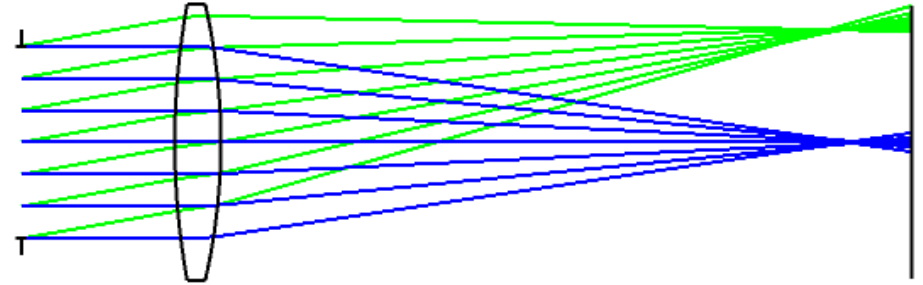




Lectures Notes on Optical Design using Zemax OpticStudio

What is Zemax?



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Zemax OpticStudio (www.zemax.com)

Zemax OpticStudio is a software for the optical design.

It is used to analyze imaging system and non-imaging system.

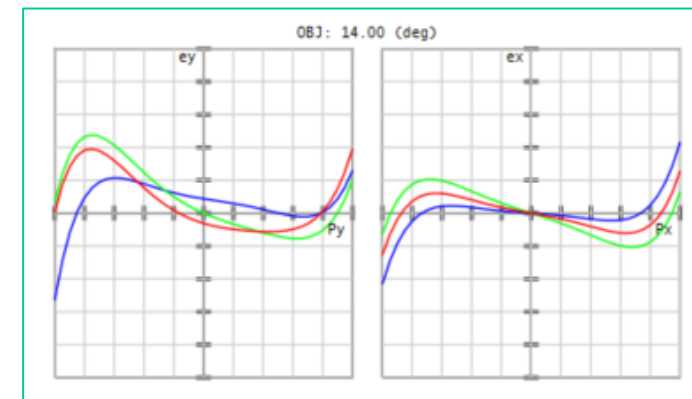
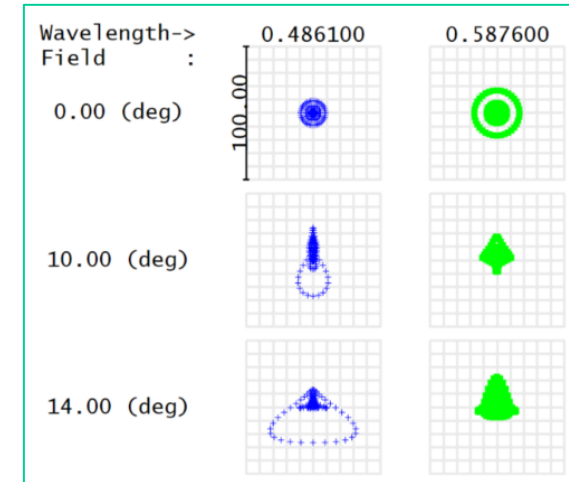
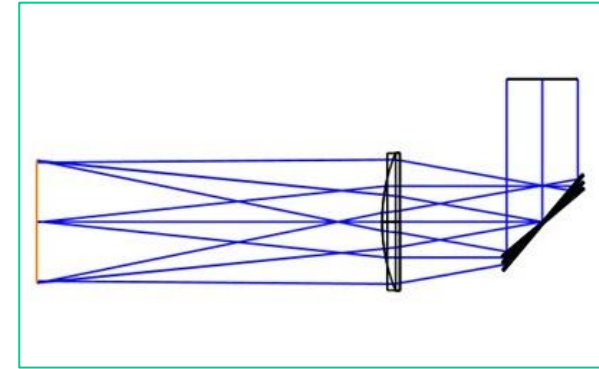
Zemax is based on **Ray Tracing**. Namely, it models propagation of rays via optical system. Ray tracing is practical only for paraxial analysis. However, computing aberrations and diffraction effects are time consuming. Hence, Optical Designers need software such as:

- Zemax OpticStudio
- Code V
- TracePro
- OSLO

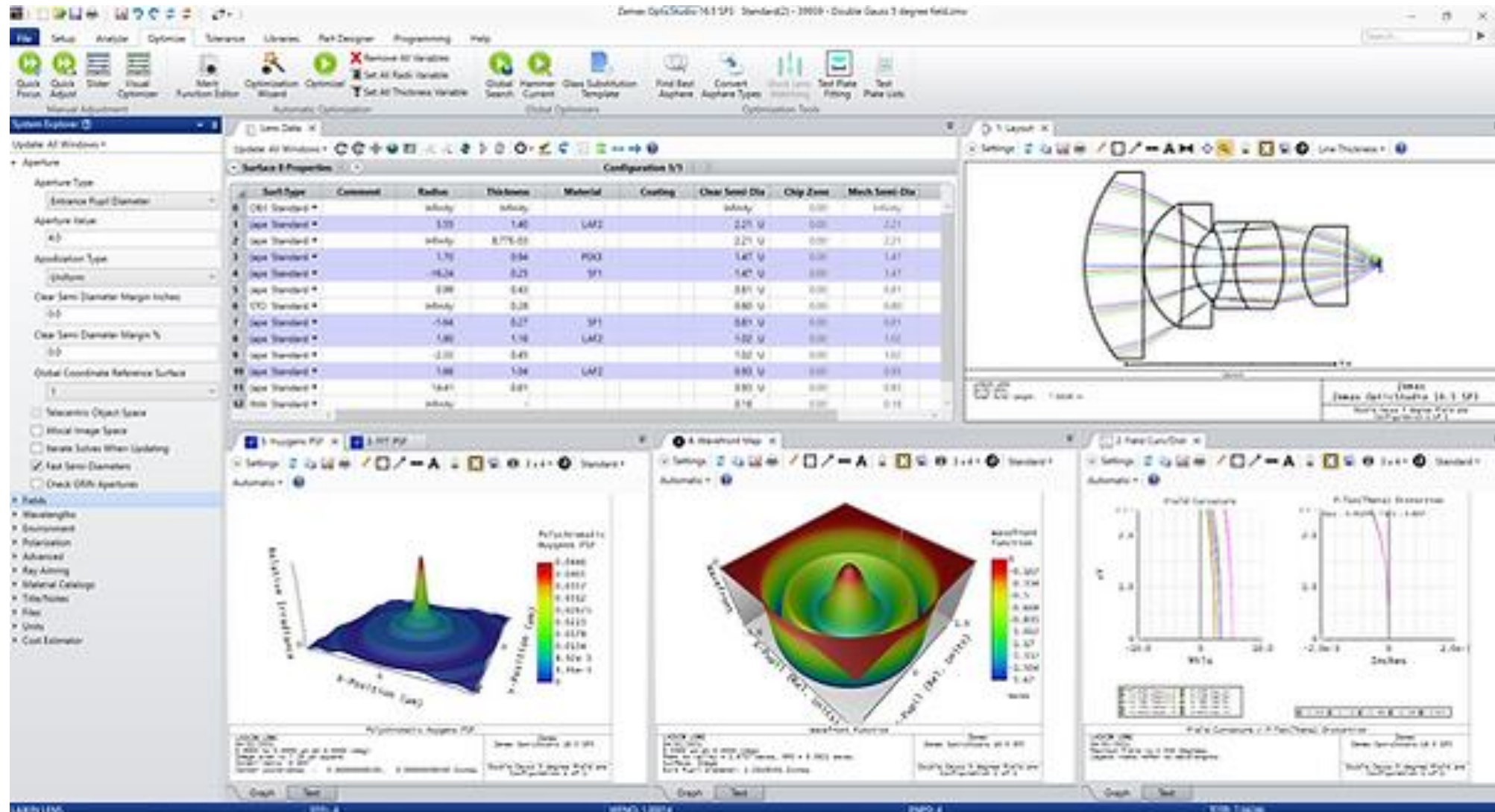
which help characterize and optimize the design.

