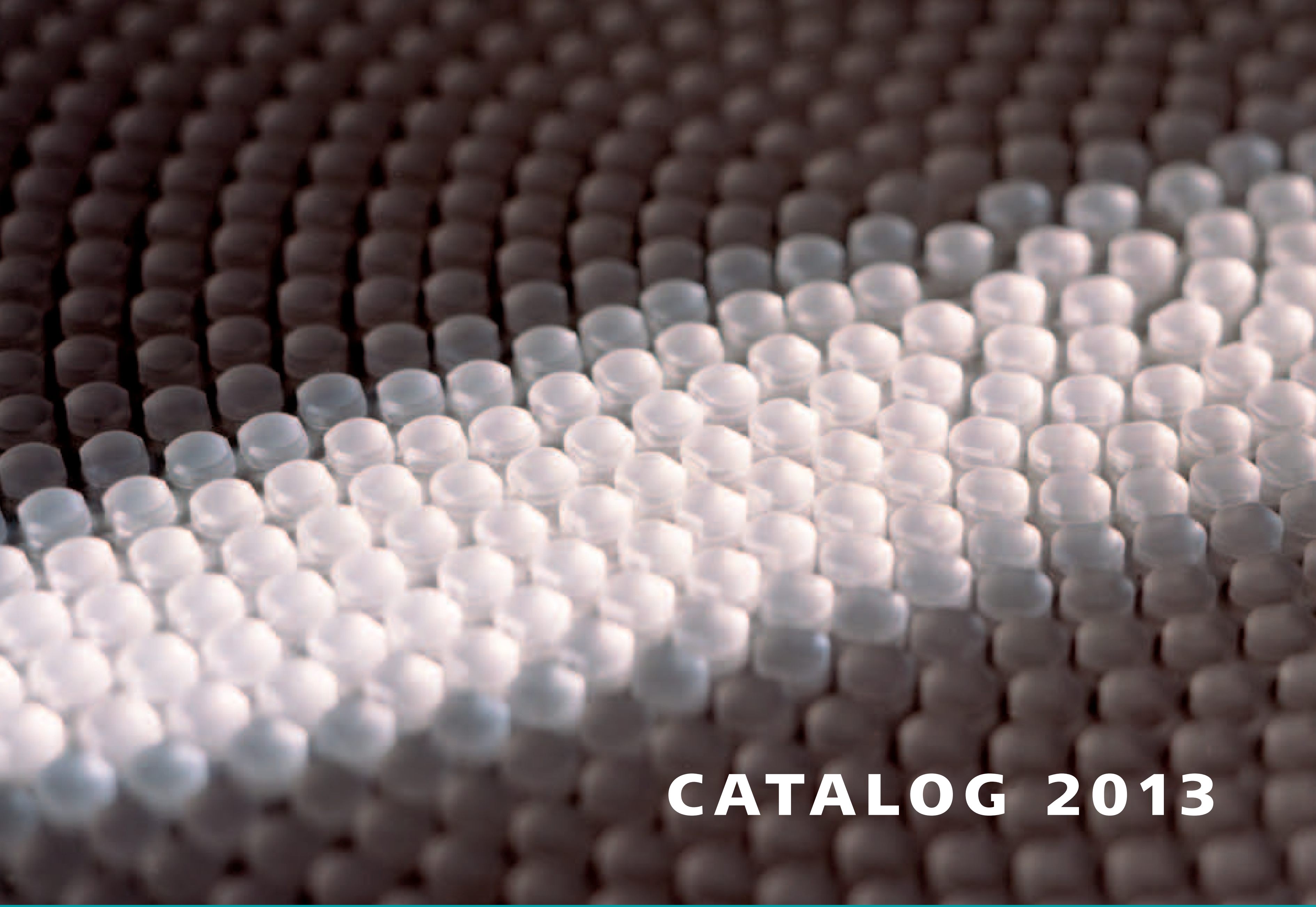
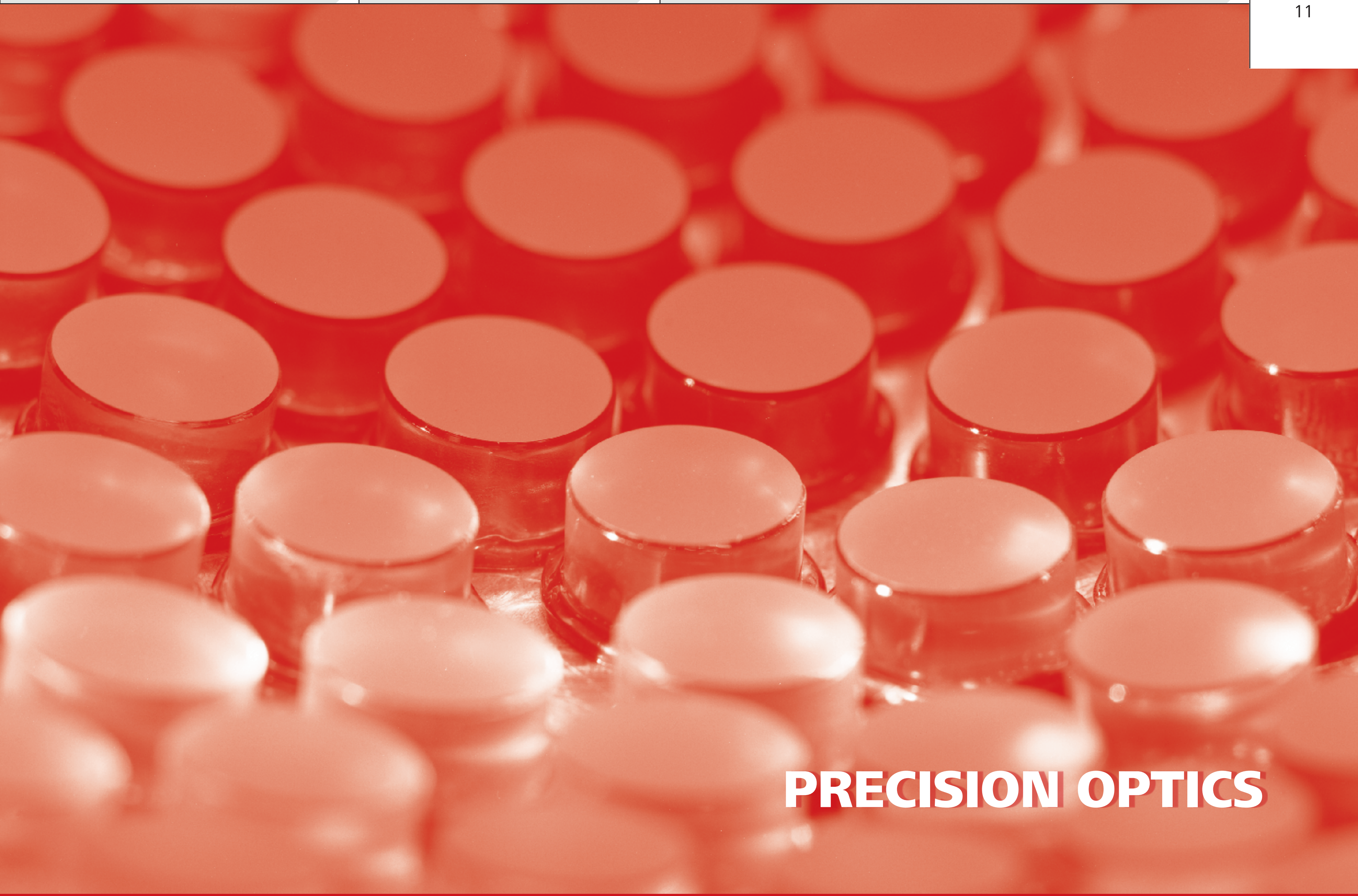


CATALOG 2013

LAYERTEC®
OPTICAL COATINGS · OPTICS

CONTENTS



PRECISION OPTICS

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 transmission. If no transmission 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. Basically all combinations of plane, convex and concave surfaces are possible. A special role plays the wedge. A wedge (e.g. 30 arcmin) can be applied 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 "+" and "-" to the light propagation. In this case "+" means "curvature with the direction of propagation", "-" means "curvature against the direction of propagation". To avoid confusion please specify concave or convex in words or by the acronyms CC or CX, respectively.

