

Manual

&

Frequently Asked Questions (FAQ)

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1. GENERAL USAGE



PanDao abstract

There are about 360 Optical Fabrication Technology Techniques (OFTTs) being used for the generation of optical elements with diameters ranging from 0.2 mm to 9.4 m and materials ranging from organic glasses through mineral glasses, crystals up to to hard metals (e.g.WC) and nanomeres. **PanDao** is the first solution that managed to digitalise all 360 OFTTs in such a way, that they can communicate with key parameters of optical products. This enables for the first time ever the **simulation of whole fabrication chains**, determining the optimum fabrication chain for a given lens at minimum cost and risk.

The human-to-human interface between optical design and manufacturing is now supported by the novel data-based **PanDao software tool** (www.PanDao.ch). PanDao reads in lens data and determines the optimal fabrication chain at minimum cost and risk.

PanDao is a cost and risk minimization software and the first of its kind:

- PanDao enables **optics designers** to optimize their designs for minimum fabrication cost and thus saving substantially:
 - It takes usually a maximum of 6 to 8 "ask PanDao" requests to optimize a two-sided lens, which can save up to thousands of Euros (taking into account a typical European batch sized fabrication order of some hundred lenses, only).
- PanDao informs **purchasing managers** and **optics engineers** about the producibility of optical designs:
 - It takes only one "ask PanDao" request to receive information about (a) the best fabrication chain, (b) essential technologies needed and (c) fabrication cost level.
 - Having that data, you are able to choose the optimum supplier at minimum risk and to negotiate the best price, usually with a considerable savings potential.
- PanDao informs **executive management** and **controlling** about fabrication cost performance of their in-house production department with respect to State-of-the-Art in industry.
- PanDao supports **optical shop floor managers** and **production planners** in optimizing their fabrication chains, steering the capacity of in-house technologies, and evaluating investment projects for new technologies to be implemented.

PanDao can be used with three different databases:

- PanDao default database,
- PanDao company-owned database ,
- PanDao digital twin;

And there are four ways to get access to PanDao's services:

- company-wide license,
- single-user license,
- Design-to-Fabrication (DesToFab) service,
- PanDao (www.PanDao.ch) and JOYA Team (<https://www.joyateam.com/>) joint Engineering service.

For further reading, please consult the our references at the end of this document or contact us at info@PanDao.ch.

What is the best way to learn how to use PanDao and to stay up-to-date?

Each purchase of a PanDao license includes a free beginners training of about 1.5 hours; additional training sessions are available. In addition, the PanDao team gives regularly advanced training courses (e.g. at conferences or exhibitions) and webinars.

For further informations, please contact us at info@PanDao.ch.

Which topics are covered by PanDao?

For a complete list of topics covered by PanDao, please refer to the development stage listed in chapter 5 of this manual.

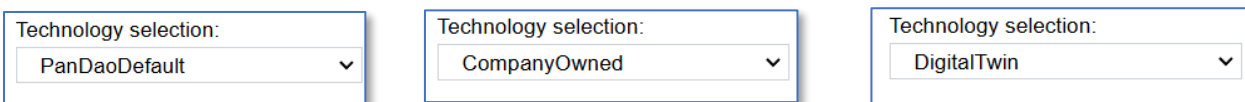
Which topics will be added next to PanDao?

The next topics to be added are determined by PanDao customer surveys and are displayed in Chapter 5, the development stage.

How does PanDao work?

PanDao reads in optics elements data (according to ISO10110 standard) and determines the optimum fabrication chain: the most cost-efficient and the fastest.

PanDao can be operated using three different databases which can be selected in the *cockpit* section of the input data surface. Please note that option “b” (company-owned) and option “c” (digital twin) are upon special request only and are not included into the PanDao default package:



- Default:** optimal fabrication chain is determined out of about 360 different optical fabrication technologie techniques (OFTTs) performing at State-of-The-Art processing level.
- Company-owned:** is an extra option where the OFTTs of your company are used (protected by NDA). That way, PanDao can generate the optimal fabrication chain using only OFTTs available at your company. Company-owned technologies are considered performing at State-of-The-Art level.
- Digital-twin:** is extra option where the OFTTs of your company are used (protected by NDA) together with their individual machining performances in your workshop. That way, PanDao can generate the optimal fabrication chain using your companys customized OFTTs performing at your individual machines level of quality, throughput and cost structures.

What is PanDao’s policy in handling my optics data?

As a principle (see GTC) PanDao tries to store as less user data as possible. If not explicitly allowed in the user tab, any optics data entered into PanDao is only used to calculate the result and immediately after that lost on the server side. Your optics data is not stored on the server and can therefore not be stolen if there would be a security breach on our side. The transfer of the data to the server is protected by https encryption. If you use company-owned or digital twin OFTTs than your data will be hard compiled into PanDao will therefore be really hard to extract if there would be security issues.

The only data stored on our side are the user data entered at registration. On the client side (the device using PanDao) the last optic requested and the last result displayed are stored in the local cookies. We can not

influence how you handle security on your devices. If this is a concern for you please discuss this with your companies IT department.

How is the cost calculation in PanDao composed?

PanDao's cost calculations

- a) **including:** machining, tooling, operators' salaries and attention needed, setup machine, machine's invest cost, bank payback time and interest, workpiece material, center grinding, protective chamfering and facets, non-circular circumference generation, workpiece mounting, dismounting, quality testing during fabrication, coating, uptime and downtime of machines per day, month and year, etc.;
 - Please note that when determining the machining cost, PanDaoi always assumes that the machine has not yet been depreciated (this means that when the depreciation period of a machine is reached, a new machine is purchased again to keep the machinery up to date).
- b) **excluding:** companies' overhead, assembly, packaging and delivery cost.

Which yield level is considered by PanDao?

By default, PanDao applies optics manufacturing at a high industrial quality level, aiming for a yield of 95%. To achieve this goal, an overproduction of 5% is considered. Thus, if 100 lenses are to be produced, PanDao assumes a production quantity of about 105 lenses.

In the cockpit tap a custom yield factor can be specified:

Cockpit

Applicability:

In industry (TRL 7-9) R and D (TRL 4-6) University (TRL 1-3)

Level of Maturity:

Established Emerging Technology

Wage level:

high wage companies Customize level

Bank interest [%]: Loan payback time [y]:

Salary operator semiskilled [€]: Salary operator technician[€]: Salary operator engineer[€]:

Daily working hours: Working days per month: Working months per year:

Others:

Molding enforced Allow block fabrication Technology selection: PanDaoDefault

Yield factor: Custom [%]

How does PanDao manage to stay up to date?

In order to ensure PanDao's State of the Art level, PanDao is regularly being updated: for more details, please consult the blog section at the PanDao webpage (www.PanDao.ch) and PanDao's LinkedIn page (www.linkedin.com/company/pandao-gmbh) or contact us at info@PanDao.ch.

How do I get started?

Each purchase of a PanDao license includes free training sessions; please contact us at info@PanDao.ch.

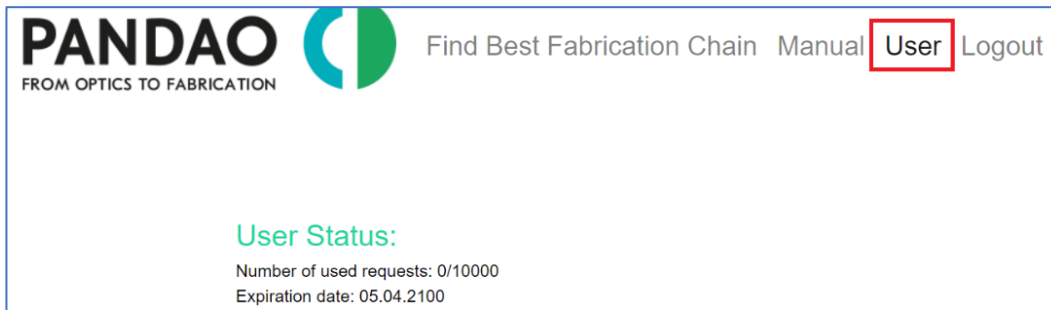
The best way to get started is:

- follow the free PanDao training sessions that are included in any license purchase,
- consult this manual,
- check out the videos on our YouTube channel,
- read our publications (see reference list at the end of this document),
- follow us for frequent news and tips and tricks at PanDao's LinkedIn page,
- read our blog entries at www.PanDao.ch and
- consider to book extra training sessions with PanDao's team, if needed,

To start PanDao, please log in at www.PanDao.ch using the log in data you received with your license.

Where can I check my current number of PanDao requests?

Please check the "PanDao/user" site which is located here:



How do I activate two level authentication?

Please navigate to the PanDao/User site and scroll down. There is a section where a QR code is displayed:

Two factor authentication activation key:

O4ASUDIMPETTY3SC

Or QR code:



Token:

Enable two factor authentication

You then need to scan the QR code or manually enter the activation key in your favorite two factor authentication app or plugin. For testing we used the [chrome authenticator plugin](#) and the [google authenticator app](#). Then enter the generated token in the "Token" field and press "Enable two factor authentication". A success message should appear. If two factor authentication is enabled every time you log into PanDao you have to enter an additional token which is generated by the plugin or app you have chosen. You can also disable this option on the users side. If you somehow are not able to generate tokens anymore (For example because you deinstalled the app you used) please contact info@pandao.ch to reset the option.

Is PanDao generating fabrication cost or selling price?

PanDao generates fabrication cost, without any financial security cushion along the fabrication chain.

How does PanDao deal with the wage levels of different countries and companies?

Please note that in every country the wage level of different companies might differ and that production qualities not necessarily depend upon the wage levels. PanDao distinguishes 3 different types of companies; high wage companies, medium-wage companies and low-wage companies. In addition, it is possible to enter one's own commercial conditions into PanDao.

The wage level can be adjusted in the cockpit section.

Why is there a difference between absolute fabrication cost between my company's production department and PanDao?

Please consider that PanDao is determining fabrication cost and not selling price. PanDao is not dealing with companies' overhead cost, assembly, packaging and delivery cost.

In order to be able to compare absolute cost levels, ensure that you are comparing the same fabrication chain.

Please customize the wage level of your or your supplier's company in the cockpit section:

Wage level:		
high wage companies	<input checked="" type="checkbox"/>	Customize level
Bank interest [%]:	Loan payback time [y]:	
5	10	
Salary operator semiskilled [€]:	Salary operator technician[€]:	Salary operator engineer[€]:
3000	4000	6000
Daily working hours:	Working days per month:	Working months per year:
14	26	11

The delta that might remain depends on the following information that would be requested by PanDao:

- all individual commercial information of your company, e.g., varying bank interest rates and level of salaries, invested machines cost and age of machines applied etc.,
- detailed description of the fabrication chain currently in use (types of machines, tools and processes etc.) and which machines are currently depreciated,
- calculating machining cost, PanDao takes only machineries into account that are applied along the fabrication chain; often departments hourly rates are calculated based on all machinery existing within the department including those, being not used this time,
- calculating operator cost, PanDao takes operator hours needed for this lens into account and not salaries of all people being employed within this department.

Additional notes:

- The calculation still depends on the basic wage level chosen. Just the customized parameters are overruled. For example, the tooling cost is still depending on the base wage level set. Otherwise, the user has to input tooling cost for all 350 technologies which is not feasible.
- The salaries are monthly values

- If your machines are already amortized, please choose a low bank interest (for example 0.0001) and a long loan payback time (1000 years) to account for this.

2. INPUT PARAMETERS

2.1. ALL SHAPES

How should I describe my lens parameters and tolerances

PanDao reads in optics elements data according to ISO10110 standard and determines the optimum fabrication chain.

PRO-OPTIC-CONVERTER: How can I determine and convert lens tolerances so that PanDao can read them in?

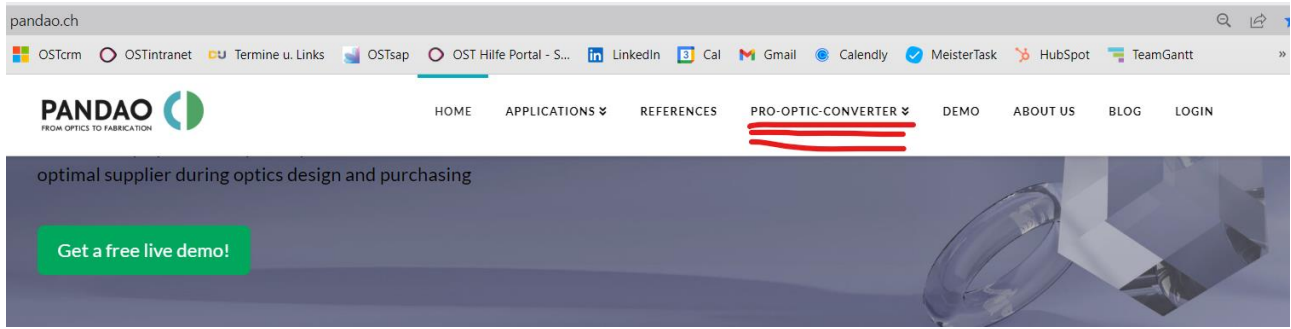
You can export lens data from your optical design software tool in a format that PanDao can read in.

Nevertheless, often technical drawings use different ways to describe tolerances (like the radial tolerance in mm instead of the power value in fringes) or apply different standards (such as the MIL standard instead of the ISO10110 standard). Furthermore, certain parameters are sometimes missing on technical drawings.

To support you in such situations, PanDao offers the **free PRO-OPTIC-CONVERTER** tool, which covers currently the following topics:

Issue	Description of the mathematical PRO-OPTIC-CONVERTER tool
Slope to mid-spatial-wavelength converter	Reads in the midspatial tolerance in terms of max. slope allowed [minutes] and converts this into the maximum allowed mid-spatial-wavelength [mm].
Radial tolerance to power converter	Reads in the radial tolerance (delta R in [mm]) and converts this into power (the "A" of 3/A(B) in ISO10110 in [fringes])
Determination of asphericity	Reading in the absolute aspherical shape, the asphericity is determined: the maximum vertical distance between the asphere's surface and its removal sphere.
Determination of the radius of the enveloping spherical surface of an asphere (the removal sphere)	Reading in the absolute aspherical shape, the radius of the enveloping spherical surface (the removal sphere) of an asphere is determined. The enveloping spherical surface is located above the aspherical surface without intersecting the asphere; this spherical surface is located as close as possible above the asphere enabling minimum volume removal during production.
Determination of the smallest radii of curvature (ROC) of aspheres and freeforms	Reading in the absolute aspherical shape, the overall smallest ROC as well as the smallest ROC of the concave parts of the surface are determined.
Edge Thickness Variance (ETV) to decenter (4/) converter	Reading in edge thickness variance (in millimeter), the decentering of the two lens surfaced is being determined (4/ in Minutes)
Find substitute material for PGM	This tool allows you to find a substitute glass with minimum delta in refractive index and that is suitable to be processed with precision glass molding (pgm): for details, please consult the "PanDao Master Class" section.
Convert aspheres description from the "power series description" to Forbes polynomials	Currently under development

Check the [PRO-OPTIC-CONVERTER](#) out at:



How do I input lens parameters into PanDao?