Zemax OpticStudio

- models the effect of **optical elements** (like lenses, aspheric surfaces, mirrors and diffractive optical elements)
- produces **standard analysis diagrams** (such as spot diagrams and ray-fan plots).
- simulates **coatings** on optical surfaces.
- has a **tolerancing** capability and thus makes it possible to analyze production and assembly faults.
- has **optimization** tools.



Zemax helps optical designer evaluate complicated optical calculations!

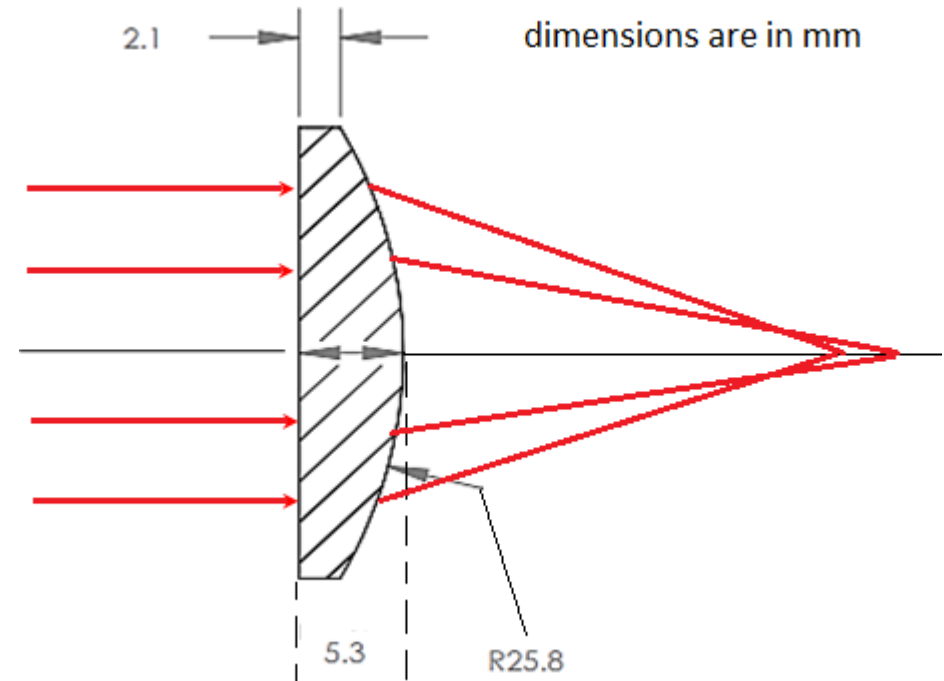


Ray Tracing

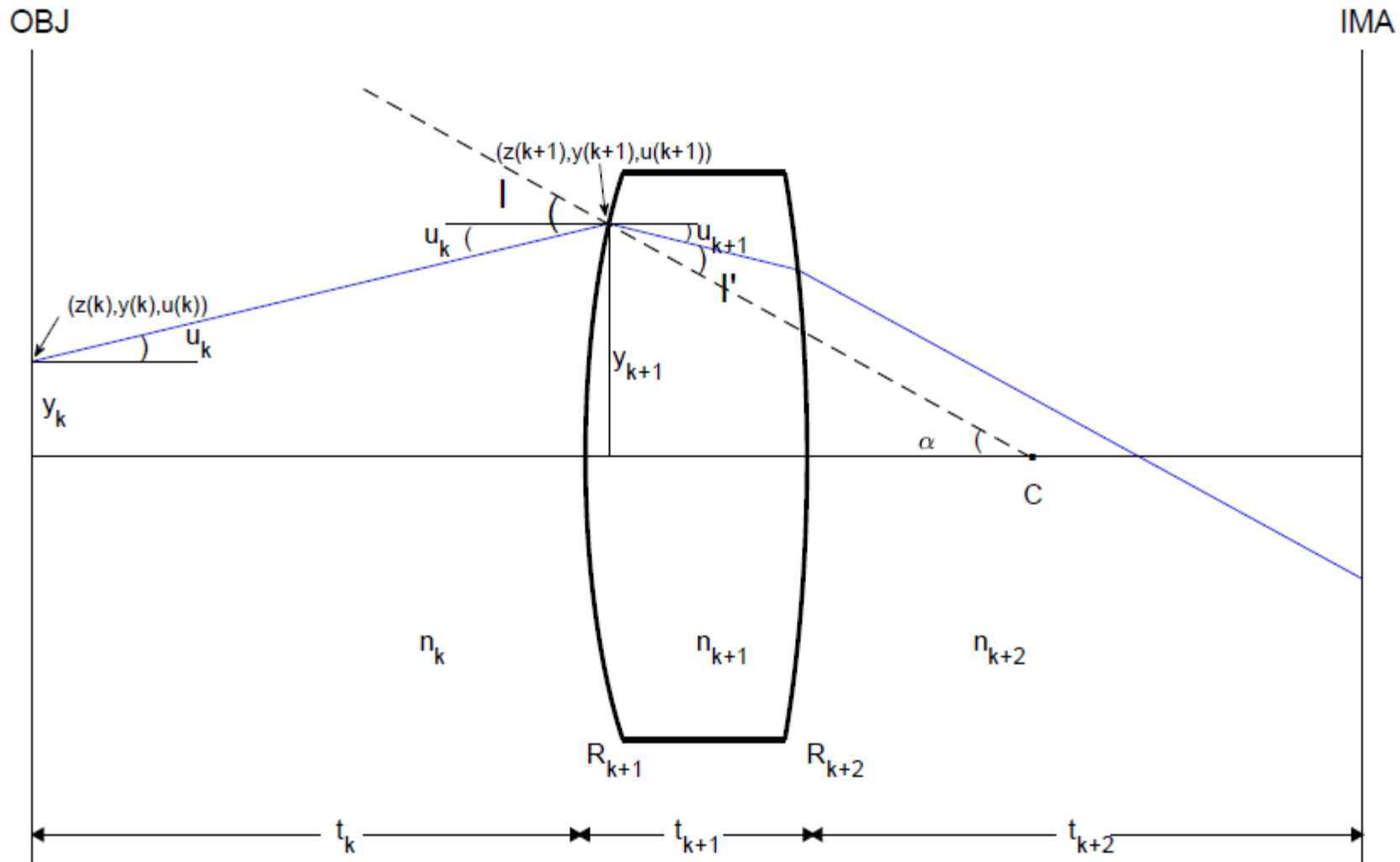
What if there is no program such as Zemax?