SIZE

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

Although often specified otherwise in optical designs the thickness description means 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.

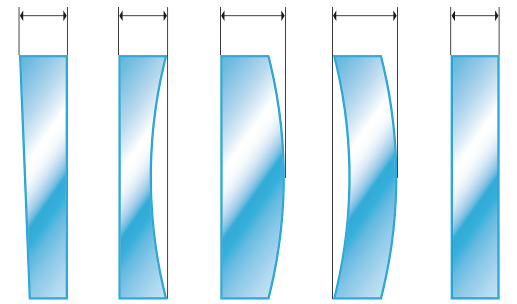


Figure 1: Conventions for the specification of the thickness of different types of substrates (schematic drawing)

In order to achieve a good form tolerance one should take care for the ratio of diameter and thickness. As a rule of thumb the thickness should be the fifth part of the diameter. Of course, other ratios are possible but the production expenditure increases.

TOLERANCES

Besides size and material the tolerances are most important for manufacturing costs and therefore also for the price. Of course, the optics must fit into the mount, so that the diameter should not be larger than specified. The most common specification is +0-0.1 mm. Mostly, the thickness is 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).

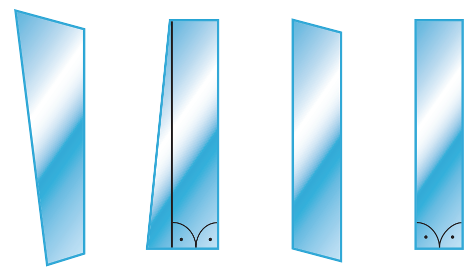


Figure 2: Different kinds of plane substrates with respect to wedge and centering (schematic drawing)

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.
Normally, the 90° angle to the side surface has a precision of 20 arcmin. Centering is an additional optics processing step which improves this accuracy to a few arcmin.
Using the same nomenclature one can describe curved substrates. It should be distinguished between mirrors and lenses. The side surfaces of mirror substrates are just parallel. Nevertheless the direction of the optical axis can be inclined to the side surfaces. After centering the side surfaces are parallel to the optical axis. In that way the mirror substrate becomes a lens.

SURFACE FORM TOLERANCE

The surface form tolerance is normally measured by interferometers and is specified in terms of lambda, which is the reference wavelength. Without further statements the reference wavelength is λ = 546 nm. To avoid confusion, one must 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 two best fitted spheres for the "peaks" and "valleys". The sagitta of this curvature with respect to an ideal plane 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 of the best fitted spheres, which is named irregularity. This is the most important value for the quality of the beam.

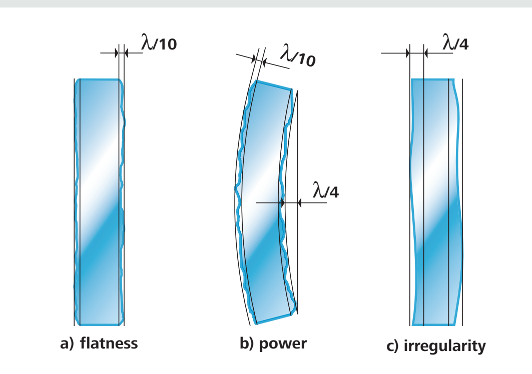


Figure 3: Schematic drawing for the explanation of substrate properties:
a) flatness of λ/10
b) spherical bending (power of λ/4)
c) irregularity of λ/4, but transmitted wavefront of λ/10

The standard ISO 10110 provides a sufficient opportunity for specifying the surface form tolerance. Having the best comparability with the measurement results all values are specified as numbers of interference fringes. They should be read as 1 fringe = λ/2. In the drawings 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 transmission (e.g. laser windows) the power as well as the irregularity do not matter. If the optics has the same thickness all over the free aperture an uprightly transmitted beam is not affected. The deviation from this equality is defined in a similar way as the flatness. It is also measured in parts of the reference wavelength and called "transmitted wavefront". For instance, the window in fig. 3c has a flatness of λ/4 but a transmitted wavefront 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.
Taking the mentioned values seriously the flatness becomes poor. Nevertheless the quality of a normally incident beam is not affected.

DEFECTS

MIL-O-13830 and ISO 10110 are different standards for the description of optical elements. This often causes obscurities. Basically, one should distinguish between scratches and digs. The scratch number in MIL-O-13830 means 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 seriously. 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 means the maximum dig diameter in hundredths of a millimeter. Maximum size digs can be one per 20 mm of diameter. According to ISO 10110 the defects are specified as item number 5. The grade number means the side length in millimeters of a quadratic area which is equivalent to the total fault area. So 5/1 x 0.025 means a surface fault area of 0.000625 mm². 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 correspond to ISO 10110. The mentioned scratch/dig values are a rough analog 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 SF14® 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.

STANDARD SPECIFICATIONS

Materials

- Fused silica:
  Corning 7980® or equivalent
- Fused silica for high power applications:
  Suprasil® 300 / 3001 / 3002 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, random oriented, special orientations on request, excimer grade (248 nm and 193 nm) on request
- Sapphire:
  single crystal, random oriented, special orientations on request
- YAG:
  undoped, single crystal, random oriented

All trademarks mentioned are the property of the respective owners.

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

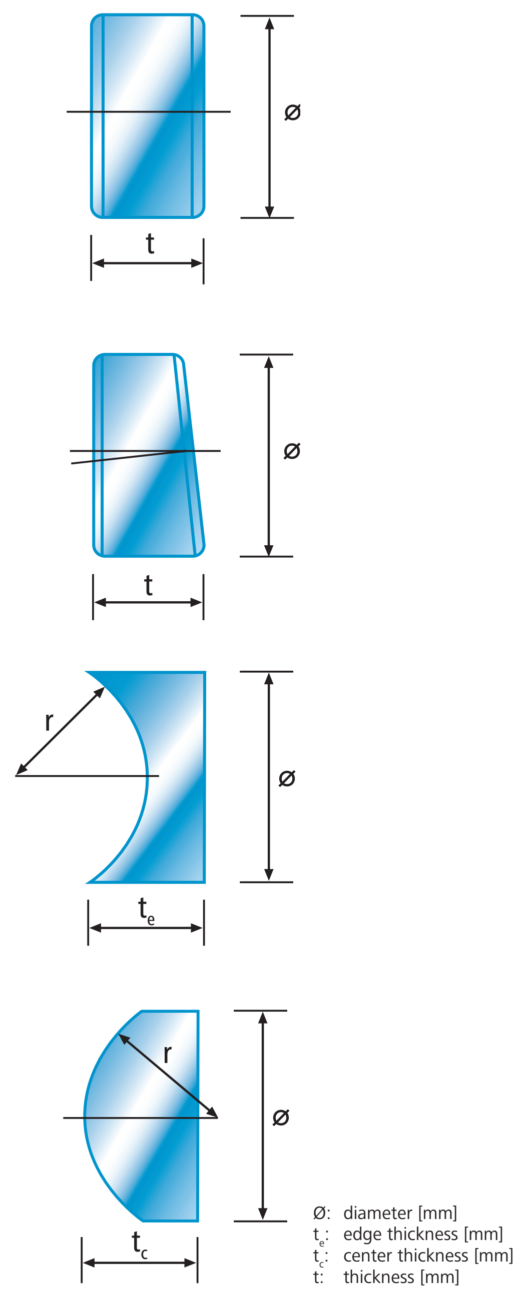
- Standard radii:
  25, 30, 38, 50, 75, 100, 150, 200, 250, 300, 400, 500, 600, 750, 1000, 2000, 3000, 4000, 5000 mm

