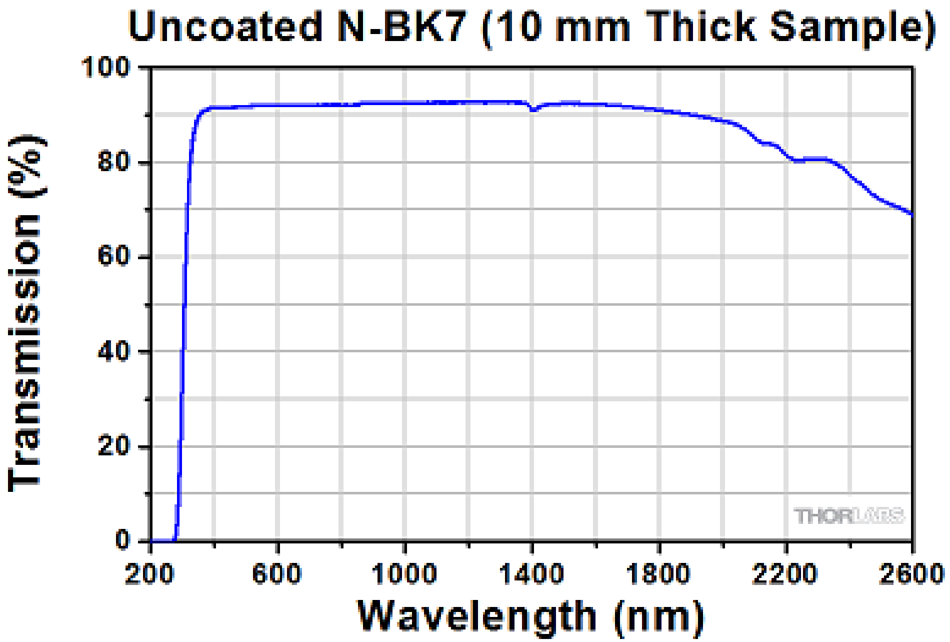
Lectures Notes on Optical Design using Zemax OpticStudio

Lecture 11

Optical Materials



Ahmet Bingül

Gaziantep University
Department of Optical
Engineering

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Optical Materials

- The most common lens material is optical glass.
  Optical glasses are classified roughly as
  crowns (n<1.6) and **flints (n>1.6) .** Crystals and plastics are also used.

- Mirrors can be made of practically anything that is capable of being polished such as window (=soda lime) glass, BK7 or zerodure.

Reference Book: Handbook of Optical Materials, M.J.Weber, CRC Press.

Reference Web : https://refractiveindex.info

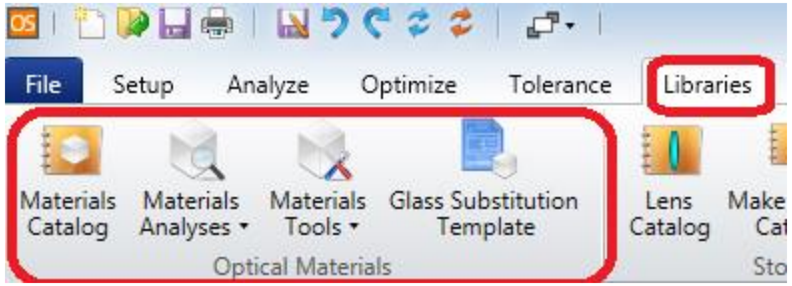
Optical Materials

- A high refractive index leads to weaker surfaces and therefore smaller aberrations. But, they are generally expansive and dense.

Material	n_d	Density (g/cc)
N-BK7	1.5168	2.51
N-K5	1.5225	2.59
N-SF2	1.6477	2.72
N-LASF9	1.8503	4.41

- The cost of material for a small lens is insignificant.
  But, for a large lens it may be a very serious matter. Especially, the mass of the lens or mirror may be important in space researches.

Optical Materials in Zemax



More information can be found under Libraries Tab:

Also use help:

Glass Catalog Sources

Material Catalogs (formerly called the glass catalogs) included with OpticStudio are developed by third party vendors without any involvement by Ansys. Ansys makes no representation as to the feasibility or functionality of the Material Catalogs. Material Catalogs are provided 'as is,' and any express or implied warranties are hereby disclaimed. Ansys has no responsibility to maintain the Material Catalogs or ensure their availability for future releases.

