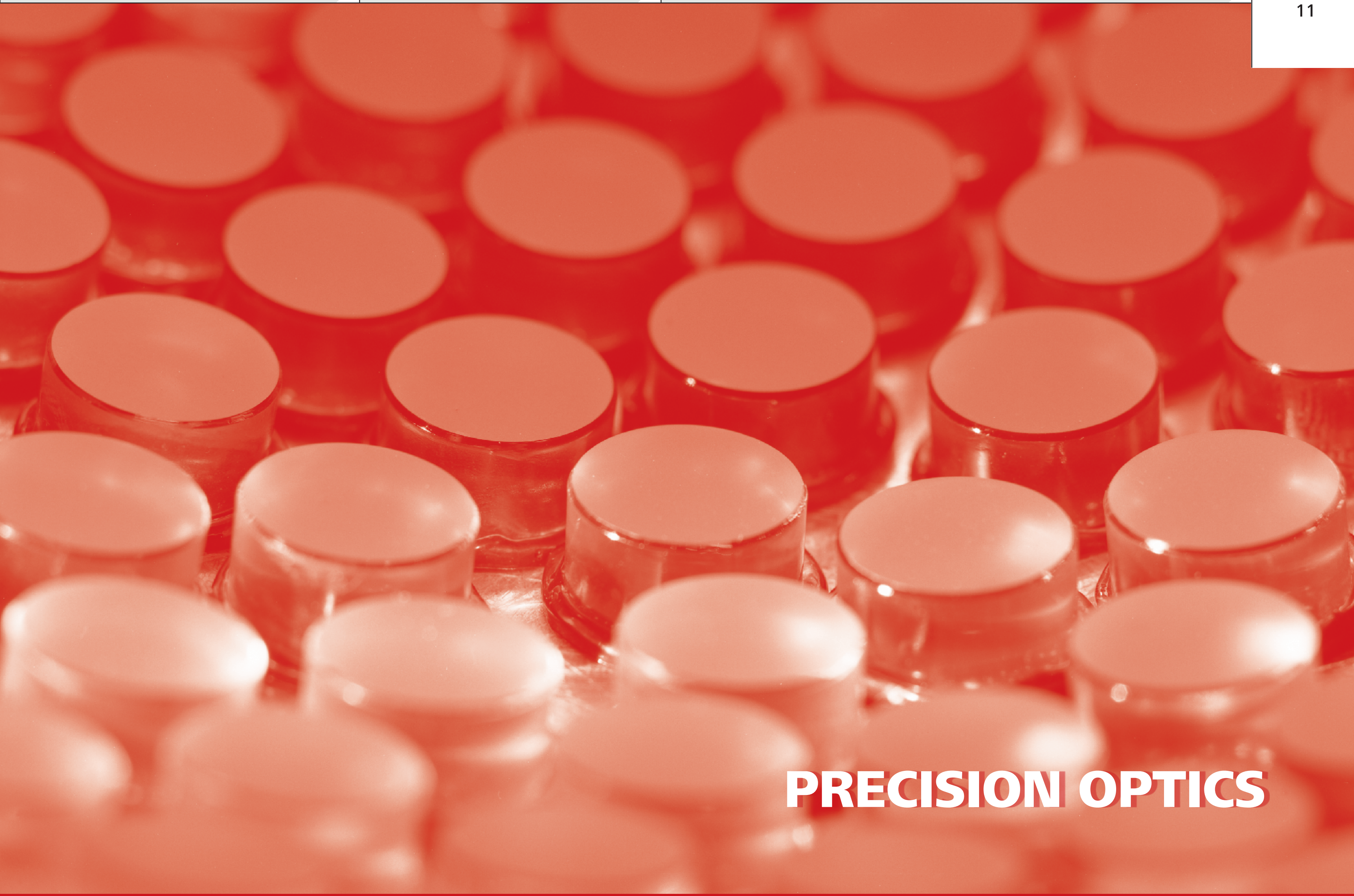


PRECISION OPTICS

LAYERTEC®
OPTICAL COATINGS · OPTICS

CONTENTS

HOW TO SPECIFY SUBSTRATES

Price and quality of substrates are determined by material, shape, size, tolerances and polishing quality.

MATERIAL

The first decision is the material of the substrate. It should be free of absorption for all wavelengths of high transmittance. If no transmittance occurs, a low cost material can be used, e.g. Borofloat® (SCHOTT AG), for metallic mirrors.
With respect to the surface form tolerance, a low thermal expansion is beneficial.

SHAPE

The shape must be specified for both sides separately. All combinations of plane, convex and concave surfaces are possible. This is also the case for wedges, e.g. 30 arcmin, which can be appied to any kind of surface, plane as well as convex or concave.
For curved substrates there are different conventions for the sign of the radius. Sometimes "+" means convex and "-" means concave. Other users refer to the direction of light propagation. In this case, "+" means "curvature in the direction of propagation" and "-" means "curvature against the direction of propagation". Please specify concave or convex in words or using the acronyms CC or CX to avoid confusion.

SIZE

The main decision should be about the size of the substrate, i.e. edge length or diameter. Small diameters are more favorable for production. The sagitta heights become lower and it is easier to achieve a good form tolerance.

Although often denoted otherwise in optical designs, LAYERTEC specifies the thickness as the maximum thickness of the substrate, i.e. the center thickness for plano-convex substrates and the edge thickness for plano-concave substrates. Consequently, the thickness of a wedged plate is measured on the thicker side.

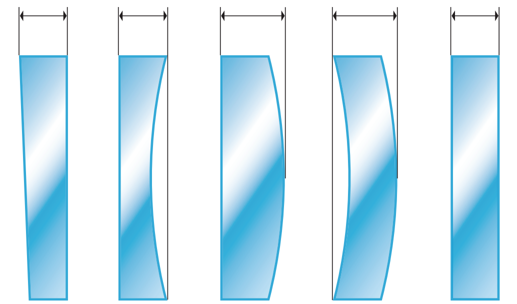


Figure 1: Conventions for the specification of the thickness of different types of substrates (schematic drawing)

In order to achieve a good form tolerance, the ratio of diameter and thicknes should be considered. As a rule of thumb the thickness should be one fifth of the diameter. Of course, other ratios are possible but production costs and therefore prices increase as well.

TOLERANCES

Besides size and material, the tolerances are most important for manufacturing costs and therefore also for prices. Of course, the optics must fit into the mount, so the diameter should not be larger than specified. Thus, the most common specification is + 0 - 0.1 mm. In contrast, the thickness is generally free in both directions. LAYERTEC usually specifies it with a tolerance of ± 0.1 mm.
There is a lot of confusion about the specification of wedge, parallelism and centering. Please note that wedge and parallelism describe the angle between the optical surfaces while centering describes the angle between the optical surfaces and the side surfaces (see fig. 2).