Dimensions

- Fused silica, ULE®, Zerodur®, N-BK7®:
  diameter 6.35 mm … 508 mm (¼ inch … 20 inches)
- Calcium fluoride, YAG, sapphire:
  diameter 6.35 mm … 50.8 mm (¼ inch … 2 inches)
- 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: 633nm)

Material		Standard Specification	On request
Fused silica	plane spherical	λ/10 λ/4 reg. (typical λ/10 reg.)	λ/30 λ/30 reg. (Ø<51 mm)
ULE® and Zerodur®	plane spherical	λ/10 λ/4 (typical λ/10 reg.)	λ/30 λ/30 reg. (Ø<51 mm)
N-BK7®	plane spherical	λ/10 λ/4 reg. (typical 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/10 λ/10 λ/10 reg.
Sapphire		λ/2	λ/10
YAG	plane spherical	λ/10 λ/4 reg. (typical λ/10 reg.)	λ/20 λ/20 reg. (Ø<51 mm)
Si	plane spherical	λ/10 λ/4 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 0.001 Scratch-Dig 10-3	< 1,2 Å	5/1 x 0.010 L1 x 0.0005 Scratch-Dig 5-1
ULE®	< 2 Å	5/3 x 0.025 L1 x 0.001 Scratch-Dig 10-5	< 2 Å	5/1 x 0.010 L1 x 0.0005 Scratch-Dig 5-1
Zerodur®	< 4 Å	5/2 x 0.040 L1 x 0.001 Scratch-Dig 10-5	< 3 Å	5/2 x 0.025 L1 x 0.0010 Scratch-Dig 10-3
N-BK7®	< 3 Å	5/2 x 0.040 L1 x 0.001 Scratch-Dig 10-5	< 3 Å	5/2 x 0.025 L1 x 0.0010 Scratch-Dig 10-3
CaF_2	< 4 Å	5/3 x 0.025 L1 x 0.0025 Scratch-Dig 20-3	< 3 Å	5/3 x 0.016 L1 x 0.0010 Scratch-Dig 10-2
Sapphire	< 5 Å	5/3 x 0.025 L20 x 0.0025 Scratch-Dig 20-3	< 3 Å	5/3 x 0.016 L1 x 0.0010 Scratch-Dig 10-2
YAG	< 3 Å	5/1 x 0.025 L2 x 0.0025 Scratch-Dig 20-3	< 3 Å	5/1 x 0.010 L1 x 0.0005 Scratch-Dig 5-1
Si	< 3 Å	5/3 x 0.025 L1 x 0.001 Scratch-Dig 10-5	< 2 Å	5/1 x 0.010 L3 x 0.0005 Scratch-Dig 5-1

All specifications according to ISO 10110 (Ø 25mm). The mentioned Scratch-Dig values are approximately equivalent to MIL-O-13830

ASPHERES, OFF-AXIS AND FREE FORM OPTICS

BASICS

Plane and spherical optics can be efficiently manufactured using traditional techniques of area grinding and polishing. The tool always works on a significant fraction of the substrate area at once. It is not or only hardly possible to manufacture surface geometries that differ from regular forms like planes, spheres, 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.

The non-spherical optics can be divided in three groups. Rotational symmetric non-spheric, off-axis and free form optics.

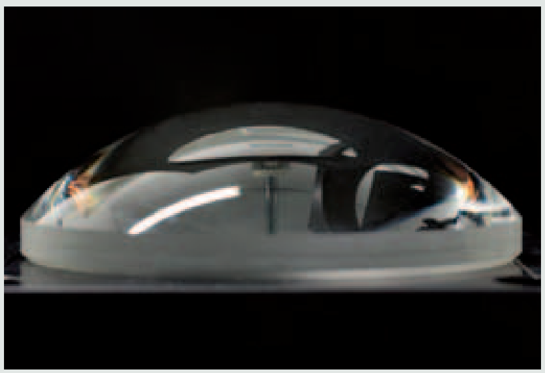


Figure 1: Aspheric lens

ROTATIONAL SYMMETRIC NON SPHERICAL OPTICS (ASPHERES)

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

$$z(r) = \frac{r^2}{R\left[1 + \sqrt{1 - (1+k)\frac{r^2}{R^2}}\right]} + A_4 r^4 + A_6 r^6 + \ldots$$

z = displacement
k = conic constant
r = distance from axis
R = radius of curvature
A_i = aspheric coefficients

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

- Ellipse: $-1 < k < 0$
- Sphere: $k = 0$
- Parabola: $k = -1$

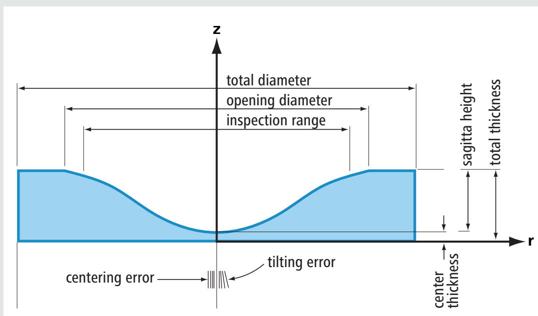


Figure 2: Profile of an aspheric mirror

	Dimension	Tolerances
Total diameter	25 … 560 mm	< 0.1 mm
Inspection range	< 550 mm	
Total thickness	< 100 mm	< 0.1 mm
Displacement	< 50 mm	
Centering error		< 50 µm
Tilting error		< 30''
Surface form tolerance		< λ/4 (< λ/10 on request)
Roughness		< 3 Å

Table 1: Production dimensions and tolerances

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.

Examples:

- Off-axis parabolas
- Off-axis ellipses
- Off-axis hyperbolas
- Off-axis spheres
- Off-axis cylinders

Example: Off-Axis Parabola (OAP)

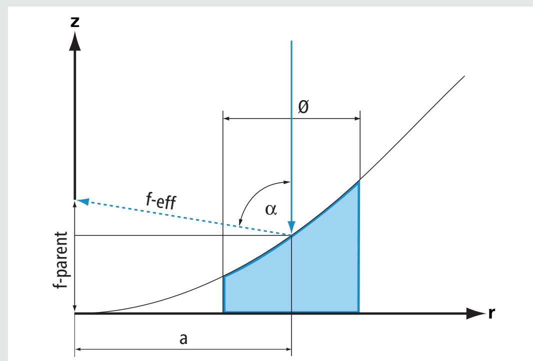


Figure 3: Schematic drawing of an off-axis parabola

The focal length of the parent parabola (parent focal length) is measured from the vertex on the optical axis. For the off-axis parabola, an effective focal length $\mathbf{f}_{eff}$ 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.