The following table lists the vendors associated with each Material Catalog:

MATERIAL CATALOG VENDORS

Catalog	Vendor	Website
AMTIR	Amorphous Materials Inc.	www.amorphousmaterials.com
ANGSTROMLINK	Fiber Optic Center, Inc.	www.FOCenter.com
APEL	Mitsui Chemicals, Inc.	www.MitsuiChemicals.com
ARCHER	Archer OpTx	www.ArcherOPTx.com
ARTON	JSR Corporation	www.JSR.co.jp
AUER-LIGHTING	Auer Lighting	https://www.auer-lighting.com/
BIREFRINGENT	Birefringent	See references below
CDGM	Chengdu Guangming	www.CDGMgd.com

Index Dispersion

- Index of refraction is defined as

$$n = \frac{c}{v}$$

c = speed of light in vacuum (or in air).

v = speed of light in material

- In non-absorbing media *n* is real. However, in absorbing media *n* is complex and it is expressed as:

$$n' = n + ik$$

k = extinction coefficient

α = aborption coeffiecent

λ = wavelength

$$\alpha = \frac{4\pi\, k}{\lambda}$$

Dispersion Formulae

(a, b, c, ... are numerical constants)

Cauchy
$$n(\lambda) = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} + \cdots$$

Hartmann
$$n(\lambda) = a + \frac{b}{(c-\lambda)} + \frac{d}{(e-\lambda)}$$

Conrady
$$n(\lambda) = a + \frac{b}{\lambda} + \frac{c}{\lambda^{3.5}}$$

Kettler-Drude
$$n^2(\lambda) = a + \frac{b}{c-\lambda^2} + \frac{d}{e-\lambda^2} + \cdots$$

Sellmeier
$$n^2(\lambda) = a + \frac{b\lambda^2}{c-\lambda^2} + \frac{d\lambda^2}{e-\lambda^2} + \frac{f\lambda^2}{g-\lambda^2} + \cdots$$

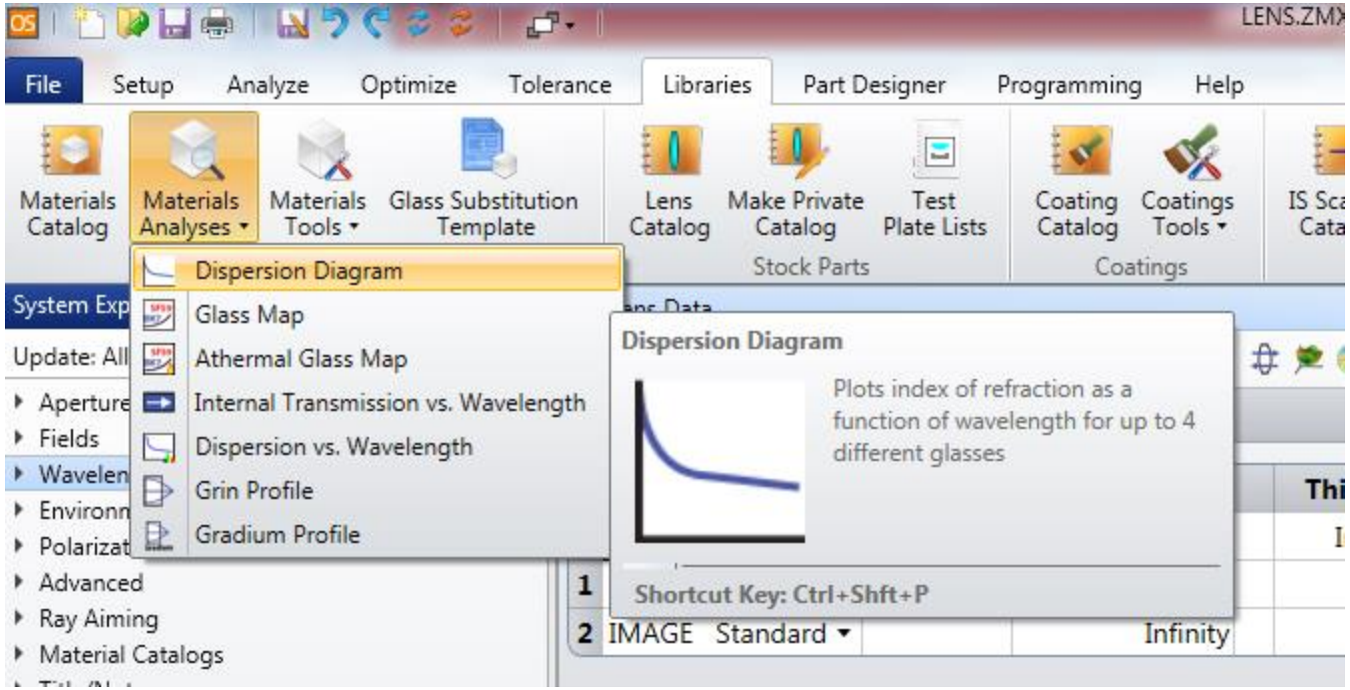
Herzberger
$$n(\lambda) = a + b\lambda^2 + \frac{e}{(\lambda^2-0.035)} + \frac{d}{(\lambda^2-0.035)^2}$$