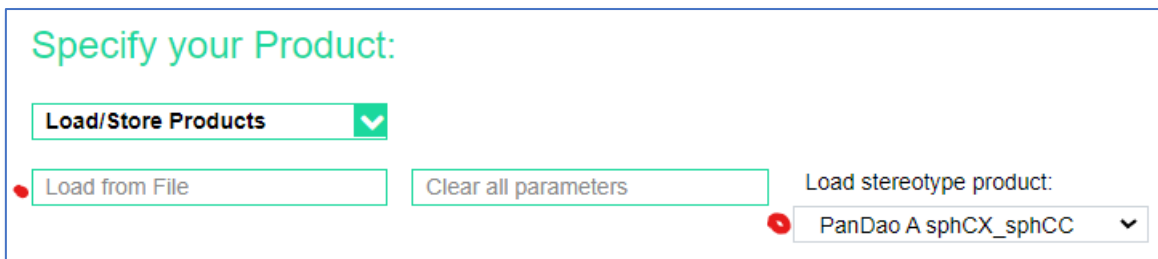
To run a PanDao analysis to determine the optimal fabrication chain for your lens, you need to enter the parameter values and tolerances of your optical element on the PanDao website.

There are five possibilities of doing this:

- a) Read-in the lens data saved by your optics design software
- b) Read-in the lens data saved by PanDao (saved by "Download lens to file")
- c) Read-in the PanDao Report, a pdf file saved by PanDao (saved by using "Download report pdf")

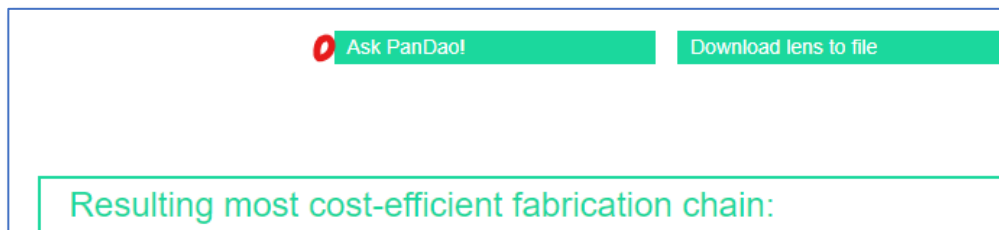


- d) load one of the stereotype lenses and change its values and tolerances to the ones you need,



- e) enter the values and tolerances of your optics directly by hand

Having done that, you are now ready to start PanDao by clicking on "ask PanDao" and get the optimal manufacturing chain for your optics at minimum cost and manufacturing risk.



Can I upload typical IR, VIS and EUV lens tolerances into PanDao?

To facilitate the introduction and testing of lenses with typical IR, VIS or EUV tolerances (depending on the wavelength of the light to which they are applied), PanDao offers 4 typical sets of lens tolerances that can be used as a STARTER KIT, which can be uploaded by using the “upload stereotype lens tolerances” button.

- IR: infrared wavelengths optics
- VIS_Imaging: imaging optics at visible light
- VIS_illumination: illuminating optics at visible light
- EUV: extreme ultra-violet lavelengths optics

^

Specify your Product:

Load/Store Products ▼

Load from File Load stereotype product: Please select: ▼ Load typical tolerances: Please select: ▼

General Information ▲

Side 1 ▲

Side 2 ▲

Options ▲

↳ IR
 → VIS IMAGE
 → VIS ILLUM
 → EUV

What types of workpiece materials are covered by PanDao?

PanDao is linked to more than 8 optics materials catalogues from the top material providers in optics. A complete list of workpiece materials (such as organic glasses, mineral glasses, IR materials, molding materials, and metals) as well as the glass catalogues currently linked to PanDao, see chapter5 of this manual: “development stage”.

How do I input workpiece material into PanDao?

Choose workpiece material in the general section. There are two choices: you can either select materials by choosing “Custom”

General Information ▼

Name: Description: Number of Sides: Two ▼ Material: Custom ▼

or by choosing “By suppliers name”

General Information ▼

Name: Description: Number of Sides: Two ▼ Material: By supplier name ▼

If “By suppliers name” is selected, you type in the brand name of the material wanted (e.g. N-BK7, LAK9G15, K-PSFn214P or SCHOTT RealView® 2.0) and PanDao collects all needed material characteristics including material cost from the material supplier’s catalogue; currently more than 8 optics materials catalogues are linked to PanDao (see chapter5).

Please note that PanDao does not support the entry of material's no longer provided by suppliers. For example, BK7 from Shott contains lead which is forbidden to use in the EU because of ecological reasons. It is no longer available in the newest catalog and therefore not supported by PanDao. If you want to use PanDao with a material not listed anymore please use the customer material option and enter the values for your material yourself.

If "Custom" is selected, PanDao will ask you to input the essentially needed data including material cost.

Material:	Custom
Material type:	glasses
Calculation type:	CostPerVolume
Material cost per volume [€/l]:	120
Acid resistance (SR):	AR3
Knoop hardness (HK):	416
Alpha (-30/70) [1/°C]:	8.1
<input checked="" type="checkbox"/>	Material suited for precision glass molding

How can input a production situation using pre-purchased blanks as starting point?

Please select "Custom" in the materials section and enter then the cost per blank. PanDao will take this cost per optical element into account and will also take the overproduction needed into account which depends on the yield set up in the "Cockpit" section (e.g. at 50% yield level a production of 20 lenses is needed to have 10 lenses ready to be shipped).

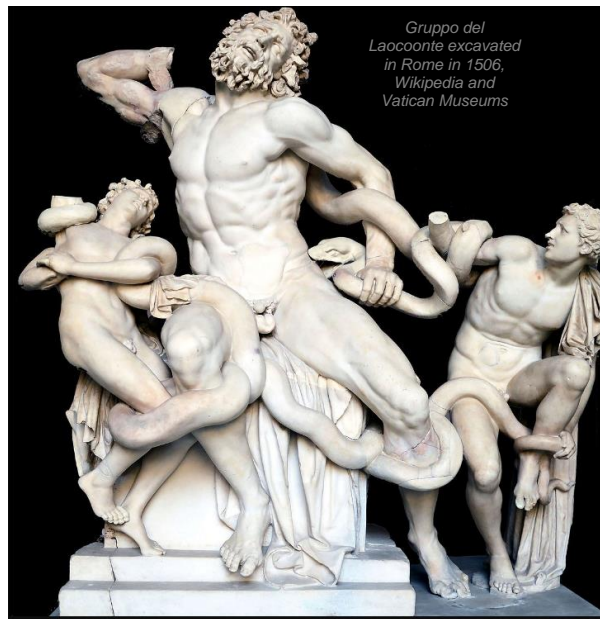
What should I do If my lens material is not listed in PanDao's material scroll down menus?

Please check if the material is part of a PanDao material group like e.g. metals or crystals.

If not, contact us at info@PanDao.ch and we will help you.

How do I determine workpiece material cost in PanDao?

The selection of a suitable blank for optical manufacturing is similar to that of the sculptor who already saw the Laocoon group in the block of marble he wanted to use and only had to uncover it.



Optical elements consist of many different materials (from PMMA to sapphire), have different dimensions (e.g., diameters from a few micrometers to several meters) and geometries (from planar plates to freeforms to conformal optics). Thus, the selection of a suitable blank is challenging and diverse, and, among others, the following blank variants exist:

- cut blocks from a melt
- purchase of a whole glass melt
- grow a crystal
- bar stock for cutting to length
- cylinders for direct rough shaping
- spheres, gobs, semi-finished products (e.g. for PGM)
- powdered or liquid workpiece blank (e.g. for injection molding, 3D printing or coatings).

Currently, PanDao's first fabrication step is rough shaping of surfaces (or molding) starting from a plano-parallel pill the size of which is determined by PanDao adding to the optics geometry the required fabrication removal heights needed. Alternatively, it is possible to start fabrication from pre-purchased blanks. In this case please enter in the custom section of materials the cost of your purchased blank.

PanDao allows three methods of entering material costs. First use the selector "Calculation type" to determine which input data should be used: Cost per volume [€/l], cost per weight [€/kg] or cost per blank. If cost per weight is selected also the density must be provided.

PanDao takes into account various fabrication process related issues such as the material to be removed and debris caused.

Due to the huge variance in selecting blank geometries, the material cost currently determined by PanDao represents an industrial-realistic benchmark that might be undercut: sometimes.

There are two cockpit to enter the lens material into PanDao:

- b) either by entry of the **supplier's glass material's name**, such as e.g. N-BK7. Please note:
 - to select this material type by a scroll-down menu,
 - that PanDao automatically knows if this material is being suited for precision glass molding (PGM),
 - that PanDao automatically collects material costs (per volume) from the supplier's website;

General Information			
Name:	Description:	Number of Sides:	Material:
PanDao A sphCX_sphCC	type A	Two	By supplier name
Batch Size:	Lens Diameter [mm]:	Center Thickness [mm]:	Calculation type:
50	7	1.234	CostPerVolume
Total Number Of Lenses:	Diameter Tolerance [mm]:	Center Thickness Tolerance [mm]:	Material name:
1000	0.01	0.04	N-BK7
<input type="checkbox"/> Suited for LIDT	<input type="checkbox"/> Outer cylinder length bigger lens diameter	Non-circular circumference[mm]:	Material cost per volume [€/l]:
		Not Specified	57.73
			Acid resistance (SR):
			AR1
			Knoop hardness (HK):
			610
			Alpha (-30/70) [1/°C]:
			7.1
			<input type="checkbox"/> Material suited for precision glass molding

- c) or by **custom** entry from a scroll down menu. Please note that
- in this case PanDao requires for glasses the entry of the Knoop hardness (HK) and of the acid resistance (AR) values. This data can easily be found in the internet from the relevant technical data sheet, e.g. N-BK7 with HK = 610 and AR = 2,
 - in this case you need to specify if a glass material is suited for precision glass molding (PGM) or not,
 - in this case have to enter material cost per volume by yourself.

General Information			
Name:	Description:	Number of Sides:	Material:
PanDao A sphCX_sphCC	type A	Two	Custom
Batch Size:	Lens Diameter [mm]:	Center Thickness [mm]:	Calculation type:
50	7	1.234	CostPerVolume
Total Number Of Lenses:	Diameter Tolerance [mm]:	Center Thickness Tolerance [mm]:	Material type:
1000	0.01	0.04	glasses
<input type="checkbox"/> Suited for LIDT	<input type="checkbox"/> Outer cylinder length bigger lens diameter	Non-circular circumference[mm]:	Material cost per volume [€/l]:
		Not Specified	57.73
			Acid resistance (SR):
			AR1
			Knoop hardness (HK):
			610
			Alpha (-30/70) [1/°C]:
			7.1
			<input type="checkbox"/> Material suited for precision glass molding

In either case, PanDao will determine material cost of your lens:

Material cost:
 Material cost for this lens: 0.02€

How do I enter 4/ centering tolerances into PanDao?

According to ISO10110, PanDao accepts currently the following centering tolerances of a lens. For each side of the lens you can enter 4/ centering tolerances: for flat, cylindrical and spherical surfaces this is specified by tilt only and for aspheres and freeforms it takes an additional “lateral decenter” to fully specify 4/.

Please note, that if you specify 4/ for both sides of the lens you specify the centering of the surfaces to the outer cylinder of the lens and if you specify only one side of the lens then this is the tolerance with respect to the other side of the lens.

How do I enter defect size (the Scratch/Dig from Mil standrad) into PanDao?

The ISO10110 standard allows maximum defect sizes on the side to be generated in terms of $5/y \cdot x$, with

- “x” describing the edge length of a square representing the defect size: e.g. 5/0.016 means that defects with an area of $0.016\text{mm} \cdot 0.016\text{mm} = 0.000256 \text{ mm}^2$ are allowed. Their lateral shape might be a square or a rectangle or any other shape.
- “y” is the maximum number of defects “x” allowed.

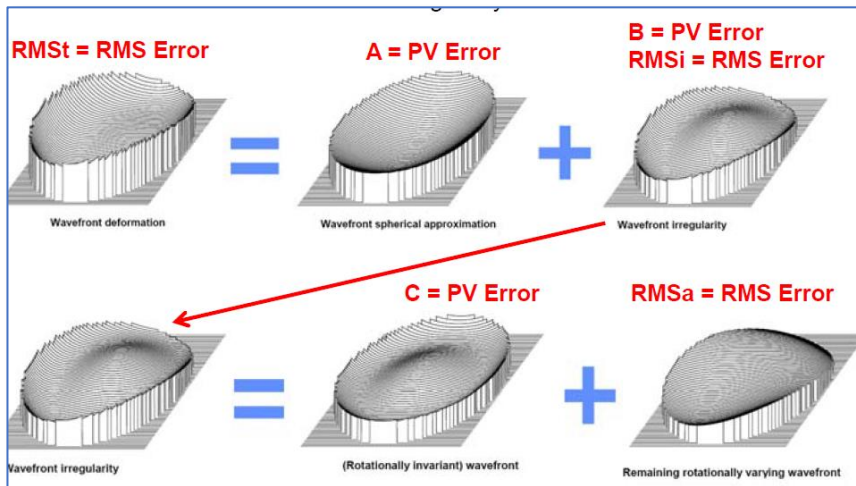
PanDao currently reads in the maximum defect sizes "x" on the side to be produced ($5/x$). The number y is not needed, since "x" impacts on the determination of the optimal fabrication chain, while "y" impacts only on the quality of handling of machinery, tooling and the cleanliness along the fabrication chain.

The screenshot shows the 'Side 1' configuration panel. Under the 'Quality' section, the 'Defect Size(5/)[mm]' field is highlighted with a red box and contains the value 0.063. Other fields include '3/Power[fringes]: 1', '3/Irregularity[fringes]: 0.3', and '3/@Wavelengt[nm]: 546.07'.

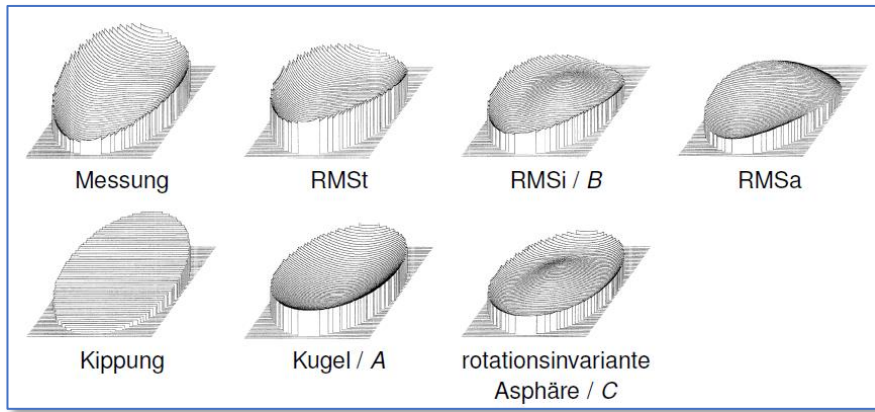
How do I enter 3/ shape accuracies into PanDao?