Consider the following exercise.

*We have 4 rays separated by 5 mm.
Calculate the intersection of each
ray with the optical axis after
refracting the plano convex lens.
Wavelength: 632.8 nm
Glass: BK7 ($n = 1.5151$)
(Use Snell's Law of refraction)*



Exact Ray Tracing



Exact Ray Tracing

- Ray transfer equation:

$$y_{k+1} = y_k + \tan u_k (z_{k+1} - z_k)$$

- Apply Snell's law of refraction at each surface. For example, for the first surface:

$$\sin \alpha = \frac{y_{k+1}}{R_{k+1}}$$

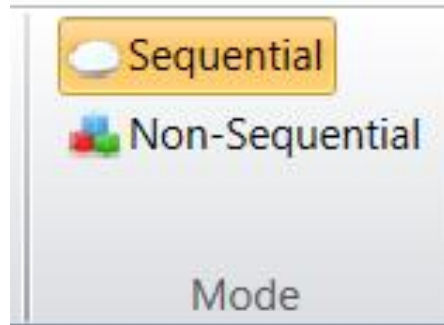
$$I = u_k + \alpha$$

$$\alpha = I' - u_{k+1}$$

$$n_{k+1} \sin I' = n_k \sin(u_k + \alpha)$$

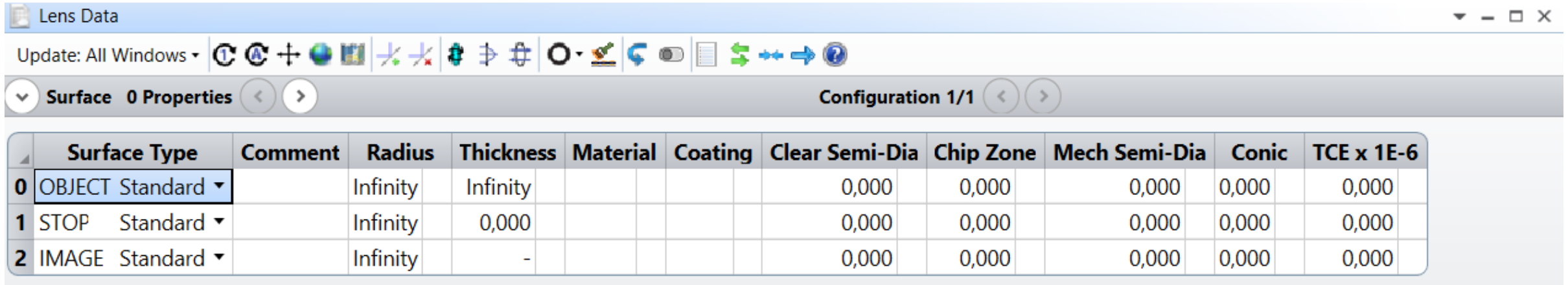
Zemax Modes

Zemax allows you to use two modes:



- **Sequential mode:** In this mode, rays propagate from one surface to another sequentially to produce an image. An integer number is assigned to each surface. We need 3 surfaces at least; Object, Stop, and Image. Rays start from the Object plane and end at the Image plane. *This mode is usually used in imaging systems.*
- **Non-sequential mode:** In this mode, light can be reflected, refracted, or scattered from a surface many times. The rays are collected by a detector. *This mode is usually used in non-imaging systems.*

Lens Data Editor (LDE)



	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT Standard ▾		Infinity	Infinity			0,000	0,000	0,000	0,000	0,000
1	STOP Standard ▾		Infinity	0,000			0,000	0,000	0,000	0,000	0,000
2	IMAGE Standard ▾		Infinity	-			0,000	0,000	0,000	0,000	0,000

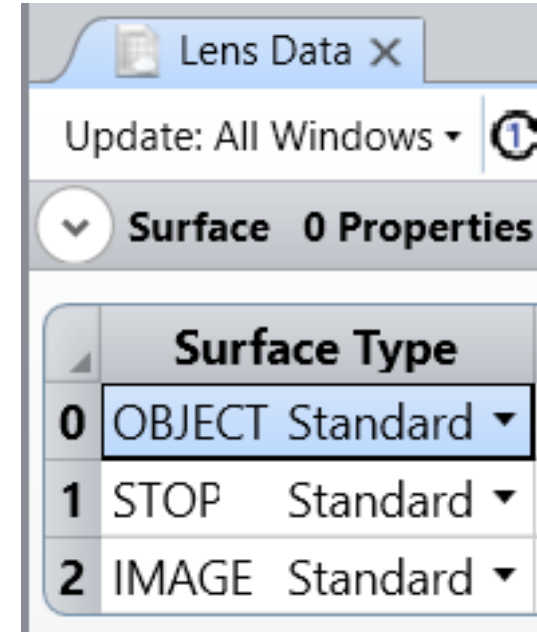
- An optical system can be formed by using LDE.
- In Zemax, many operations are performed by defining surfaces which can be lens, mirror, ...

LDE: Surface Type

Surface type can be:

- Spherical (Standard)
- Even Asphere
- Paraxial
- Grating
- ...

In the design, we usually prefer standard surfaces.