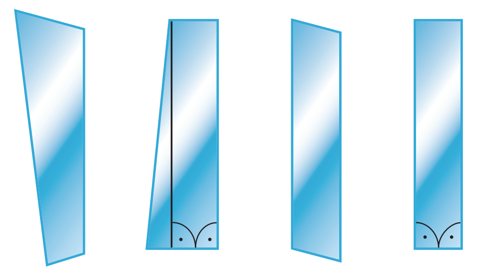


Figure 2: Different kinds of plane substrates with respect to wedge and centering (schematic drawing)

LAYERTEC standard substrates have a parallelism better than 5 arcmin. Specially made parallels may have a parallelism as low as 10 arcsec. Standard wedged substrates have wedges of 0.5° or 1°. Larger wedge angles are possible depending on the substrate size.
In general, the 90° angle between optical and side surface has a precision of 20 arcmin. Centering is an additional optics processing step which improves this accuracy to a few arcmin.
Curved substrates can be described using the same nomenclature. It should be distinguished between mirrors and lenses. The side surfaces of mirror substrates are parallel. Nevertheless, the direction of the optical axis can be inclined with respect to the side surfaces. After centering, the side surfaces are parallel to the optical axis.

SURFACE FORM TOLERANCE

The surface form tolerance is usually measured by interferometers and specified in terms of lambda, which is the reference wavelength (λ = 546 nm if not otherwise stated). In order to avoid confusion, it is necessary to clearly distinguish between flatness, power and irregularity. In the following, flatness and irregularity shall be explained for a plane surface. Generally speaking, every real surface is more or less curved. Imagine that the "peaks" and "valleys" of a real surface are covered by parallel planes (see fig. 3). The distance between these planes is called the flatness. This flatness consists of two contributions. The first contribution is a spherical bend of the surface, which may be described by a best fitted sphere to the surface. With respect to an ideal plane, the sagitta of this curvature is denoted as power. This spherical bend does not affect the quality of the reflected beam. It just causes a finite focal length. The second contribution is the deviation from the best fitted sphere, which is named irregularity. This is the most important value for the quality of the beam.

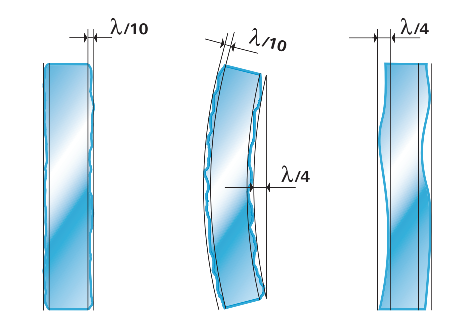


Figure 3: Schematic drawing for the explanation of substrate properties:
a) Flatness of $\lambda/10$
b) Spherical bending (power of $\lambda/4$)
c) Irregularity of $\lambda/4$, but transmitted wavefront of $\lambda/10$

The standard ISO 10110 provides a sufficient method for specifying the surface form tolerance. Having the best comparability with the measurement results, all values are specified as numbers of interference fringes, with 1 fringe = λ / 2. In technical drawings according to ISO 10110, the surface form tolerance is allocated as item number three:

3 / power (irregularity)

Example: A slightly bent (λ / 4) optics which is regular (λ / 10) would be specified as follows:

3 / 0.5 (0.2)

Using the optics only for transmittance (e.g. laser windows), power as well as irregularity do not matter. A transmitted beam is not affected if the optics has the same thickness all over the free aperture. The influence of thickness deviations on the transmitted beam is defined in a similar way as the flatness. It is also measured in parts of the reference wavelength and called "transmitted wave front". For instance, the window in fig. 3c has a flatness of λ / 4 but a transmitted wave front of λ / 10.

COATING STRESS

Thin substrates cannot withstand the coating stress. The coating will cause a spherical deformation. This means that a finite sagitta or power occurs. In case of circular substrates, the irregularity is not affected by this issue.
Even if power deviation is considered, the quality of a beam under normal incidence is not affected.

DEFECTS

MIL-O-13830 and ISO 10110 are different standards for the description of optical elements. This often causes obscurities. Basically, scratches and digs have to be distinguished. The scratch number in MIL-O-13830 refers to the visibility of the biggest scratch compared to the corresponding one on a norm template. Actually "10" is the smallest scratch on this template. Thus, better qualities cannot be specified legitimately. Moreover, the MIL norm does not specify a directly measured scratch width. Sometimes the number is interpreted as tenths of a micron, sometimes as microns. Actually, a direct measurement never corresponds to the MIL norm.

In contrast to the scratch, the dig number can be measured easily. The numerical value is equal to the maximum dig diameter in hundredths of a millimeter. One maximum-size dig per 20 mm diameter is allowed. According to ISO 10110, defects are specified as item number 5. The grade number is the side length in millimeters of a square area which is equivalent to the total defect area. So, 5 / 1 x 0.025 describes a surface defect area of 625 µm². Additionally, scratches of any length are denoted with a leading L. A long scratch with a width of 4 microns would be specified as L 1 x 0.004.
All these explanations are very simplified. For a detailed specification please read the complete text of the relevant standard.

PLEASE NOTE:

There is no direct conversion between MIL-O-13830 and ISO 10110. All specifications in this catalog are according to ISO 10110. The mentioned scratch/dig values are rough approximations to MIL-O-13830.

STANDARD QUALITY SUBSTRATES

The precision optics facility of LAYERTEC produces plane and spherically curved mirror substrates, lenses and prisms of fused silica, optical glasses like N-BK7® and some crystalline materials, e.g. calcium fluoride and YAG. In the following you can find information on the specifications of our standard substrates.

Please do not hesitate to contact us also for other sizes, shapes, radii and materials or for special components. For cylindrical, aspherical and free form optics see page 16.

STANDARD SPECIFICATIONS

Materials

- Fused silica:
  Corning 7980® or equivalent
- Fused silica for high power applications:
  Suprasil® 300 / 3001 / 3002 / Corning 7979® or equivalent
- UV fused silica (excimer grade):
  SQ1 E-193® and SQ1 E-248®
- IR fused silica:
  Infrasil 302® or equivalent
- ULE®
- Zerodur®
- N-BK7® or equivalent
- CaF_2:
  single crystal, randomly oriented, special orientations on request, excimer grade (248 nm and 193 nm) on request
- Sapphire:
  single crystal, C-cut
- YAG:
  undoped, single crystal, randomly oriented

Plane substrates, parallels and wedges

- Standard plane substrates:
  wedge < 5 arcmin
- Standard parallels:
  wedge < 1 arcmin or wedge < 10 arcsec
- Standard wedges:
  wedge = 30 arcmin or wedge = 1 deg