PanDao accepts currently (as described in ISO10110) shape accuracies in terms of $3(A(B/C))$ with

- “A” being the power tolerance (power error to best fit spherical surface),
- “B” being the irregularity: the deviation from the best-fit-spherical surface and
- “C” being the rotationally invariant tolerance (symmetric irregularity error to best fit sphere to B)



Tiziani et.al



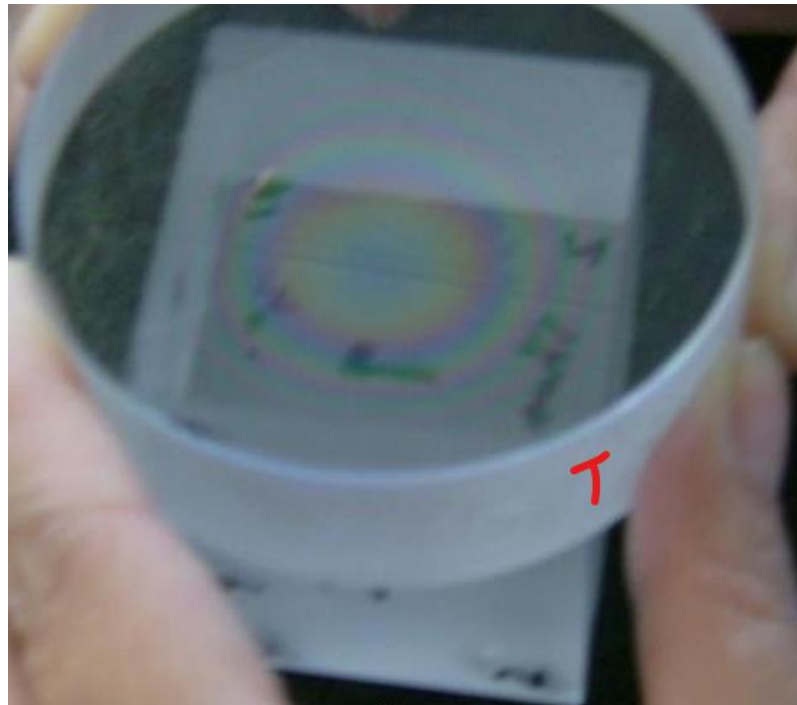
Langenbach

With the “Wavefront deformation tolerance” selected you can choose which one of the three parameter you want to specify.

Quality:

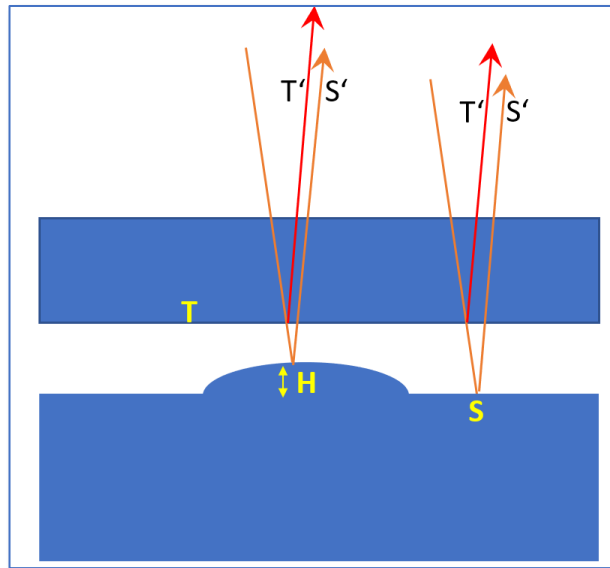
3/Wavefront deformation tolerance: 3/A(B/C)			
3/A Power[fringes]: 3	3/(B)Irregularity[fringes]: 2	3/(C)Rotationally invariant[fringes]: 1	3/@Wavelength[nm]: 546.07
Roughness: Custom (Sq [nm rms]) 1.5	smallest midspatial wavelength accepted [mm]: 5	Defect Size(5/)[mm]: 0.1	

The units are fringes, wave (not surface), an approach derived from the ancient technique of measuring shape deviations using test plates (T) produced by master opticians hand polishing (a testing setup also found in Fizeau interferometers):



The shape error (surface height H) of the surface under test (S) is measured by comparing the shape of surface S with the perfect (usually $< 1/20$ lambda shape accuracy) and identical shape of surface T of the

test plate. This is done by interfering the light rays T' and S'. Consequently, a height deviation H of the surface S appears in the interferogram as 2*H.(=wave).



As a default, PanDao reads in shape accuracy 3/A(B) measured at 546.07nm wavelength. The 546.1 nm line is a green emission line of mercury. Before the invention of the laser, it had commonly been used in various applications, including optical testing, alignment, and calibration. Typically, the mercury vapor lamp, which is a discharge lamp containing mercury, is used as a light source to produce these emission lines. When the mercury vapor lamp is electrically stimulated, it emits light at various wavelengths, including the green line at 546.1 nm. According to ISO10110, PanDao allows the setup of any other test wavelengths by simply adjusting the entry in field 3/@lambda:

Quality:

3/Wavefront deformation tolerance:

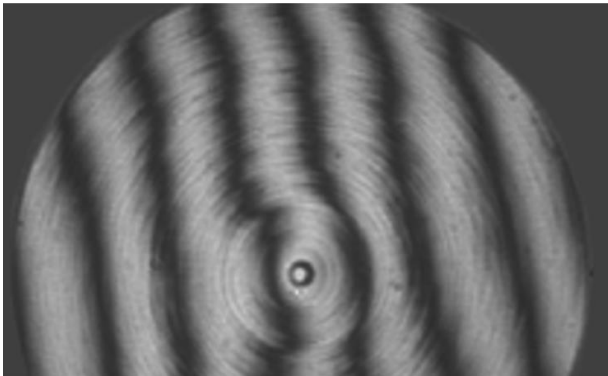
3/A Power[fringes]: <input type="text" value="3"/>	3/(B)Irregularity[fringes]: <input type="text" value="2"/>	3/(C)Rotationally invariant[fringes]: <input type="text" value="1"/>	3/@Wavelength[nm]: <input type="text" value="546.07"/>
Roughness: <input type="text" value="Custom (Sq [nm rms])"/>	smallest midspatial wavelength accepted [mm]: <input type="text" value="5"/>	Defect Size(5/)[mm]: <input type="text" value="0.1"/>	

As an example given, a height deviation H of the irregularity B of 1 micron equals $B = (1000/546.07)*2 = 3.66$ fringes; and if we assume a power error of 2 micron height the shape accuracy of this surface equals **3/7.32(3.66)**.

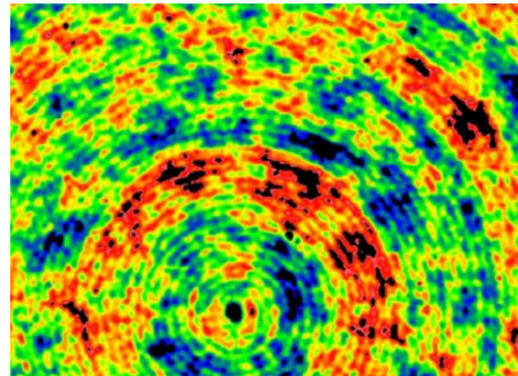
How do I enter midspatial tolerances into PanDao and what is the “smallest midspatial wavelength”?



Midsptcial waves on a 6400 km radius planet

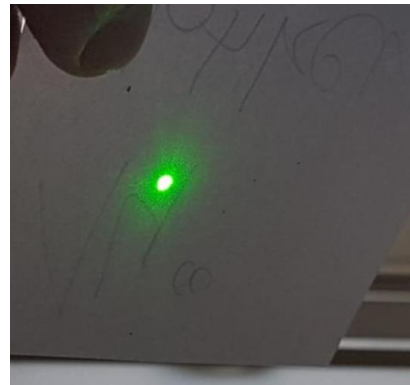
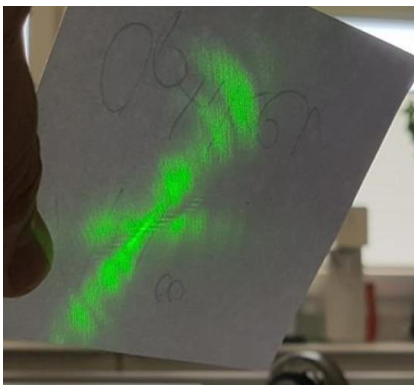


The non-straight edges of the fringes are caused by midspatials of a suboptimally set up cnc polishing process



Concentric midspatials on an pre-polished optic caused by a suboptimally performed point contact cnc grinding process

Midspatial surface errors are located along the Power Spectral Density plot (PSD: a measure for how many spatial frequencies are present on the surface) between the low frequency shape errors and the high frequency roughness errors. As a rule of thumb midspatials “start” at surface wavelengths that are smaller than about a 5th of the clear aperture. Midspatials are responsible for miss-led light rays, unwanted lateral brightness distributions within the generated image or may cause scattering effects or halos.



Focus of a lens with midspatials present

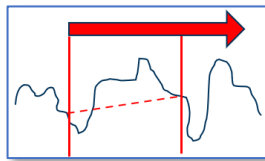
Same lens focus with removed midspatials

Typically, optical midspatial shape errors origin from:

- machine vibrations
- sub-aperture tool contacts
- removing a lot of material during sub-aperture polishing
- alignment of coordinate systems of testing and machining
- resonance frequencies of machines and tools
- fixed ratio w-tool to w-workpiece
- quality of CAD data files generating CNC machining files (e.g. splines and NURBS)

Among the multiple ways to specify midspatial tolerances of an optical surface, two are most common: SLOPE and Mid-Spatial-Wavelength (MSW).

- SLOPE specifies a maximum allowed local inclination [minutes] (usually, but not necessarily for a defined sampling length):



- MSW specifies the smallest allowed midspatial wavelength [mm] while the maximum allowed amplitude depends on the shape accuracy tolerancing:



Both (SLOPE and MSW) can be converted into each other using PanDao's "PRO-OPTICS-CONVERTER" tool (see relevant chapter of this manual and www.PanDao.ch).

PanDao reads in MSW:

- Please select if Mid-Spatials are specified, not specified or not allowed here:

Quality:
3/Wavefront deformation tolerance:
3/A(B) [v]
3/A Power[fringes]: 2
3/(B)Irregularity[fringes]: 1
3/@Wavelength[nm]: 546.07
Roughness: Custom (Sq [nm rms]) [v] 1.5
Midspatialwavelength[mm]: Not allowed [v]
Defect Size(5/)[mm]: 0.064
Add-ons:
Coatina: [v] Decenter Tilt(4/)[min]: [v]

- If specified please input the Mid-Spatial-Wavelength in mm here:

Quality:
3/Wavefront deformation tolerance:
3/A(B) [v]
3/A Power[fringes]: 2
3/(B)Irregularity[fringes]: 1
3/@Wavelength[nm]: 546.07
Roughness: Custom (Sq [nm rms]) [v] 1.5
Midspatialwavelength[mm]: Specified [v] 10
Defect Size(5/)[mm]: 0.064

- the maximum allowed amplitude of the MSW depends on the values of the shape accuracy tolerances (3/A(B,C) and has not to be specified as PanDao deals with this automatically.

Typically, no midspatials are allowed for flat and spherical surfaces, which corresponds to MSW=0.

How do I select if my lens should withstand a high level of Laser Induced damage Threshold (LIDT)?

Please select "suited for LIDT" to determine lens fabrication chains for lens intensity levels of up to appr. 30 J/cm². Please note that PanDao does not evaluate if the chosen lens material is suited for LIDT.

General Information	
Name:	PanDao C2 asphCX_plano
Batch Size:	1000
Total Number Of Lenses:	5000
<input type="checkbox"/> Suited for LIDT	

How do I input a rod lens into PanDao?

Fabrication chains for rod lens generation have special characteristics and rules.

Please notify PanDao at:

General Information			
Name:	PanDao C2 asphCX_plano	Description:	type C
Batch Size:	1000	Lens Diameter [mm]:	220
Total Number Of Lenses:	5000	Diameter Tolerance [mm]:	0.1
<input type="checkbox"/> Suited for LIDT		<input checked="" type="checkbox"/> Outer cylinder length bigger lens diameter	

Please note that for rod lenses currently no block fabrication is considered.

How do I input clearaperture for cylinders and freeforms into PanDao?

For cylinders and freeforms the clearaperture can either be circular or rectangular. For circular clearapertures only one parameter is needed. For rectangular openings the diameter and shoulder length must be specified:

Global:

Shape: cylinders

Clear Aperture Diameter[mm]: 6.2

Geometry: Convex

Clear Aperture Shoulder Length[mm]: 1

Clear Aperture Shape: Rectangular

How do I select the right types of Optical Fabrication Technology Techniques (OFTTs) to be considered by PanDao's?

PanDao determines the optimal fabrication chain for a given lens. The following selections can be made for the Optical Fabrication Technology Techniques (OFTTs) to be considered by PanDao:

Options

Applicability:

In industry R and D University

Level of Maturity:

Established Emerging Technology

How do I select or omit block fabrication?

Whenever possible (if lens spherical radius is much bigger than lens diameter), PanDao considers block fabrication where a multiple samples holder is used to machine in parallel instead of sequentially: E.g.:



Block fabrication can be switched on and off in the cockpit section:

Others:

Molding enforced Allow block fabrication

Technology selection: CompanyOwned

How do I select or omit Optical Fabrication Technologies (OFTs) to be considered by PanDao?

Select the characteristics of Optical fabrication Technology Techniques (OFTTs) in the Cockpit section of PanDao by using the two selection criteria “Applicability” and “level-of-Maturity”:

Cockpit

Applicability:

- In industry (TRL 7-9) Prototyping (TRL 4-6) Research (TRL 1-3)

Level of Maturity:

- Established Emerging Technology

- a) **Applicability:** in the cockpit section of the input surface at least one of the three choices must be activated with a tick: “In industry”, “Prototyping” and/or “Research”,
- b) **Level-of-Maturity:** in the cockpit section of the input surface at least one of the two choices must be activated with a tick: “established” and/or “emerging technologies”.

After you have received information about an optimal fabrication chain for one optical element you can omit one or several of the listed OFTs and start a new PanDao request to build the best chain possible without the selected OFTs available.

In order to do so, please copy and paste the OFT’s name from the output into the field “exclude OFTTs” which is located in the cockpit section:

Cockpit

Applicability:

In industry (TRL 7-9) Prototyping (TRL 4-6) Research (TRL 1-3)

Level of Maturity:

Established Emerging Technology

Wage level:

high wage companies Customize level

Others:

Molding enforced Allow block fabrication Technology selection: PanDaoDefault Yield factor: PanDaoDefault

Pea puffer disabled

Result:

Exclude technologies:

Ignore technology Remove

How do I select the correct “Wage-Level” for my lens?

PanDao distinguishes 3 different types of companies: high, medium and low wage level companies. Please note that in every country the wage level might differ and that production qualities not necessarily depend upon the wage levels:

Cockpit

Applicability:

- In industry (TRL 7-9)
- Prototyping (TRL 4-6)
- Research (TRL 1-3)

Level of Maturity:

- Established
- Emerging Technology

Wage level:

high wage companies Customize level

a) **High-wage companies:** e.g. existing in Germany, France, UK, USA, Japan, Singapore, Switzerland, Austria and Italy

Wage level:
high wage companies

b) **Medium-wage companies:** e.g. existing in Romania, Bulgaria, Turkey, Portugal, Mexico, Taiwan and Serbia.

Wage level:
medium wage companies

c) **Low-wage companies:** e.g. existing in China, India, Indonesia and Korea

Wage level:
low wage companies

In addition, it is possible to enter one’s own commercial conditions by choosing custom input: e.g. bank interest, investment payback time to the bank and salaries of engineers or technicians.

Wage level:
high wage companies Customize level

What are typical surface roughness ranges and values?