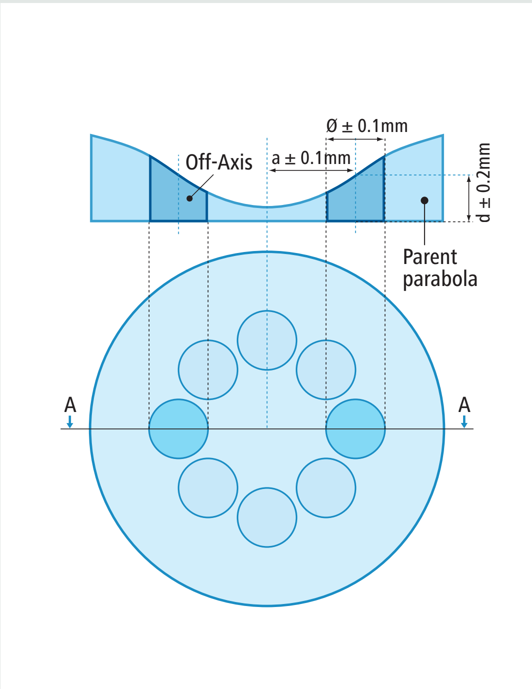


Figure 4: Manufacturing off-axis parabolas as pieces of one "parent parabola"

FREE FORM SURFACES

Free form surfaces are always customer specific, defined by a number of points or equations. No symmetry may be assumed. Free form surfaces are manufactured as single pieces.
Table 2 shows LAYERTEC's production dimensions and tolerances for free form surfaces.

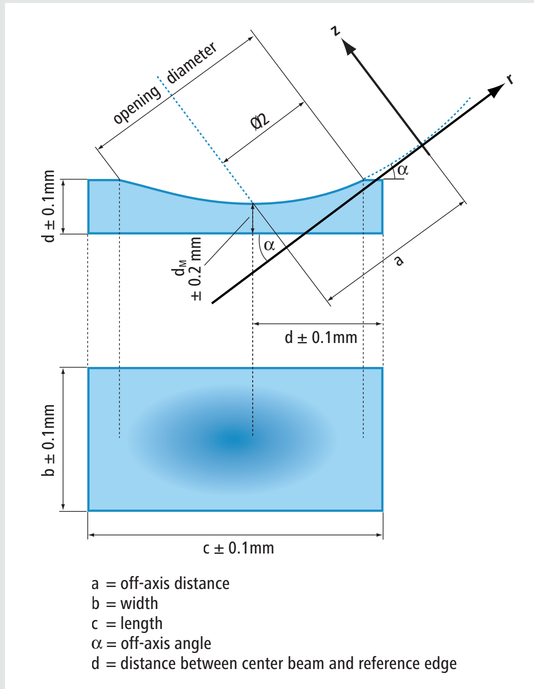


Figure 5: Basic properties of a free form substrate

	Dimension	Tolerances
Ø	< 150 mm (< 200 mm on request)	0.2 mm
b	< 150 mm	0.1 mm
c	< 250 mm	0.1 mm
α	< 45°	
d	< 60 mm	0.1 mm
a		
Surface form tolerance		< λ/2 (λ/4 on request)
Roughness		< 3 Å

Table 2: Dimensions and tolerances of free form substrates

MATERIALS

The surface quality as well as the final tolerances depend very strongly on the material of the substrate. LAYERTEC has an optimized process for fused silica.
In special cases materials like Zerodur®, ULE® or N-BK7® may be used.

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. Measures one line 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 a diameter of 420 mm.
- **Interferometer with reference surface**
  Compares the surface to a well known reference surface. Precision < 50 nm, diameter 300 mm. Preferably concave surfaces.
- **Interferometer with hologram**
  Compares the surface to the wavefront which is generated by a computer generated hologram (CGH).

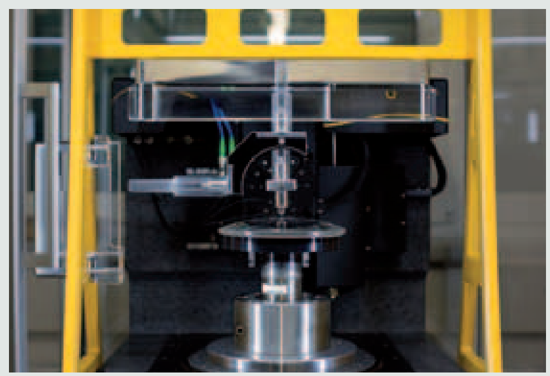


Figure 6: LuphoScan single point interferometer

SPECIAL OPTICAL COMPONENTS

ETALONS

In optics, the etalon as a kind of a Fabry-Pérot interferometer is typically made of a transparent plate with two reflecting surfaces. Its transmission spectrum as a function of wavelength exhibits peaks of large transmission corresponding to resonances of the etalon. Etalons are widely used in telecommunications, lasers and spectroscopy for controlling and measuring the wavelength of laser sources.

LAYERTEC offers etalons of various materials and customized diameters depending on the wavelength range. Subject to the diameter thicknesses down to 50 µm and a parallelism < 1 arcsec are possible. 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 the minimal required thickness the below mentioned wave plates are available:

Order	Ø = 38 mm	Ø = 25 mm	Ø = 12.7 mm	Precision	Parallelism
λ/2	**Available wavelenghts**				
K=0	——	——	λ = 900 nm	±1 µm	< 1 arcsec
K=1	λ = 900 nm	λ = 800 nm	λ = 350 nm	±1 µm	< 1 arcsec
K=2	λ = 550 nm	λ = 500 nm	λ = 300 nm	±1 µm	< 1 arcsec
λ/4	**Available wavelenghts**				
K=1	λ = 1060 nm	λ = 940 nm	λ = 400 nm	±1 µm	< 1 arcsec
K=2	λ = 620 nm	λ = 530 nm	λ = 300 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. Besides rectangular substrates, wedges and prisms uncommon optics are possible.
Typical issues are defined holes through the optics. So called D-cuts and notches can be produced.

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, ZGP or LBO. Our polishing technology also allows us the careful handling and processing of small crystal sizes or extraordinary forms. Do not hesitate to contact us for your special problem.

LARGE SCALE OPTICS

LAYERTEC has built up a production line for plane and spherical optics up to a diameter of 500 mm. The production line also includes interferometers. Measurements for large optics are described on page 22. These optics can be coated using magnetron sputtering. The main products are large scale laser mirrors. A coating uniformity of ± 0.5 % was demonstrated which enables also the production of large scale thin film polarizers and other complex coating designs.

