No.	Stock
+25 mm	S-01142	✓	–	
+30 mm	S-01282	✓	–	
+38 mm	S-01283	✓	–	
+50 mm	S-01041	✓	S-00791	✓
+75 mm	S-01284	✓	S-00078	✓
+100 mm	S-01285	✓	S-00079	✓
+150 mm	S-01127	✓	S-01304	✓
+200 mm	S-01286	✓	S-00080	✓
+250 mm	S-00551	✓	S-00391	✓
+300 mm	S-00267	✓	S-01305	✓
+350 mm	S-01287	✓	S-01306	✓
+500 mm	S-00266	✓	S-00081	✓
+750 mm	S-01288	✓	S-00452	✓
+1 m	S-00552	✓	S-00453	✓
+1.5 m	S-01289	✓	S-00826	✓
+2 m	S-00553	✓	S-00373	✓
+3 m	S-01290	✓	S-00315	✓
+4 m	S-01291	✓	S-01307	✓
+5 m	S-01292	✓	S-01055	✓
+10 m	S-01293	✓	S-01308	✓

✓ available from stock



Tolerances

Diameter Ø: +0.0 / −0.1 mm
Thickness t: ±0.1 mm
Radius of curvature: ±1%
Centering/Wedge: < 5 min. of arc
Chamfer: 0.1–0.3 mm x 45°
Clear aperture: > 80%
Surface imperfection tolerance: 5/3 x 0.025

Our plano-convex substrates are polished on both sides and can be used …

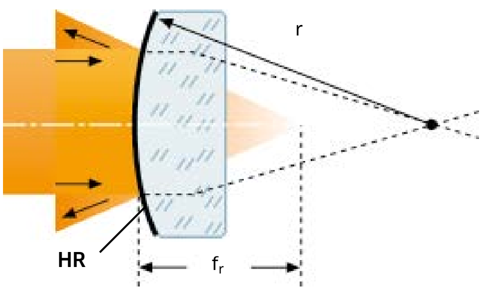
… with a *reflecting coating on the convex side as diverging mirrors* with the focal length

$$f_r = \frac{r}{2}$$

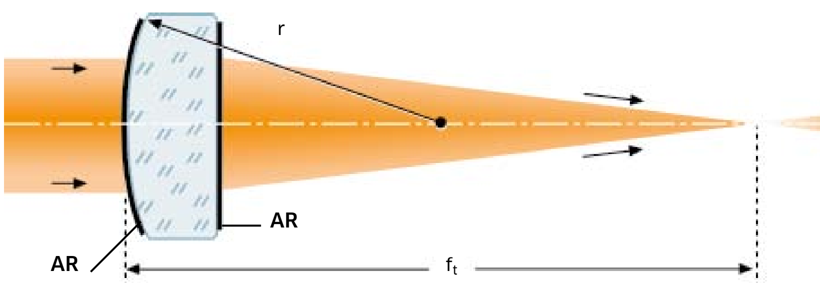
… in *transmission as focussing lenses* with the focal length

$$f_t = \frac{r}{(n-1)} \approx 2r$$

Plano-convex reflector

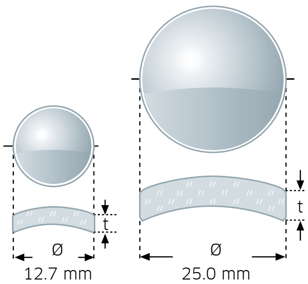


Plano-convex lens



Other sizes and materials available on request.

Zero lenses



Zero lenses have a convex and a concave side with the same radius of curvature: $r = r_1 = -r_2$. The transmitted beam has the very long focal length:

$$f_t \approx \frac{6r^2}{t}$$

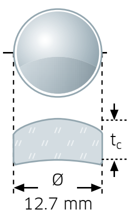
With additional plano-convex lenses, the transmitted and reflected beam can be focussed to the same point similar to cavity lenses.

Tolerances
Diameter Ø: +0.0/-0.1 mm
Thickness t: ±0.1 mm
Radius of curvature: ±1%
Centering/Wedge: < 5 min. of arc
Chamfer: 0.1-0.3 mm x 45°
Clear aperture: > 80%
Surface imperfection tolerance: 5/3 x 0.025

Radius $r_1 = -r_2$	UV-FS Ø 12.7 x 6.35 mm Article-No.	Stock	UV-FS Ø 25 x 6.35 mm Article-No.	Stock
30 mm	S-00304	✔	–	
38 mm	S-01083	✔	–	
50 mm	S-00597	✔	S-01088	✔
75 mm	S-00598	✔	S-01089	✔
100 mm	S-00599	✔	S-01090	✔
150 mm	S-00337	✔	S-00497	✔
200 mm	S-01084	✔	S-01091	✔
250 mm	S-00263	✔	S-01092	✔
300 mm	S-00276	✔	S-00493	✔
350 mm	S-00262	✔	S-00256	✔
500 mm	S-00261	✔	S-00257	✔
750 mm	S-00260	✔	S-00259	✔
1.5 m	S-01085	✔	S-01093	✔
2 m	S-01086	✔	S-01094	✔
5 m	S-01087	✔	S-01095	✔

✔ available from stock

Cavity lenses



Cavity lenses are positive meniscus lenses, designed for collinear pumping. Back focal length (BFL) is equal to the second radius of curvature:

$$BFL = r_2 = \frac{r_1 \cdot n}{n - 1} - t_c$$

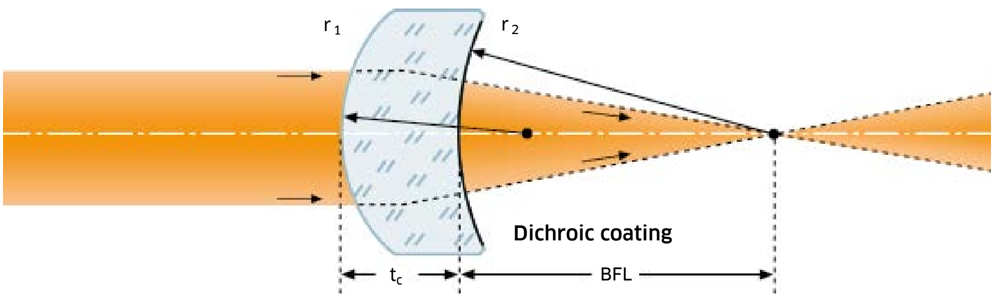
Cavity lenses are optically designed for 514 nm, but can be used in the range 200-2500 nm without significant differences.

Tolerances
Diameter Ø: +0.0/-0.1 mm
Thickness t: ±0.1 mm
Radius of curvature: ±1%
Centering/Wedge: < 5 min. of arc
Chamfer: 0.1-0.3 mm x 45°
Clear aperture: > 80%
Surface imperfection tolerance: 5/3 x 0.025

Radius r_2 = BFL	UV-FS Ø 12.7 x 6.35 mm Article-No.	Stock
18 mm	S-01333	✔
25 mm	S-01601	✔
38 mm	S-01602	✔
50 mm	S-01334	✔
75 mm	S-01603	✔
100 mm	S-01604	✔
150 mm	S-01605	✔
200 mm	S-01606	✔
250 mm	S-01607	✔
350 mm	S-01608	✔
500 mm	S-01609	✔

✔ available from stock

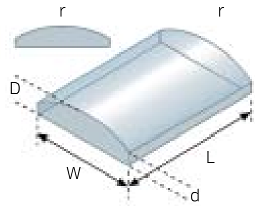
Cavity lens

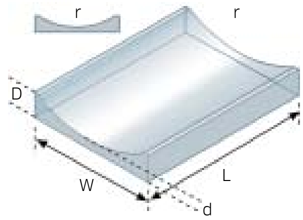


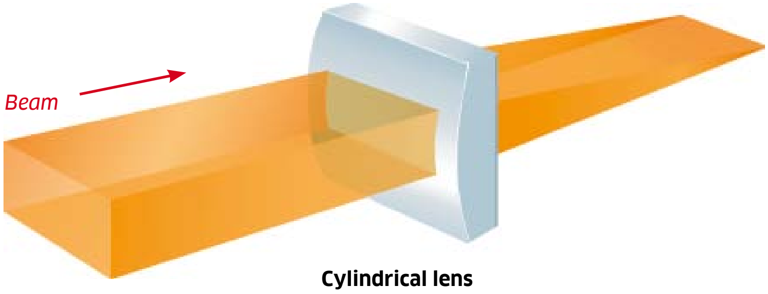
Cylindrical lenses

We offer a large range of cylindrical lenses and achromates with diverse surfaces, e.g.
- plane/bi-convex,
- plane/bi-concave,
- toric and crossed (anamorphotic) types.

These can be produced in economically adequate lot quantities on customer demand in all common Fused Silica, CaF_2, MgF_2 and other optical glasses.