Plano-concave and plano-convex substrates

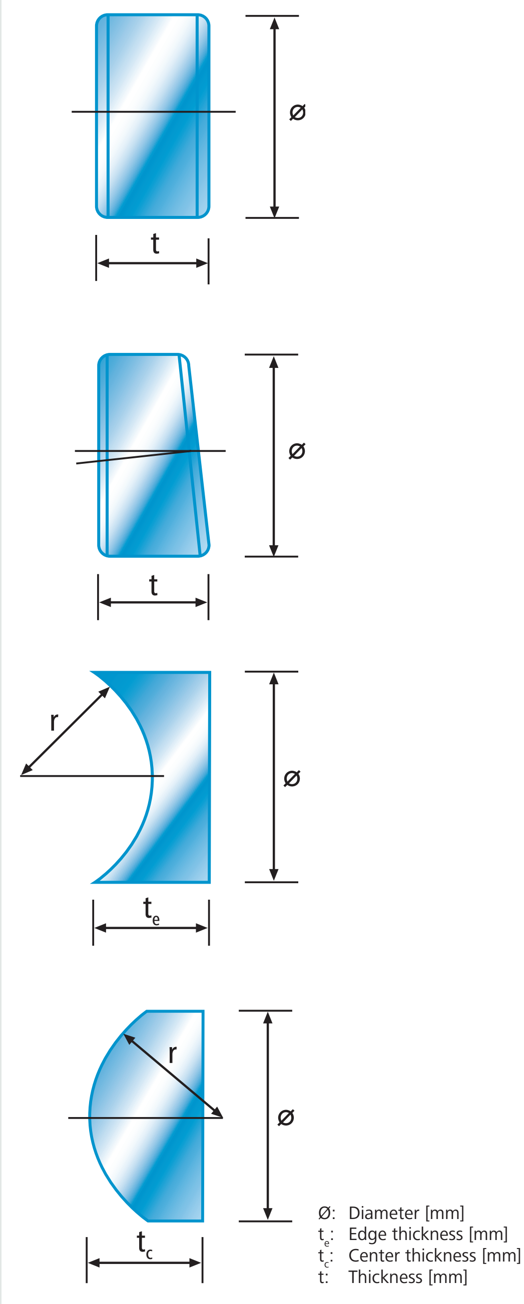
- Standard radii:
  25, 30, 38, 50, 75, 100, 150, 200, 250, 300, 400, 500, 600, 750, 1000, 2000, 3000, 4000, 5000 mm
- Other radii on request

Dimensions

- Fused silica, ULE®, Zerodur®:
  diameter 3 mm … 600 mm
- Calcium fluoride, sapphire:
  diameter 3 mm … 50.8 mm
- YAG: diameter 3 mm ... 38.1 mm
- Rectangular substrates and other diameters available on request

Tolerances

- Diameter:
  + 0 mm, - 0.1 mm
- Thickness:
  ± 0.1 mm
- Clear aperture:
  central 85 % of dimension
- Chamfer:
  0.2 … 0.4 mm at 45°



Surface form tolerance (reference wavelength: 546 nm)

Material		Standard Specification	On request
Fused silica	plane spherical	λ / 10 λ / 10 reg.	λ / 30 λ / 30 reg. (Ø < 51 mm)
ULE® and Zerodur®	plane spherical	λ / 10 λ / 10 reg.	λ / 30 λ / 30 reg. (Ø < 51 mm)
N-BK7®	plane spherical	λ / 10 λ / 10 reg.	λ / 30 λ / 30 reg. (Ø < 51 mm)
CaF_2	plane Ø < 26 mm plane Ø < 51 mm spherical	λ / 10 λ / 4 λ / 4 reg.	λ / 20 λ / 20 λ / 20 reg.
Sapphire		λ / 10	λ / 30
YAG	plane spherical	λ / 10 λ / 8 reg. (typical λ / 10 reg.)	λ / 30 λ / 30 reg. (Ø < 51 mm)
Si	plane spherical	λ / 10 λ / 8 reg. (typical λ / 10 reg.)	λ / 20 λ / 20 reg. (Ø < 51 mm)

Surface quality

Material	Standard Roughness*	Standard Specification	On request	
Fused silica	< 2 Å	5 / 1 x 0.025 L1 x 0.004 Scratch-Dig 10-3	< 1.5 Å	5 / 1 x 0.016 L1 x 0.0005 Scratch-Dig 5-1
ULE®	< 2 Å	5 / 3 x 0.025 L1 x 0.004 Scratch-Dig 10-5	< 2 Å	5 / 1 x 0.016 L1 x 0.0005 Scratch-Dig 5-1
Zerodur®	< 4 Å	5 / 2 x 0.040 L1 x 0.004 Scratch-Dig 10-5	< 3 Å	5 / 2 x 0.025 L1 x 0.0010 Scratch-Dig 10-3
N-BK7®	< 3 Å	5 / 1 x 0.040 L1 x 0.004 Scratch-Dig 10-5	< 2 Å	5 / 2 x 0.025 L1 x 0.0010 Scratch-Dig 10-3
CaF_2	< 3 Å	5 / 3 x 0.025 L10 x 0.004 Scratch-Dig 20-5	< 1.5 Å	5 / 3 x 0.016 L1 x 0.0010 Scratch-Dig 10-2
Sapphire	< 3 Å	5 / 1 x 0.025 L10 x 0.004 Scratch-Dig 20-3	< 2 Å	5 / 1 x 0.016 L1 x 0.0010 Scratch-Dig 10-2
YAG	< 2 Å	5 / 1 x 0.025 L2 x 0.004 Scratch-Dig 20-3	< 2 Å	5 / 1 x 0.016 L1 x 0.0005 Scratch-Dig 5-1
Si	< 10 Å	5 / 3 x 0.025 L10 x 0.004 Scratch-Dig 10-5	< 6 Å	5 / 3 x 0.016 L3 x 0.0005 Scratch-Dig 5-1

All specifications according to ISO 10110 (Ø 25 mm). The mentioned Scratch-Dig values are approximately equivalent to MIL-O-13830.
* Valid for measurements with optical profilometer taking into account spatial structures in the 0.663 – 42.5 µm range.

ASPHERES, OFF-AXIS AND FREE FORM OPTICS

BASICS

Plane and spherical optics can be efficiently manufactured by using traditional techniques of area grinding and polishing. The tool always works on a significant fraction of the substrate area at once. However, it is hardly possible to manufacture surface geometries that differ from regular forms like planes, spheres or cylinders.

Using ultra precision CNC machinery, surfaces can be processed zonally, i.e. the tool works on one point at a time. The possible surface forms and tolerances are only limited by the precision of the machine and the measurement equipment. In contrast to the areal techniques, zonal processing usually works with one single piece per run only.

Non-spherical optics can be divided into three categories: rotationally symmetric, off-axis and free form optics.

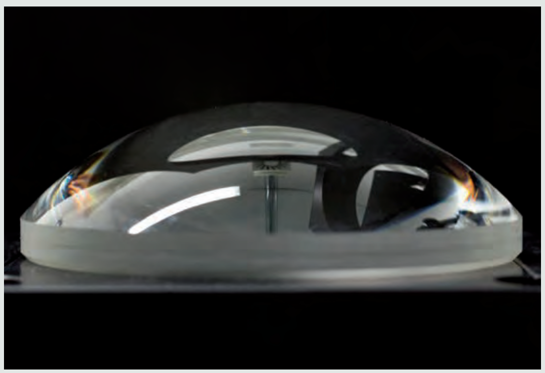


Figure 1: Aspheric lens

ROTATIONALLY SYMMETRIC NON-SPHERICAL OPTICS (ASPHERES)

Although the term “asphere” may stand for any non-spherical optics, it is often restricted to rotationally symmetric optics. They are described by the following equation (ISO 10110):

$$z(r) = \frac{r^2}{R\left[1+\sqrt{1-(1+k)\frac{r^2}{R^2}}\right]} + A_3 r^3 + A_4 r^4 + \dots$$

z = sagitta
k = conic constant
r = distance from axis, $r = \sqrt{x^2 + y^2}$
R = radius of curvature
A_i = aspheric coefficients

Neglecting the aspheric coefficients leads to a profile of conic sections:

- Sphere: $k = 0$
- Ellipse: $-1 < k < \infty$
- Parabola: $k = -1$
- Hyperbola: $k < -1$