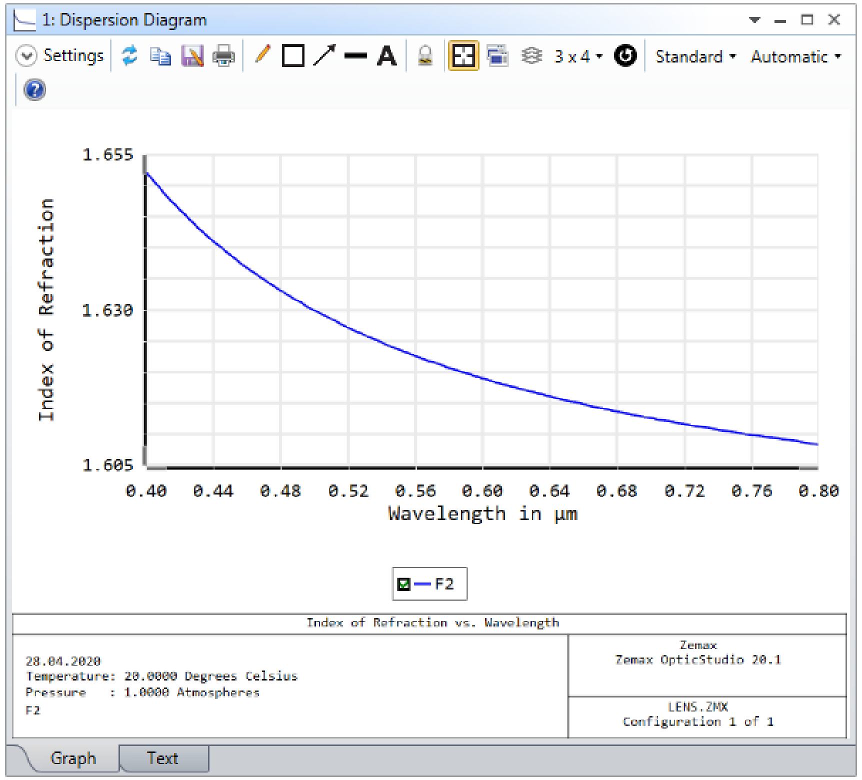
Old Schott
$$n^2(\lambda) = a + b\lambda^2 + \frac{c}{\lambda^2} + \frac{d}{\lambda^4} + \frac{e}{\lambda^6} + \frac{f}{\lambda^8}$$

Example 1: Dispersion Curve in Zemax

The index of refraction of an optical material varies with wavelength. In Zemax, dispersion curve for a glass can be obtained in **Libraries** Tab.