LDE: Radius & Thickness

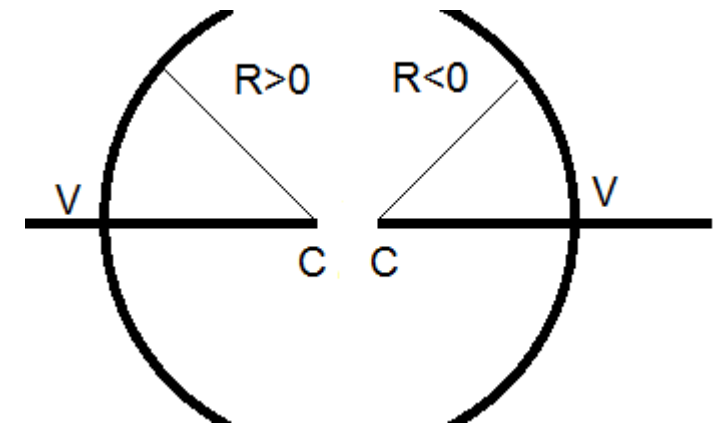
- **Radius**

defines Radius of Curvature of the surface.
Radius can be + or -

- **Thickness**

defines the center distance between
two surfaces to separate the optical surfaces.
Thickness can be + or -

Lens Data					
Update: All Windows					
Surface 0 Properties					
	Surface Type	Comment	Radius	Thickness	
0	OBJECT Standard		Infinity	Infinity	
1	STOP Standard		Infinity	0,000	
2	IMAGE Standard		Infinity	-	



LDE: Material (Glass)

Material is used to input optical material.

It can be written manually or selected from Library.

Materials Catalog

Catalog: AMBILIGHT.AGF
Glass: AMBILIGHT.AGF
Rename: AMTIR.AGF
Formula: ANGSTROMLINK.AGF
Status: APELAGF
Standard

Glass catalog for Ambilight properties, updated 02-01-2008

n0: 1,00000000E+000 D0: 0,0000E+000
A: 0,00000000E+000 D1: 0,0000E+000
B: 0,00000000E+000 D2: 0,0000E+000
E0: 0,0000E+000
E1: 0,0000E+000
Ltk: 0,0000E+000
TCE: 0
Temp: 20
p: 1
dPgF: 0
Minimum Wavelength: 0,30000000
Maximum Wavelength: 1,00000000

Nd: -- Vd: --
☐ Ignore Thermal Expansion
☐ Exclude Substitution
☐ Meta Material (Negative Index)

Melt Freq: ? Comment: Custom transmission to account for measured loss
Rel Cost: ? CR: ? FR: ? SR: ? AR: ? PR: ?

Save Catalog Insert Glass Sort By -> Name: v
Save Catalog As Cut Glass Glass Report Catalog Report
Reload Catalog Copy Glass Transmission Compute Nd/Vd
Exit Paste Glass Fit Index Data Fit Melt Data

LDE: Coating

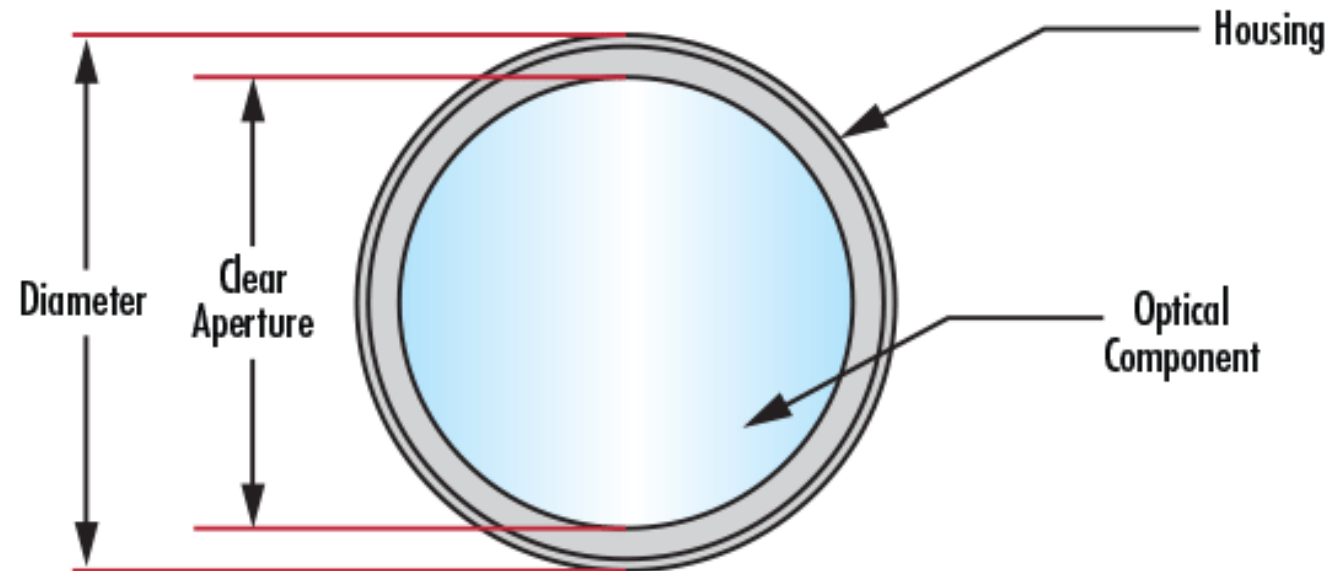
It allows you to select a coating material to apply on the surface.

The screenshot shows the 'Lens Data' software interface. The 'Surface 1 Properties' tab is active, and the 'Coating' property is selected in the left sidebar. A dropdown menu is open, showing a list of coating options: None, NULL, AR, WAR, HEAR1, HEAR2, GAP, COPPER, GOLD, METAL, METAL2, SILVER, AIR0010, ETALON, and FP. The 'None' option is currently selected. Below the dropdown, a table displays the properties for the selected surface (Surface 1).

Surface Type	Coating	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0 OBJECT Standard					0,000	0,000	0,000	0,000	0,000
1 Standard		00			0,000	0,000	0,000	0,000	0,000
2 STOP Standard		00			0,000	0,000	0,000	0,000	0,000
3 IMAGE Standard		Infinity	-		0,000	0,000	0,000	0,000	0,000