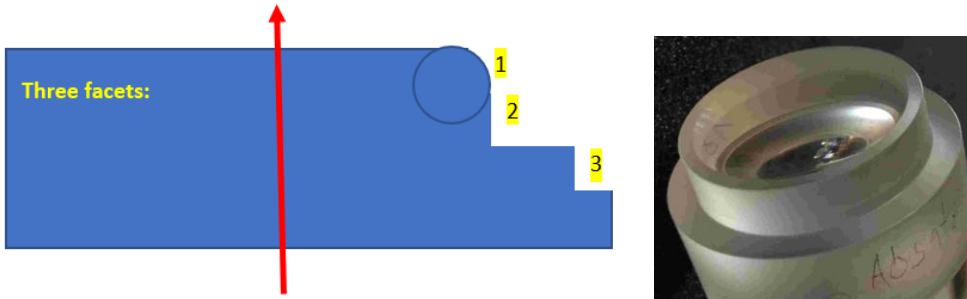
PanDao asks surface roughness values in terms of Sq [nm rms] over a spatial bandwidth of 0.002mm to 0.08mm; derived from DIN ISO 10110-8:

Range	Rq over spatial bandwidth of 0.002 mm to 1 mm
P1	≤ 8 nm rms
P2	≤ 4 nm rms
P3	≤ 2 nm rms
P4	≤ 1 nm rms

What are Facets?

In PanDao, for each optical element the cost for protective chamfers is included in the center grinding cost.

The so-called facet stages are being generated by molding or as a cnc grinding step after the center grinding step has been finished (on the same machine). Facet stages are binary-like step structures at the outer edge of the lens located between the clear aperture and lens diameter to e.g., serve mounting issues of the lens into the objective.



How do I enter Facets?

Choose at a side of the lens the number of facets required, e.g. 3

Number Of Facets:		
<input type="text" value="3"/>		
Height facet 1[mm]:	Height facet 2[mm]:	Height facet 3[mm]:
<input type="text" value="0.5"/>	<input type="text" value="1"/>	<input type="text" value="0.01"/>
Width facet 1[mm]:	Width facet 2[mm]:	Width facet 3[mm]:
<input type="text" value="0.2"/>	<input type="text" value="3"/>	<input type="text" value="0.1"/>

NumberOfFacets:

3

In this case three extra windows open each asking height and length of the facet [in mm].

- For rectangular facet shapes (No.2 and 3 in the picture in the facets chapter): enter the height and width e.g. facet 1: 0.5 mm / 0.1 mm.
- For circular or “axicon-like” chamfers (No.1 in the picture in the facets chapter): enter only their height and depth but neither the radius nor the hypotenuse (of the axicon).

Facet 1:

Height (parallel to optical axis in mm)

Width (rectangular to the optical axis in mm)

Facet 2:

Height (parallel to optical axis in mm)

Width (rectangular to the optical axis in mm)

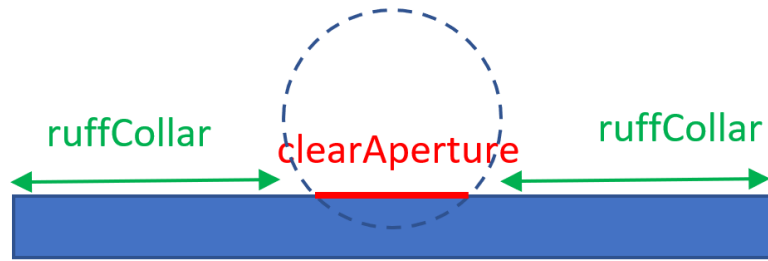
Facet 3:

Height (parallel to optical axis in mm)

Width (rectangular to the optical axis in mm)

How do I enter plano Facets for spherical lenses?

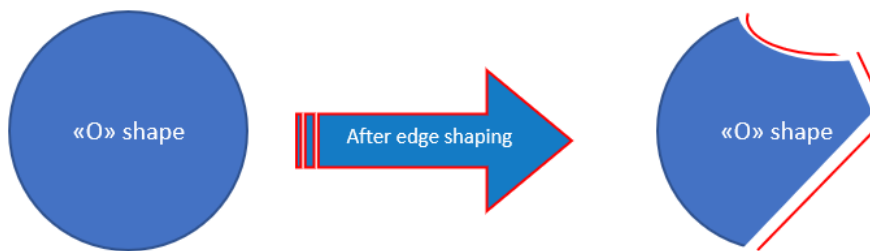
Often, concave, spherical surfaces are being generated into plano parallel plates. In that case, a huge plano facet (called the ruff collar in the picture below) covers the area between clear aperture and lens diameter. Ad extremum, this covers the situation where an hemisphere is being generated with $2 * R < \text{lens Diameter}$.



In that case, please describe the facet with its correct width and a height removal of 0.010 mm.

What are non-circular perimeters?

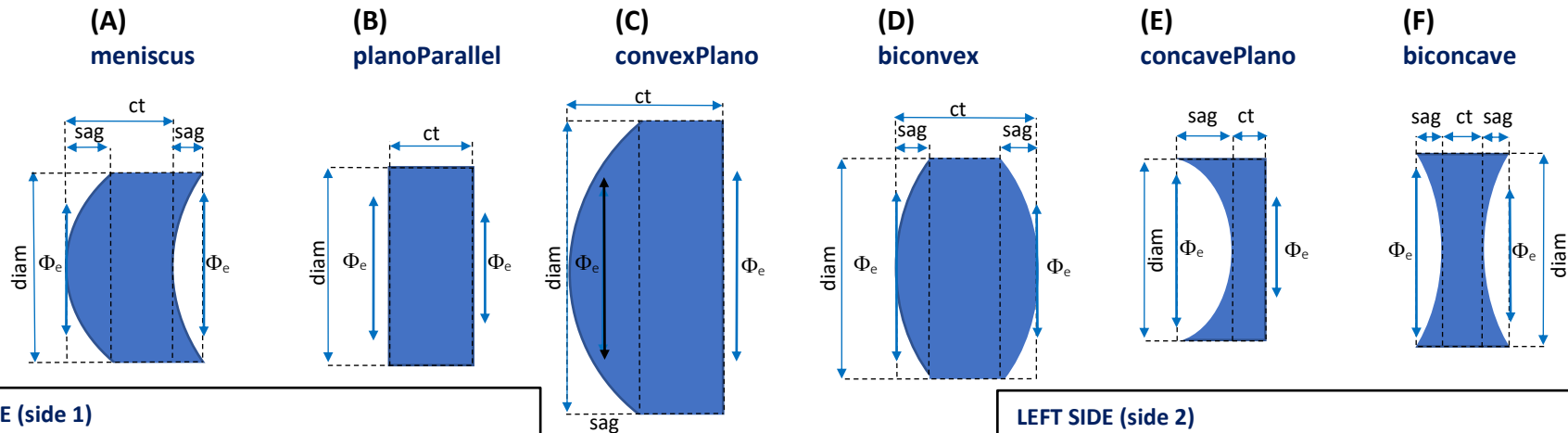
For mounting purposes, the outer lens cylinder might have a non-circular shape, e.g. a “D” shape. These non-“O” shaped lens cylinder shapes might be more complex than flat and circular shape segments (visible if the lens is observed parallel to the optical axis (top view)):



PanDao asks the overall **non-circular circumference** length which is the overall length of the non-cylindrical shapes along the lens perimeter as indicated with the red lines in the example above.

General Information <input checked="" type="checkbox"/>		
Name:	Description:	Number of Sides:
D1 biconvexSphericalLens	biconvex standard lens that	Two
Batch Size:	Lens Diameter [mm]:	Center Thickness [mm]:
200	50	20
Total Number Of Lenses:	Diameter Tolerance [mm]:	Center Thickness Tolerance [mm]:
5000	0.1	0.05
<input type="checkbox"/> Suited for LIDT	<input type="checkbox"/> Outer cylinder length bigger lens diameter	<input checked="" type="checkbox"/> Non-circular circumference[mm]:
		Not Specified

Possible lens geometries and input parameters



LEFT SIDE (side 1)

clearAperture Φ_e
 prot.chamfer (length)
 coating (AR/special)
 3/power(irregularity)
 4/ (for flats use 3/)
 5/
 6/ (if $> 10J/cm^2 = LIDT$)
 Sq surface roughness
 smallest midSpatialWavelength:
 sag

if spherical surface (YES/NO):

R:

if aspherical surface (YES/NO):

smallest radius of curvature
 asphericity
 radius of removal sphere:
 contains concave parts (YES/NO)?
 smallest concave radius of curvature (SCRC)

if cylindrical surface (YES/NO):

clearAperture shoulder length Φ_e :

if off-axis aspherical surface (YES/NO):

[see off-axis aspheres section below](#)

if freeform (YES/NO):

[see freeformss section below](#)

MATERIAL:

if glass (YES/NO):
 HK:
 AR:

DIMENSIONS

center thickness ct
*(for of-axis aspheres and freeforms:
 enter local minimum lens thickness)*
 ct tolerance
 lens diameter
 diam tolerance

PRODUCTION ORDER

totalNumber pcs
 batchSize pcs:

LEFT SIDE (side 2)

clearAperture Φ_e
 prot.chamfer (length)
 coating (AR/special)
 3/power(irregularity)
 4/ (for flats use 3/)
 5/
 6/ (if $> 10J/cm^2 = LIDT$)
 Sq surface roughness
 smallest midSpatialWavelength:
 sag

if spherical surface (YES/NO):

R:

if aspherical surface (YES/NO):

smallest radius of curvature
 asphericity
 radius of removal sphere:
 contains concave parts (YES/NO)?
 smallest concave radius of curvature (SCRC)

if cylindrical surface (YES/NO):

clearAperture shoulder length Φ_e :

if off-axis aspherical surface (YES/NO):

[see off-axis aspheres section below](#)

if freeform (YES/NO):

[see freeformss section below](#)

2.2. CYLINDRICAL SURFACES

What is the current PanDao status on cylindrical surfaces?

PanDao covers the generation cylindrical surfaces for which numerous optical fabrication technologies are existing.

As standard, PanDao reads in circular optical elements featuring a lens diameter (to be inputted in the general input section) . For other outer diameter shapes than a circle, e.g. a rectangle, please use the PanDao feature “non-circular circumference”

The screenshot shows the 'General Information' form in PanDao. The fields are as follows:

Name:	PanDao D2 asphCX_sphCX	Description:	type D asphericalCV_sphericalCV	Number of Sides:	Two
Batch Size:	200	Lens Diameter [mm]:	75	Center Thickness [mm]:	60
Total Number Of Lenses:	10000	Diameter Tolerance [mm]:	0.1	Center Thickness Tolerance [mm]:	0.05
<input type="checkbox"/> Suited for LIDT		<input type="checkbox"/> Outer cylinder length bigger lens diameter		Non-circular circumference[mm]:	Not Specified

as described in chapter 2.1 “*what are non-circular perimeters?*”

There are two cockpit for the shape of the clear aperture: circular and rectangular which can be selected in the scroll down menu:

The screenshot shows the 'Side 2' form in PanDao. The fields are as follows:

Shape:	Clear Aperture Diameter[mm]:	Clear Aperture Shoulder Length[mm]:	Geometry:
cylinders	72	10	Convex
Clear Aperture Shape:			
Rectangular			

A-circular surface shapes (e.g. for fast axis collimation FAC optics) are not yet covered by PanDao (see development stage in chapter5).

2.3. ASPHERICAL SURFACES

What is the current status of PanDao on aspherical surfaces?

Aspherical surfaces are rotary symmetric surfaces with a non-circular cross-section which are usually described by a power series description as follows:

$$z = \frac{y^2}{R(1 + \sqrt{1 - (1+K)y^2/R^2})} + Ay^4 + By^6 + Cy^8 + Dy^{10} + Ey^{12} + Fy^{14}$$

As input, PanDao does not require the absolute shape description, but rather parameters derived from it that are relevant for setting up optical manufacturing processes along the manufacturing chain, e.g. smallest radius of curvature, asphericity etc. These parameters can be determined by using PanDao's PRO-OPTIC CONVERTER (see chapter 2.1 "PRO-OPTIC-CONVERTER: How can I determine and convert lens tolerances so that PanDao can reads them?").

The conversion from power series description to Greg Forbes polynomials is currently under development and will be added to the PRO-OPTIC CONVERTER soon.

What is the "removal sphere" for a given aspherical, off-axis aspherical or freeform surface?

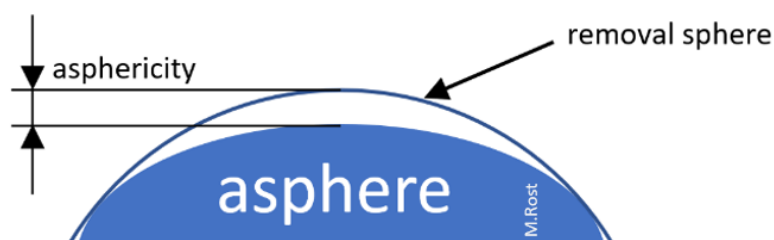
The removal sphere is the enveloping spherical surface that is located outside of the material not intersecting with the surface to be generated; it is located as close as possible above the surface to be generated without intersecting.

You can find this parameter in the output data generated by the optical design software.

What should I enter, if (e.g. for freeform surfaces) no "removal sphere" is known?

Please enter earth radius 6400'000'000 mm = 6400 km

What is "asphericity"?



In contrary to optics design, PanDao defines asphericity as the maximum vertical distance from the “removal sphere” to the aspherical, off-axis aspherical or freeform surface.

You can find this parameter in the output data generated by the optical design software.

How do I define the centering tolerance for an aspherical surface?

Aspherical shapes have no point symmetry. Therefore, tilting and side shifting result in different decenter effects and have to be defined separately.

Consequently, for aspherical surfaces, ISO 10110 uses e.g., the following notation **4/x (y)** with “x” describing the lens tilt in minutes and “y” being the maximum allowed lens side shift in mm:

Add-ons:			
Coating:	Decenter(4/):	Decenter Tilt(4/)[min]:	Decenter side shift(4/)[mm]:
None ▼	Specified: ▼	30	0.01

What is aspheres generation by aspherisation?

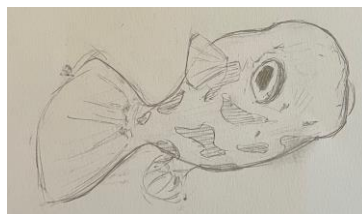
Traditionally, aspherical surfaces are being cnc point-contact ground and subsequently sub-aperture ccp-polished (ccp: computer controlled polishing). At certain tolerance and characteristic parameters combinations, e.g. for small asphericities (the distance to the best fit enveloping spherical surface), it is advantageous to generate the enveloping best fit spherical surface first and subsequently using the ccp method only for final aspherisation

You can find all the details and an example in the following paper:

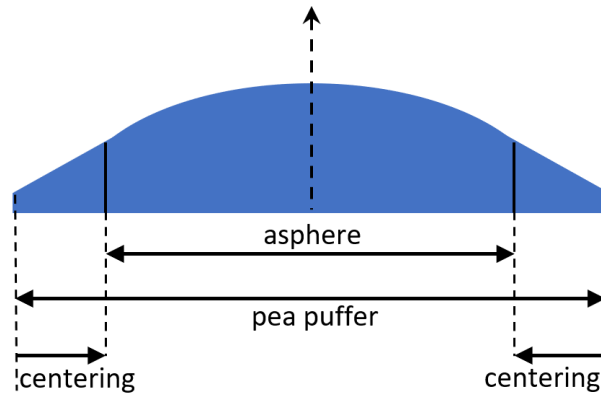
- O.Faehnle, J.DeGrote Nelson et.al. “The pea puffer aspheres: circumference optimized aspheres ccp polishing”, EOSAM24 conference on “Optical system design, tolerancing and fabrication”, European Optical Society (EOS), Napels, Italy, September 2024.