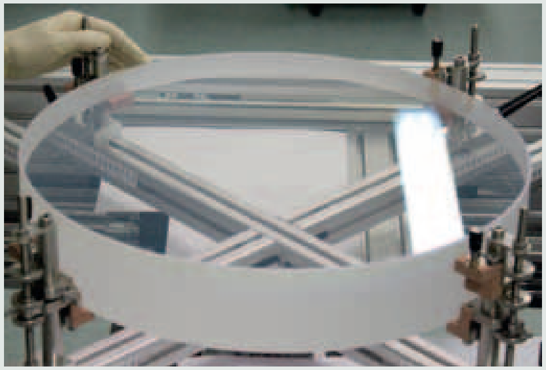


Figure 1: Mirror substrate with a diameter of 500 mm

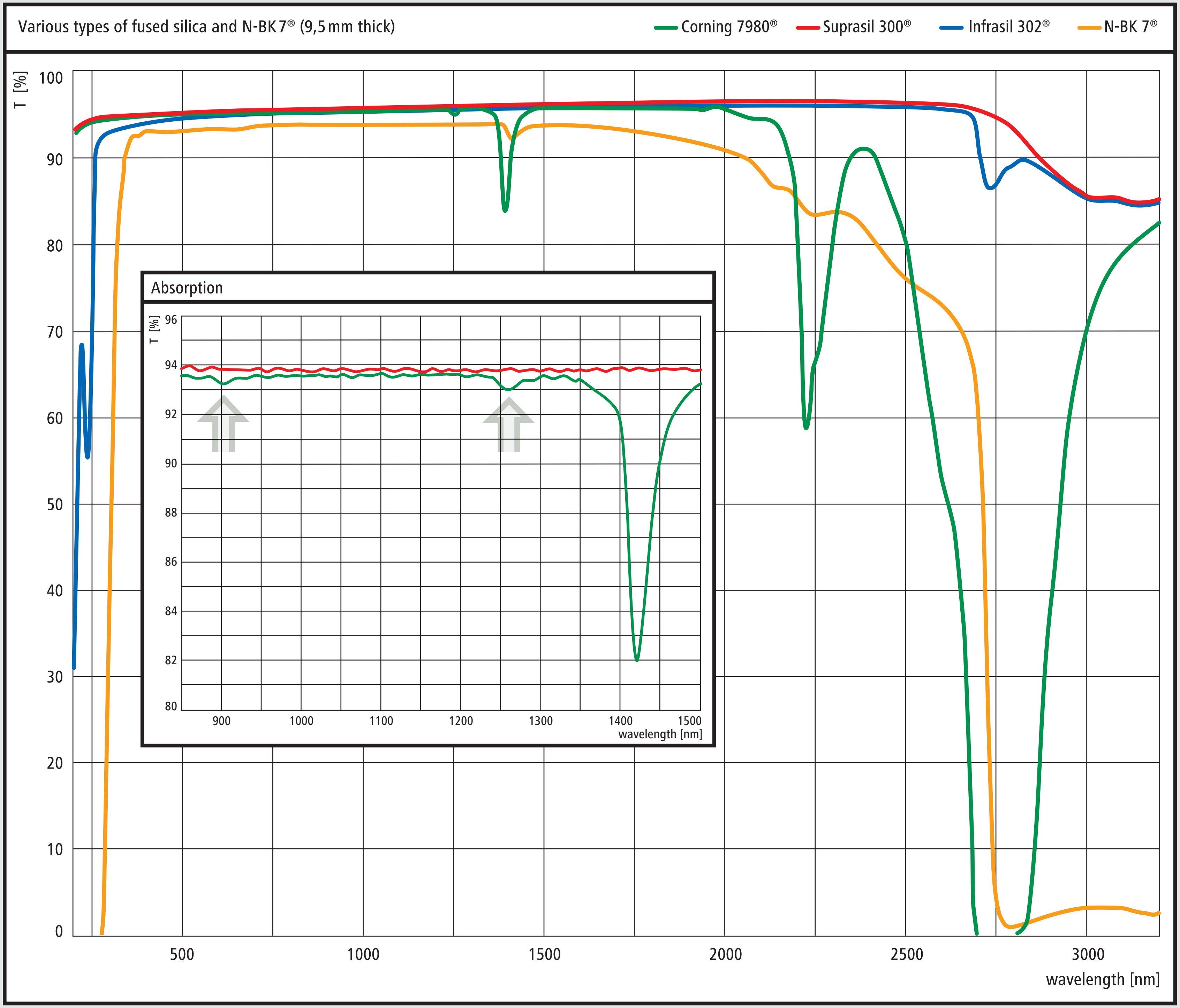
SUBSTRATE MATERIALS FOR UV, VIS AND NIR/IR OPTICS

	YAG (undoped)	Sapphire	BaF_2	CaF_2	Infrasil®1)	Fused silica (UV)	N-BK7®2)	SF10®2)
Wavelength range free of absorption	400 nm – 4 µm	400 nm – 4 µm	400 nm – 10 µm	130 nm – 7 µm	300 nm – 3 µm	190 nm – 2.0 µm[3]	400 nm – 1.8 µm	400 nm – 2.0 µm
Refractive index at								
200 nm				1.49516		1.55051		
300 nm				1.45403		1.48779		
500 nm	1.8450	1.775	1.479	1.43648	1.46233	1.46243	1.5214	1.7432
1 µm	1.8197	1.756	1.468	1.42888	1.45042	1.45051	1.5075	1.7039
3 µm	1.7855	1.71	1.461	1.41785	1.41941			
5 µm		1.624	1.451	1.39896				
9 µm			1.408	1.32677				
Absorbing in the 3 µm region	no	no	no	no	yes	yes	yes	yes
Absorbing in the 940 nm region	For high power applications at 940 nm we recommend the fused silica types SUPRASIL 300®1) and SUPRASIL 3001/3002®1)							
Birefringence	no	yes	no	no[4]	no	no	no	no
Thermal expansion coefficient $[10^{-6} K]$ [5]	7	5	19	18	0.5	0.5	7	8
Resistance against temperature gradients and thermal shock	high	high	very low	low	high	high	medium	medium
GDD fs^2 per mm								
400 nm	240	150	90	68	98	98	120	640
800 nm	97	58	38	28	36	36	45	160
1064 nm	61	29	26	17	16	16	22	100
1500 nm	13	-25	13	1,9	-22	-22	-19	38
2000 nm	-59	-120	-2,4	-21	-100	-100	-99	-36
TOD fs^3 per mm								
400 nm	75	47	27	19	30	30	41	500
800 nm	57	42	20	16	27	27	32	100
1064 nm	71	65	22	21	44	44	49	100
1500 nm	140	180	34	46	130	130	140	140
2000 nm	360	530	72	120	450	450	460	350

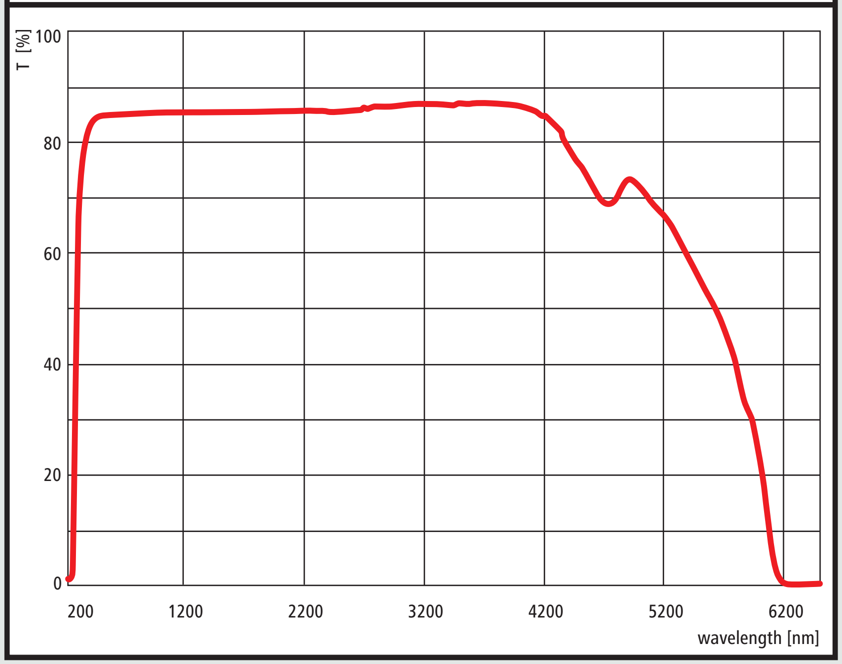
1) Registered trademark of Heraeus Quarzglas GmbH & Co. KG
2) Registered trademark of SCHOTT AG
3) Absorption band within this wavelength range, please see transmission curve
4) Measurable effects only in the VUV wavelength range
5) The values given here are rounded, because the measurements of different 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 can not guarantee the correctness of the values given.