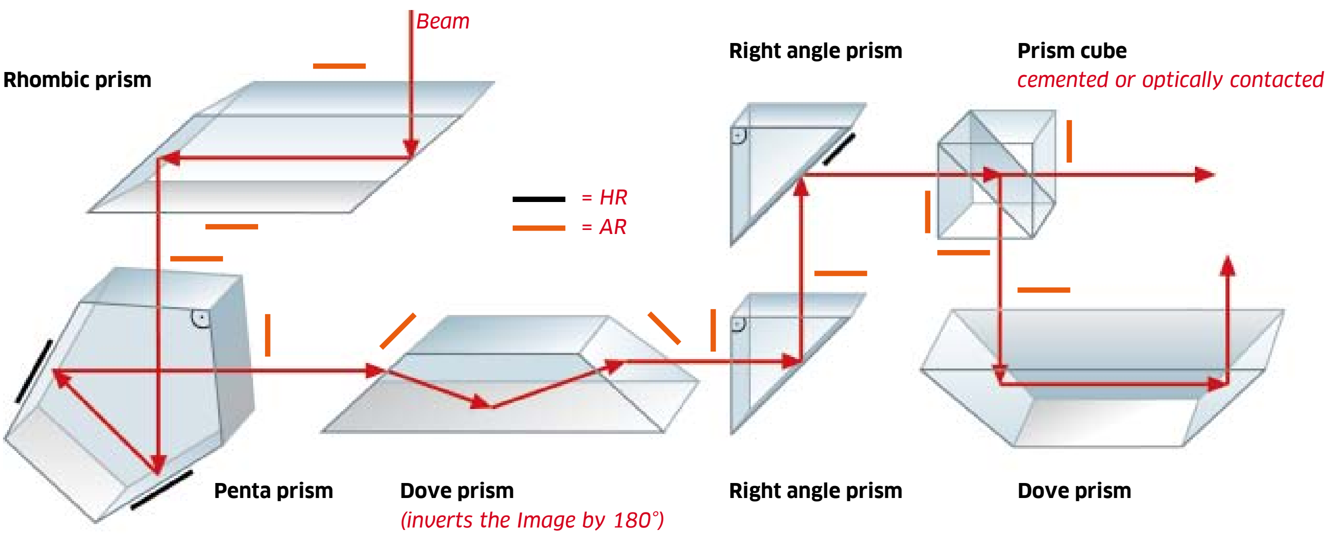


Cylindrical lens

Prisms

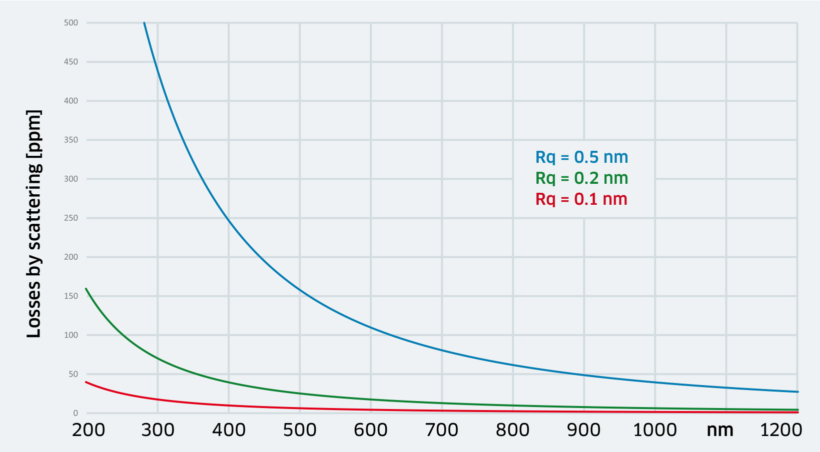
LASEROPTIK offers a broad variety of prisms and prism cubes on customer demand in economically adequate lot quantities and all common Fused Silica, CaF_2, MgF_2 and other optical glasses.

Dielectric beam splitter coatings, high reflection systems and antireflection layers as well as metallic layers are available upon your request.

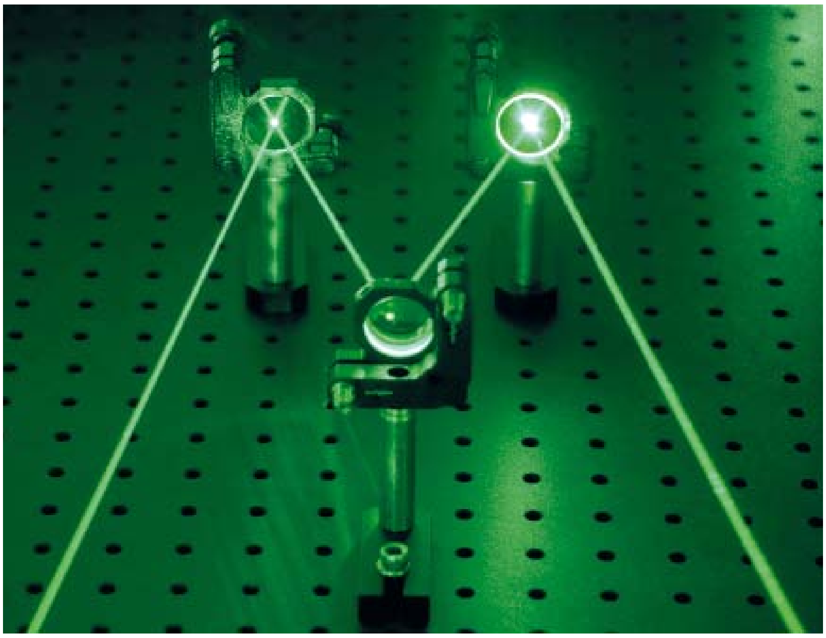


Other sizes and materials available on request.

Premium and super-polished substrates



Total back scattering TSB of a mirror, calculated for several surface roughness



Same coating on substrates with different surface roughness

For low loss applications like laser gyroscope or resonators with the highest finesse you need mirrors with lowest scattering. Besides using the optimum coating technique (IBS, see page 78) the choice of the substrates becomes more important, too.

All our substrates as listed on the previous pages have a high quality but for the named applications you need substrates with a superior polishing quality, in particular with the lowest possible roughness and surface form errors.

The diagram shows how the scattering will increase due to increasing surface roughness, depending on the wavelength used. A standard polished surface will have a roughness of about 0.5 nm (RMS).

At 532 nm the differences are visible with the naked eye. The substrates in the picture are coated in the same run but have different amounts of surface roughness. The right optic uses a standard substrate (Rq = 0.5 nm), the left one a super-polished one (Rq < 0.1nm).

As you can see, the scattering on the super-polished substrate is significantly reduced.

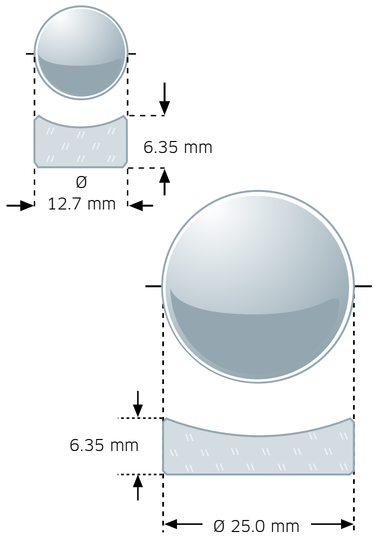
To ensure the lowest possible scattering for our IBS coatings LASEROPTIK offers two classes of substrates with optimized roughness:
Premium: Rq < 0.2 nm
Super-polished: Rq < 0.1 nm

The measured roughness value does of course depend on the technical set-up of the device, like the magnification or field of view. For a better comparison LASEROPTIK specifies the scan length, for the following items the RMS-roughness Rq is measured with 0.3 µm – 1 mm (resolution – scan length).

Premium (Rq < 0.2 nm)

Radius	UV-FS Ø 12.7 x 6.35 mm Article-No.	Stock	UV-FS Ø 25 x 6.35 mm Article-No.	Stock
plano	S-08458	✔	S-08457	✔
-30 mm	S-08449	✔	–	
-50 mm	S-08444	✔	–	
-100 mm	S-08442	✔	–	
-150 mm	S-08447	✔	–	
-200 mm	S-08443	✔	–	
-250 mm	S-08451	✔	–	
-300 mm	S-08448	✔	S-08454	✔
-400 mm	S-08446	✔	S-08453	✔
-500 mm	S-08441	✔	S-08456	✔
-1000 mm	S-08450	✔	S-08455	✔
-1500 mm	S-09959		S-08452	✔
-2000 mm	S-08445	✔	S-09960	

✔ available from stock



Super-polished (Rq < 0.1 nm)

Radius	UV-FS Ø 12.7 x 6.35 mm Article-No.	Stock	UV-FS Ø 25 x 6.35 mm Article-No.	Stock
plano	S-09965	✔	S-09966	✔
-500 mm	S-09961	✔	S-09962	
-1000 mm	S-09963		S-09964	✔

✔ available from stock

Tolerances

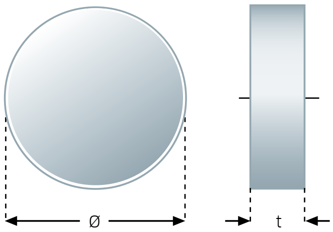
Diameter Ø: +0.0/-0.1 mm
Thickness t: ±0.1 mm
Flatness: 3/0.1 (0.1/0.05) compares to λ/20
Radius of curvature: ±1%
Centering/Wedge: < 5 min. of arc
Chamfer: 0.1-0.3 mm x 45°
Clear aperture: > 80%
Surface imperfection tolerance: 5/3 x 0.025