What is pea puffer asphere polishing?

First published by PanDao GmbH in 2024 at the “optical design, tolerancing and fabrication conference” of the European Optical Society (EOS) in Naples, **Pea Puffer** asphere polishing is a fabrication method for aspheres with small clear apertures.



Pea puffer is applied in certain situations, e.g. if an asphere is unsuited for certain ccp finishing methods [O.Faehnle, OFT&T conference, Monterey, 2012]. In this case, PanDao adds pea puffer polishing to the 360 standard OFTTs (Optical Fabrication Technology Techniques).



For the asphere to be generated, a bigger pea puffer lens is fabricated enabling a bigger spectrum of applicable OFTTs. Subsequently the pea puffer lens is centered down to the originally required diameter of the asphere.

In some circumstances this

- enables the manufacture of some aspheres which would normally not be possible,
- enables cost reductions because cheaper OFTTs can be applied.

The PanDao tool will tell you if the pea puffer asphere fabrication method has been applied.

In the cockpit, you can also disable the usages of pea puffer for comparison:

Others:			
<input type="checkbox"/> Molding enforced	<input checked="" type="checkbox"/> Allow block fabrication	Technology selection:	Yield factor:
<input type="checkbox"/> Pea puffer disable		PanDaoDefault	PanDaoDefault

You can find all the details about Pea Puffer in the following paper:

- O.Faehnle, J.DeGrote Nelson et.al. "[The pea puffer aspheres: circumference optimized aspheres ccp polishing](#)", EOSAM24 conference on "Optical system design, tolerancing and fabrication", European Optical Society (EOS), Napels, Italy, September 2024.

2.4. OFF-AXIS ASPHERICAL SURFACES

Off-axis aspheres: what is “offsetR”?

“offsetR” is the lateral distance from the symmetry axis of the asphere to the center of the clear aperture of the off-axis asphere.

Off-axis asphere: what should I enter at Center Thickness?

Please consult the stereotype lens drawings: Please enter the local minimum lens thickness called “gauge”.

Off-axis aspheres: what should I enter at “smallest radius of curvature” and at “smallest concave radius of curvature (SCRC)”?

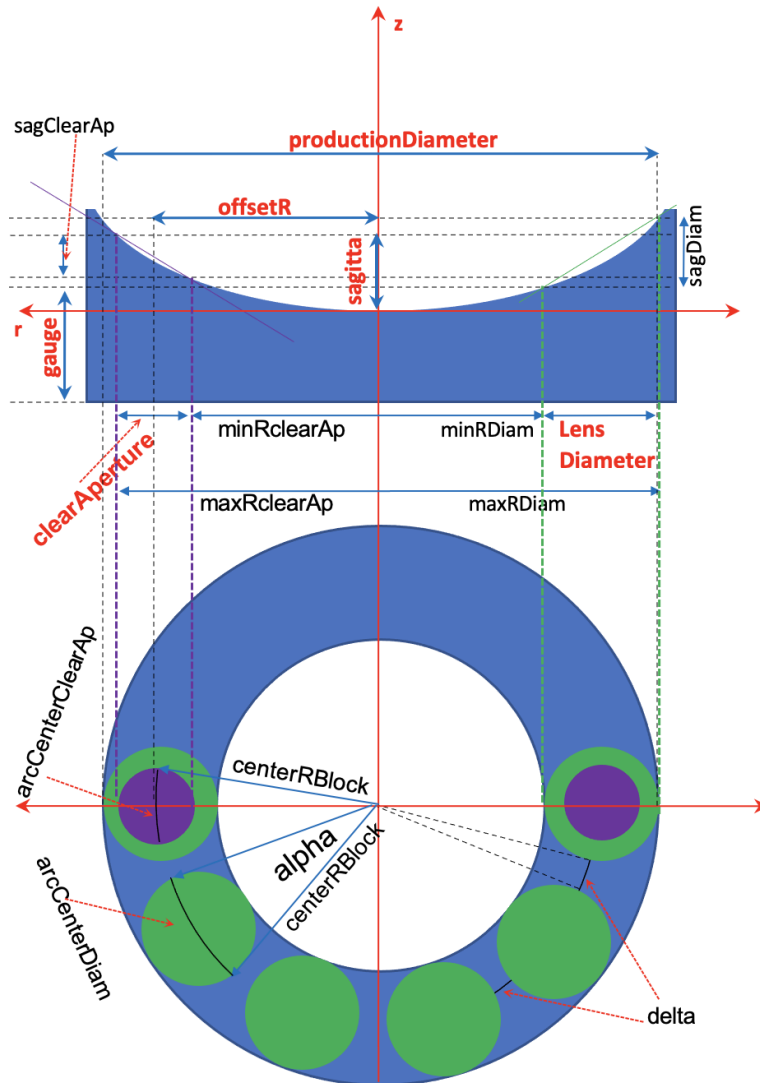
Please consult the stereotype lens drawings: Please enter the smallest radii of curvature of the whole aspherical surface out of which the off-axis asphere is being generated with production diameter = $2 * (\text{minRClearAberture} + \text{lens diameter})$.

Off-axis aspheres: How do I enter the 4/ centering accuracy?

There is currently no 4/ specified: Please enter 4/ at the other side of the lens, only. Currently, no center grinding cost for freeforms are generated.

Please note that cost for setting *fiducials* needed for matching the coordinate systems of (a) the machine and (b) the testing device and (c) the mounting setup are not taken into account, currently.

Off-axis aspheres definitions



LEFT SIDE (side 1)

clearAperture Φ :
 prot.chamfer (length): -
 coating (AR/special):
 3/power(irregularity)
 4/centering accuracy, not applicable: [see FAQ](#)
 5/
 6/ (if $> 10J/cm^2 = LIDT$)
 Sq surface roughness
 smallest midSpatialWavelength:
 sagitta

off-axis asphere:

smallest radius of curvature
 (of the whole asphere within
 production diameter)
 asphericity
 radius removal sphere:
 contains concave parts (YES/NO)?
 SCRC
 (smallest concave radius of curvature
 of the whole asphere within production diameter)
 offsetR
 sagDiam
 sagClearApp

MATERIAL:

if glass (YES/NO):
 HK:
 AR:

DIMENSIONS

"center thickness" **ct = gauge**
 (for off-axis aspheres and freeforms: enter local
 minimum lens thickness = gauge as center
 thickness)
 ct tolerance
 lens diameter
 production diameter
 (= $2 * (\text{minRDiam} + 2 * \text{lensDiameter})$)
 diam tolerance

PRODUCTION ORDER

totalNumber pcs
 batchSize pcs:

RIGHT SIDE (side 2):

currently flats only !

2.5. FREEFORMS

What should I enter at Center Thickness?

Please consult the stereotype lens drawings: Please enter the local minimum lens thickness called “gauge” located under the maximum sagitta (sag) of the freeform.

What is the definition of the parameter “MLC of SCRC”?

The “MLC of SCRC” is the Maximum Local Cross section (MLC) of the area with the Smallest Concave Radius of Curvature (SCRC). Please consult the freeform stereotype drawing.

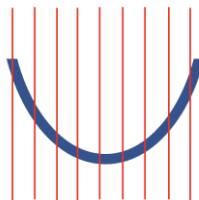
Do freeform surfaces have any symmetry?

No. Freeforms do not have any kind of symmetry and are defined by a data cloud: $z(x,y)$.

What should I enter at “MLC of SCRC” (Maximum Local Cross section (MLC) of the area with the Smallest Concave Radius of Curvature (SCRC))?

Please consult the stereotype lens drawings:

- a) if MLC is known, please enter MLC of SCRC in mm;
- b) if local radii are continuously varying along the clear aperture ($dR/(dx, dy) \neq 0$) then Please enter 0.01 mm (which is a typical incremental distance between data points used in CNC programming).



How do I enter the 4/ centering accuracy for freeform optics?

There is currently no 4/ specified: Please enter 4/ at the other side of the lens, only. Currently, no center grinding cost for freeforms are generated.

Please note that cost for setting *fiducials* needed for matching the coordinate systems of (a) the machine and (b) the testing device and (c) the mounting setup are not taken into account, currently.

What is the definition of the parameter “localSag at SCRC”?

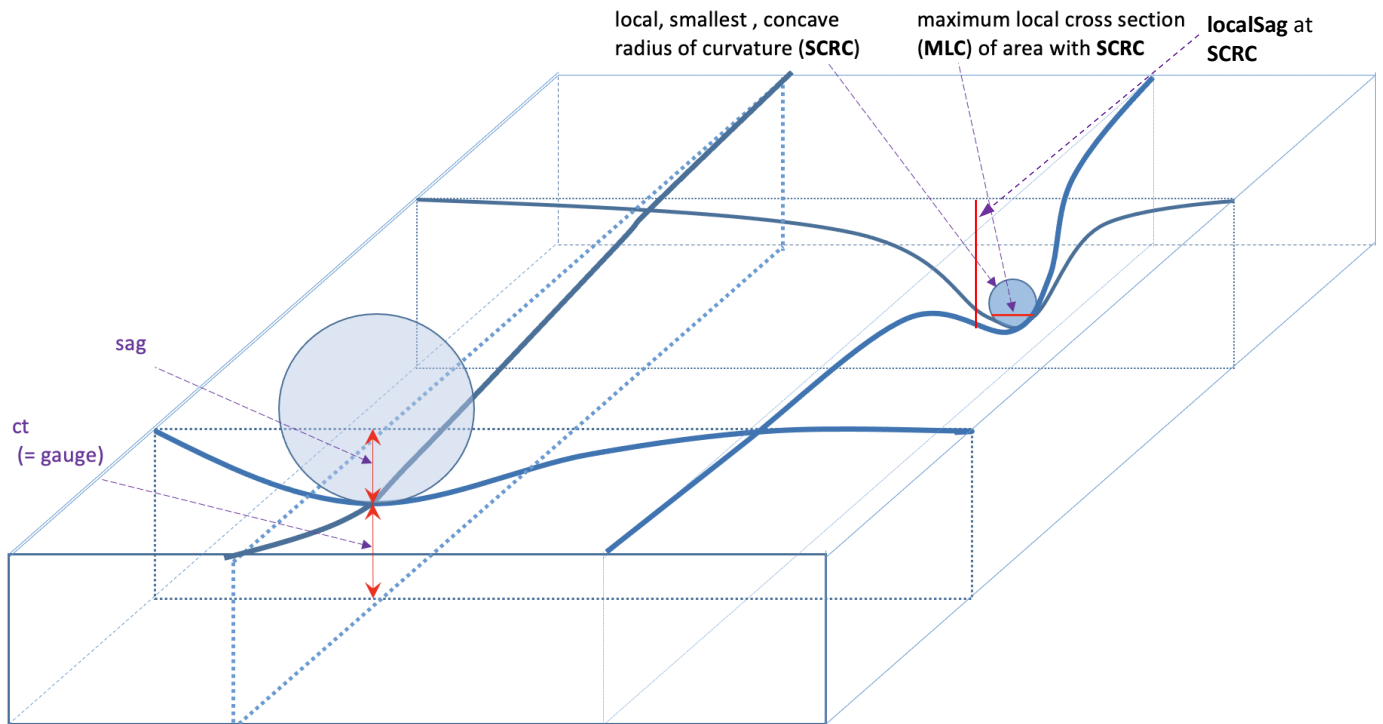
The “localSag at SCRC” is the local sagitta at the point $z(x,y)$ where the smallest concave radius of curvature (SCRC) is located. Please consult the freeform stereotype drawing.

Why is PanDao not informing about centering of freeform optics?

There is currently no industry standard for free-form centering; it is done, for example, by fiducials, extended ring assembly, or optically or by wafer stack technologies.

PanDao advises on request within the DesignToFabrication service

Freeforms definitions



LEFT SIDE (side 1)

clearAperture Φ_e :
 prot.chamfer (length):
 coating (AR/special):
 3/power(irregularity)
 4/centering accuracy, not applicable: [see FAQ](#)
 5/
 6/ (if $> 10\text{J}/\text{cm}^2 = \text{LIDT}$)
 Sq surface roughness
 smallest midSpatialWavelength:
 sag

if freeform (YES/NO):

smallest radius of curvature
 asphericity: [see FAQ](#)
 radius of removal sphere: [see FAQ](#)
 contains concave parts (YES/NO)?
 smallest concave radius of curvature (SCRC)
MLC of SCRC
 (Maximum Local Cross section (MLC) of the area with the Smallest Concave Radius of Curvature (SCRC))
localSag at SCRC
 (local sagitta at the point $z(x,y)$ where SCRC is located)

MATERIAL:

if glass (YES/NO):
 HK:
 AR:
 Alpha:

DIMENSIONS

“center thickness” **ct = gauge**
 (for of-axis aspheres and freeforms:
 enter local minimum lens thickness =
 gauge as center thickness)
 ct tolerance
 lens diameter
 diam tolerance

PRODUCTION ORDER

totalNumber pcs
 batchSize pcs:

RIGHT SIDE (side 2): any shape allowed

2.6. Prisms

Prisms generation is currently under beta testing and not yet covered by PanDao (see chapter 5, development stage).

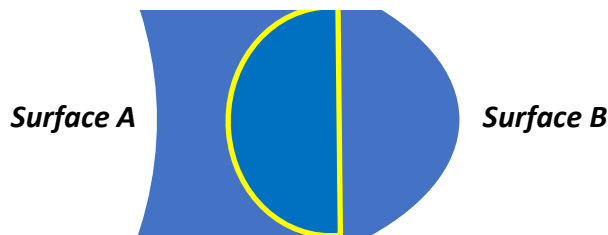
2.7. CEMENTED OPTICS

How do I manage centering tolerances of cemented optical elements?

For cemented optics (e.g. doublets, triplets or quadruplets), the centering tolerance is often specified on the technical drawing of the cemented element rather than on the drawing of its lenses.

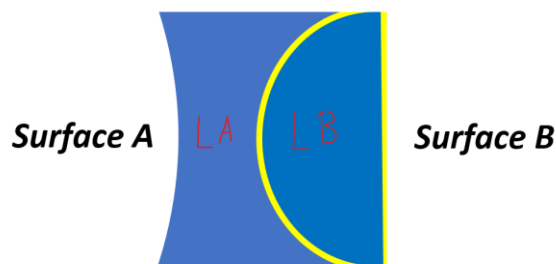
In this case, please input into PanDao the cemented element as if it would be one single lens. The two sides of this virtual lens are its outer surfaces of the cemented element (see below surface A and B of the triplet shown) and its center thickness is the sum of the center thicknesses of its individual lenses.

That way, PanDao copes with center grinding, circumference generation and multiple facets grinding of cemented optics.



How do I determine cementing cost (assembly of lenses into cemented optical doublets, triplets etc.)?