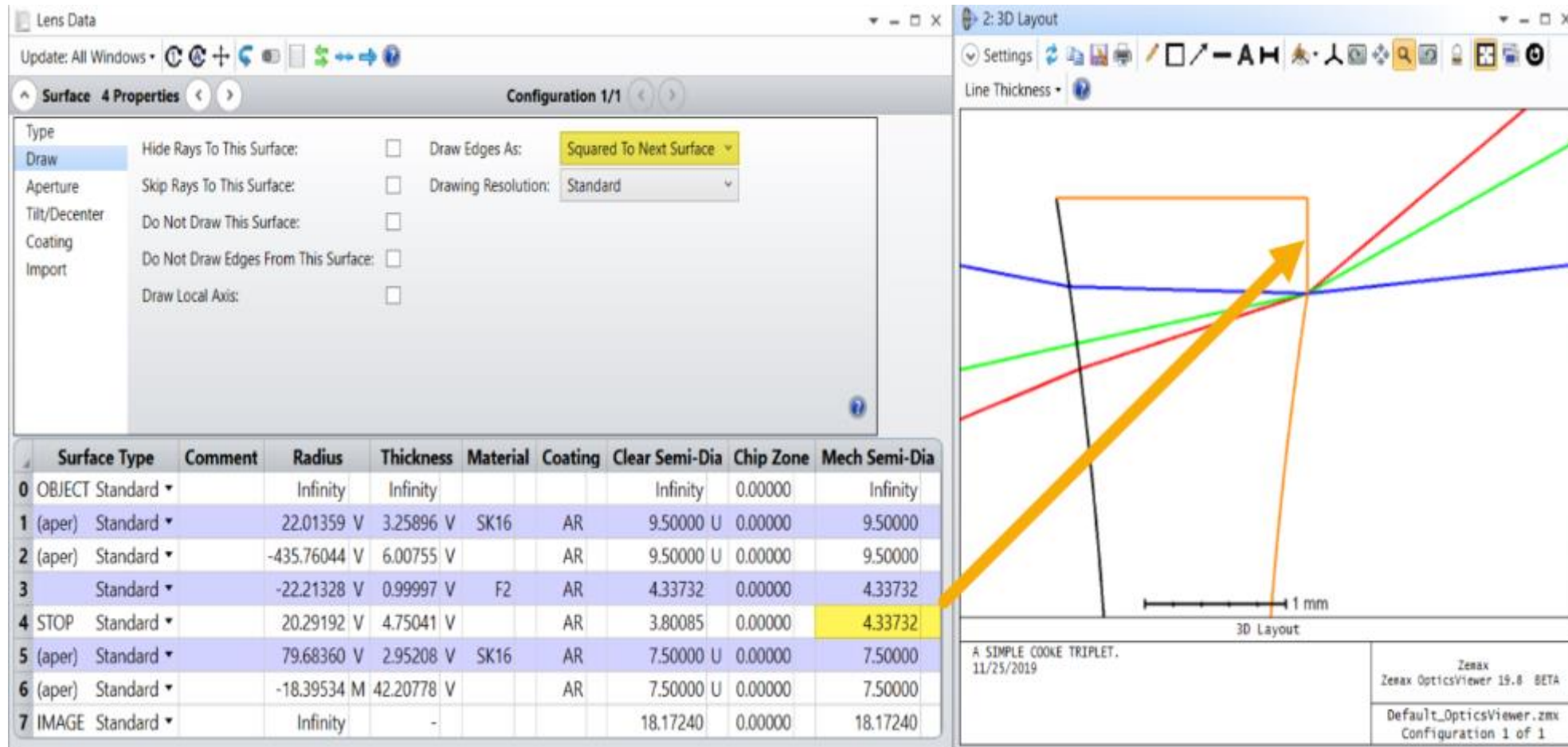
LDE: Clear Semi-Diameter

The size of Clear Semi-Diameter defines the effective optical area where light passes through the surface. This surface is polished and maybe coated.



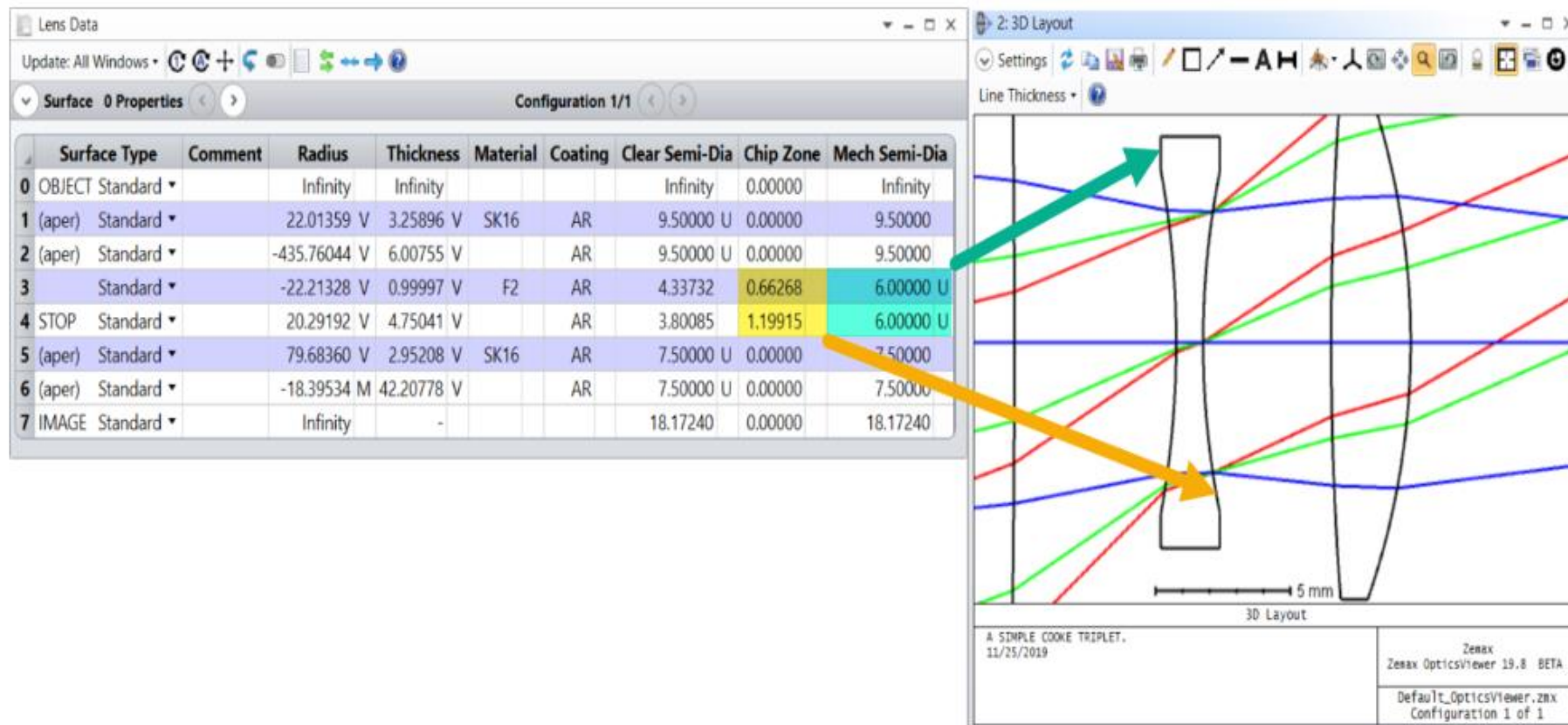
LDE: Mechanical Semi-Diameter

Mech Semi-Diameter is related to diameter where light does not pass through the surface. By default, it is equal to the Clear Semi-Diameter.