Quality can be inspected by our inhouse test equipment (for more information see page 118):

Optical profiler (Zygo NewView 9000)

Automated roughness testing

Laser testing lab



Tolerances

Diameter Ø:	+0.0/-0.1 mm
Thickness t:	±0.1 mm
Chamfer:	0.1-0.3 mm x 45°
Clear aperture:	> 80%

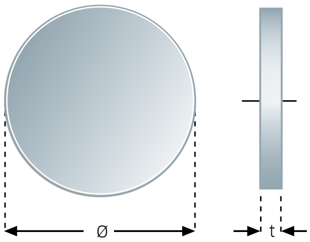
Surface imperfection tolerance:
acc. to DIN ISO 10110-7

Plane-parallels, wedge < 10"

Diameter Ø mm	Thickness t mm	Wedge Parallelism	Flatness λ (633 nm)	Surface imp.tol.	UV-FS Article-No.	Stock
25	6.35	<10"	λ/10	5/3 x 0.040	S-01015	✔
50	9.5	<10"	λ/10	5/3 x 0.040	S-01016	✔

✔ available from stock

Etalons, wedge < 0.2"



25.0 mm

Tolerances

Diameter Ø:	+0.0/-0.1 mm
Thickness t:	±20% (< 0.3 mm) ±5% (≥ 0.3 mm) ±0.1 mm (≥ 2 mm)
Chamfer:	0.1-0.3 mm x 45° (for t > 0.5 mm)
Clear aperture:	Ø 20 mm

Surface imperfection tolerance:
acc. to DIN ISO 10110-7

Fabry-Perot etalons are extremely narrow line width filters with a series of sharp transmission peaks, separated by the free spectral range (FSR). FSR depends only on the optical thickness of the etalons, whereas the finesse (F) is determined not only by the reflectivity of the coatings, but mainly by surface quality, parallelism, homogeneity of the substrate material and defect-free coatings. Solid etalons can be tuned by tilting and by temperature change.

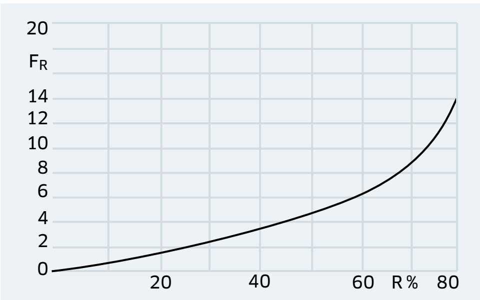
If a minimum resolvable resolution Δλ is needed, the reflectivity finesse F_R can be calculated with

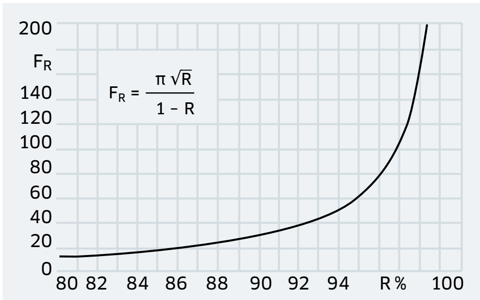
$$F_R = \frac{FSR}{\Delta\lambda} = \frac{\pi\sqrt{R}}{1 - R}$$

The final finesse of the etalon is in most cases limited by the flatness finesse F_F (flatness of λ/20 gives F_F = 20) for beam diameter 20 mm. With thinner beams F_F can grow to > 200. Pairs of etalons in series may be used to obtain ultra high resolution combined with a very long FSR. The resulting finesse of such a combination can be one order of magnitude higher.

Besides lower costs, solid etalons offer the following advantages over air spaced etalons for intracavity use:

- higher transmission
- lower size
- harder coatings with
- higher damage threshold





Please specify thickness, center wavelength and reflectivity in your order.

Please contact LASEROPTIK to discuss your specific requirements.

Diam. Ø mm	Thickn. t mm	Wedge Parallelism	Flatness λ (633 nm)	Surface imp.tol.	Suprasil 311 Article-No.	Stock	FSR nm @ 633 nm	FSR GHz
25	0.1	<0.2"	λ/20 in T	5/3 x 0.040	S-00209	✔	1.38	1000
25	0.2	<0.2"	λ/20 in T	5/3 x 0.040	S-00185	✔	0.69	500
25	0.3	<0.2"	λ/20 in T	5/3 x 0.040	S-00740		0.46	330
25	0.5	<0.2"	λ/20 in T	5/3 x 0.040	S-00353	✔	0.28	200
25	1	<0.2"	λ/20 in T	5/3 x 0.040	S-01001		0.14	100
25	2	<0.2"	λ/20 in T	5/3 x 0.040	S-00932		0.069	50
25	3	<0.2"	λ/20 in T	5/3 x 0.040	S-00933		0.046	33
25	4	<0.2"	λ/20 in T	5/3 x 0.040	S-00029	✔	0.034	25
25	5	<0.2"	λ/20 in T	5/3 x 0.040	S-00206		0.028	20
25	6.35	<0.2"	λ/20	5/3 x 0.040	S-00934		0.022	16
25	10	<0.2"	λ/20	5/3 x 0.040	S-00754	✔	0.014	10
25	20	<0.2"	λ/20	5/3 x 0.040	S-00495		0.007	5

✔ available from stock

CaF_2 substrates

Length a mm	Width b mm	Thickness t mm	Surface imp. tol.	157 nm Article-No.	Stock	193 nm Article-No.	Stock	248 nm Article-No.	Stock	VIS/IR Article-No.	Stock
50	27	2	5/3 x 0.040	S-00728		S-00195	✓	S-01636		S-00333	✓
60	35	2	5/3 x 0.040	S-00562	✓	S-00194	✓	S-01637	✓	S-00334	✓

Diameter Ø mm	Thickness t mm	Surface imp. tol.	157 nm Article-No.	Stock	193 nm Article-No.	Stock	248 nm Article-No.	Stock	VIS/IR Article-No.	Stock
12.7	3	5/3 x 0.063	S-01638		S-00653	✓	S-01639		S-01640	✓
25	6.35	5/3 x 0.063	S-00374		S-00748	✓	S-01641		S-00169	✓
38	6.35	5/3 x 0.063	S-01642		S-01643	✓	S-01644		S-00753	
50	9.5	5/3 x 0.10	S-01645		S-01221		S-01646		S-01647	✓

✓ available from stock

Transmission diagram of CaF_2 substrates see page 96.

Tolerances CaF_2

Length/Width: +0.0/−0.1 mm
Thickness t: ±0.1 mm
Parallelism/Wedge: < 5 min. of arc
Chamfer: 0.1–0.3 mm x 45° (for t > 0.5 mm)
Clear aperture: > 80%
Flatn. round substr.: λ/4
Flatn. rectang. substr.: λ/2
Surface imperfection tolerance: acc. to DIN ISO 10110-7

MgF_2 substrates

Diam. Ø mm	Thickn. t mm	Flatness λ (633 nm)	Surface imp.tol.	VUV-MgF2 Article-No.	Stock
12.7	3	λ/4	5/3 x 0.063	S-01648	
25	6.35	λ/4	5/3 x 0.063	S-00046	
38	6.35	λ/4	5/3 x 0.063	S-01649	
50	9.5	λ/4	5/3 x 0.10	S-01650	

✓ available from stock

Transmission diagram of MgF_2 substrates see page 96.

ZnSe substrates

Diam. Ø mm	Thickn. t mm	Flatness λ (633 nm)	Surface imp.tol.	ZnSe Article-No.	Stock
25.4	3	λ/4	5/3 x 0.063	S-00271	✓
25.4	6.35	λ/4	5/3 x 0.063	S-01692	✓
38.1	5	λ/4	5/3 x 0.063	S-01693	
50.8	6.35	λ/4	5/3 x 0.10	S-00387	

✓ available from stock

Transmission diagram of ZnSe substrates see page 97.

Sapphire substrates

Diam. Ø mm	Thickn. t mm	Flatness λ (633 nm)	Surface imp.tol.	Sapphire Article-No.	Stock
12.7	3	λ/10	5/3 x 0.063	S-00469	
25.4	3	λ/4	5/3 x 0.063	S-01630	✓

✓ available from stock

Transmission diagram of Sapphire substrates see page 95.

Undoped YAG substrates

Diam. Ø mm	Thickn. t mm	Flatness λ (633 nm)	Surface imp.tol.	undoped YAG Article-No.	Stock
12.7	3	λ/4	5/3 x 0.063	S-01479	✓
25.4	3	λ/4	5/3 x 0.063	S-00876	✓

✓ available from stock

Transmission diagram of YAG substrates see page 95.