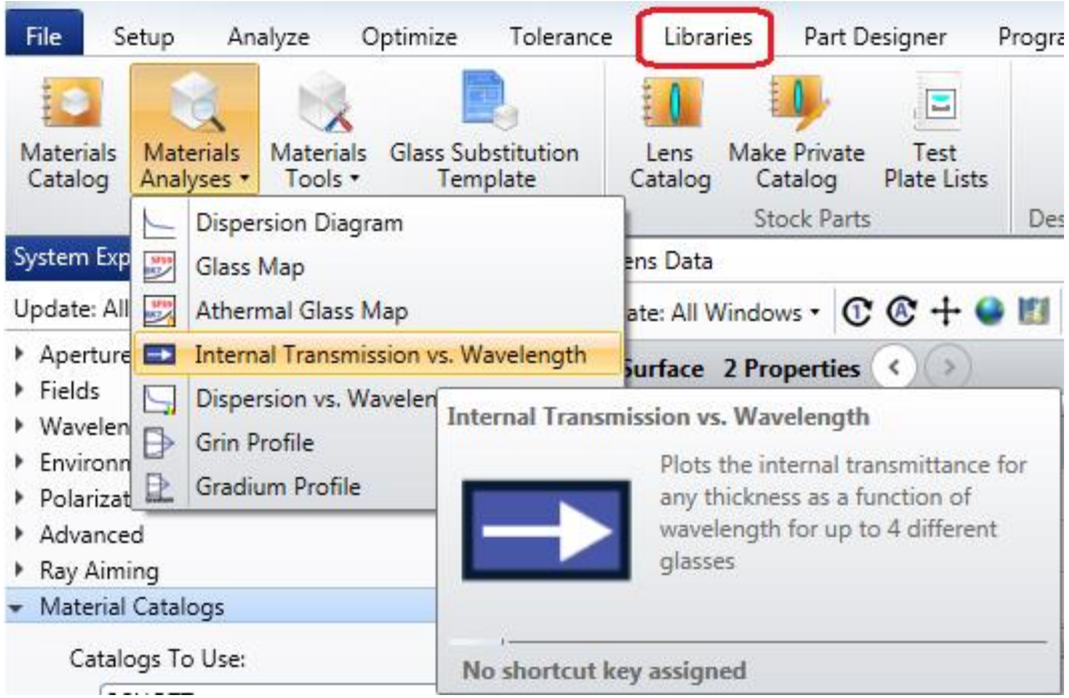
Click on **Material Analysis** then invoke **Dispersion Diagram**.

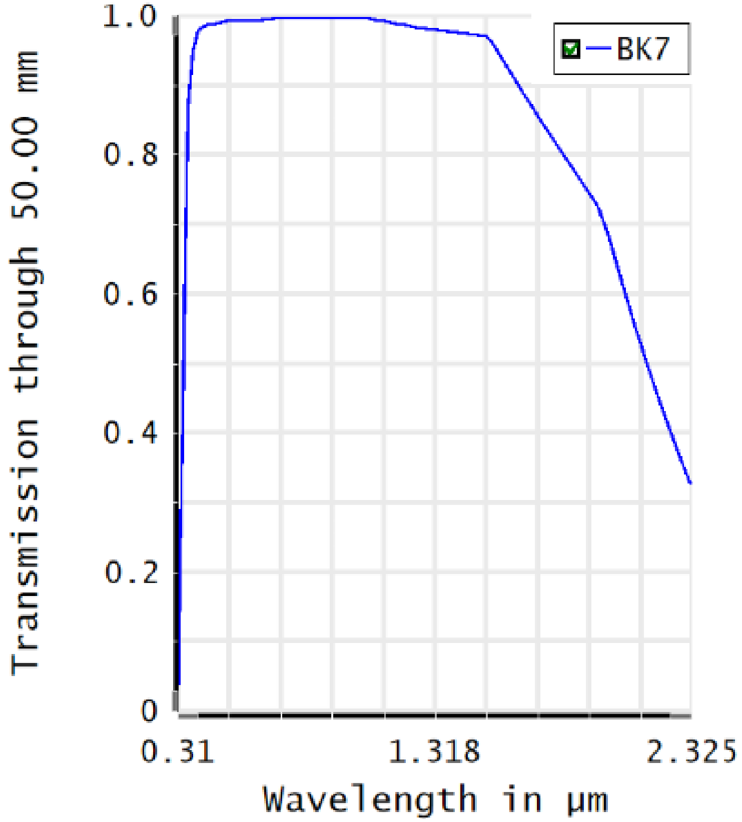




Example 2: Transmission of BK7

- In Zemax, you can plot the internal transmittance as a function of wavelength for glasses. Fresnel reflections from surfaces are ignored.





Infrared Materials

- Infrared Materials are not generally usable in the visible range.
  - **Germanium**: Transmittance for 2 μm-14 μm is T ≈ 45%.
  - **N-BK7**: Transmittance for 2 μm-14 μm is T ≈ 0 %