LDE: Chip Zone

The chip zone is simply an extension of the clear aperture, usually meant provide extra space for mounting the lens so that the mounting assembly doesn't block light through system.

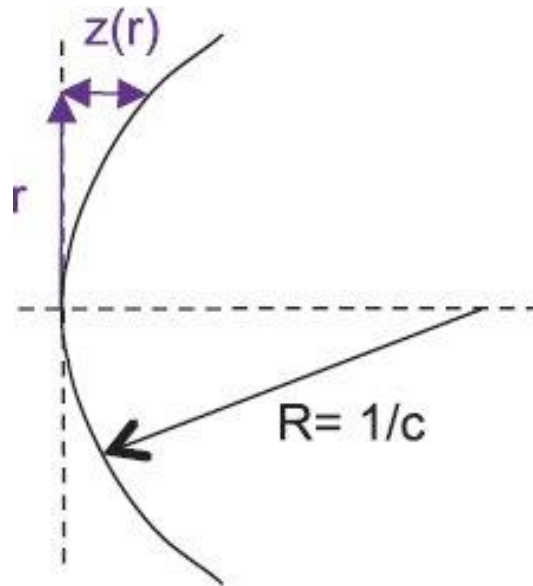


LDE: Conic

Optical systems comprise lenses and mirrors made with precise surfaces.

Optical surfaces can be divided into spherical and aspherical surfaces.

In Zemax, you can form different types of surfaces by using conic constants (K).
It can be used to assign an aspherical property to the standard surface.



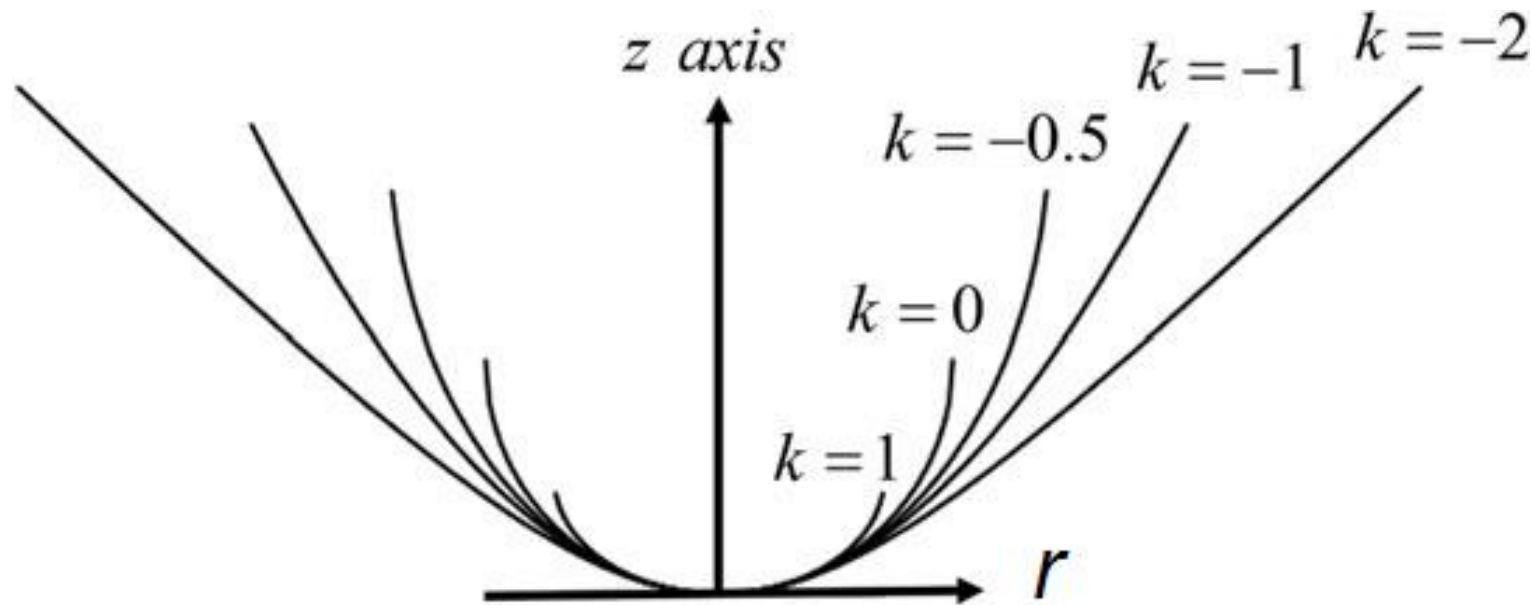
$$z(r) = \frac{cr^2}{1 + \sqrt{1 - (1 + \kappa)(cr)^2}}$$

Hyperboloid	↔	$\kappa < -1$
Prolate Ellipsoid	↔	$-1 < \kappa < 0$
Paraboloid	↔	$\kappa = -1$
Sphere	↔	$\kappa = 0$
Oblate Ellipsoid	↔	$0 > \kappa > -1$

Why do we need Conic Surface?

For a given image quality, the choice of optical surfaces has a major impact on the packaging and cost of a lens system.