Tolerances
MgF_2, ZnSe, Sapphire, undoped YAG

Diameter: +0.0/−0.1 mm
Thickness t: ±0.1 mm
Parallelism/Wedge: < 5 min. of arc
Chamfer: 0.1–0.3 mm x 45°
Clear aperture: > 80%
Surface imperfection tolerance: acc. to DIN ISO 10110-7

Other sizes and materials available on request.

About us

Production flow
Substrate cleaning
Measuring methods
History
Appendix

Production flow

Ordering from stock

Inquiry & quotation
before ordering

Customer gets into contact with our experts

- by phone, fax, e-mail *cover III*
- by LOOP (LASEROPTIK Online Portal) *page 5*

+ choose or calculate design according to customer's needs *page 21*
+ choose suitable substrates *page 90*
+ need faster turnaround, use LASEROPTIK EXPRESS *page 4*

→ *send quotation including computed curve*

Order scheduling
after ordering

Draw up process control quality plan for every order

- guides the order to every production step
- includes all nessecary information

+ schedule runs on coating machine
+ commission substrates
+ commission substrate holders

→ *send formal order confirmation*

Pre-production
between ordering and coating

Check availability of

- substrates and holders
- coating materials

+ fit machine parameters to coating design
+ check if customer-owned substrates will arrive two weeks before coating date

→ *reschedule if customer-owned substrates are delayed*

Substrates cleaning
immediately before coating

Clean substrates *page 116*

- 100% inspection under stereomicroscope

+ substrates can be supplied by LASEROPTIK and/or by customer *page 100*

→ *if customer owned substrates have unusual defects, we ask for exceptional approval*

Coating process

Different coating techniques are available
page 20

- in-situ measurement of optical and/or physical thickness
- post coating treatment

+ takes up to 1.5 hours for reaching temperature and high vacuum
+ coating time varies from 5 min. (single AR) to over 36 hours (IBS filters)

Measurement
after coating

Normally witness samples are used for measurements

- to avoid damaging of the substrates
- samples have similar refractive index and matching size for the measurement setup

+ standard measurement by spectrometer
+ more measurement tools are available

page 118

Final inspection
before shipping

100% inspection under stereomicroscope

- special inspections after customer's specification are possible

+ dust-free packaging in flowbox / cleanroom
+ every optic is marked directly or on its packaging

Shipping

Working with all standard delivery services

- best on customer's international account number
- faster shipment can be arranged at additional costs

+ extra soft wrap for a secure transport
+ including invoice and measured curves

LASEROPTIK is ISO:9001-certified since 1998

Substrate cleaning

The quality of the coatings is a critical point in the production of high power laser components. And that quality starts with the cleaning of the substrates before coating, to eliminate all possible contamination.

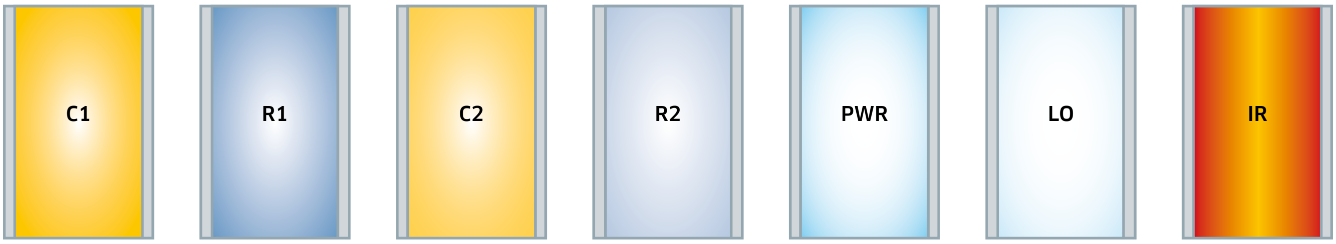
At LASEROPTIK all suitable substrates are automatically cleaned in one of three available multi chamber ultrasonic cleaning lines.

A robot system moves the substrates automatically, following identical process steps. The total process takes 30 to 50 minutes.

If substrates are not suited for automatic cleaning (for example hygroscopic material), they are manually cleaned under laminar flow conditions. This process is similar to the one described on the next page, „Cleaning of coated optics“.

Both, substrate cleaning and coatings are performed in well maintained cleanrooms. In any case cleaned substrates are inspected for 100% under a stereomicroscope before mounting them into the substrate holders and fixing them in the coating machine immediately afterwards.

Cleaning line process



1. Cleaning with ultrasonic (generators for 40/80 kHz). Power and duration are varied due to the needs of the material to clean and its condition. Used detergents are alkalescent.

2. The cleaning goods are rinsed with reverse osmosis (RO) water.

3. Repeat step 1.

4. Repeat step 2.

5. Pure water rinse with DI water (de-ionized), produced in circulating systems. Lift-out, slowly lifting out of the DI water to guarantee residue-free drying.

6. Final drying by IR-radiation.

Cleaning of coated optics

We recommend to clean coated optics with clean air only. If the surface is very dirty you can try the following steps:

1) Blow off the optic with clean air or nitrogen to remove particles.

2) Fold cleaning tissue (like lens cleaning tissue Whatman 105) or microfiber cloth (Toraysee MK14.5H) into a suitable form according to the size of the surface to be cleaned.

3) Moisten the tissue or cloth with recommended solvents like isopropanol or ethanol.

4) Clean the coated surface with uniform circular movements and low pressure. Coated optics produced by IAD, IP, MS and IBS can normally resist some more pressure.

5) The removal of the tissue or cloth from the coated surface should be straight and without any pressure.

6) Check the cleaning results with a bright light source and/or under a microscope.

7) Repeat the cleaning processes if the optic is still dirty.

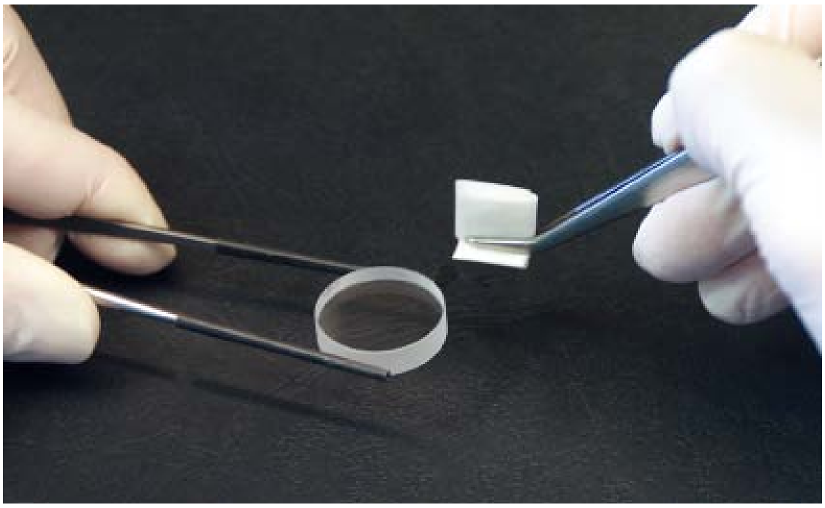
Please note the following:

- To avoid fingerprints use powder free clean gloves (latex, nitrile).
- If you use tweezers to hold the substrate use tweezers with protected tips (e.g. rubber or cork).
- When cleaning small optics hold the folded tissue or cloth with clamp tweezers.
- Change the tissue or cloth as often as possible.

This cleaning recommendation refers to optics which are coated with metal oxide layers and/or with a protective layer.

For more information about cleaning of coated optics please contact us. We can assist you even on the phone.

Ultrasonic cleaning line for substrates in cleanroom environment



Cleaning manually

Measuring methods for laser optics

LASEROPTIK has nearly 40 years of experience with high quality coatings. During these years we collected valuable knowledge about the properties of our optics from the best laboratories we could find: the experiences and feedbacks of our customers.

Additionally, we developed new coating techniques, measurement devices and improved coating materials in co-operation with research partners like Laser Zentrum Hannover e.V. (LZH), Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) in Jena or Institut für Nanophotonik Göttingen e.V. (IFNANO, formerly LLG).

To guarantee stable high quality of our optics LASEROPTIK owns a wide range of measuring equipment:

OPTICAL SURFACE INSPECTION

Uncoated and coated optics are inspected with standard OLYMPUS microscopes, ZEISS differential interference contrast microscopes and for larger surfaces with a Keyence flexible microscope. For automated surface characterization we use an Argos 200.

Zeiss differential interference contrast microscope

Argos 200

Keyence flexible microscope

SURFACE ROUGHNESS

For the production of low loss components it is necessary to quantify the surface roughness. This rms-value is measured by a Zygo NewView 9000 white light interferometer. The measuring sensitivity goes below 0.1 nm rms.

Zygo NewView 9000

THIN FILM STRESS

For many applications it is important to know exactly the thin film stress, respectively to compensate for the bending of the optics due to this stress. LASEROPTIK uses an in-situ stress measurement system and interferometric measurements for the quantification of the induced stress.