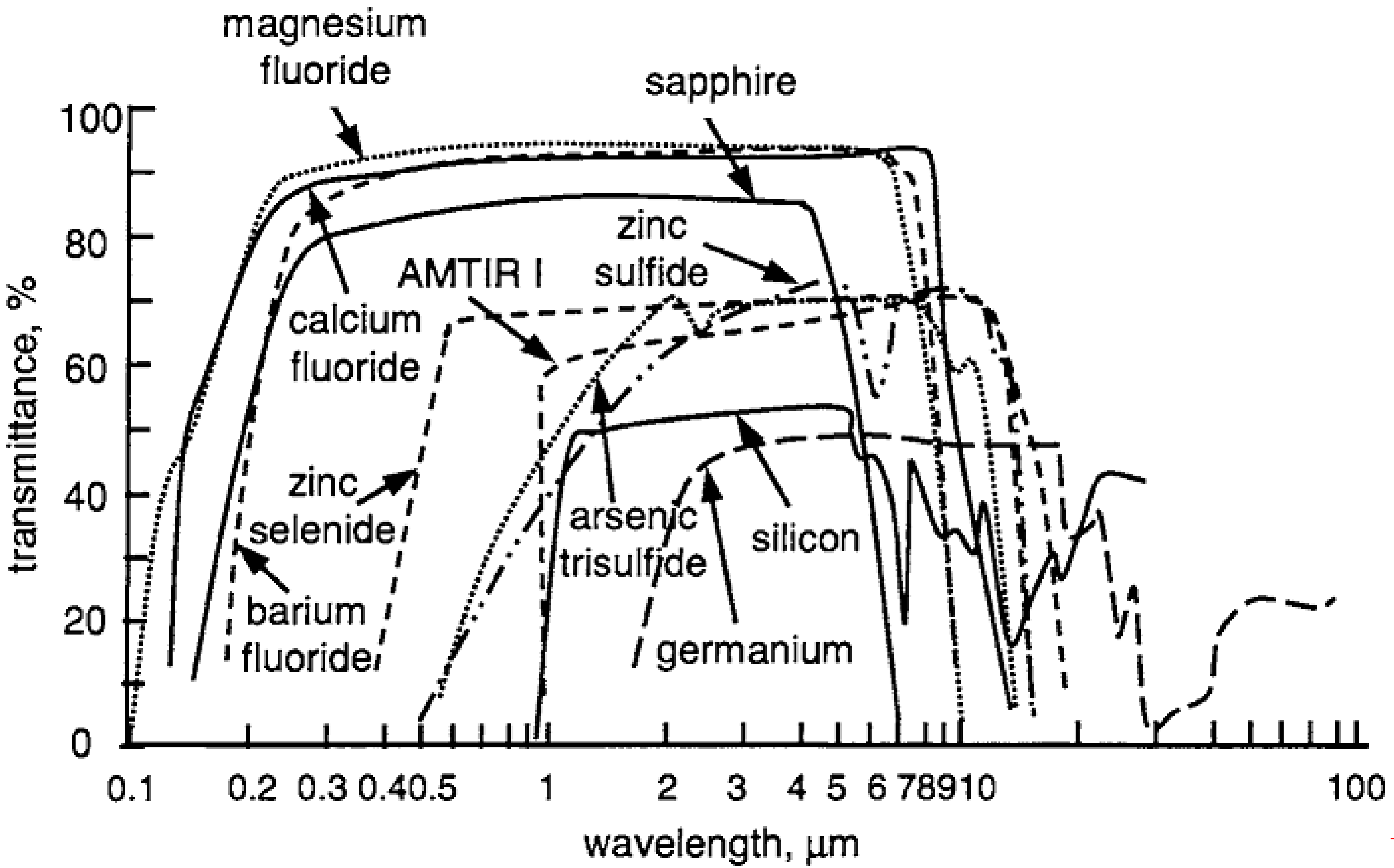
- Table shows properties of common optical materials in Thermal Infrared

Material	Refractive Index at 4 μm	Refractive Index at 10 μm	*dn*/*dt*/°C	Comments
Germanium	4.0243	4.0032	0.000396	Expensive, large *dn*/*dt*
Silicon	3.4255	3.4179*	0.000150	Large *dn*/*dt*
Zinc sulfide, CVD	2.2520	2.2005	0.0000433	
Zinc selenide, CVD	2.4331	2.4065	0.000060	Expensive, very low absorption
AMTIR I (Ge/As/SE:33/12/55)	2.5141	2.4976	0.000072	