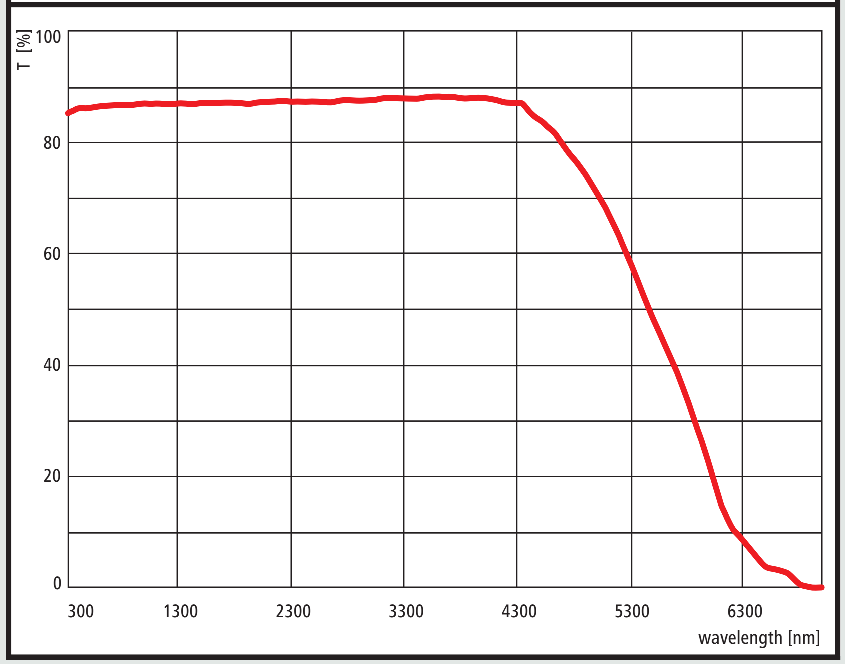
TRANSMISSION CURVES



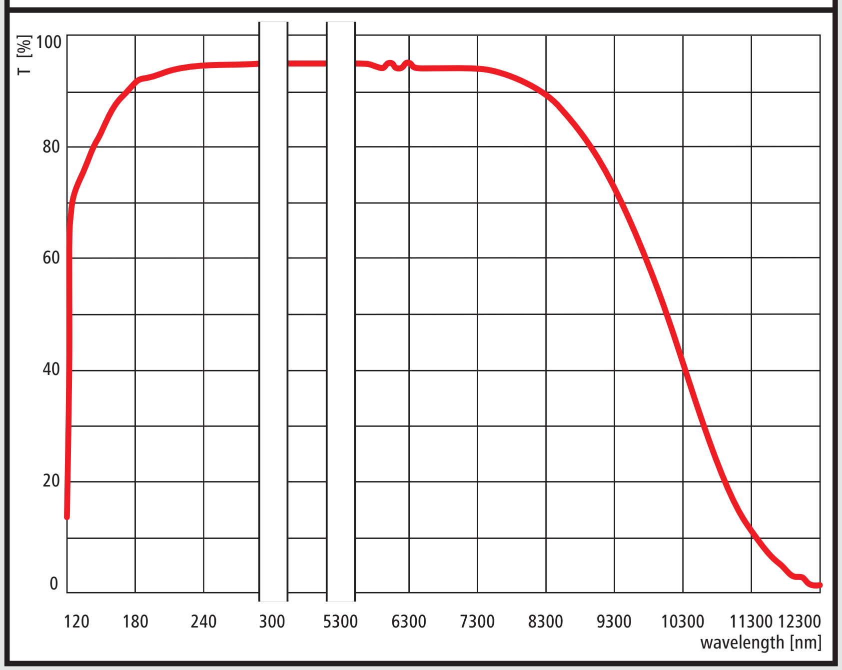
YAG undoped (3 mm thick)



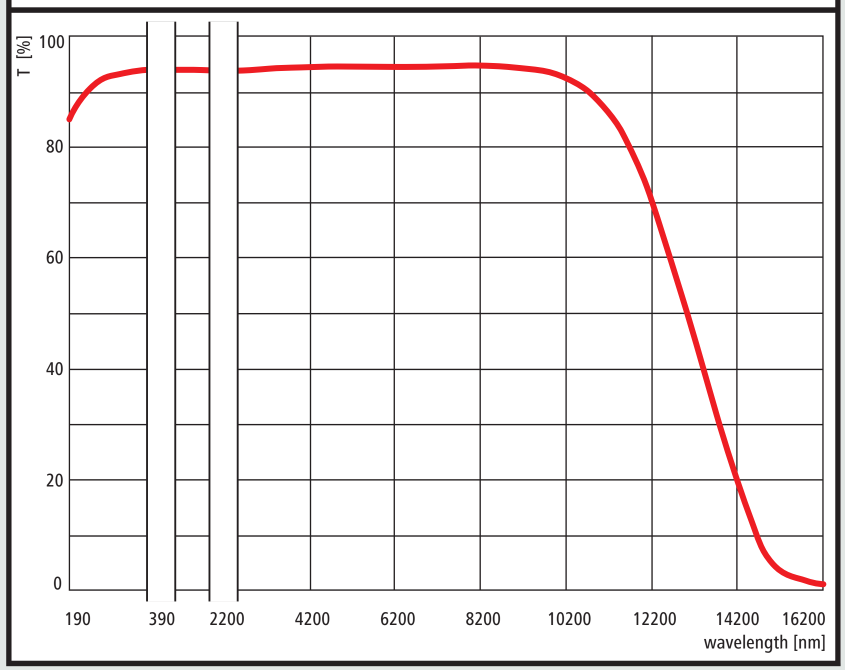
Sapphire (3 mm thick)



Calcium fluoride (3 mm thick)



Barium fluoride (3 mm thick)



MEASUREMENT TOOLS FOR PRECISION OPTICS

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, spherically and parabolically curved surfaces. Additionally, a tactile measurement device (Taylor Hobson PGI 1240 Asphere) is available for general aspheric and grinded surfaces. Besides the purpose of quality control, surface form measurement is a key function for the zonal polishing technology which is established at LAYERTEC.

Abbreviations

- **P-V:** The peak-to valley height difference
- **ROC:** Radius of curvature of a spherically curved surface.
- **λ**: measuring wavelength of the laser interferometer (e.g. 633 nm or 546 nm). The P-V value is stated in a fractional amount of λ. The concrete value of λ is stated in our protocols.

For detailed information about the standards concerning surface form measurement please refer to DIN EN ISO 10110-5.

Accuracy of interferometric measurements

Without special calibration procedures, the accuracy of an interferometric measurement cannot be better than the accuracy of the reference surface. With calibration the accuracy can be increased by factor 2 or more. Furthermore the precision is influenced by the size of the region (clear aperture) which is measured, and when it is about curved surfaces, by the radius of curvature itself. The accuracy values stated as "P-V better than …" in the following articles are minimum guaranteed values. Very often accuracies in the region of λ/20 or better will be achieved.

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 protocols 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 P-V = λ/8 over Ø ≤ 100 mm, but typically 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 (thus disturbing air turbulences during the measurement are kept small).

Large aperture interferometry

Especially 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.

Figure 1 shows the height map of a flat surface with a diameter of Ø = 520 mm which was measured with the MiniFIZ 300 interferometer and the stitching configuration at LAYERTEC.

The measurements of spherically curved concave surfaces are carried out with a Twyman-Green interferometer (PhaseCam 5030® from 4D-Technology). This interferometer uses a special technology which allows measurement times in the region of a few milliseconds. Thus, the interferometer is insensitive to vibrational errors when measuring over long distances up to 20m 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).

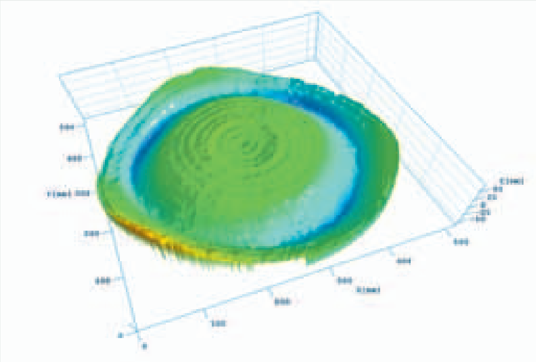


Figure 1: Height map of a flat surface with a diameter of Ø = 520 mm polished and measured at LAYERTEC. The P-V value is λ/10 over the full aperture (Ø = 500 mm inspection area) after zonal correction.