FOCAL LENGTH AND WEDGE

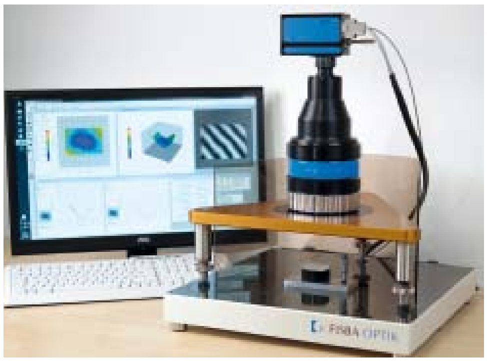
Optical standard parameters like effective focal length (EFL), back focal length (BFL), radius of curvature or centering errors are inspected using an OptiSpheric®. Radii of 5 mm up to 500 mm and centering errors in the range of 10" to 5' can be detected. Additionally it is possible to measure wedges from 10" to 1.5°.

OptiSpheric 1000 AF

FLATNESS

To check the accuracy of the surface, we use an interferometer with a measuring wavelength of 632.8 nm and a Zygo Verifire MST with a measuring wavelength of 1053 nm. 12" is possible as the maximum aperture. These devices can measure flatness up to λ/20 at room temperature. The flatness can be measured in transmission and reflection according to ISO 10110.

Zygo Verifire MST



Interferometer for smaller optics

REFLECTANCE AND TRANSMITTANCE

The most important quality tool in optical thin film production is the spectrophotometer. LASER-OPTIK uses different types to measure transmittance respectively reflectance from vacuum-UV (120 nm) to infrared up to 50 µm. Besides a VUV-spectrometer built by LZH we mainly use PERKIN-ELMER spectrometers (Lambda 19/883/900/950/1050/ Frontier Optica). To give the coating engineers always a prompt access to a spectrometer for getting a fast feedback on the current production processes we provide one spectrometer for every two coating machines.

PERKIN-ELMER spectrometers

GROUP DELAY (GD) AND GROUP DELAY DISPERSION (GDD)

For ultrafast optics used with femtosecond pulsed lasers, the control of the phase respectively the group delay and group delay dispersion of the coatings is of great importance. We employ a custom built white-light interferometer as well as commercial systems to benefit from a wide range of dispersion measurements covering the UV up to the mid infrared.

Measurements can be performed in a wavelength range from 350–2400 nm, with an angle of incidence 0–60° and for both polarizations simultaneously. It is possible to measure single mirrors as well as mirror pairs.

Custom-built white light interferometer

CAVITY RING-DOWN (CRD)
The accuracy of reflectance measurements with spectrophotometers is limited. Therefore, a cavity ring-down setup is employed to measure high reflectance for the wavelengths 635 nm and 1064 nm.

By analyzing the power decay in the cavity, reflectance can be measured in a range from 99.5 to 99.999%. Typical application examples for cavity ring-down measurement are low-loss mirrors.

Cavity ring-down setup

ENVIRONMENTAL TESTING
A climate chamber and other equipment (e.g. abrasion-test-set) for environmental testing enable us to deliver optics fully certified for customer applications according to MIL and ISO standards.

Climate chamber and abrasion-test-set

SCATTERING
Forward and backward scattering can be detected in the wavelength range from 190–800 nm by a custom-made measuring device based on a Coblentz sphere. We also offer external qualifications at the IOF or LZH.

ABSORPTION AND LASER INDUCED DAMAGE THRESHOLD (LIDT)
Absorption measurements allow us to constantly verify and improve the quality of our coatings. Our in-house measurement capabilities cover the irradiation wavelengths 308 nm, 355 nm, 532 nm and 1064 nm.

Absorption measurement

Moreover, LASEROPTIK benefits from a long-standing cooperation with domestic and international partners for characterizing optical components. The most important measurements are laser damage threshold (LIDT according to ISO 21254), optical losses, i.e. absorptance (ISO 11551) and scattering (ISO 13696).

To produce high power optics you have to consider the different mechanisms of laser induced damages and the influences of the substrates and coating materials. Therefore we would like to provide some background information on the following pages.

Customized product qualification

We develop and offer customized solutions for the verification of product specifications and further demands.

Laser Induced Damage Threshold (LIDT)

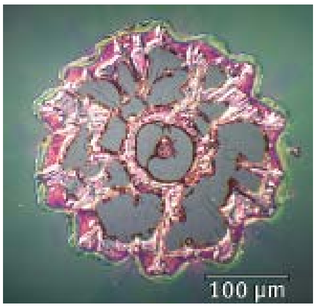


Figure 1: Absorption induced melting

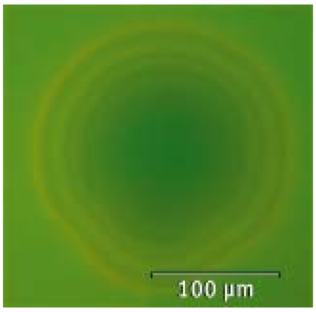


Figure 2: Absorption induced recrystallization

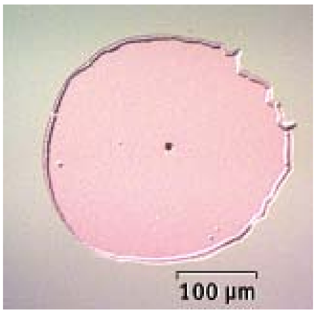


Figure 3: Absorption induced stress

The Laser Induced Damage Threshold (LIDT) of optical components is a critical quality parameter for laser systems and their applications operated at high power levels. Historically optical materials could be optimized to excellent quality as well as power handling capability, and consequently, the problem of laser induced damage shifted from the bulk to the surface of the optical component during the last decades.

During production the optical surface is objected to various influences, which modify its structure and composition. However the thin film coating system, which is deposited onto the optical surface to adapt its reflectance and transmittance to the application, contributes predominantly to the reduction of the LIDT-values. It is considered the most critical element in the development of high power laser components.

The following contains a short overview of some major aspects of laser damage in optics including a summary of the observed damage mechanisms in thin films, an introduction into LIDT measurements according to the recent ISO-Standard series, and a few remarks concerning scaling of LIDT values.

Laser damage mechanisms

Laser damage in optical coatings may be initiated and driven by a variety of interactions of matter with radiation. In many cases optical absorption processes couple thermal energy into the coating structure under irradiation and cause a sharp increase of temperature until a catastrophic failure by mechanical disruption or overheating occurs. A typical damage site attributed to such an absorption induced coating failure is depicted in *Figure 1*.

In this example the laser induced temperature rise was sufficient to reach the melting point of the material leading to an evaporation of coating material and a change in its crystalline structure. If laser power densities slightly exceed the damage threshold of the material, you often can observe discoloration or increased surface roughness in the center of the laser beam and no removal of material *(s. Fig. 2)*.

Thermal expansion driven by laser induced heating may also result in a mechanical stress level exceeding the adhesion strength of the coating to the substrate. Corresponding typical damage morphologies clearly indicate a delamination of layers from the surface of the optical component in the center of the laser beam area *(s. Fig. 3)*.

These damaging effects are results of instantaneous heating of the coating material in the area of interaction with the laser beam. This can be modeled on the basis of adapted heat diffusion equations and corresponding boundary conditions. For the temperature rise (ΔT) in the center of an irradiated circular component and a Gaussian beam profile with power (P) a first order expression can be derived:

Equation (1)

$$\Delta T = \frac{2\beta_s P}{\pi^{3/2} k w} \tan^{-1}\left(\frac{16\kappa t_l}{w^2}\right)^{1/2}$$

Obviously, the temperature rise is dependent on the thermal properties (k: thermal conductivity, κ: thermal diffusivity), on the surface absorption of the component (β_s), and on the beam diameter (w).

For long irradiation times t_l compared to the typical heat diffusion time w^2/κ equation (1) can be reduced to the following asymptotic approximation:

Equation (2)

$$\Delta T \rightarrow \frac{\beta_s P}{\pi^{1/2} k w} \qquad t_l \rightarrow \infty$$

This asymptotic behavior applies to long irradiation times or cw-operation of the laser. In contrast to this, the short pulse regime is represented by the first equation.

For damages dominated by absorption the following can be stated:

- short pulses: LIDT ~ power density P/w^2
- long irradiation times or cw: LIDT ~ linear power density P/w

In practice absorption induced damage of laser components is occasionally observed in coating materials for the DUV/VUV-wavelengths and in the MIR-range.

For the VIS- and NIR-spectral range modern optical coating production processes have been developed resulting in extremely small absorption losses. For these layer systems laser damage is dominated by defects which are embedded in the layer structure and which possess a significantly higher absorption than the surrounding layer material. Under laser irradiation, these absorbing defects heat up much faster than the surrounding material and explode removing the covering layer structure. A typical damage site of such a defect or inclusion dominated damage is characterized by small craters in the beam area *(s. Fig. 5)*.

Since the specific optical, thermal and geometric properties of the defects are usually not known in detail, a theoretical description of defect induced damage can only provide trends in the scaling of damage with laser parameters and the material properties. Precise modelling is even more complicated by the statistical distribution of defects in size and physical properties demanding for defect characterization techniques with extremely high sensitivity down to the nm-scale on the experimental side.

Defect induced breakdown is the type of damage predominantly observed for most laser operation regimes. It is still a topic of intensiv research in laser damage as well as in the development of deposition processes with reduced defect generation.