In general, *conic surfaces improves the optical performance of the system.*



Zemax Training

<https://www.zemax.com/pages/training>

<https://www.youtube.com/c/DesignOpticsFast>

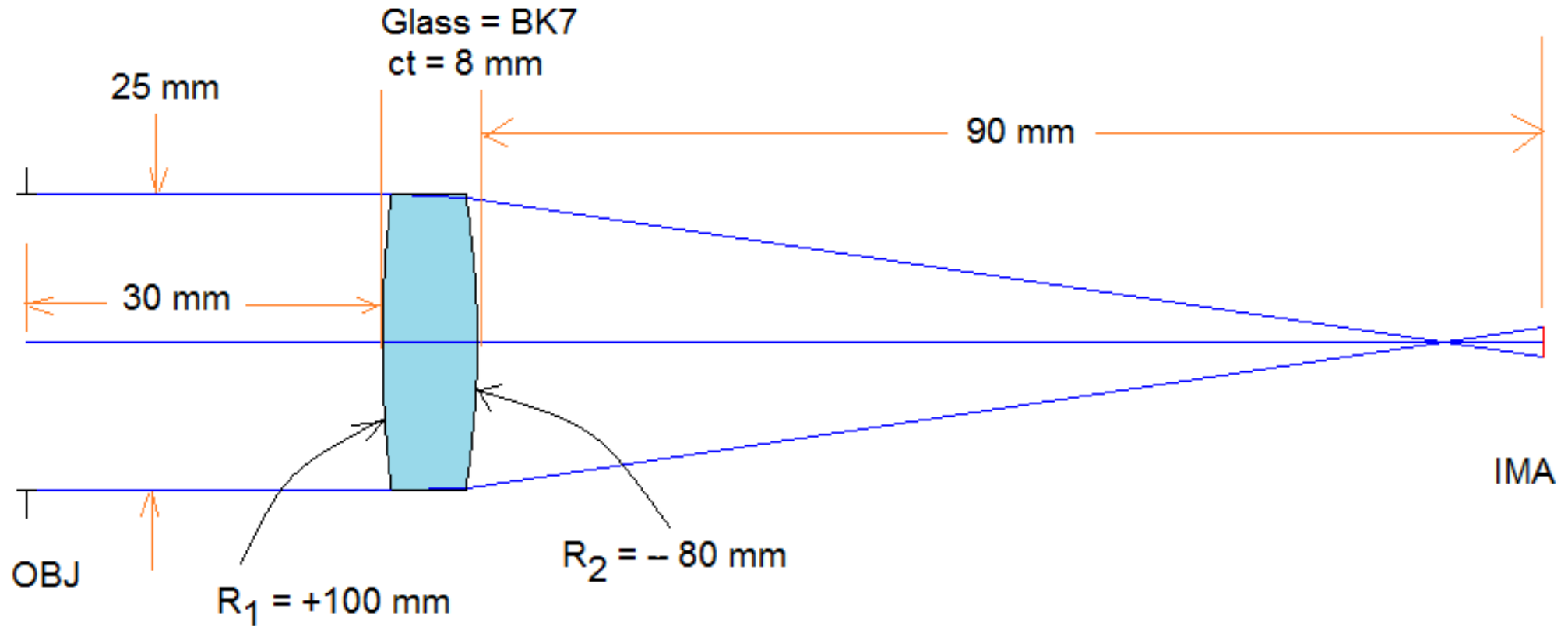
<https://www.youtube.com/user/opticsrealm>

<http://www1.gantep.edu.tr/~bingul/opac202>

Example: Adding Simple Lens in Zemax

Now we will see very simple application in Zemax; adding a single lens.

Consider the following lens. $\lambda = 0.65 \mu\text{m}$ and SFOV = 0° and 10° . (Namely, FOV = 20°).



System Explorer

Update: All Windows

Aperture

Aperture Type:

Entrance Pupil Diameter

Aperture Value:

25.0

Apodization Type:

Uniform

Clear Semi Diameter Margin Millimeters:

0.0

Clear Semi Diameter Margin %

0.0

Global Coordinate Reference Surface

1

☐ Telecentric Object Space

☐ Afocal Image Space

☐ Iterate Solves When Updating

☒ Fast Semi-Diameters

☐ Check GRIN Apertures

Fields

Open Field Data Editor

Settings

Field 1 (X = 0.000, Y = 0.000, Weight = 1.000)

Field 2 (X = 0.000, Y = 10.000, Weight = 1.000)

Add Field

Wavelengths

Settings

Wavelength 1 (0.650 μm , Weight = 1.000)

☒ Enable

☒ Primary

Wavelength (μm):

0.650

Weight:

1.000

Lens Data

Update: All Windows

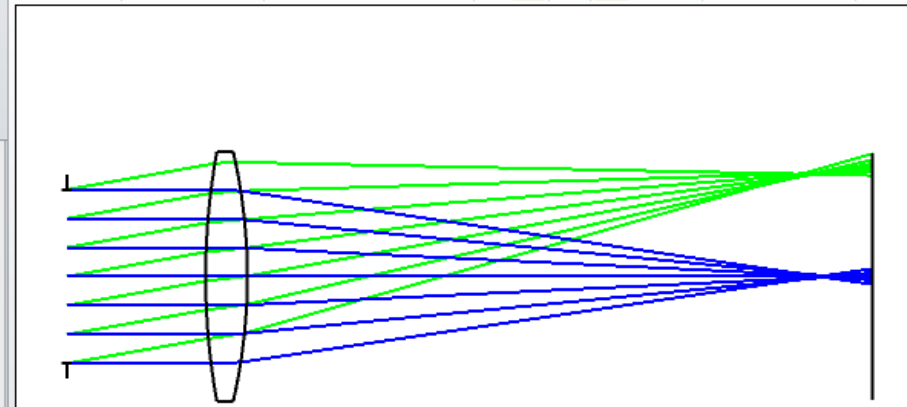
Surface 3 Properties

Configuration 1/1

	Surface Type	Comment	Radius	Thickness	Material	Conic	Clear Semi-Dia	Chip Zone	Mech Semi-Di
0	OBJECT Standard		Infinity	Infinity		0.000	Infinity	0.000	Infinity
1	STOP Standard		Infinity	20.000		0.000	12.500	0.000	12.500
2	(aper) Standard		100.000	6.000	N-BK7	0.000	18.000 U	0.000	18.000
3	(aper) Standard		-80.000	90.000		0.000	18.000 U	0.000	18.000
4	IMAGE Standard		Infinity	-		0.000	17.668	0.000	17.668