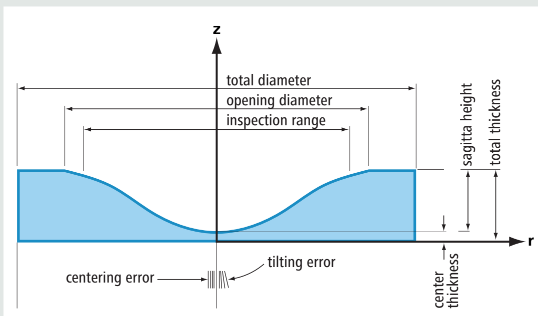


Figure 2: Profile of an aspheric mirror

	Dimension	Tolerances
Total diameter	25 – 560 mm	< 0.1 mm
Inspection range	< 550 mm	
Total thickness	< 100 mm	< 0.1 mm
Sagitta	< 50 mm	
Centering error		< 50 µm
Tilting error		< 30 ''
Surface form tolerance (PV)		< λ / 4 (< λ / 10 on request)
Roughness*		< 4 Å (< 2 Å on request)

Table 1: Production dimensions and tolerances

* Valid for measurements with optical profilometer taking into account spatial structures in the 0.65 - 55 µm range.

OFF-AXIS SURFACES

An off-axis surface can be seen as a section of a bigger on-axis surface. The focal point still is on the original optical axis but not the center of the section. It is located off axis.

Off-axis surfaces derived from aspheres are described by the mentioned equation, the off-axis distance a and / or the off-axis angle α.

Example: Off-Axis Parabola (OAP)

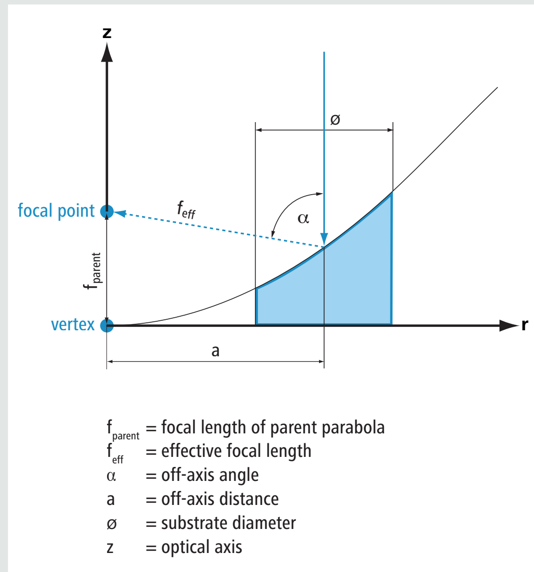


Figure 3: Schematic drawing of an off-axis parabola

The focal length of the parent parabola f_{parent} is measured from the vertex on the optical axis. For the off-axis parabola, an effective focal length f_{eff} is introduced.
The off-axis distance is measured from the optical axis to the middle of the OAP. The radius R denotes the radius of curvature in the vertex of the parent parabola. The conic constant k is -1.

In principle an off-axis substrate can always be mechanically cut from an on-axis substrate. The alternative way is a direct manufacturing. Depending on the size and tolerances, both ways are possible. Fig. 4 shows the common process of manufacturing a number of smaller OAPs from a parent parabola.

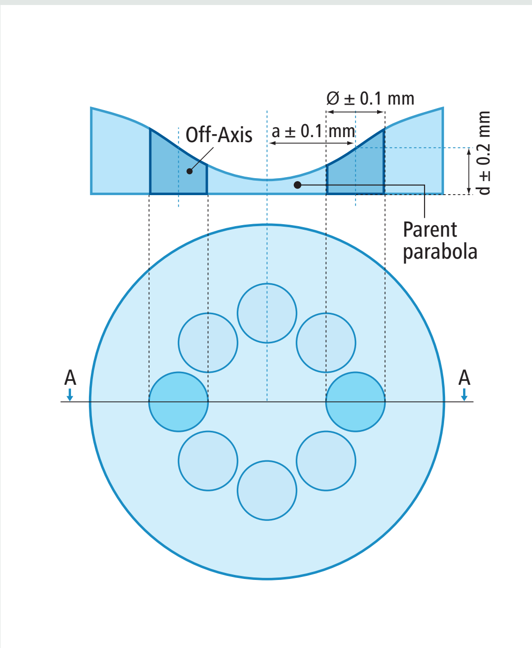


Figure 4: Manufacturing off-axis parabolas as pieces of one "parent parabola"

FREE FORM SURFACES

In general, free form surfaces do not exhibit any symmetries. They are always customer specific and can be defined by an equation. Additional specification of tabulated sagitta values is highly recommend. Free form surfaces are manufactured as single pieces. With respect to machining, the production of an off-axis asphere from a single piece represents a free form as well. Table 2 shows LAYERTEC's production dimensions and tolerances for free form surfaces.

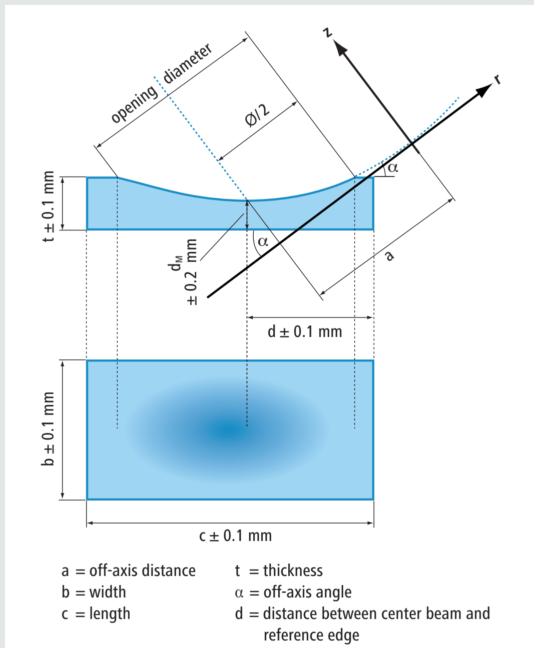


Figure 5: Basic dimensional parameters of a free form substrate

	Dimension	Tolerances
Ø	< 300 mm	0.2 mm
b	< 300 mm	0.1 mm
c	< 450 mm	0.1 mm
α	< 45°	
t	< 80 mm	0.1 mm
d		0.1 mm
Surface form tolerance (PV)		< λ / 10 on request (λ/10 on request)
Roughness*		< 4 Å (< 2 Å on request)

Table 2: Dimensions and tolerances of free form substrates

* Valid for measurements with optical profilometer taking into account spatial structures in the 0.65 - 55 µm range.

MATERIALS

The surface quality and the final tolerances strongly depend on the material of the substrate. LAYERTEC uses a process optimized for fused silica. Materials like Zerodur®, ULE® or N-BK7® may be used in special cases.

MEASUREMENT

Measuring aspheric surfaces requires sophisticated devices. LAYERTEC applies 4 different measurement principles.

- **Tactile measuring**
  A tip has mechanical contact to the surface and its excursion is recorded. One line is measured at a time. Precision < 200 nm on a 200 mm line.
- **Single point interferometer**
  Contactless measurement of the surface, measuring the surface point by point. Precision < 50 nm on ≤ Ø 420 mm.
- **Interferometer with reference surface**
  The surface is compared to a well-known reference surface. Precision < 50 nm, on Ø ≤ 300 mm. Concave surfaces preferred.
- **Interferometer with hologram**
  The surface is compared to the wave front provided by a computer generated hologram (CGH).