Besides thermal effects, direct electronic excitation may be considered as driving mechanism for short pulse laser damage. These types of dielectric breakdown mechanisms moved into the focus of research after ultrashort pulse lasers with high output power could be developed. The excitation of electrons into the conduction band of a dielectric material by multiphoton processes becomes more probable at the extremely high power densities of pulses with durations in the ps- and fs-range. These electrons can contribute to a further increase of the free electron density in the conduction band via a stepwise excitation to higher energy levels and a subsequent relaxation with energy transfer to a valence band electron to perform a transition to the conduction band (Avalanche effect).

In this model, damage occurs at a critical electron density in the conduction band in the range of a few 10^{21} $1/cm^3$. After reaching this state, laser radiation is instantly coupled into the free electron plasma leading to catastrophic damage of the material. During the last decade, theoretical models describing damage in the ultrashort pulse regime have been developed to a state which allows the forecast of the damage behavior as a function of the electronic properties of the involved dielectrics. In many practical applications a variety of additional influences may also impair the power handling capability of a laser component.

Weak points are improper handling and cleaning as well as contamination of the coated surfaces. Under special environmental conditions, the laser radiation may even induce the growth of contamination on the optics via transportation effects or photochemical reactions and initiate laser damage by increased surface absorption. Voids, grooves, pores or scratches on the optical surface also reduce the damage threshold of the optical element, because they act as concentrators for the electric field.

To avoid laser induced damages:

- Use the right substrates with low absorption, low water content and good polishing if necessary.
- LASEROPTIK uses the best fitting coating materials and coating techniques (low absorption, low defects and best electronic properties) for your applications. And we produce under cleanroom conditions.
- Handle coated optics with care and in appropriate environmental conditions.

Measurement of LIDT-values

After long technical discussion, extending over more than ten years, the standard series ISO 11254 for the measurement of LIDT-values had been published in the time period from 2000 to 2006. In view of new developments in laser technology this standard was revised and is now published as a new series, ISO 21254.
Besides the measurement protocols and data evaluation procedures for damage testing with single pulse and multiple pulses described in the first three parts, this revised standard series also contains an ISO Technical Report on damage detection in modern measurement facilities. The basic arrangement of a damage test facility according to ISO 21254 is illustrated in *Figure 6*.

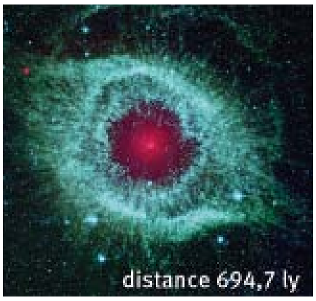


Figure 4: Helix nebula, infrared, Spitzer Space Telescope, NASA

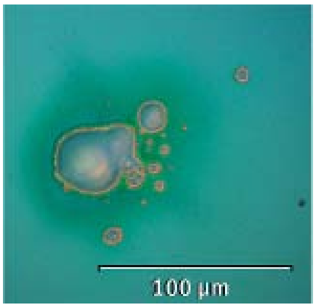


Figure 5: Defect induced damage

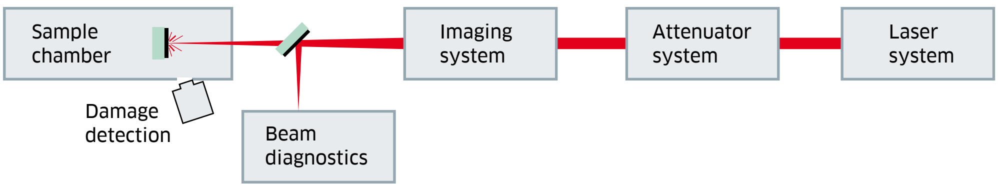


Figure 6: Fundamental setup for the measurement of laser induced damage thresholds.

Operating as the central element in transversal and longitudinal single mode, the test laser source is used with its beam parameters precisely monitored by a beam diagnostic system. The spatial and temporal profile as well as the energy of the laser radiation in the target plane are recorded with the diagnostic system and evaluated in respect to the error budget of the measurement.

To induce damage of a component an optical imaging system concentrates the laser radiation on a sample surface within a well-defined spot of sufficiently high energy density. To tune the laser fluence in the target plane an adjustable attenuator is installed between the laser source and the imaging device. A positioning system moves the test sites on the sample surface into the test beam. Normally this process is controlled by a computer that, in modern laser damage facilities, at the same time also controls the complete measurement procedure.

In the classical so-called 1 on 1-testing procedure, each test site is exposed only one time to a single laser pulse. The complete 1 on 1-measurement protocol consists of multiple irradiation cycles with pulses of different energies, covering specific low fluence values without damage and high values always causing damage.

After the irradiation sequence, the specimen is inspected in respect to the damage state of the individual sites by Nomarski interference contrast microscopy, which is the standard routine according to ISO 21254, or any other highly resolving surface measurement technique with similar sensitivity. The resulting raw data of the test routine comprises of a set of fluence values with assigned damage states.

For the presentation of the final result, the damage probability as the ratio of the number of damaged sites to the total number of sites exposed is calculated for a representative series of fluence values. Subsequently, these damage probability values are plotted as a function of fluence representing the final result of the test. An example for such a diagram, which is often called the survival curve of the optical component, is illustrated in *Figure 7*.

The damage threshold is given as the highest quantity of laser radiation for which the extrapolated probability of damage is zero. Even though today 1 on 1-thresholds are mainly of academic interest and of limited importance for practical applications they are still listed in many catalogues of optics manufacturers. A more realistic scenario is simulated in S on 1-tests involving an extended irradiation of the sample with a series of pulses. The test is performed similar to the 1 on 1-protocol with the exception that each test site is exposed to a train of a defined number S of identical pulses of preselected laser fluence. In this test procedure damage can actually occur before delivery of the complete train of pulses to a site.

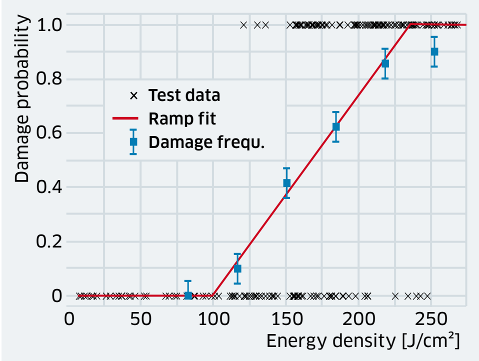


Figure 7: Survival curve 1 on 1-damage test

As a consequence, the test facility has to be equipped with an online damage detection system which ceases the laser irradiation and records the number of pulses N until damage occurred. The generated data is evaluated by deriving survival curves for preselected numbers of pulses providing the so-called characteristic damage curve as the final result of the test. An example for such a plot of the energy density values for selected damage probabilities as a function of the number of pulses is depicted in *Figure 8*.

An interesting practical aspect is the extrapolation of the characteristic damage curve to high pulse numbers in the order of 10^9 to 10^{12} shots which may allow for a rough estimation of the lifetime of test component.

For a certification of optical components in respect to their power handling capability, the third part of ISO 21254 describes testing protocols of a defined surface fraction at highest power levels expected in the application. The fundamental approach of these tests is an overlapping interrogation of the entire test area of the optical component, to identify weak spots on the surface and to achieve a high level of confidence for an error-free operation of the optic in the application.

Accordingly, the original component intended for direct use is probed in the certification procedure instead of representative samples, which are tested in 1 on 1- or S on 1-test protocols. LIDT is measured at the facilities of our partner Laser Zentrum Hannover e.V. (LZH).

Scaling of laser damage

For the application of laser coatings, some rough scaling rules can be derived from the developed models (see also page 17). The most prominent estimation for the LIDT-values is the square root rule for the pulse duration (τ):

LIDT ~ τ^x ; x = 0.5

Typically this can be used in the pulse duration regime between 0.1 to 10 ns. The dependency can be extended to other pulse regimes up to pulse lengths in the ms-range, if the exponent is replaced by figures ranging between 0.5 and 2. However, this scaling applies mainly for thermal damage processes and has to be applied with extreme care, particularly for extrapolations spanning more than one order of magnitude in pulse duration. Especially below values of 20 ps, a transition from thermal processes to the described electronic effects has to be accounted for, and the τ^x-scaling may no longer be applicable.

For most materials and under most operating conditions you can observe a decrease of the LIDT value with decreasing wavelength. Scaling with wavelength always implicates the risk that damage mechanisms may change with wavelength, especially when absorption bands are approached. Often, a delay in the range of several 10 seconds between the start of irradiation and the onset of damage has to be taken into account for thermal processes.