PanDao covers cementing of two optical surfaces, e.g. cementing lensB (LB) on top of lensA (LA):



Currently, cementing is restricted to spherical and flat glass optical surfaces, only. Please proceed as follows:

- Load lensA into PanDao
- Select the surface you want to cement the second lens (LB) onto: usually this is the side of the lens where the 4/ specification is defined.
- Select the glass type of lensB to enter its coefficient of thermal expansion: "alpha" by either selecting "supplier name" (e.g. N-BK7) or by selecting "custom material":

Cementing:	Material name:	Alpha (-30/70) [1/°C]:
By supplier name <input type="text"/>	<input type="text"/>	<input type="text"/>

Cementing:	Alpha (-30/70) [1°C]:
Custom material <input type="text"/>	<input type="text"/>

d) Enter the temperature range the cemented optic will be exposed to (in degrees Kelvin):

Temperature range [°C]:
<input type="text"/>

e) Enter the decenter 4/ value of surface B to surface A of the semented element (please collect this value from the technical drawing of the cemented element).

f) Enter the diameter of lens cemented to the surface:

Diameter of lens cemented to[mm]:
<input type="text"/>

g) Enter the thickness of the layer between the two surfaces. Typically, this value is not on the drawing and only fabrication specialists can determine accurate values. If you don't know what to enter, please enter 10um as standard value:

Layer thickness [um]:
<input type="text" value="10"/>

PanDao will display the best cementing technology and its cost per cemented doublet.

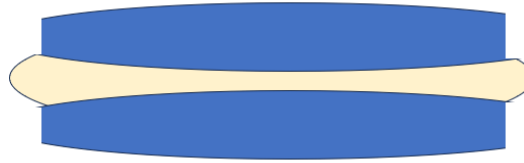
Please note that PanDao currently

- excludes cementing of lenses larger than 150 mm in diameter: If you require the cementing process for larger lens diameters, please contact us at info@PanDao.ch.
- covers optics cementing only for glasses, calcium fluoride, crystals, glass ceramics, chalcogenide glasses and fused silica
- allows cementing of flat and spherical surfaces.

Please respect the following delicate rules for an optimal result at minimum risk of cement cracking

- The sides to be cemented must have the same type of shape and shape accuracy.
- A so-called plus fit must be selected, coordinated shape deviations of both surfaces within the permitted range (see 3/ of both sides), which ensure a cement gap that increases monotonically towards the outside;
- An index-matching cement is to be used and typically a 12 hour (cement dependent) rest period is to be respected after UV initiation of the cementing process;
- Cement layer thicknesses of at least 5 microns and typically not more than 10 to 20 microns lead to the best result: to guarantee this, the use of microspheres of defined refractive index can be considered; these can be positioned randomly along the cross-section of the lenses (if the refractive index of the spheres matches the one of the cement) or outside of the free apertures only: The latter offering the advantage that they are ground away in the last process step during center grinding.

- The volume of cement applied should be large enough to allow a bead of cement on the outside of the optic to function as a reservoir, preventing cement cracks during curing and the associated shrinkage



Sketch of shape accuracies ratio within the allowed shape deviations (3/) and the bead of cement at the outside

3. OUTPUT PARAMETERS

What are general boundary conditions for PanDao's output?

Tools and materials are available.

If you'll choose one of the input parameters "out of range", PanDao delivers an error message without counting this request.

What is the output of PanDao?

PanDao determines two optimized fabrication chains: (a) the most cost-efficient and (b) the fastest fabrication chain. In addition, PanDao informs about center grinding, testing, coating and material cost needed.

Resulting most cost-efficient fabrication chain:

<p>Side 1:</p> <ul style="list-style-type: none">• curve generator rough grinding • fabrication cost: 1.78€• cnc full aperture flats grinding • fabrication cost: 1.67€• cnc full aperture flats polishing • fabrication cost: 2.25€• block fabrication is used <p>Cost 5.70€ Capability factor: 0.998 Chain uniqueness: 27</p>	<p>Side 2:</p> <ul style="list-style-type: none">• curve generator rough grinding • fabrication cost: 0.44€• block fabrication is used• curve generator grinding • fabrication cost: 0.31€• block fabrication is used• cnc full aperture polishing • fabrication cost: 0.50€• block fabrication is used <p>Cost 1.26€ Capability factor: 0.998 Chain uniqueness: 2</p>
--	---

Total fabrication cost: 6.95€
Serial batch lead time: 5.0501 days

In general, there are three different possible answers given by PanDao:

- h) the two optimized fabrication chains as described and shown above,
- i) the two optimized fabrication chains together with a risk-alert,

Side 1: High risk of failure or low yield numbers because center thickness to clear aperture ratio is smaller than 1:8
Side 2: High risk of failure or low yield numbers because center thickness to clear aperture ratio is smaller than 1:8

Resulting most cost-efficient fabrication chain:

<p>Side 1:</p> <ul style="list-style-type: none">• curve generator rough grinding • fabrication cost: 1.17€• curve generator grinding • fabrication cost: 1.04€• cnc full aperture polishing	<p>Side 2:</p> <ul style="list-style-type: none">• curve generator rough grinding • fabrication cost: 1.17€• curve generator grinding • fabrication cost: 1.04€• cnc full aperture polishing
--	--

- j) no fabrication chain possible for the lens data inputted; in this case, PanDao delivers the message "can't fabricate":

Resulting most cost-efficient fabrication chain:

Side 1:

- Can't fabricate side (See manual)

What should I do if my lens data generates the message "can't fabricate" or if unexpected responses are displayed?

Please proceed according to the following scheme when troubleshooting:

- a) double check your input data
 - Aspheres, off-axis aspheres and freeforms need a mid-spatial wavelength > 0.08 mm
 - Cockpit/Applicability: at least one of the three choices must be activated with a tick: "in industry", "RnD" and/or "university".
 - Cockpit/Level-of-Maturity: at least one of the two choices must be activated with a tick: "established" and/or "emerging technologies".
 - Double check your 4/ centering tolerance
 - General: Double check if you activated the tick for "Material suited for precision glass molding".
 - Try to enable "emerging technologies" in the cockpit/Level-of-Maturity" section.
 - Double check if you selected the desired material.
- b) load a stereotype product (from the scroll-down menu at the PanDao "specify your product" input page) and convert this data step by step into your lens data.
- c) contact us at info@PanDao.ch and request a PanDao DesignToFabrication service for this lens: our experts will analyze your lens data and provide a detailed manufacturability report for this lens, including suggestions on which input data should be changed or optimized.

What is Prototype Batch Lead Time (PBLT)?

Prototyping Batch Lead Time (PBLT) is the minimum time needed to produce a first batch under the following boundary conditions: (a) using one fabrication chain only (production applied sequentially and not in parallel), (b) prototyping batch orders are classified with top priority and (c) taking industrial-realistic handover times of one day per production step into account.

Prototyping lead time is an information needed for the prototyping phase and therefore being displayed only for batch sizes smaller than 50 lenses.

Prototype batch lead time: 9.00 days

What is Serial Batch Lead Time (SBLT)?

Serial Batch Lead Time (SBLT) is the minimum time needed to produce a batch in serial production under the following boundary conditions: (a) using one fabrication chain only (production applied sequentially and not in parallel), (b) taking industrial-realistic handover times per production step into account and (c) applying a batch-controlled workshop manufacturing approach.

For the fastest production chain, it is assumed that the chain is optimally filled, the transfer times are minimized and the most complex production step determines the cycle rate.

Serial batch lead time: 3.9064 days

What is “most cost-effective fabrication chain”?

Based on lens' input data given, PanDao determines **as standard output** the best fabrication chain in terms of causing minimum fabrication cost at maximum yield; this is also called the cheapest fabrication chain.

Please note, that the most cost-effective fabrication chain is not necessarily the fastest fabrication chain.

Resulting most cost-efficient fabrication chain:

What is the “fastest fabrication chain”?

In addition to the “most cost-effective fabrication chain”, PanDao determines the “fastest fabrication chain”: optimized for speed at reasonable risk while ignoring cost issues.

PanDao delivers information about both chains: the fastest and the most cost-effective: e.g. “...the “fastest chain” produces each batch 1.28 times faster than the “cheapest chain” at 2.9 times more cost.

Resulting fastest fabrication chain:

What is “chain uniqueness”?

This output parameter helps in the risk assessment of the most cost-effective fabrication chain determined. ‘Chain uniqueness’ informs about how many fabrication chains exist within a fabrication cost band of 20 % above (and including) the cheapest fabrication chain.

In the example below, there are two other manufacturing chains existing that do not cost more than 20% more than the optimal manufacturing chain and use other technologies.

<p>Side 1:</p> <ul style="list-style-type: none"> • curve generator rough grinding • fabrication cost: 0.54€ • block fabrication is used • curve generator grinding • fabrication cost: 0.42€ • block fabrication is used • cnc full aperture polishing • fabrication cost: 0.65€ • block fabrication is used <p>Cost 1.61€ Capability factor: 0.998 Chain uniqueness: 2</p>

What is “chain capability”?

The ‘chain capability’ is a measure of the level at which the fabrication technologies must perform their duty in the best manufacturing chain.

At ‘chain capability’ 100 %, the chain has to be applied at state-of-the-art processing level.

Below 100%, tolerancing could be further tightened (up to capability = 100%) without the need of a technology change.

The chain in the example shown below has a ‘Capability factor’ of 99.8% (Capability factor: 0.988)

Side 1:

- curve generator rough grinding
 - fabrication cost: 0.54€
 - block fabrication is used
- curve generator grinding
 - fabrication cost: 0.42€
 - block fabrication is used
- cnc full aperture polishing
 - fabrication cost: 0.65€
 - block fabrication is used

Cost 1.61€
✔ Capability factor: 0.998
Chain uniqueness: 2

What is the difference between the “most cost-effective fabrication chain” and the “fastest fabrication chain”?

The “most cost-effective fabrication chain” is the chain with minimum fabrication cost at maximum yield; it is not necessarily the fastest chain possible.

The “fastest fabrication chain” is the fastest possible fabrication chain optimized for speed at reasonable yield while ignoring cost issues.

Chain comparison: ✔

During serial production, the fastest chain is 3.88 times faster than the most cost-efficient, but causing 1.06 times more cost.

How can I document PanDao’s results (the PanDao Report)?

You can save lens input data any time and reload later for further analysis by PanDao or by your optical design software. You can furthermore download a full PanDao report of your lens as a pdf file or a commercial summary as an Excel file; PanDao reports can be downloaded here:

Specify your Product:

Load/Store Products ✔

Load from File Load stereotype product: ✔


General Information ^

Side 1 ^

Side 2 ^

Options ^

- “Download lens to file”: the PanDao input data is downloaded into a json file and can be reloaded into PanDao any time.
- Download report pdf”: a full report including cost and risk information as well as a management summary and literature references to all required optical fabrication technologies.
 - The PanDao report can be read-in as input
 - Please avoid Inverted commas, “”, in the description section of the lens



PANDAO
FROM OPTICS TO FABRICATION

www.pandao.ch

Producibility report for PanDao Report:

Description:
The PanDao report summarizes all output generated by PanDao AND can be used to re-load the lens data again into PanDao .

Management summary:

	Total fabrication cost [€]	Lead time [days]
cheapest chain	10.99	4.350
fastest chain	14.95	4.350

Production:
Batch size: 300
Total number of lenses: 300

Options:
Wage level: low wage companies
Technology selection: PanDaoDefault
Excluded technologies:
Applicability: In Industry
Level of maturity: Established
Enforce modling: false
Allow block fabrication: true

- “Download summary csv”: download an Excel file with the cost details of your lens; You can use the "Delete old csv entries" button to write the cost information to a new Excel file: this allows you to sum up the cost informations for an entire objective into one file.

	A	B	C	D	E	F	G
	name	most cost efficient chain cost [Euro]	fastest chain cost [Euro]	center grinding cost [Euro]	coating cost [Euro]	testing cost [Euro]	material cost [Euro]
1							
2	PanDao Report	8.92	12.88	0.05	1.07	0.87	0.0815
3							

4. PanDao MASTER CLASS: specialities and tricks in optics fabrication

Tips and tricks for high level usage of PanDao.

4.1. General usage

The following is valid for the usage of PanDao with all three databases: “default”, “company-owned” and “digital twin”.

Technology selection:
PanDaoDefault ▾

Technology selection:
CompanyOwned ▾

Technology selection:
DigitalTwin ▾

How can I use PanDao for proposal writing for funded projects for e.g. EU or Innosuisse or DFG?

In the Cockpit section, select all "Applicability" and all "Level of Maturity" categories at rather low TRF levels (Technology Readiness Levels). Then review the PanDao results for your lens design under development. The resulting manufacturing chains may be suitable as a proof of concept for the project proposal.

Many thanks to Hansruedi Moser, who was the first person to win a huge project grant based a.o. on the submitted Pandao analysis of the field of technologies existing, identifying the novel technology opportunity.

Applicability:

- In industry (TRL 7-9) Prototyping (TRL 4-6) Research (TRL 1-3)

Level of Maturity:

- Established Emerging Technology

How can I determine, if a substitute glass that is suitable for precision glass molding might enable a more cost-efficient fabrication chain?

Many optical designs use mineral glasses that are not suitable for precision glass molding (pgm). In order to determine whether a redesign using a moldable pgm glass would make sense, PanDao offers a way to check in advance if (and how much more) a redesign would be cost-effective in terms of manufacturing costs.

To that aim,

1. open the PRO-OPTIC-CONVERTER and type in the glass used so far.
2. PanDao will determine out of more than six different glass manufacturers catalogues, e.g. Hoya, Sumita, Schott, Nikon, Ohara, Vitron or CDGM, a pgm substitute glass featuring a minimal difference in refractive index value.
3. Subsequently, please read your design into PanDao with the glass type substituted by the pro-optic-converter-identified pgm glass.
4. If this pgm substitute glass allows the use of pgm, enabling cheaper production, then will make sense to start redesigning the lens shape and tolerances to adapt to the substitute glass.

PRO-OPTIC -CONVERTER

Find substitute material for PGM	This tool allows you to find a substitute glass with minimum delta in refractive index and that is suitable to be processed with precision glass molding (pgm): for details, please consult the “PanDao Master Class” section.
----------------------------------	--

Find Substitute Material for PGM:

In case the optical design is based on a type of glass that is not suited for precision glass molding (PGM), pro-optics-converter helps to find a substitute type of glass. If you run a PanDao analysis with this new glass, you may be able to reduce your designs cost.

Non PGM reference material name:

Refractive index nd: 1.62004

Ask PanDao!

Result:
 Found substitute glass: K-SSK9 from Sumita with nd: 1.62001 which is 0.00185% off the reference glass.
 or: P-SK60 from same supplier as reference glass with nd: 1.61035 which is 0.60173% off the reference glass.

Disclaimer:
 Please counter-check the results. Despite thorough controls by our means, errors are possible. Use at your own risk(GTC applies).

How can I select the best production strategy for an off-axis asphere?

Please note that there are two possible ways to generate off-axis aspherical optics and that the cost of both can be determined applying PanDao:

- input of the lens as an off-axis aspherical element or
- input of the lens as a freeform element.

Subsequently, you can choose the best variant for you taking cost and availability of technologies into account.