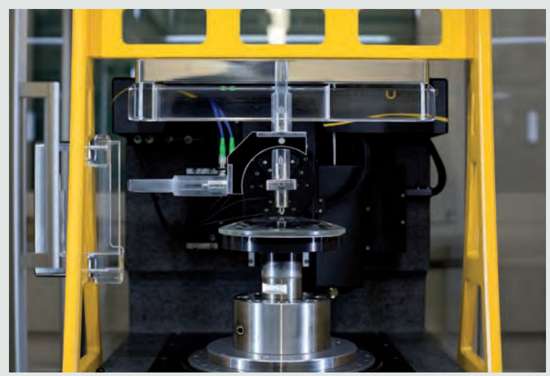


Figure 6: LuphoScan single point interferometer

SPECIAL OPTICAL COMPONENTS

ETALONS

As a kind of a Fabry-Pérot interferometer, the etalon is typically made of a transparent plate with two reflective surfaces. Its transmittance spectrum, as a function of wavelength, exhibits peaks of high transmittance corresponding to resonances of the etalon. Etalons are widely used in telecommunication, lasers and spectroscopy for controlling and measuring the wavelength of laser sources.

LAYERTEC offers etalons of customized diameters and various materials depending on the wavelength range. Thicknesses down to 50 µm and a parallelism < 1 arcsec are possible subject to the diameter. Do not hesitate to contact us for the customized diameter and thickness you need.

	Thickness			Parallelism
	Ø = 50 mm	Ø = 25 mm	Ø = 12.7 mm	
Fused Silica	≥ 200 µm	≥ 130 µm	≥ 50 µm	< 1 arcsec
YAG	≥ 200 µm	≥ 130 µm	≥ 50 µm	< 1 arcsec
CaF_2	——	≥ 300 µm	≥ 100 µm	< 5 arcsec

WAVEPLATES

LAYERTEC offers customer specific retardation plates made of crystalline quartz. Due to requirements for mechanical stability, a minimum thickness is required depending on diameter. Thus, there is a constraint with respect to the shortest available wavelength for a given wave-plate order. For two frequently requested diameters, examples are given below. Other diameters are available on request.

Order	Ø = 25 mm	Ø = 18 mm	Precision	Parallelism
λ / 2	**Available wavelengths**			
K = 0	——	λ > 1530 nm	± 1 µm	< 1 arcsec
K = 1	λ > 720 nm	λ > 560 nm	± 1 µm	< 1 arcsec
K = 2	λ > 450 nm	λ > 350 nm	± 1 µm	< 1 arcsec
λ / 4	**Available wavelengths**			
K = 1	λ > 860 nm	λ > 660 nm	± 1 µm	< 1 arcsec
K = 2	λ > 500 nm	λ > 380 nm	± 1 µm	< 1 arcsec

CUSTOMIZED PRISMS AND SHAPES

In addition to the mentioned circular substrates, LAYERTEC is able to produce a lot of different shapes. Customized optics are possible besides rectangular substrates, wedges and prisms. Typical examples feature defined holes through the optics. So-called D-cuts and notches can be produced as well.

POLISHING OF CRYSTALS

Besides the high quality optical coatings on crystals (see pages 116, 117), LAYERTEC supports the polishing of various types of crystals such as YAG, KGW, KYW, KTP, LBO or BBO. This polishing technology also enables the careful handling and processing of small crystal sizes or extraordinary forms. Do not hesitate to contact LAYERTEC for your special project.

ULTRASONIC DRILLING

Using ultrasonic drilling, LAYERTEC is able to manufacture holes and other structures in a variety of forms and sizes in glass, ceramics or crystals in a low-tension way. Coated as well as uncoated optics may be processed.

LARGE SCALE OPTICS

LAYERTEC is able to produce plane, spherical and aspherical optics up to a diameter of 600 mm. This also includes interferometers. Measurements for large optics are described on page 22. These optics can be coated using magnetron sputtering and IAD. The main products are large scale laser mirrors. A coating homogeneity of ± 0.5 % was demonstrated which also enables the production of large scale thin film polarizers and other complex coating designs.

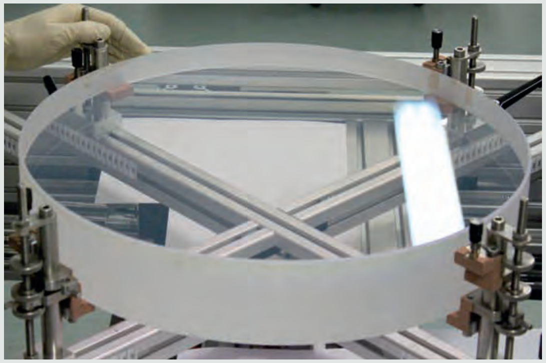


Figure 1: Mirror substrate with a diameter of 500 mm

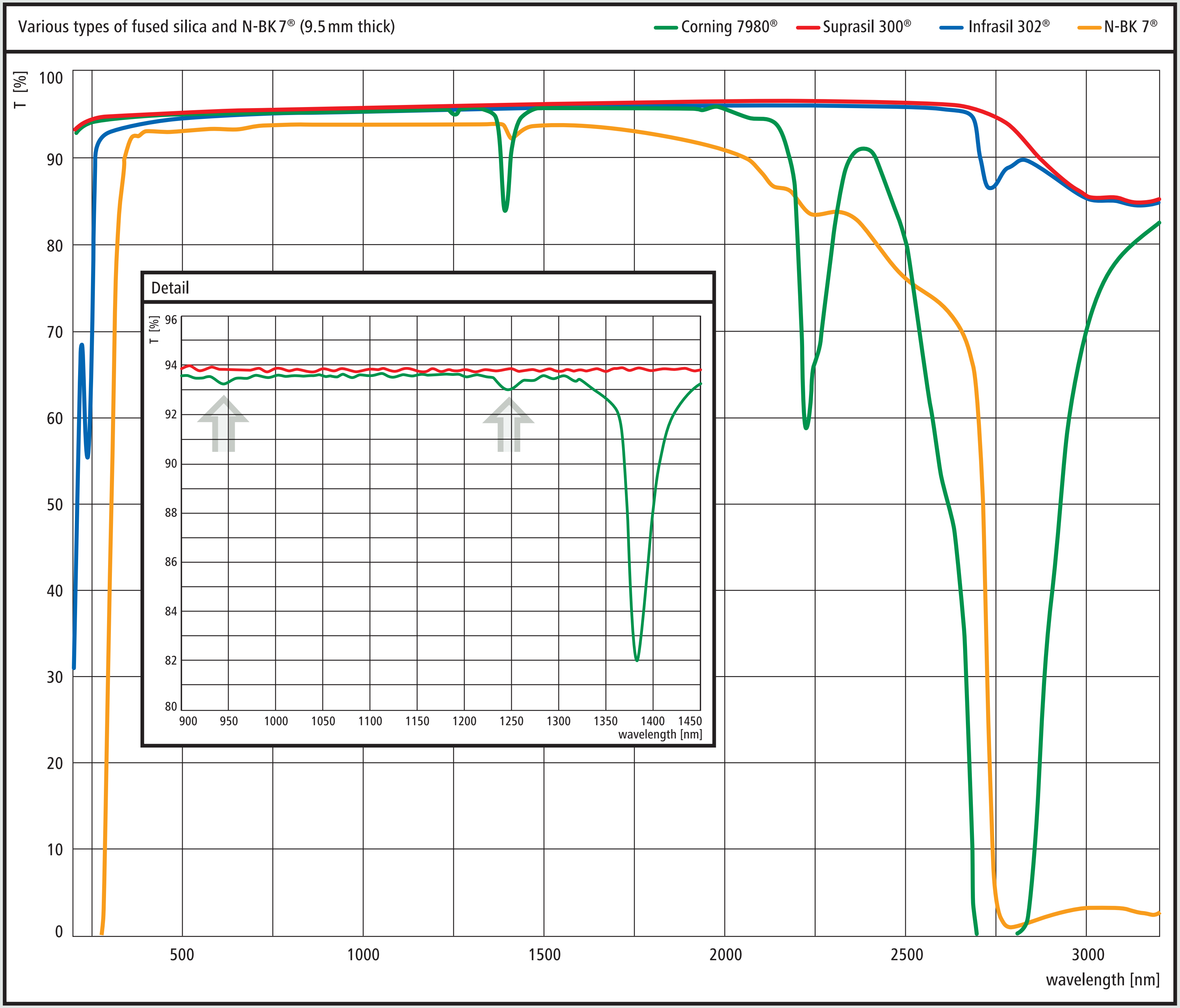
SUBSTRATE MATERIALS FOR UV, VIS AND NIR/IR OPTICS