Concerning the variation of LIDT-values with beam diameter, numerous investigations indicate a decrease in thresholds for increasing beam diameters. Specifically for inclusion dominated breakdown, the event of damage for a certain site on the coating will be essentially dependent on the distribution of inclusions at that position. In the case of defect damage, for example, with beam sizes smaller than the mean distance between defects vulnerable to damage in the coating, the probability for interrogating a critical defect will be low, and the threshold will be high depending on the quality of the coated material. The probability of interrogating a critical defect will asymptotically reach unity with increasing beam diameter, and the LIDT will approach its

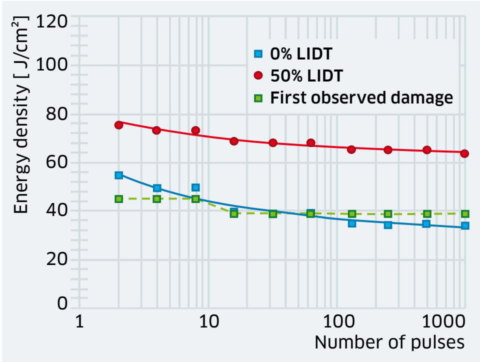


Figure 8: Characteristic damage curve, S on 1

smaller value related to defect damage. In most practical situations, the beam size exceed the mean distance of defects by far, and therefore, the onset of laser induced damage can be estimated as virtually independent of the beam diameter for inclusion dominated breakdown.

As mentioned above for pure absorption induced damage and with shorter pulse durations, approximation for the beam diameter dependence of LIDT on the basis of P/w^2 is often acceptable (page 122). But with cw-lasers or long pulses in the µs- to ms-range, the scaling of the threshold with the beam diameter should be performed in terms of P/w according to equation 2. This P/w scaling results in lower thresholds than the scaling with intensity, which is often erroneously assumed by users, leading to a fatal overestimation of LIDT-values in these operation regimes, one example:

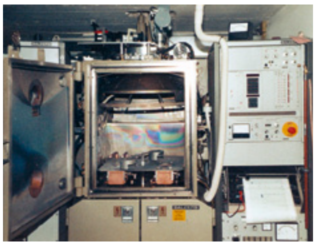
A mirror shows a maximum safe power of 100 W with a beam diameter of 0.5 mm. Using the power density for scaling to a beam diameter of 5 mm the safe operation power would be 10 kW. Scaling with the linear power density only 1 kW will be safe!

In summary, LIDT-values of optical components and thin films are crucially dependent on the operation conditions of the applied laser system. The mentioned change of damage effects from thermal to electronic mechanisms is only one representative example among a variety of many other observed phenomena. As a consequence, threshold values should be scaled with extreme care and for only small intervals in cases, where the fundamental damage mechanism is clarified. In all other situations, the extrapolation of threshold values is extremely unreliable and may lead to severe hazards in the laser system.

Recommended further reading:
Ristau, D. : Laser-induced damage in optical materials, CRC Press (January 9, 2015), ISBN-13: 978-1439872161

History

Dr. Johannes Ebert († 31.07.2019), working on a coating machine in the early 1970s



"Paula", the first coating machine

The "Optics Barn", the first company building

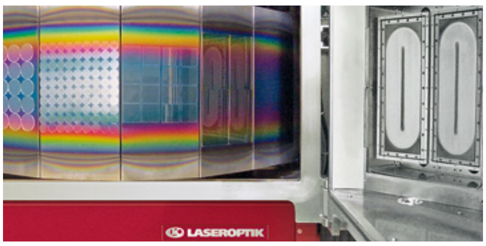
1984 LASEROPTIK was founded by Dr. Johannes Ebert, with involvement of his wife Angelika and today's senior coating manager Werner Moorhoff. In the 12 preceding years Dr. Ebert had gained experience in the manufacturing and characterisation of thin films at the Institute of Quantum Optics at the University of Hanover. He became a pioneer in the development of plasma- and ion-guns, for the reduction of absorption- and scatter-losses and for the improvement of the damage resistance of high power coatings.

1986 As spin-off of the "Institute of Quantum Optics" the "Laser Zentrum Hannover e.V. (LZH)" is founded in close vicinity (only 10 km) to LASEROPTIK's site: The beginning of a constructive and fruitful cooperation.

1990 LASEROPTIK runs 3 Balzers coating machines, two of them in Dr. Ebert's modified basement at home.

1992 A new company building is erected and furnished with 7 additional Balzers coating machines over the following years. The "Optics Barn" ("Optikscheune") is constructed in the style of a Lower Saxony half-timbered house and is equipped with the latest cleanroom technology.

1999 LASEROPTIK starts a two year R&D effort with DSI Inc., USA. In close collaboration with the american engineering experts, Martin Ebert, the founder's elder son, develops a unique magnetron sputtering system and establishes this technology at LASEROPTIK.

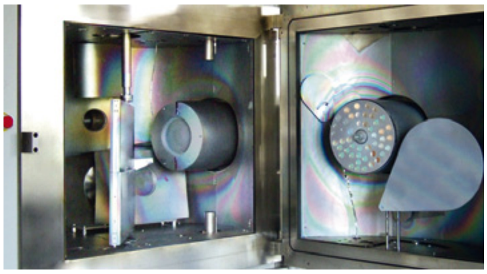


"Gabrielle", the unique MS-system developed by LASEROPTIK

2002 Under the leadership of Dr. Ebert's sons Martin and Wolfgang a new company building – the "Laserhof" – is erected. It provides additional space for a number of coating machines in three cleanrooms.

2006 LASEROPTIK EXPRESS – a rapid prototyping and overnight coating service – is running. More than 100 orders were processed in the first year.

2007 LASEROPTIK is the first professional coating company outside the USA to offer IBS coatings. Due to the high demand, the capacity has increased to today's 18 machines including 4 ones for large optics.



"Kelly", the first IBS coating machine at LASEROPTIK

2008 Dr. Wolfgang Ebert is taking over the general management from his father. Starting work for the company in 1997, he learned the skills of a thin film engineer from scratch. Since then he has left his own footprints as head of new programs and initiatives like the EXPRESS service, LOOP, the development of IBS, innovative coating concepts and various other strategic and pragmatic advances.

2008 LASEROPTIK proudly describes itself as a high-tech family business. This means besides taking care of the long term growth and continuous reinvestments to give our customers and suppliers a reliable perspective, we take the responsibility for our employees very seriously.

In 2023 a staff of more than 100 employees (laser physicists, engineers, technicians, precision opticians) ...

The company runs its own corporate childcare with a kindergarten teacher, for the children of the employees, starting at the age of 1 year.
The working culture at LASEROPTIK is also expressed in company outings and annual family events such as ball rolling ("Bosseln") across the fields in wintertime, summer parties and excursions.

2009 The Ebert family erected a nesting place on the grounds of LASEROPTIK in order to support the resettlement of the endangered white stork (lat. *ciconia ciconia*). The initiative was successful, until today 25 young storks grew up.

In the natural habitats on the company's ground a lot of other protected species such as frogs, salamanders, owls and bats can be observed.

To save energy and environmental resources, the waste heat of the coating chambers is used for heating the laboratories and offices. LASEROPTIK has a recycling and waste management in place and is supplied by 100% ecological power from regenerative sources.

2011 LOOP is introduced, the LASEROPTIK Online Portal. It allows to individually configure and buy laser optics online. The web-based system gives access to more than 1200 different coatings, including tolerances and theoretical calculations.

2014 Due to market demand, LASEROPTIK has started a second building extension of the "Laserhof" with additional 3500 m^2 and tailored clean rooms, e.g. for grand IBS machines.

2017 LASEROPTIK was awarded the national SME prize ("Deutscher Mittelstandspreis"), for their social ethics and ecological orientation.

2021 LASEROPTIK was privileged to be visited by chancellor Dr. Angela Merkel. After a tour through the cleanrooms and around the production facilities she was impressed by the expertise and the worldwide reputation of our specialized products.

"Bosseln" – a cross-country enjoyment in winter and springtime

Our nesting place for the white storks

LOOP is the most comfortable way to configure, order and buy online from the LASEROPTIK stock.

Chancellor Dr. Angela Merkel visited LASEROPTIK on September 17, 2021.
That was an exciting, fascinating and joyful day for the whole LASEROPTIK team!

... works on your coating needs at LASEROPTIK.