Ultraviolet Materials

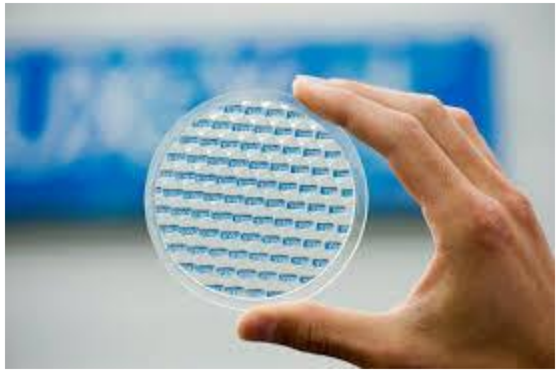
For UV region of the spectrum, we have only relatively few materials:

- UV-grade fused silica
- Crystal quartz
- Sapphire
- CaF
- MgF
- LiF


magnesium fluoride
sapphire
zinc sulfide
AMTIR I
calcium fluoride
zinc selenide
barium fluoride
arsenic trisulfide
silicon
germanium
transmittance, %
0
20
40
60
80
100
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
6
7
8
9
10
100
wavelength, µm

Optical Plastics (Polymers)

Optical plastics suitable for lens manufacture.
Plastics have found extensive applications especially in **Illumination Engineering**.



Properties of Frequently Used Plastic Optical Materials

Properties	Acrylic (PMMA)	Polycarbonate (PC)	Polystyrene (PS)
Refractive index			
N_F (486.1 nm)	1.497	1.599	1.604
N_d (587.6 nm)	1.491	1.585	1.590
N_C (656.3 nm)	1.489	1.579	1.584
Abbe value	57.2	34.0	30.8
Transmission (%)	92	85–91	87–92
Visible spectrum			
3.174 mm thickness			
Specific gravity	1.19	1.20	1.06

Plastic Lenses

Advantages

1. Ease and economy of manufacture in large quantities.

2. Low cost of the raw material.

3. The ability to mold the mount around the lens in one operation.

4. Lens thicknesses and airspaces are easier to maintain.

5. Aspheric surfaces can be molded as easily as spheres.

6. A dye can be incorporated in the raw material if desired.

Disadvantages

1. The small variety and low refractive index of available plastics.

2. The softness of the completed lenses.

3. The high thermal expansion (eight times that of glass).

4. The high temperature coefficient of refractive index (120 times that of glass).

5. Plane surfaces do not mold well.

6. The difficulty of making a small number of lenses because of mold cost.

7. Plastics easily acquire high static charges, which pick up dust.

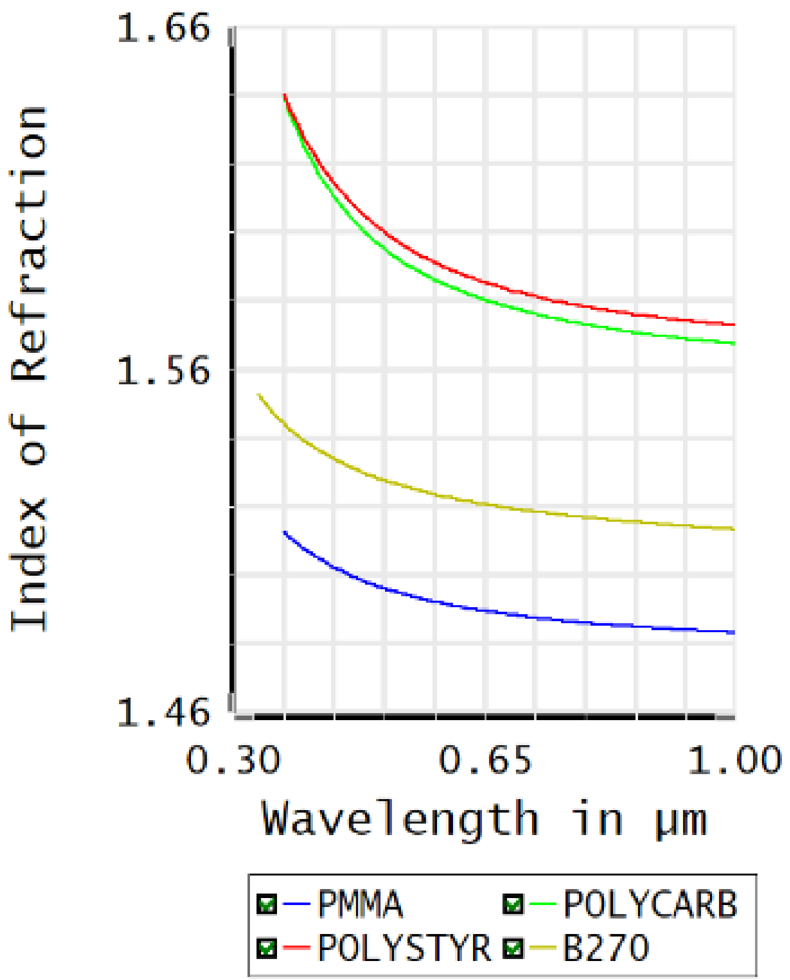
8. Plastic lenses cannot be cemented.