	Fused silica (UV)	Infrasil®[1]	YAG (undoped)	Sapphire (C-cut)	CaF_2	N-BK7®[2]	Si
Wavelength range free of absorption	190 nm – 2.0 µm[3]	300 nm – 3 µm	400 nm – 4 µm	400 nm – 4 µm	130 nm – 7 µm	400 nm – 1.8 µm	1.4 – 6 µm
Refractive index at							
200 nm	1.55051				1.49516		
300 nm	1.48779				1.45403		
500 nm	1.46243	1.48799	1.8450	1.775	1.43648	1.5214	
1 µm	1.45051	1.45042	1.8197	1.756	1.42888	1.5075	
3 µm		1.41941	1.7855	1.71	1.41785		3.4381
5 µm				1.624	1.39896		3.4273
9 µm					1.32677		
Absorbing in the 3 µm region	yes	yes	no	no	no	yes	no
Absorbing in the 940 nm region	For high power applications at 940 nm the fused silica types SUPRASIL 300®[1] and SUPRASIL 3001/3002®[1] are recommend.						
Birefringence	no	no	no	yes	no[4]	no	no
Thermal expansion coefficient $[10^{-6} K]$[5]	0.5	0.5	7	5	18	7	2.6
Resistance against temperature gradients and thermal shock	high	high	high	high	low	medium	low
GDD fs^2 per mm							
400 nm	98	98	240	150	68	120	
800 nm	36	36	97	58	28	45	
1064 nm	16	16	61	29	17	22	
1500 nm	-22	-22	13	-25	1.9	-19	
2000 nm	-100	-100	-59	-120	-21	-99	
TOD fs^3 per mm							
400 nm	30	30	75	47	19	41	
800 nm	27	27	57	42	16	32	
1064 nm	44	44	71	65	21	49	
1500 nm	130	130	140	180	46	140	
2000 nm	450	450	360	530	120	460	

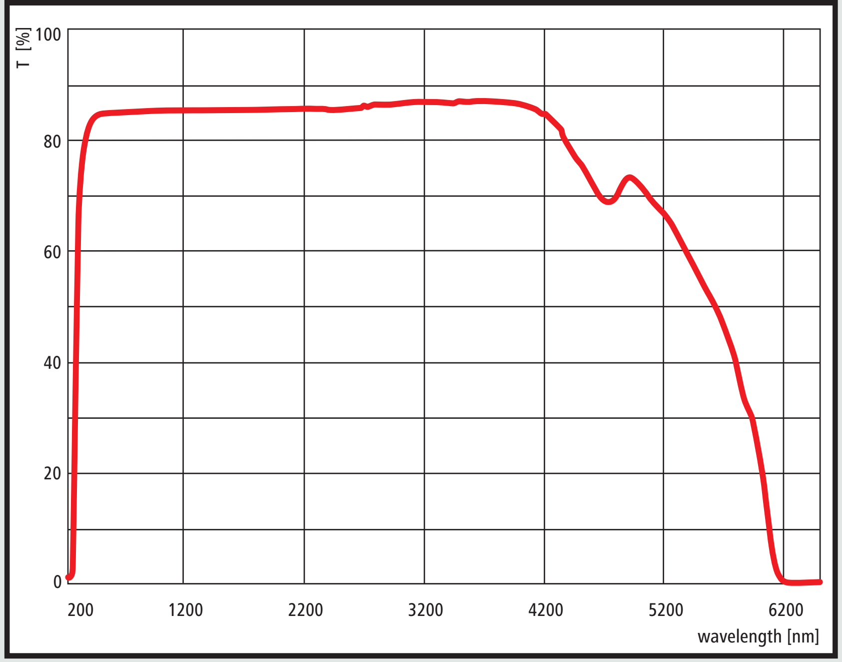
1) Registered trademark of Heraeus Quarzglas GmbH & Co. KG
2) Registered trademark of SCHOTT AG
3) Absorption band within this wavelength range, please see transmittance curve
4) Measurable effects only in the VUV wavelength range
5) The values given here are rounded, because the measurements of different authors in the literature are inconsistent.
Please note that the thermal expansion coefficient of crystals depends also on the crystal orientation.

All values are for informational purposes only. LAYERTEC cannot guarantee the correctness of the values given.