Appendix

Abbreviations

ALD	*atomic layer deposition*
AOI	*angle of incidence*
AR	*anti reflection coating*
ARS	*angle resolved scatter*
avg	*average*
BB…	*broadband…*
BFL	*back focal length*
BS	*beamsplitter*
BW	*bandwidth*
CA	*clear aperture*
cc	*concave*
CP	*cube polarizer*
CRD	*cavity ring-down*
cw	*continuous wave*
CWL	*center wavelength*
cx	*convex*
DAR	*double AR*
DR	*double reflector*
EAR	*single layer AR coating*
EBE	*electron beam evaporation*
EFL	*effective focal length*
F	*finesse*
FC	*fiber coupling*
F_F	*flatness finesse*
FL	*focal length*
F_R	*reflectivity finesse*
f_r	*focal length in reflection*
FS	*Fused Silica*
FSR	*free spectral range*
f_t	*focal length in transmission*
FWHM	*full width half maximum*
GD	*group dispersion*
GDD	*group delay dispersion*
GTI	*Gires-Tournois-interferometer*
GVD	*group velocity dispersion*
HBW	*half bandwidth*
HR	*high reflection coating*
IAD	*ion assisted deposition*
IBS	*ion beam sputtering*
IP	*ion plating*
IR	*infrared*
IR-FS	*Fused Silica with low OH-content*
ISO	*International Standards Organization*
IVA	*inversely variable attenuator*
λ	*wavelength*
LIDT	*laser induced damage threshold*
LOOP	*LaserOptic Online Portal*
LP	*long (wave) pass*
MIR	*middle infrared; 2.5–50 µm*
MS	*magnetron sputtering*
NA	*numerical aperture*
N-BK7	*borosilicate crown glass*
NIR	*near infrared; 780–2500 nm*
NP…	*nonpolarizing …*
Ø	*diameter*
OAP	*off axis parabola*
OC	*output coupler*
OD	*optical density*
OPO	*optical parametric oscillator*
ord.	*ordinary*
pl	*plano*
ppm	*parts per million*
p-pol	*p-polarized light*
PR	*partial reflector*
PV	*peak to valley*
QWOT	*quarter wave optical thickness*
QWS	*quarter wave stack*
R	*reflectance*
RF	*radio frequency*
Rp	*p-polarization reflectance*
Rs	*s-polarization reflectance*
rms	*root mean square*
ROC	*radius of curvature*
SP	*short (wave) pass*
s-pol	*s-polarized light*
t	*thickness*
T	*transmittance*
t_c	*center thickness*
TE	*thermal evaporation*
TFP	*thin film polarizer*
T_i	*internal transmittance*
TIR	*total internal reflection*
TIS	*total integrated scattering*
Tp	*p-polarization transmittance*
Ts	*s-polarization transmittance*
TSB	*total back scattering*
UHV	*ultra-high vacuum*
u-pol	*unpolarized light u = (s+p)/2*
US	*ultrasonic*
UV	*ultraviolet; 180–379 nm*
UV-FS	*Fused Silica with high UV-transmittance*
VA	*variable attenuator*
VIS	*visible light; 380–779 nm*
VLT	*visible light transmission*
VUV	*vacuum ultraviolet; 120–179 nm*

Helpful formulas

Fresnel reflectivity: $R = \left(\frac{n-1}{n+1}\right)^2$ — with normal incidence in air

Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Total reflection: $\sin\theta_T = \frac{n_2}{n_1}$; $n_2 < n_1$

Brewster's angle: $\theta_B = \arctan\left(\frac{n_{substrate}}{n_{medium}}\right)$

Numerical aperture: $NA = n \cdot \sin\theta$

Optical density: $OD = \log_{10}(T^{-1})$ →

OD	T
4	0.01 %
3	0.1 %
2	1.0 %
1	10.0 %

Free spectral range: $FSR = \frac{\lambda^2}{2 \cdot n \cdot d}$ — n is the refractive index of the cavity and d the cavity gap

Reflectivity finesse: $F_R = \frac{FSR}{\Delta\lambda} = \frac{\pi \cdot \sqrt{R}}{1-R}$

Wavenumber: $\tilde{\nu} = \frac{10^4}{\lambda\ [\mu m]}\ cm^{-1}$ →

Electron volts: $E = \frac{1.24}{\lambda\ [\mu m]}\ eV$ →

λ	$\tilde{\nu}$	E
193 nm	51813 cm^{-1}	6.42 eV
355 nm	28169 cm^{-1}	3.49 eV
532 nm	18797 cm^{-1}	2.33 eV
1064 nm	9398 cm^{-1}	1.17 eV
1550 nm	6452 cm^{-1}	0.80 eV
2940 nm	3401 cm^{-1}	0.42 eV

Planck's constant: $h = \frac{E}{\upsilon} = 6.62607 \cdot 10^{-34}\ Js$

Speed of light: $c = 299\ 792\ 458\ \frac{m}{s}$ — in vacuum

LO solving equation: $\frac{1}{n}\sin x = \frac{1}{\not{n}}\,\text{si}\not{n}\,x = \text{six} = 6$

Mean free path: $l = \frac{6.7 \cdot 10^{-3}}{P\ [mbar]}\ cm$ — air at room temperature

Temperature: $°C = K - 273 = \frac{5}{9}(°F - 32)$

Pressure:

	mbar	Pa	atm	Torr	psi
1 mbar =	1	100	$9.87 \cdot 10^{-4}$	0.75	$1.45 \cdot 10^{-2}$
1 Pa =	0.01	1	$9.87 \cdot 10^{-6}$	$7.50 \cdot 10^{-3}$	$1.45 \cdot 10^{-4}$
1 atm =	1013	$1.01 \cdot 10^{5}$	1	760	14.696
1 Torr =	1.33	133	$1.316 \cdot 10^{-3}$	1	$1.934 \cdot 10^{-2}$
1 psi =	68.95	6895	$6.804 \cdot 10^{-2}$	51.71	1

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References

LASEROPTIK has many customers worldwide, small and large and in between.

The confidentiality of information about our customers, their products and technologies is very important to us.

Nevertheless we gratefully appreciate to be able to name the following, authorized references:

COHERENT

DESY

eli beamlines

JENOPTIK

TRUMPF

WaveLight®

Final questions

1) How many frogs did you find in this catalog?
2) How much thicker is a human hair compared to a standard coating HR 1064 nm/0°?
3) How many optics were needed to build the globe placed next to Dr. Merkel on page 127?
4) Did you see the EXPRESS dog running through the pages?
5) Which coating was first entered into our data system?
6) Do you have any questions?
7) What do we have to take into account for your quotation? Find the hidden words.

L	I	U	Z	T	R	P	E	W	Q	A	D	A	N	K	E	S	D	F	G	H	I	F
L	O	S	S	E	S	A	C	O	H	R	A	D	I	F	F	I	C	U	L	T	Y	J
L	M	E	N	B	V	L	C	X	A	Y	A	S	D	F	R	G	H	F	R	O	D	L
A	W	S	X	E	N	A	Z	G	R	U	T	E	M	P	E	R	A	T	U	R	E	L
C	A	D	F	T	G	V	G	Z	D	I	I	L	O	P	D	L	K	F	B	J	B	O
H	V	Q	W	E	E	A	R	T	N	Z	F	L	U	I	O	P	I	A	E	S	E	D
E	E	G	J	E	N	N	Y	D	E	F	F	I	C	I	E	N	C	Y	T	L	R	N
N	L	U	Z	Y	V	H	S	J	S	K	A	L	M	N	D	B	V	K	T	I	T	U
O	E	R	D	S	I	A	G	I	S	Y	N	X	C	T	K	E	L	L	Y	D	V	O
K	N	S	F	G	R	H	L	J	O	K	Y	S	H	E	R	T	A	A	L	T	P	F
I	G	U	E	H	O	M	O	G	E	N	E	I	T	Y	R	T	Z	R	U	I	O	G
E	T	L	W	Q	N	A	R	D	S	F	S	Z	G	H	C	L	E	A	N	I	N	G
H	H	A	P	D	M	S	I	Y	X	I	Z	E	C	V	H	B	N	M	L	K	J	E
E	S	F	A	G	E	R	A	T	H	L	R	Z	V	U	A	S	I	G	O	P	S	R
K	Z	Q	U	A	N	T	I	T	Y	A	E	V	F	E	N	C	M	A	R	I	A	E
N	W	H	L	N	T	B	D	G	T	S	F	C	D	E	N	A	W	B	A	S	L	T
A	I	D	A	U	J	N	M	K	I	E	L	L	I	M	A	T	E	R	I	A	L	S
D	L	O	F	R	I	E	D	A	P	R	E	L	M	J	U	T	E	I	Z	H	Y	A
Q	M	W	E	F	L	E	D	C	V	O	C	F	R	T	L	E	N	E	G	B	N	E
S	A	X	U	C	A	B	S	O	R	P	T	I	O	N	B	R	C	L	N	N	M	Y
G	C	O	S	T	S	H	J	K	O	T	I	Y	X	I	C	I	V	L	S	A	R	A
I	Y	O	K	O	E	Q	W	E	S	I	O	T	W	O	F	N	G	E	H	J	N	S
F	D	F	P	Q	R	O	P	T	I	K	N	J	S	B	F	G	T	Z	K	G	D	D

1) Two frogs can be seen, one placed into each coating machine on page 24 and 25.
2) A human hair is about 10-20 times thicker than a standard coating HR1064 nm/0° (see information on page 13).
3) The globe is built out of 1429 coated optics. Doesn´t it look pretty?
4) Use the lower right corner of this catalogue as flip-book.
5) HT 532 nm HR 1064 nm/0° [B-00001] was the first coating we entered into our system, see page 41. Today the system shows more than 26,000 different coating designs.
6) Contact us, see cover III or next page.
7) Absorption, cleaning, costs, difficulty, efficiency, environment, GDD, hardness, homogeneity, LIDT, losses, materials, quantity, reflection, scattering, size, temperature, wavelengths (see comparison on page 21). And even more is hidden...

LASEROPTIK GmbH
Horster Str. 20 · 30826 Garbsen · Germany

Phone +49 5131 4597-0
Fax +49 5131 4597-20
E-mail service@laseroptik.de
www.laseroptik.com

Printed in Germany