Side 1 ▼

Global:

Shape:

Side 1 ▼

Global:

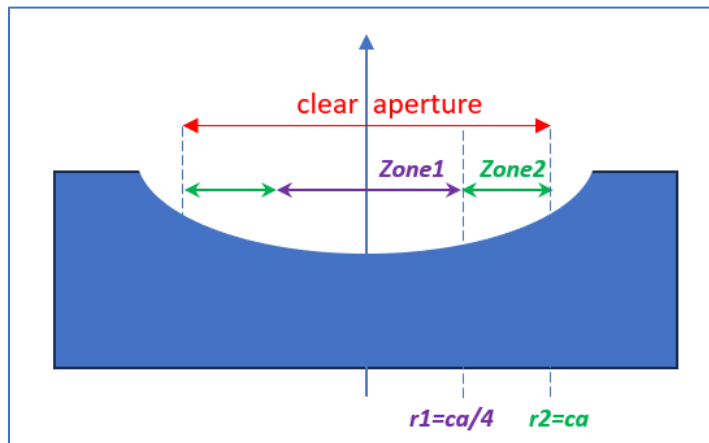
Shape:

How can I apply PanDao to optics with different zonal quality levels within the clear aperture?

PanDao can be applied to determine the optimum cost, risk and fabrication chains for optics with multiple zonal quality levels (featuring e.g. different values of surface roughness or shape accuracy or midspatial wavelength or defect size). This requires a series of “ask PanDao” requests.

For example, consider a lens surface with two zonal quality levels within the clear aperture (ca):

- Zone1**, a central zone from the optical axis (at $r = 0$ mm) to $r = ca/4$, and
- Zone2**, a second zone from here to the clear aperture.



Lets assume that Zone1 has more stringent quality requirements than Zone2. In order to “pandao” (ask PanDao) this lens, the following procedure is required:

- a) *Pandao* this side of the lens
 - i. applying for the whole clear aperture the Zone2 quality; use lens diameter as required: Save the result as “PanDao_A”.
- b) *Pandao* this side of the lens applying for Zone1 ($ca/2$) the Zone2 quality; set clear aperture lensDiameter = ca = Save the result as “PanDao_B”.
- c) *Pandao* this side of the lens applying for Zone1 ($ca/2$) the Zone1 quality; set lensDiameter=ca. Save the result as “PanDao_C”.
- d) The final PanDao result for this side of the lens = Pandao-A – PanDao_B + PanDao_C

Production of a large number of small-diameter plano parallel plates?

There are two ways to determine the production of plano parallel plates:

- a) input the plano parallel plate directly into PanDao.
- b) Singling out of a big plate:
 - i. Input a plano parallel plate into PanDao that contains a large number of the required small-diameter plano parallel plates. In this case, you need to determine the number “n” of the smaller plano parallel plates that can be drilled out of the bigger one (taking into account the wall thickness of the grinding cup wheel to be applied).
 - ii. Subsequently you will need to determine the cost of singling out the eventual small plano parallel plates you want to generate. To that aim, you the center grinding cost of the direct generation of one smaller plano parallel plate as described in paragraph “a)” above.
 - iii. Finally, the cost of one small plano parallel plate equals the cost for the generation of the bigger plano parallel plate (devided by the number of small parts contained) plus the drilling cost for singling.

Production of a large number of small-diameter optics with a convex, spherical side?

In case the combination of order size, tolerances and properties of the lens allows it, PanDao reports that the fabrication chain of the convex, spherical surface of this lens could possibly be replaced by purchasing a glass sphere instead. In this case the opposite side of the convex side will be generated out of the purchased sphere directly:

Ask PanDao!
Download lens to file
Download report pdf
Download summary csv

Side 2: Instead of generating this side, a glass sphere can be purchased instead. If this is done, for the total fabrication cost subtract this side's cost from the total cost displayed below.

This strategy is appropriate if the PanDao manufacturing cost of this convex, spherical side plus the material cost would exceed the purchase price of the glass sphere.

All other costs that PanDao calculates (e.g. coating, the manufacturing costs of the second side, testing costs, center grinding, etc.) remain in place.

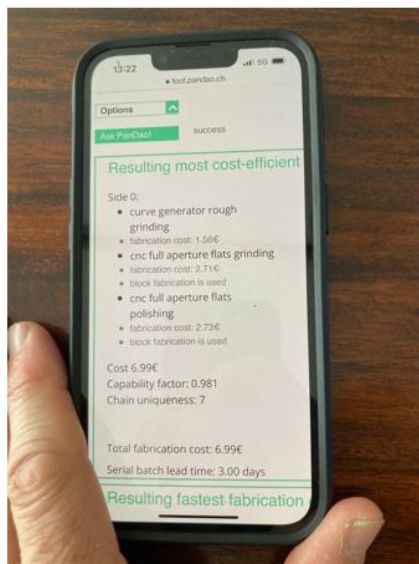
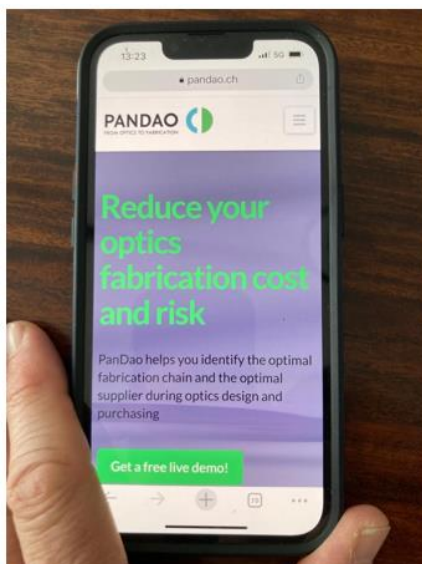
Optimization of lens specifications for minimal project risk?

Once PanDao has determined the optimal manufacturing chain for a lens, the design can be performance stabilized at the same cost. The most performance-relevant parameters are tightened with PanDao to such an extent that this does not cause any cost increase.

lens parameter	tolerancing level required by optical designer	tolerancing level possible without any higher fabrication cost or risk
surface roughness	3 nm rms	1 nm rms
decenter	5'	1'
scratch & dig	3*0.024	3* 0.024
shape accuracy	3/5(2)	3/4(2)

How can I use PanDao during supplier negotiations?

During negotiations, the customer and supplier can review the optimal manufacturing chain, estimate cost and required technologies. In this way, additional cost become visible if a required technology is not available, as well as the cost impact of changes in tolerances and order size. This leads to a better understanding of each other and more efficient contracts that can be relied upon...



How can I check for a given lens its cost assuming tolerancing in the EUV or Visible or IR range?

PanDao offers the possibility for a given optical element which is defined by shape and geometry, coating and mechanical features (such as facets), to determine its optimum cost and fabrication chain in the following application regimes **by just one click**:

1. Infrared optics quality
2. Visible – imaging optics quality
3. Visible – illumination optics quality and
4. EUV optics quality.

To that aim, load the lens to be tested into PanDao and apply this scroll down menu to select one of the four quality regimes listed above:

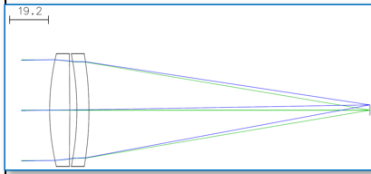
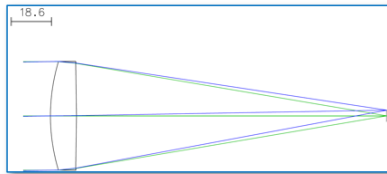
Specify your Product:

Load stereotype product:
 Load typical tolerances:

Many thanks to Nic for this brilliant idea !!

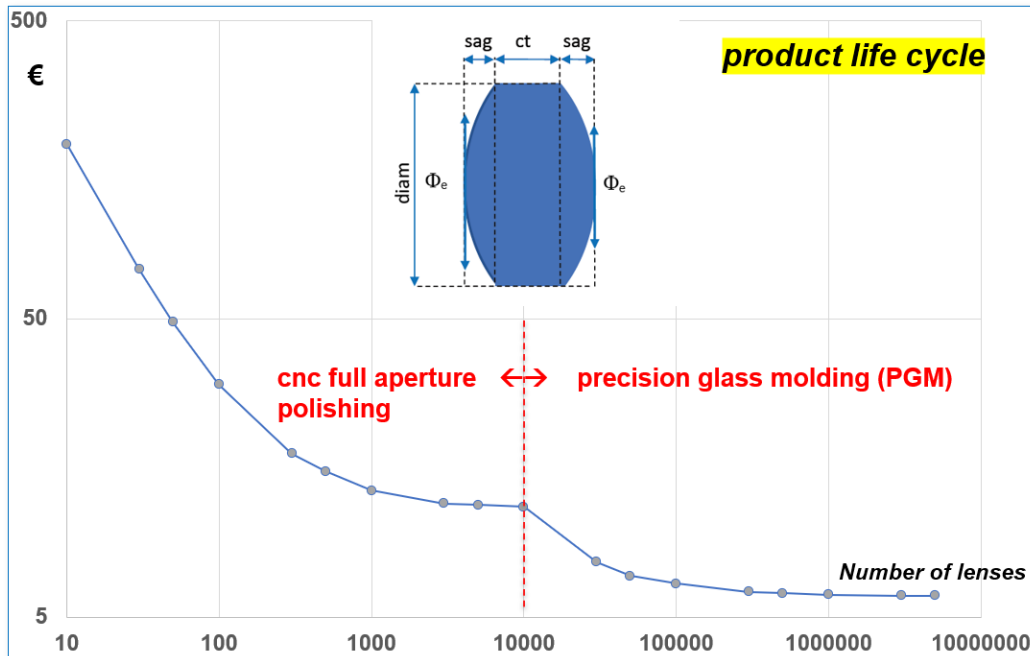
Comparison of competing optical designs?

In case two (or more) competing optical designs have been generated at similar optical performance levels, PanDao can be used to choose the one causing minimum fabrication cost (or fastest delivery times) at smallest manufacturing risk:

	• focal length = 150, D = 50, NA = 0.1667, field = 5.2mm	
design	spherical doublet , N-SF57, HK520, AR1 	aspherical lens K-PBK40, HK610, AR1 
material cost	24.2 €	4.4 €
fabrication cost	18.61 €	32.25 €

How can I carry out optics life cycle analyses?

With PanDao, the entire cost lifecycle of a lens can be determined, from prototyping through pilot series to series production. PanDao recognizes when a technology change takes place and thus enables the optimization of order sizes for minimum costs.



How do I determine the cost of a possibly competing chain that applies molding?

In case the type of material **is suited** for molding (either precision glass molding or injection molding) and the optimal manufacturing chains displayed are not molding,

- the costs of a possibly competing manufacturing chain which uses molding (precision glass molding (pgm) or injection molding) can be determined. Please ask PanDao again but this time with the "Enforce Molding" field (located in the "Cockpit" section) must be switched:

Options ▼

Applicability:

In industry

Level of Maturity:

Established

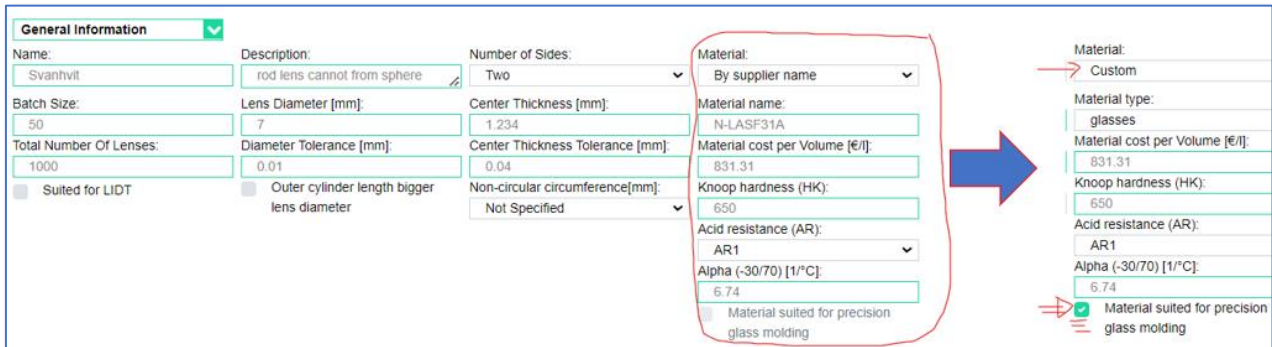
Others:

Molding enforced

In case the type of material **is not** suited for molding (either precision glass molding or injection molding) and you want to find out if it makes sense to determine in optical design a substitute glass that is well suited for molding, you can ask PanDao (see picture below):

- Change the material selection from "by suppliers name" to "custom".
- Now you are allowed to set the tick at "Material suited for precision glass molding" (see picture below)
- Then ask PanDao again with "Enforce Molding" field (located in the "Cockpit" section) switched on.

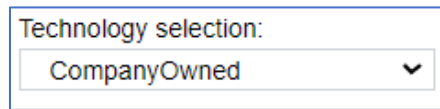
- If the manufacturing situation allows molding, PanDao will display the molding chain and you will see how much money you could potentially save by making an optical design change towards a moldable type of material.



The screenshot shows a software interface for material selection. On the left, there is a 'General Information' section with various input fields for lens parameters. A red circle highlights the 'Material' section, which includes a dropdown menu for 'By supplier name' and several input fields for material properties like 'Material name', 'Material cost per Volume', 'Knoop hardness', 'Acid resistance', and 'Alpha'. A blue arrow points from this section to the right, where another 'Material' section is visible. This section has a dropdown menu for 'Material' set to 'Custom' and a red arrow pointing to it. Below the 'Material' dropdown, there are several input fields for material properties, including 'Material type', 'Material cost per Volume', 'Knoop hardness', 'Acid resistance', and 'Alpha'. A red arrow points to the 'Material' dropdown menu in this section, and a green checkmark is visible next to the 'Material suited for precision glass molding' checkbox.

4.2. Company-owned database

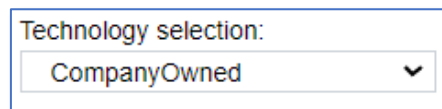
The following is valid for the usage of PanDao with the “company-owned” database.



The screenshot shows a dropdown menu labeled 'Technology selection:'. The selected option is 'CompanyOwned'.

How can I determine fabrication chains which use only technologies available at my or my supplier’s company?

If the company-owned database is being chosen in the cockpit menu, PanDao determines the best fabrication chain for the limited custom list of company-owned fabrication technologies, only. These technologies are being applied at State-of-the-Art performance.



The screenshot shows a dropdown menu labeled 'Technology selection:'. The selected option is 'CompanyOwned'.

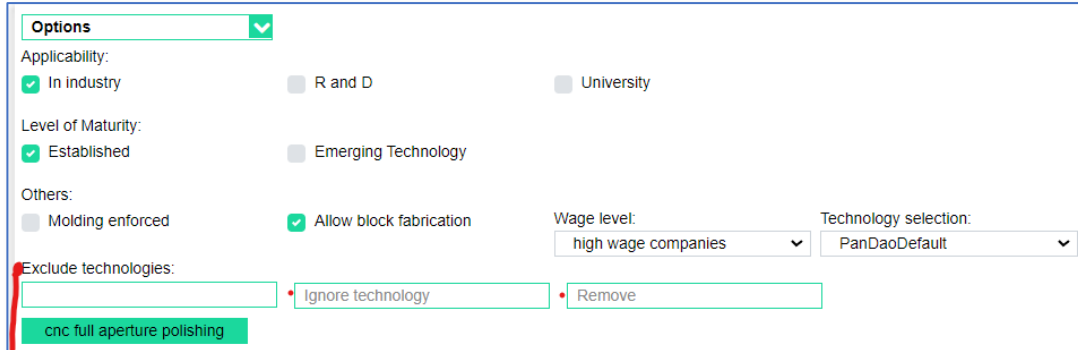
Determine the need for investment in new machineries by checking the difference between the PanDao results using "owned" and "default" databases.