SURFACE ROUGHNESS MEASUREMENT

The surface roughness value of an optical surface is denoted as roughness parameter Rq or Sq. This parameter is also named "RMS roughness" because it is calculated as the root mean square of the surface height values. The letter "R" indicates that only a 2-dimensional roughness profile is basis of calculation according to ISO 4287/1. The letter "S" means a 3-dimensional measurement and calculation (3D-Reference ISO/DIS 25178-2).

For the aim of measuring and stating roughness parameters of optical surfaces, the corresponding measurement device and the spectral range within which the optical surface should be used, has to be taken into account. The spatial resolution of the roughness measurement device plays an important role with respect to the roughness value. A higher spatial resolution allows the detection of smaller surface structures and higher spatial frequencies, respectively. Furthermore, the amount of stray light losses on the surface depends on the spatial frequencies of the surface structures and the wavelength of the light itself. Fig. 2 shows the spatial frequencies which influence the scattering losses in different spectral ranges and typical spatial resolutions of roughness measurement devices.

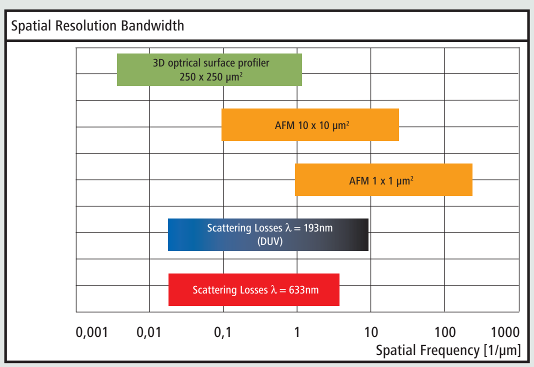
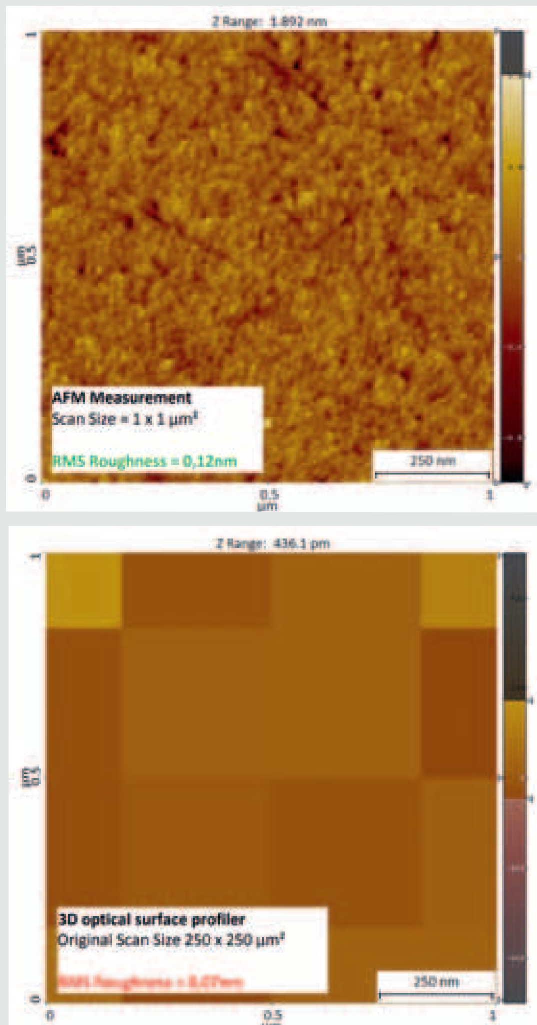


Figure 2: Spatial frequency resolution of AFM and 3D optical surface profiler at LAYERTEC for typical scan sizes. Additionally, the figure shows the spatial frequency ranges which influence the scattering losses in the VIS and DUV spectral range*.

Generally, for the characterization of optical surfaces which are appointed to be used in the NIR, VIS and UV spectral range, surface roughness measurements should be accomplished with spatial resolutions which are equal or better than 10/µm to obtain roughness information over the entire relevant spatial frequency range. Fig. 3 clarifies the differences between an AFM measurement and an optical surface profiler measurement with respect to the calculated RMS roughness and the spatial resolution.



LAYERTEC has available a phase shifting 3D optical surface profiler (Sensofar) and a scanning probe microscope (AFM) DI Nanoscope 3100 for the purpose of measuring and analyzing the surface roughness of optical components. The optical profiler has a low spatial resolution <2/µm but the acquisition time of a measurement amounts only a few seconds. Thus, the device is used for the measurement of optics with lower surface roughness requirements and for the general inspection of the polishing processes. Surface defects and inhomogeneities can be characterized too. The AFM is used for the characterization of polished surfaces which have roughness values Sq<0,5nm. This device has a very high spatial as well as vertical resolution, but the acquisition time is approximately 10 – 30 minutes. Therefore it is primarily used for the further development of the polishing processes. Our premium polish and especially our optics for UV applications with Sq < 0,2nm are checked for the reason of quality control in regular periods of time. The standard AFM measurement parameters at LAYERTEC are: Scan size of 10 x 10 µm² and a spatial resolution of 25/µm (see fig. 2). Measurement reports are available on request.

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

Figure 3: Surface roughness measurement of a super polished Low Loss substrate for an UV application made of fused silica. Both images show the same region on the surface, but they were recorded with different measurement devices (optical surface profiler and AFM). The color bar scaling is ±1nm for both images. At equivalent lateral pixel scaling, the AFM measurement with high spatial resolution shows fine structures which are relevant for stray light losses. The optical profiler measurement only shows a few pixels but no significant information about the surface roughness and structures. Moreover, the roughness value obtained from such undersampled measurements is too low, that means that the value seems to be too good.

CLEANING OF OPTICAL SURFACES

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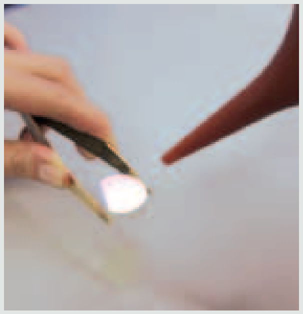

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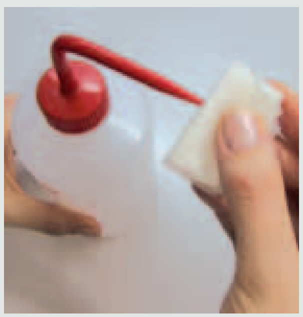

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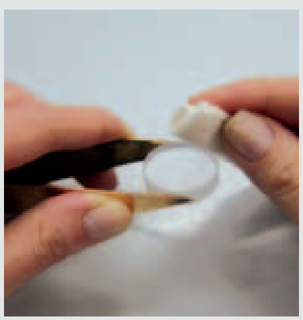

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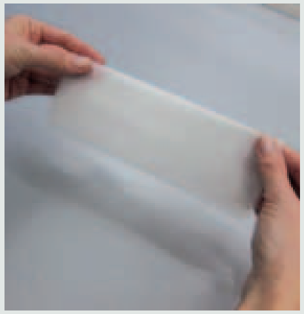
Prerequisites:

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

Pre-cleaning:

- Clean hands with soap or use clean gloves (latex, nitrile)
- Blow off dust from all sides of the sample (2)
- Moisten tissue with acetone (3)
- Remove coarse soil from the edge and the chamfer (4)

* Compared to alcohol we find acetone to be the better solvent as it significantly reduces the formation of streaks



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Preparation of the cleaning tissue:

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

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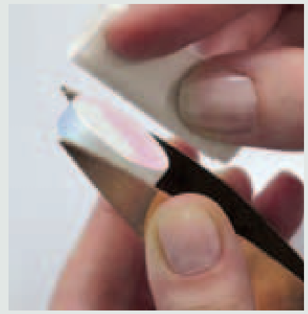

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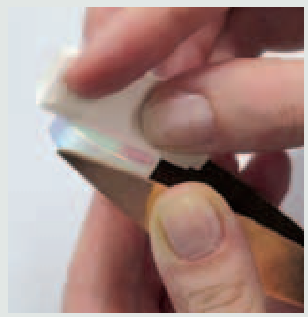

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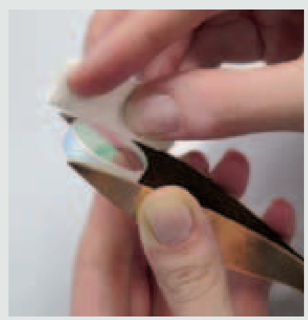

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Cleaning of the optical surface:

- Moisten the tissue with acetone (9)
- A wet tissue will result in streaks
- Hold the sample with tweezers (16)
- Slide the curved tissue from one edge of the sample to the other (10 … 12)
- The tissue may be folded around and used again once
- Repeat steps 9 … 12 with a new tissue until the sample is clean

HINTS


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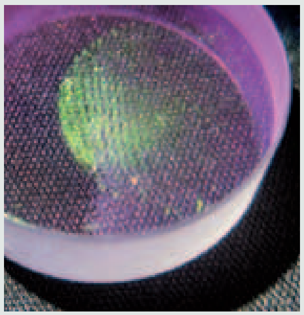
Small samples:

- Put sample onto a concave polished glass support to pick it up easily (13)
- Use special tweezers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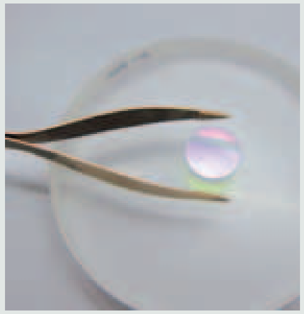
Fingerprints on sputtered coatings (14):

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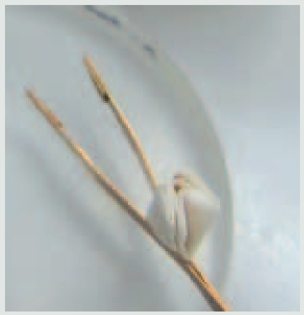
Storage:

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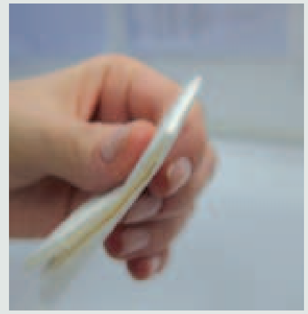
Holding the tissue:

- Use the tweezers to hold the moistened tissue (16)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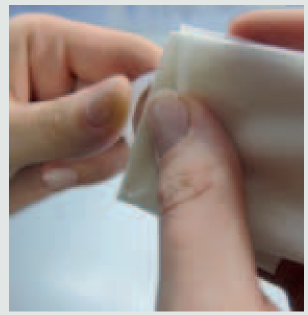
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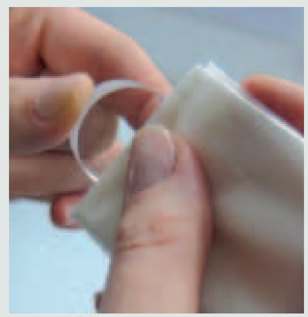
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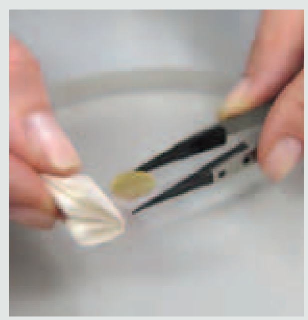
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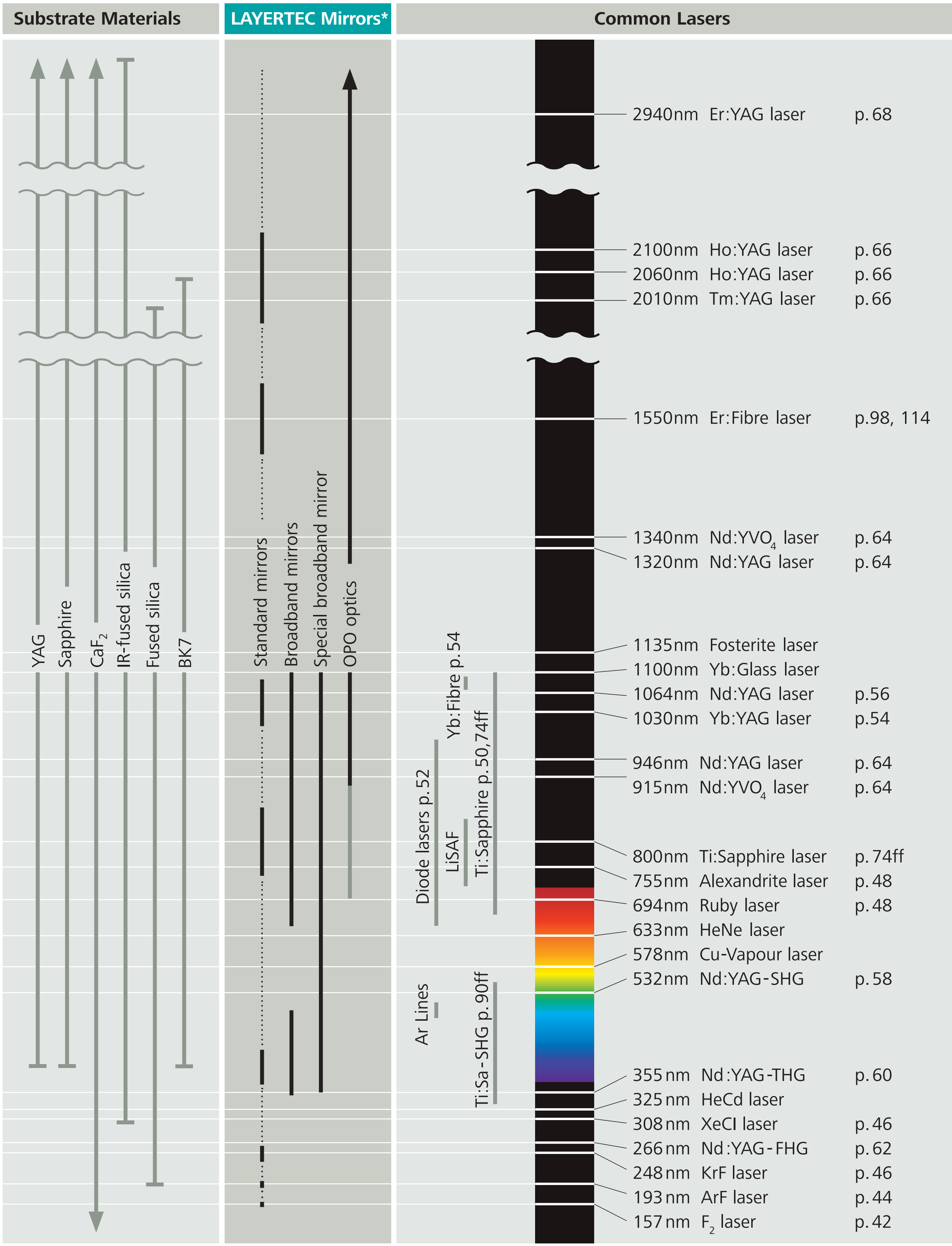
Cleaning of concave surfaces:

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

REGISTER



*Bandwidths of selected LAYERTEC mirrors