9. Plastic lenses can be coated only with some difficulty

Plastic Materials in Zemax

In Zemax, you can find the plastics in different catalogs. Famous plastics used in industry are given below:

Material Name	Catalog Name
PMMA	MISC
POLYCARB	MISC
POLYSTYR	MISC
E48R	ZEON
B270	SCHOTT



Glass Used in Aerospace Applications (2024)

Selecting suitable optical material is important when designing aerospace optical systems.

Schott and Ohara companies offer a variety of i-line glasses with enhanced blue transmittance which are successfully utilized in space applications.

	Glass Type	Code
OHARA	S-FPL51Y	497.811
OHARA	S-FSL5Y	487.703
OHARA	BSL7Y	516.643
OHARA	BAL15Y	557.587
OHARA	BAL35Y	589.612
OHARA	BSM51Y	603.606
OHARA	PBL1Y	548.458
OHARA	PBL6Y	532.490
OHARA	PBL25Y	581.408
OHARA	PBL26Y	567.428
OHARA	PBM2Y	620.363
OHARA	PBM8Y	596.393
OHARA	PBM18Y	596.387
OHARA	PBL35Y	582.409
OHARA	S-BSL7R	516.641
OHARA	S-BAL35R	589.610
OHARA	PBM2R	620.365
OHARA	PBM8R	596.394
OHARA	S-BSM22R	622.532

	Glass Type	Code
SCHOTT	BK7 HT	517.642
SCHOTT	F2 HT	620.364
SCHOTT	BK7 G18	520.636
SCHOTT	K 5 G20	523.568
SCHOTT	LaK9 G15	691.547
SCHOTT	LF 5 G15	584.408
SCHOTT	N-BAK4HT	569.560
SCHOTT	N-KZFS4HT	613.445
SCHOTT	N-LASF9HT	850.322
SCHOTT	N-SF57HT	847.238
SCHOTT	N-SF7HTUltra	847.238
SCHOTT	N-SF6HT	805.254
SCHOTT	N-SF6HTUltra	805.254
SCHOTT	N-SK2HT	607.567
SCHOTT	SF57HTUltra	847.238
SCHOTT	SF6HT	805.254

0: Catalog Report

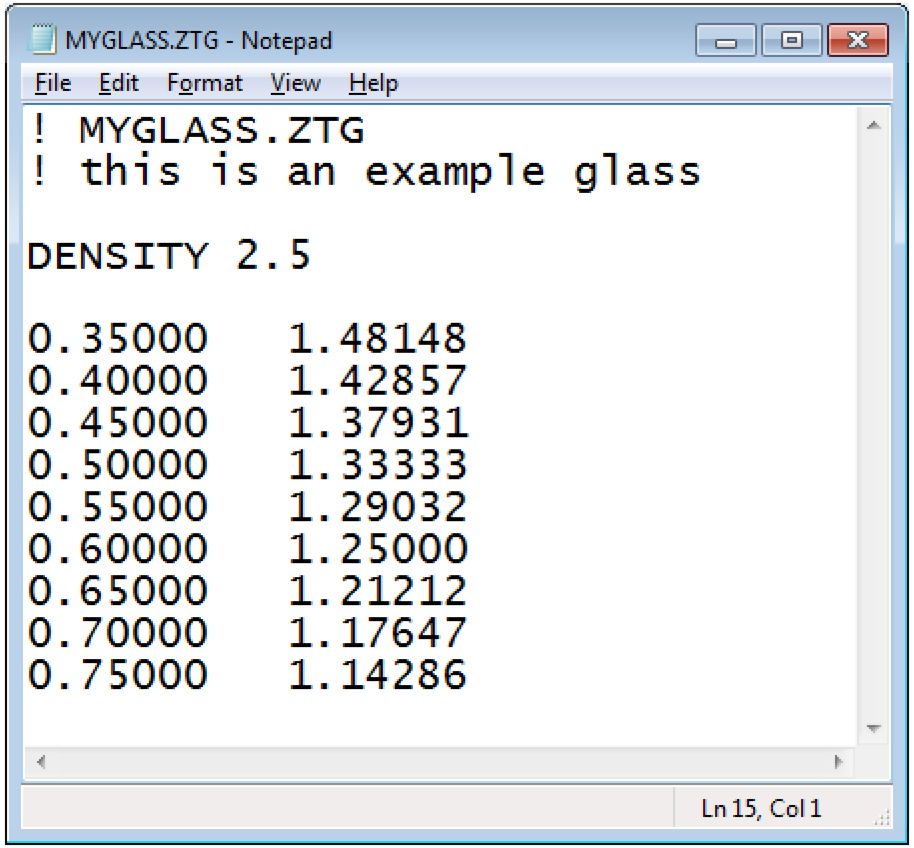
```
Listing of data for catalog RAD_HARD.AGF

Total number of glasses: 7
Standard glasses        : 7
Preferred glasses       : 0
Obsolete glasses        : 0
Special glasses         : 0
Melt glasses            : 0

Name          Stat      Nd
BK7G18        Stan      1.519747   63
F2G12         Stan      1.620722   36
K5G20         Stan      1.523439   56
LAK9G15       Stan      1.690636   54
LF5G15        Stan      1.583970   40
SF6G05        Stan      1.809061   25
SF8G07        Stan      1.694763   30
```