1: Layout

Settings



Layout

18.01.2024
Total Axial Length: 116.00000 mm

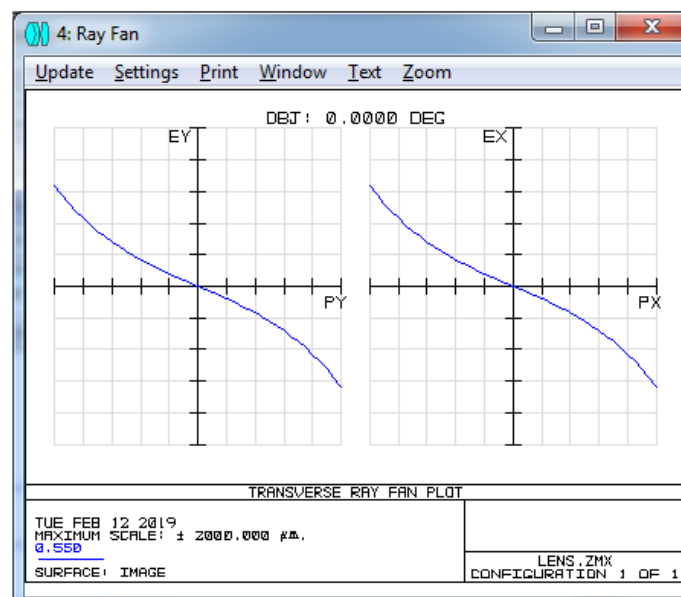
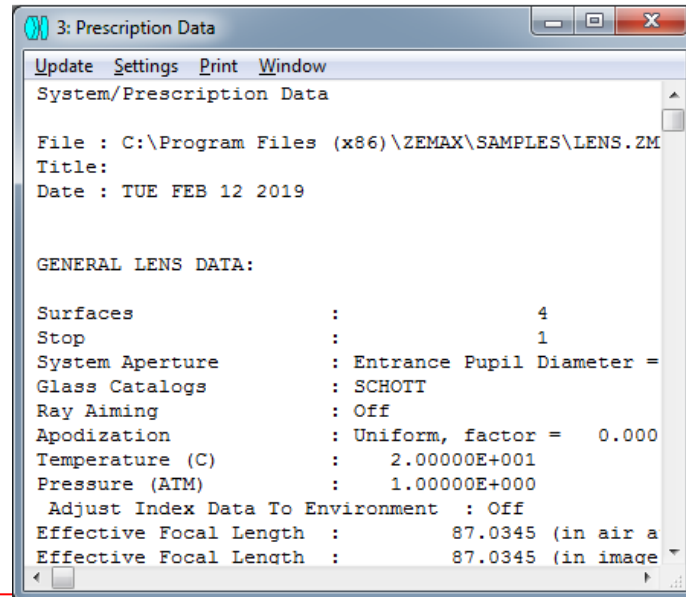
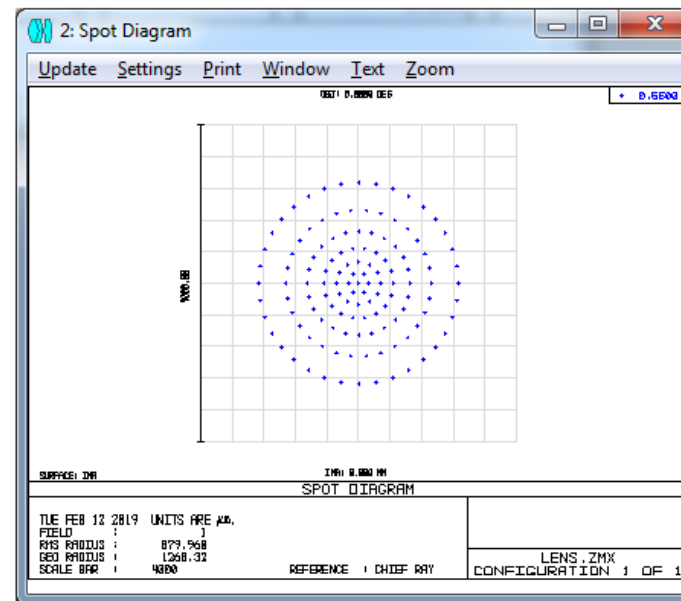
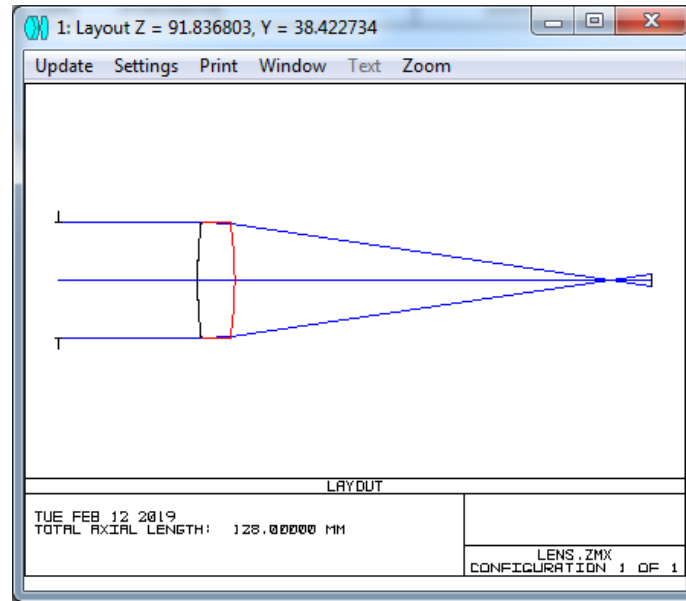
Zemax
Ansys Zemax OpticStudio 2023 R1.00

LENS.zos
Configuration 1 of 1

System Performance

Analysis	Description
Layout	A layout may be opened by navigating to Analyze...System Viewer...Cross-Section . The Cross-Section option plots a YZ cross section through the lens, and is only valid for rotationally symmetric, axial systems. A layout diagram is always a useful visual representation of the current optical system.
Spot Diagram	A spot diagram may be accessed by navigating to Analyze...Spot Image Quality...Rays & Spots...Standard Spot Diagram . The spot diagram gives indication of the image of a point object. In the absence of aberrations, a point object will converge to a perfect image point. By default, OpticStudio plots the spot diagram for each field point.
OPD Fan	The Optical Path Difference (OPD) fan can be opened by selecting Analyze...Image Quality...Aberrations...Optical Path . The OPD fan is a plot of the optical path difference as a function of pupil coordinate. In a perfect optical system, the optical path of the wavefront will be identical to that of an aberration-free spherical wavefront in the exit pupil.
Ray Fan	The Ray Fan plot in OpticStudio may be opened by selecting Analyze...Image Quality...Aberrations...Rays Aberration . The Ray Fan plots ray aberrations as a function of pupil coordinate. Generally, a given ray which passes through the optical system an onto the image surface, its point of intersection falls on some small but nonzero distance away from the chief ray. Once again, in a perfect optical system, the ray aberrations should be zero across the pupil.

Example Performance Data & Plots



Setting Index of Refraction of a Material

In Material column, you can also set the index of the glass instead of glass name.
For example, to add a material whose index is $n = 1.5$

The screenshot shows the 'Lens Data' window with a table of surface properties. The table has columns: Surface Type, Comment, Radius, Thickness, Material, Coating, and Clear Semi-Dia. The rows are numbered 0 to 4. A red arrow points to the 'Material' column of surface 2, with the text 'CLICK HERE'. A dropdown menu is open, showing 'Solve Type' options: Fixed, Model (highlighted), Pickup, Substitute, and Offset. Below the table, a 'Glass solve on surface 2' dialog box is shown, with 'Solve Type' set to 'Model' and 'Index Nd' set to 1.5 (highlighted with a red box).

	Surface Type	Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia
0	OBJECT Standard		Infinity	Infinity			0.000
1	STOP Standard		Infinity	25.000			15.000
2	Standard		100.000	8.000			15.000
3	Standard		-80.000	90.000			
4	IMAGE Standard		Infinity	-			

Glass solve on surface 2

Solve Type: **Model**

Index Nd: **1.5**

Abbe Vd: 0

dPgF: 0