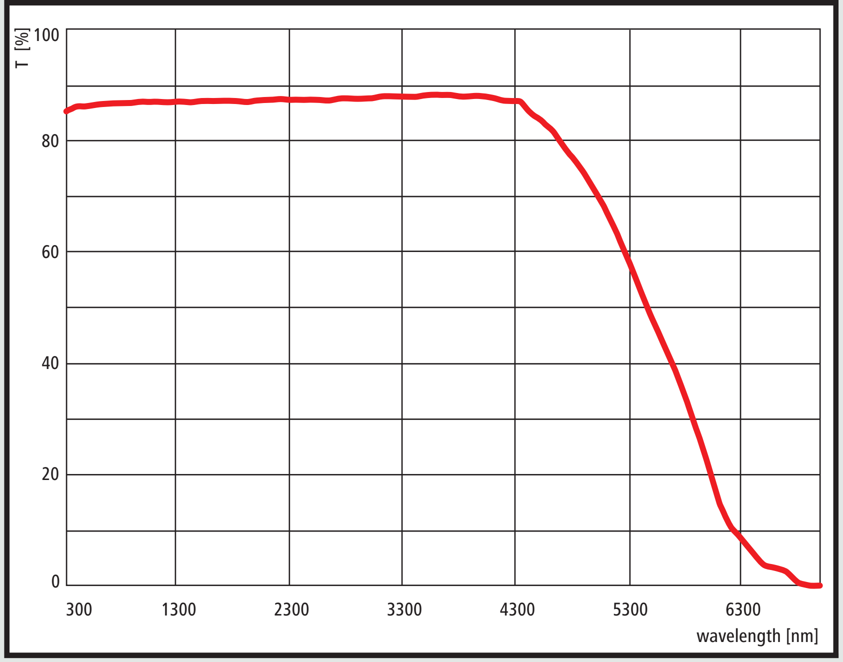
TRANSMITTANCE CURVES



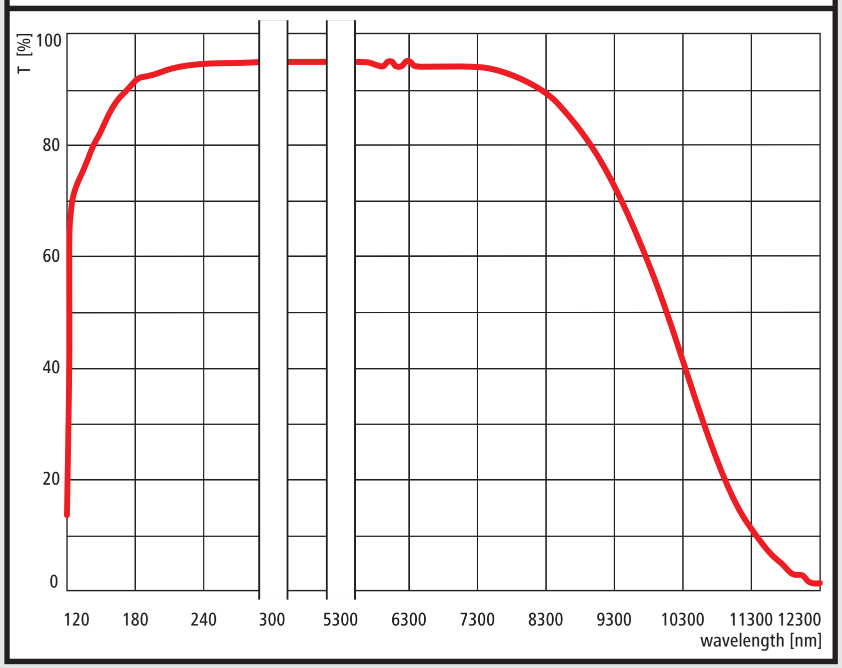
YAG undoped (3 mm thick)



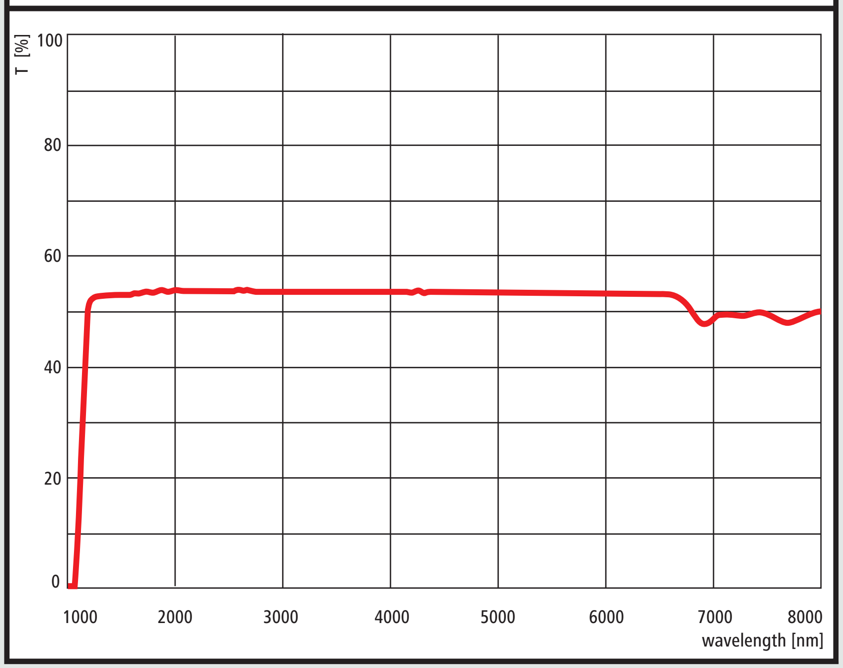
Sapphire (3 mm thick)



Calcium fluoride (3 mm thick)



Silicon (3 mm thick)



MEASUREMENT TOOLS FOR PRECISION OPTICS

DEVIATIONS FROM THE IDEAL SURFACE

Any machined substrate exhibits deviations from its theoretical design. The effect of these deviations on the optical funcionality of the optics can be categorized with respect to the spatial dimension of the deviations.

The inverse length of this spatial dimension – the spatial frequency – is used to mathematically describe the different kinds of deviations. A rough classification of deviations distinguishes between Form (low spatial frequencies), Waviness (mid-spatial frequencies) and Roughness (high spatial frequencies).

Form deviations affect the wavefront of the passing light while leaving the direction of propagation nearly unchanged. They lead to a distortion of the image or a significant alteration of the focal intensity distribution near the optical axis.

Waviness deviations also conserve the total energy of the propagating beam but mainly affect focal regions away from the optical axis. For example, periodical deviations in this frequency band can give rise to the formation of parasitic secondary foci.

Finally, Roughness affects the propagating wavefront on spatially small regions. These disturbances lead to an effective scattering of energy off the direction of the main beam. Thus, there is a widespread intensity background resulting in a reduction of image contrast.

A quantitative distinction of Form, Waviness and Roughness involves different optical and geometrical parameters, mainly the operating wavelength as well as numerical aperture and focal length. Thus, the same surface deviation may lead to a significantly different optical behavior when used in different applications.

SURFACE FORM MEASUREMENT

For the measurement of surface form and regularity, the precision optics facility of LAYERTEC is equipped with laser interferometers and special interferometer setups for plane, spherical and parabolic surfaces. Additionally, a tactile measurement device (Taylor Hobson PGI 1240 Asphere) is available for general aspheric and ground surfaces. Besides the purpose of quality control, surface form measurement is a key function for the zonal polishing technology established at LAYERTEC.

Abbreviations

- **P-V:** The peak-to valley height difference
- **ROC:** Radius of curvature of a spherically curved surface.
- **λ**: measurement wavelength of the laser interferometer (e.g. 546 nm). The P-V value is stated in a fractional amount of λ. The actual value of λ is stated in measurement reports.

For detailed information about the standards concerning surface form measurement please see ISO 10110-5.

Accuracy of interferometric measurements

Without special calibration procedures, the accuracy of an interferometric measurement is only as accurate as the reference surface. Calibration can increase the accuracy by a factor of 2 or more. Furthermore, the precision is influenced by the size of the measured area and in case of a curved surface by the radius of curvature itself. The accuracy values stated as "P-V better than …" in the following articles are guaranteed values. Very often accuracies of λ / 20 or better will be achieved.

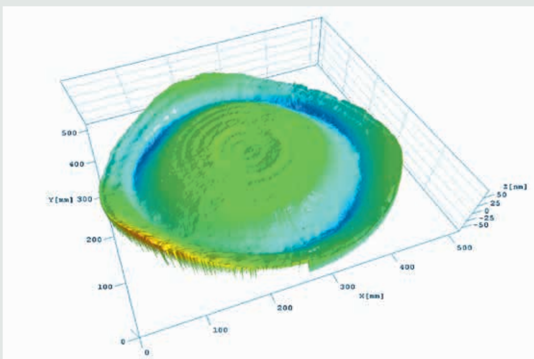


Figure 1: Height map of a flat surface with a diameter of Ø = 520 mm polished and measured at LAYERTEC. The P-V value is λ / 10 over the full aperture (Ø = 500 mm inspection area) after zonal correction.