The delta in fabrication cost for one lens if PanDao’s default or PanDao’s company-owned database is being applied can be used to determine the need for a possible investment project for buying and implementing a new technology.


Applying capacity management

Applying the omit and the enforced cockpit it is possible to manage the capacity of technologies available at your company.

- **Omit Technologies:** In case one of the technologies contained in the optimal fabrication chain should be avoided: copy&paste the name into the “exclude Technology” field in the cockpit and PanDao will determine the optimal fabrication chain without using this technology



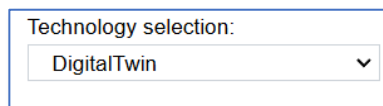
- **Enforced OFTT:** select the technologies from your customized list of OFTTs that PanDao should enforce to be used for finding the optimal fabrication chain.



In this way, you can steer the capacities in your production department while taking into account the resulting additional costs.

4.3. Company’s digital twin

In this case, PanDao determines the best fabrication chain for the limited, customized list of company internal fabrication technologies, only. These technologies are being applied not at State-of-the-Art performance, but at the performance level defined by customer. With this option its possible to create a digital twin of the fabrication of a company.



How can I compare the performance of my machines with that of state-of-the-art machines?

Determine fabrication cost for a lens using the “digital twin” and subsequently enforce PanDao to use the same fabrication chain for this lens using the “default” database. The difference in SBLT (serial batch lead time) and fabrication cost indicates the difference in performance of your machines with state-of-the-art machinery.

How can I determine of the need for replacement investments in machinery?

The delta in cost between the results of using PanDao "digital twin" and "default" databases is a measure for the difference of performance of the machines at your company to the current state-of-the-art and can be used to determine commercially the need of starting an investment project to buy new machines.

5. PanDao's development stage

In order to ensure PanDao's state of the art level, PanDao is regularly being updated: for more details, please consult the blog section at the PanDao webpage (www.PanDao.ch) and PanDao's LinkedIn page (www.linkedin.com/company/pandao-gmbh).

PanDao		development stage
input	lens data according to ISO10110 standard and number of lenses to be produced	(a) read-in directly from your optical design software's output, (b) use a PanDao stereotype lens or (c) type in manually
taking into account	various materials	Glasses, crystals, metals (magnetic and non magnetic), glass ceramics, ceramics, PMMA, PC, COC, SG95, UV hardening polymeres, CR39, Zeonex, binderless tungsten carbide (WC), SiC, fused silica, silicon, germanium, CaF2, Zerodur, CaF2, sapphire, ZnSe, ZnS, chalcogenide glasses
	IR materials	CaF2, BK7, Si, Ge, fused silica, sapphire, CVD_ZincSelenide_FLIR, CVD_ZincSulfide_FLIR, CVD_ZincSulfide_CLEAR, ChalcogenideGlasses
	all existing optical fabrication techniques	currently appr. 360
	processing cost	ok
	operator cost	ok
	tooling and mounting cost	ok
	uptime and downtime of machines	ok
	job setup time on the machine	ok
	company's commercial settings: bank interest and loan payback times, salaries, wage level, etc.	PanDao offers the selection of three companies wage levels for fabrication cost calculations. In addition, it is also possible to input one's individual commercial parameters
output	using 360 technologies: determination of optimal optics fabrication chains, e.g. the most-cost efficient chain and the fastest chain	ok
	center grinding cost of single elements <u>and</u> of cemented elements: taking eight different center grinding technologies into account	ok
	material cost	ok
	coating cost	ok
	testing cost	ok
	<i>cementing cost (e.g. doublet)</i>	ok
	fabrication risk analysis	ok
	manufacturing chain quality assessment	ok
cost impact analysis	ok	
included	optics with any combinations of flat, spherical, cylindrical, freeform, off-axis aspherical or aspherical surfaces	ok
	maximum number of optical surfaces	two
	<i>prisms</i>	not yet: currently under development
	lens facet stages and protective chamfers	ok
	non-circular lens perimeter shapes	ok
	clear apertures	from 0.3 mm to 1.5 m
	surface quality	from IR to EUV optics

	order's batch size	from prototyping to mass production
optional	using technologies available <u>at your or your supplier's company</u> : determination of optimal optics fabrication chains, e.g. the most-cost efficient chain and the fastest chain	ok
	capacity steering tool for your workshop's technologies	ok
currently excluded	overhead cost	this strongly varies from department to department and company to company and is typically a corporate secret
	prisms, acylinders, wedge plates, beam splitters, glass-spheres, GRIN lenses, nanomere materials, consumer glass (e.g.: bottles, windows, pipettes), mechanical components, glass fiber, lithography or on-chip optics, diffractive optics, meta-surfaces and holograms.	not yet included...

Included material catalogues:

Company name:	Last updated:	Cost information available?	Comments:
Schott	16.09.2024	yes	Alpha value at: -30 to 70°C
Sumita	15.04.2024	no	Alpha value at: -30 to 70°C
Ohara	24.01.2024	yes	Alpha value at: -30 to 70°C
Hoya	21.04.2021	no	Alpha value at: -30 to 70°C
Nikon/Hikari	01.07.2022	no	Glasses alpha value at: -30 to 70°C FusedSilica alpha value at 25 to 100°C
CDGM	01.9.2024	yes	Alpha value at: -30 to 70°C, F2 and F5 are duplicated names with materials from Schott. They are renamed to F2-CDGM and F5-CDGM.
Corning	21.07.2015	no	FusedSilica only alpha 0 to 200°C
Haraeuse	18.1.2024	no	FusedSilica alpha at 0°C from graph
Leoni	01.01.2011	no	FusedSilica only alpha 25 to 100°C
Vitron	08.06.2014	no	ChalcogenideGlasses for IR

If you use any material supplier who is not listed here or you think something is off:

- please let us know: info@pandao.ch

6. PanDao's references

Abstract Along our trail towards harmony between optics designers and optics manufacturers, PanDao carries out research, holds webinars, gives invited university lectures and publishes scientific papers together with collaboration partners around the globe.

PanDao sincerely thanks all co-authors for invaluable discussions, support and friendship: Prof. Daewook Kim, University of Arizona, USA; Prof. Jens Bliedtner, University of Jena, Germany; Prof. Irina Livshits, University of St.Petersburg, Russia; Prof. Jyrki Saarinen, University of East Finland; Finland, Mrs. Olga Resnik and Mr. Yosi Arazi, JOYA Team, Israel, Prof. David Walker and Prof. Guoyu Yu, Huddersfield University, UK; Ray Williamson, SPIE fellow, consultant, USA; and Eckhard Langenbach, senior optics designer and member ISO standard commission, Switzerland.

Since PanDao was founded in 2019

- we published
 - **3 full journal papers,**
 - **4 invited conference papers in USA, Japan and Germany,**
 - 8 contributed conference papers,
 - 3 white papers at PhotonicsViews journal (Wiley publishers) and ElectroOptics Journal,
 - 2 book chapters to standard works in Optical Technologies,
- we gave
 - 11 webinars and seminars
 - 4 tutorials at Optical Design and Fabrication conferences in Canada, Portugal, Italy, and France
 - 13 invited university lectures in USA, UK, Japan and Germany.
- and Jose Pozo (CTO Optica www.optica.org) recorded a PanDao Company Video https://www.linkedin.com/posts/josepozophotonics_stgallen-switzerland-activity-6974711562188034048-DY9y?utm_source=share&utm_medium=member_desktop

Webinars & Seminars

- 2024: EPIC “Technology Meeting on Photonics for XR: through emerging technologies and challenges”, at Microsoft company, Espoo, Finland (<https://epic-assoc.com/events/epic-technology-meeting-on-photonics-for-xr-through-emerging-technologies-and-challenges-at-microsoft/>)
- 2024: Optica “Freeform Optics Industry Summit”, at Opimax company, Rochester, New York, USA (https://www.optica.org/events/industry_events/2024/optica_freeform_optics_industry_summit_at_opimax/)
- 2023: EPIC “Technology Meeting on Optical Design and Simulations: Tools and Use-cases”, online (<https://epic-assoc.com/events/epic-online-technology-meeting-on-optical-design-and-simulations-tools-and-use-cases/>),
- 2023: Ansys, Optics Studio Release presentation: “Optics Studio’s new feature: Export Data To PanDao”, online,
- 2022: three webinars: 1) PhotonicsMedia, 2) EPIC new product release, 3) interview and Webinar with Dr. Jose Pozo (now CTO Optica (OSA))
- 2021: four webinars: 1) PhotonicsMedia, 2) BayernPhotonics, 3) Zemax Envision, 4) EPIC new product release

Tutorials:

- 2024 September: EOSAM24 conference, Naples, Italy
- 2023 September: EOSAM23 conference, Dijon, France
- 2023 June: “Optical Design and Fabrication (ODF)” congress, Quebec City, Canada
- 2022: EOSAM22 conference, Porto, Portugal
- 2021: EOSAM21 conference, Rome, Italy

University lectures

- 2023: University of Tokio (Japan), University of Rochester (USA), University of Arizona (USA), University of Huddersfield (USA), EAH Fachhochschule Jena (Germany)
- 2022: University of Rochester (USA), University of Arizona (USA), University of Huddersfield (USA), EAH Fachhochschule Jena (Germany)
- 2021: University of Rochester (USA), University of Arizona (USA), University of Huddersfield (USA), EAH Fachhochschule Jena (Germany)

White Papers

- [1] “Do you speak optica? Streamlining optics fabrication”, Electro Optics Journal 2022
<https://www.electrooptics.com/feature/do-you-speak-optica-streamlining-optics-fabrication>,
- [2] “Develop and apply innovative methods and tools”, PhotonicsViews Journal, 18: 1-1.,
<https://doi.org/10.1002/phvs.202170401>, 2021
- [3] “Optical fabrication chain design”, PhotonicsViews, 18: 43-45. <https://doi.org/10.1002/phvs.202100051>, 2021

Books contributions

- [1] **Book chapter** O. Faehnle, Irina Livshits, Jyrki Saarinen, Daewook Kim and Jens Bliedtner, “ Modulation optischer Fertigungsketten?“, Jahrbuch für Optik und Feinmechanik 2020, Herausgeber: Dr.-Ing. Wolf-Dieter Prenzel, ISBN978-3-00-068425-8, OPTIK-Verlag Dr. Prenzel, Gorlitz, Deutschland, 67., 2022
- [2] **Book chapter** O.Faehnle, “Optikfertigungskettendesign” in Jens Bliedtner, Günter Gräfe, «Optiktechnologie», book, Hanser, ISBN 978-3-446-42466-1, 2022

Scientific Papers

- [1] **Invited conference paper:** O.Faehnle, “Optics design optimizations by fabrication chains simulations”, SPIE International Conference on Optics-photonics Design & Fabrication (ODF), JSAP (The Japan Society of Applied Physics), Tucson, Arizona, USA , July 2024
- [2] O.Faehnle, J.DeGrote Nelson et.al. “The pea puffer aspheres: circumference optimized aspheres ccp polishing”, EOSAM24 conference on “Optical system design tolerancing an fabrication“, European Optical Society (EOS), Napels, Italy, September 2024
- [3] **Journal paper** Walker, D., Ahuir-Torres, J.I., Akar, Y., O.Faehnle et al. “Bridging the Divide Between Iterative Optical Polishing and Automation”, in the J. of Nanomanuf Metrol 6, 26 (2023), <https://doi.org/10.1007/s41871-023-00197-3>, 2023
- [4] Fabian Duerr, Oliver Faehnle and Hugo Thienpont, “Starting Point Generation for Imaging Systems under Practical Constraint”, OSA’s Intenational Optical Design Conference (IODC), part of the Optical Design and Fabrication congress (ODF), Quebec City, Canada, June 2023
- [5] **Invited conference paper:** O.Faehnle, Rolf Rascher and Marco Tinner, “Next step in Optics Fabrication: moving from machining to processing”, 12. Wetzlarer Herbsttagung "Moderne Optikfertigung«, Wetzlar, Germany, September 2022
- [6] O.Resnik, O.Faehnle and Y.Arazi, “Dynamic optimization of optical design process by means of producibility modulations”, EOSAM22 conference on “Optical system design tolerancing an fabrication“, European Optical Society (EOS), Porto, Portugal, September 2022
- [7] **Invited conference paper:** O.Faehnle and I.Livshits, “Modeling of Optical Fabrication Chains during Optics Design”, SPIE International Conference on Optics-photonics Design & Fabrication (ODF), JSAP (The Japan Society of Applied Physics), Sapporo, Japan , August 2022
- [8] M.Tinner, I.Livshits and O.Faehnle, " Producibility analyses during the optical design stage", DGaO Tagung, Bremen, Germany 2021.
- [9] O.Faehnle and I.Livshits, “Optical Fabrication Chain Modeling”, SPIE conference on “Optical System Design”, Madrid, Spain, 2021

- [10] O.Faehnle and I.Livshits, “Manufacturing risk management in optical design”, EOSAM21 conference on “Optical system design tolerancing an fabrication“, European Optical Society (EOS), Rome, Italy, September 2021
- [11] I.Livshits, A.Petukhov, J.Saarinen, O.Faehnle, “Supervised Machine Learning in Relation to the Simplest Classification of Optical Systems”, “Optical Design and Fabrication” conference, Taiwan 2021
- [12] **Invited conference paper:** O.Faehnle and I.Livshits, “Optical Fabrication Process Modeling”, OSA (Optica) Optical Fabrication and Testing conference (OF&T), part of the Optical Design and Fabrication congress (ODF), Rode Island, NY, USA , June 2021
- [13] O.Faehnle, E.Langenbach and I. Livshits, “Balancing optical system design and optical fabrication chain design”, SPIE conference on “Precision Optics Manufacturing”, Deggendorf Institute of Technology, Deggendorf, Germany, April 2021
- [14] **Journal paper:** I.Livshits, T.Tochilina, O.Faehnle and S.Volkova, “Design strategy and management of aberration correction process for lens with high complexity index”, Scientific and Technical Journal of Information Technologies, Mechanics and Optics, 2021, vol. 21, no. 1, pp. 40–51 (in Russian). doi: 10.17586/2226-1494-2021-21-1-40-51, **2021**
- [15] **Journal paper:** I.Livshits and O.Faehnle, “Producibility analysis of a lens system during the optical design stage”, Scientific and Technical Journal of Information Technologies, Mechanics and Optics, ISSN 2226-1494 (print), ISSN 2500-0373 (online), St. Petersburg, Russia, doi: 10.17586/2226-1494-2020-20-5-625-633, No.5 2020
- [16] M.Tinner, O.Faehnle and I.Livshits, “PanDao fabrication cost impact analysis software tool for optical designers”, EOSAM20 conference on “Optical system design tolerancing an fabrication“, European Optical Society (EOS), due to CoronaVirus: “proceedings only”, <https://doi.org/10.1051/epjconf/202023803014>, September 2020.
- [17] O.Faehnle, “Abrasive Jet Polishing Approaches to the Manufacture of Micro-optics with Complex Shapes”, OSA Optical Fabrication and Testing Conference, Monterey, CA, USA , June 2012

For frequently updates on PanDao’s activities and updates:

- read our blog entries: <https://pandao.ch/blog/>
- watch our YouTube channel: <https://www.youtube.com/channel/UC318X9TJZWs2xeTjzeE40zg>
- follow PanDao at **LinkedIn**: <https://ch.linkedin.com/company/pandao-gmbh>
- contact us at info@PanDao.ch