Standard measurements

In general, the form tolerance of spherical and plane optics with diameters Ø ≤ 100 mm can be measured with an accuracy of P-V better than λ / 10 by using ZYGO Fizeau interferometers. To cover a measurement range of ROC = ± 1200 mm over an aperture of Ø = 100 mm, LAYERTEC uses high precision JenFIZAR Fizeau objectives. In many cases, a higher accuracy up to P-V = λ / 30 is possible. Measurement reports can be provided on request.

Large Radius Test (LRT)

Surfaces with radii of curvature beyond ± 1200 mm are tested with a special Fizeau zoom lens setup called Large Radius Test (LRT). This setup was developed by DIOPTIC GmbH in cooperation with LAYERTEC.
Its operating range is ROC = ± 1000 mm … ± 20.000 mm at working distances lower than 500 mm. The accuracy is guaranteed as P-V = λ / 8 over Ø ≤ 100 mm, but typically it is better than P-V = λ / 15. LRT has the advantages that only one Fizeau-objective is needed to cover a wide range of radii of curvature and that the working distance is kept small. This reduces the influence of disturbing air turbulences during the measurement.

Large aperture interferometry

For laser optics with large dimensions, LAYERTEC uses high performance interferometers. A wavelength-shifting Fizeau interferometer (ADE Phaseshift MiniFIZ

300®) is used for flat surfaces. LAYERTEC has enlarged the measurement aperture of the system with a special stitching setup. The measurement range of the system is:

- P-V up to λ / 50 (633 nm) at Ø ≤ 300 mm with a full aperture measurement
- P-V better than λ / 10 (633 nm) at Ø ≤ 600 mm with a special stitching measurement setup. See Figure 1 for an exemplary measurement on Ø 520 mm.

The interferometric measurements of spherical concave surfaces are carried out using a Twyman-Green interferometer (PhaseCam 5030®; 4D-Technology). This interferometer uses a special technology which allows measurement times in the region of a few milliseconds. Therefore, the interferometer is insensitive to vibrational errors when measuring over long distances up to 20 m between the device and the specimen. The measurement accuracy of the system is P-V better than λ / 10 at Ø ≤ 600 mm with a full aperture measurement (in case of concave surfaces).

SURFACE ROUGHNESS MEASUREMENT

In many applications, scattered light represents a crucial restriction to the proper operation of an optical device. For one thing, scattered light reduces the intensity of the light propagating through the system, leading to optical losses. It also leads to a noise background of light reducing the overall contrast of imaging optics.
The amount of scattered light produced by an optic is mainly determined by its surface roughness. Thus, requirements to the surface roughness are often necessary to guarantee the proper operation of a device.
For a quantitative comparison, the RMS roughness is a widely-used measure to specify optical surfaces. It is defined as the root mean square of the surface height profile z:

$$Rq = \sqrt{\frac{1}{L}\int z^2(x)\,dx}, \quad Sq = \sqrt{\frac{1}{A}\iint z^2(x,y)\,dxdy}$$

Here the letter 'R' indicates line scans according to ISO 4287-1 while the letter 'S' refers to a scan on a two-dimensional base area as described in ISO 25178-2. The scan field size (maximum spatial frequency) as well as the resolution of the measurement setup (minimum spatial frequency) affect the numerical value of Rq and Sq. For that reason, the specification of an RMS roughness value requires the specification of the underlying band of spatial frequencies as well. Often, technical drawings are lacking information on the frequency band and thus become meaningless.

By using the power spectral density (PSD) of a surface, the distribution of the surface roughness with respect to the spatial frequencies becomes obvious. The RMS value of a surface simply follows from integration of the PSD over the given spatial frequency band. Generally, the scattered light of optical surfaces produced for the NIR, VIS and UV spectral range is dominated by spatial frequencies ranging from 0.01 to 10 μm^{-1}.

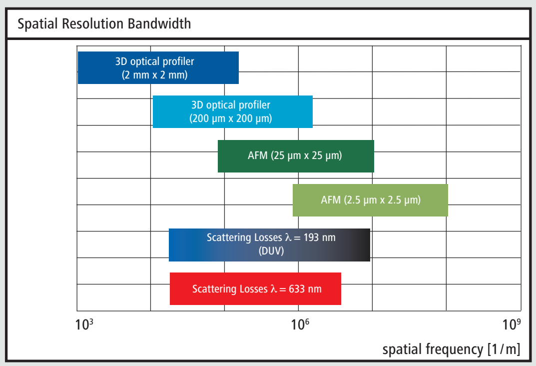


Figure 2: Spatial frequency resolution of AFM and 3D optical surface profiler at LAYERTEC for typical scan sizes. Additionally, the figure shows the spatial frequency ranges which influence the scattering losses in the VIS and DUV spectral range.

At LAYERTEC, a phase shifting optical surface profiler (Sensofar) and a scanning probe microscope (AFM) DI Nanoscope 3100 are used to cover the given frequency band (see fig. 2). The optical profiler covers low spatial frequencies and has an aquisition time of a few seconds. It is used for the general inspection of the polishing process and is able to identify surface defects and inhomogeneities. The AFM addresses high spatial frequencies using scan field sizes of 2.5 x 2.5 µm² and 25 x 25 µm² and has an aquisition time of 10 to 30 minutes. Therefore, it is used primarily for the development of polishing processes. It further serves to monitor the LAYERTEC premium-polishing process and especially optics for UV applications with Sq < 2 Å (spatial bandwidth: 7 - 1200 nm) with respect to quality control. Measurement reports are available on request.

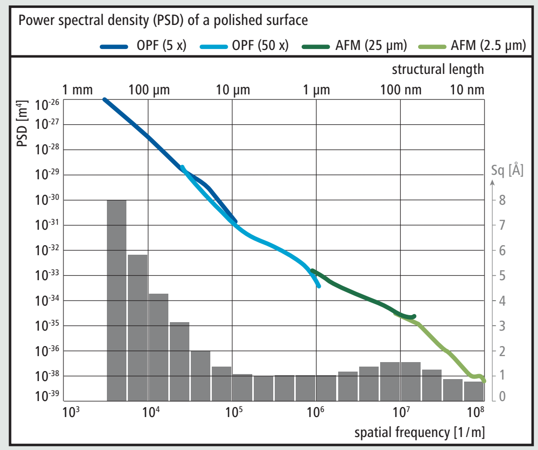


Figure 3: PSD of a LAYERTEC standard polish obtained by combining measurements using AFM and optical profiler. The right axis shows Sq values on a logarithmic grid over spatial frequencies. To obtain the total roughness Sq_{tot} over multiple bars Sq_i, square values have to be added $Sq_{tot}^2 = Sq_1^2 + Sq_2^2 + \ldots$

For more information on scattering losses please see: A. Duparré, "Light scattering on thin dielectric films" in "Thin films for optical coatings", eds. R. Hummel and K. Günther, p. 273 – 303, CRC Press, Boca Raton, 1995.