Example 3: How To Enter Glass Data at Specific Wavelengths

Zemax is supplied with the glass catalogs of the major manufacturers (which are built-in to Zemax), but there are times when you still need to add your own glass data. There are several methods to do this in Zemax.

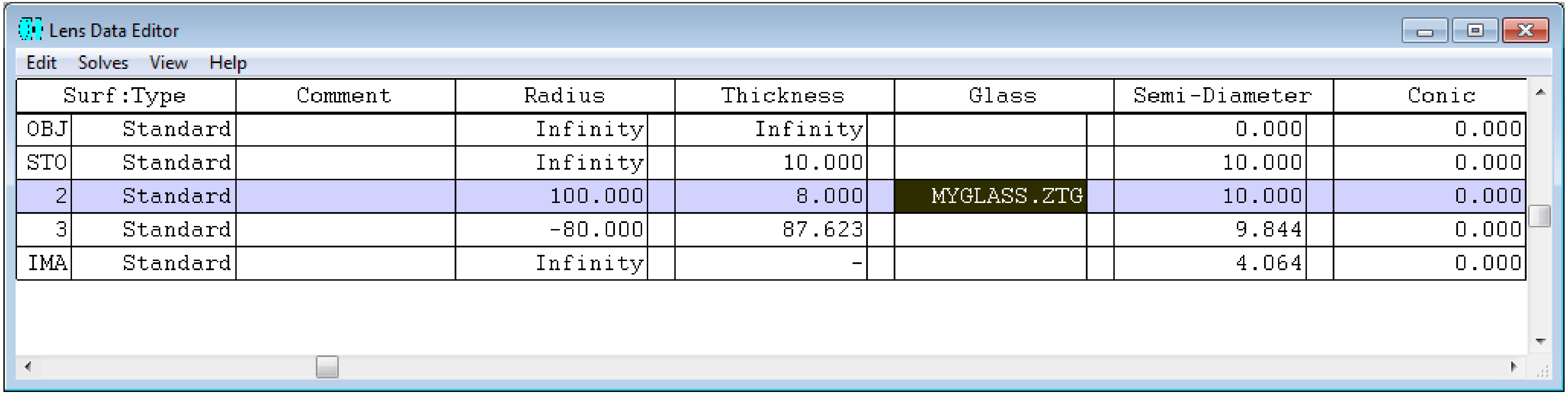
Zemax **T**able **G**lass file is a simple ASCII list.
Open notepad save the data as shown.
Note
Density : is in gram/cubic centimeter (g/cc)
1st column : Wavelength in μm
2nd column: index of refraction

Filename:
MYGLASS.ZTG
Path:
C:\<ZemaxFolder>\Glasscat




```
! MYGLASS.ZTG
! this is an example glass

DENSITY 2.5

0.35000   1.48148
0.40000   1.42857
0.45000   1.37931
0.50000   1.33333
0.55000   1.29032
0.60000   1.25000
0.65000   1.21212
0.70000   1.17647
0.75000   1.14286
```

In the lens data editor, write the file name and its extension in the Glass (Material) column as below.



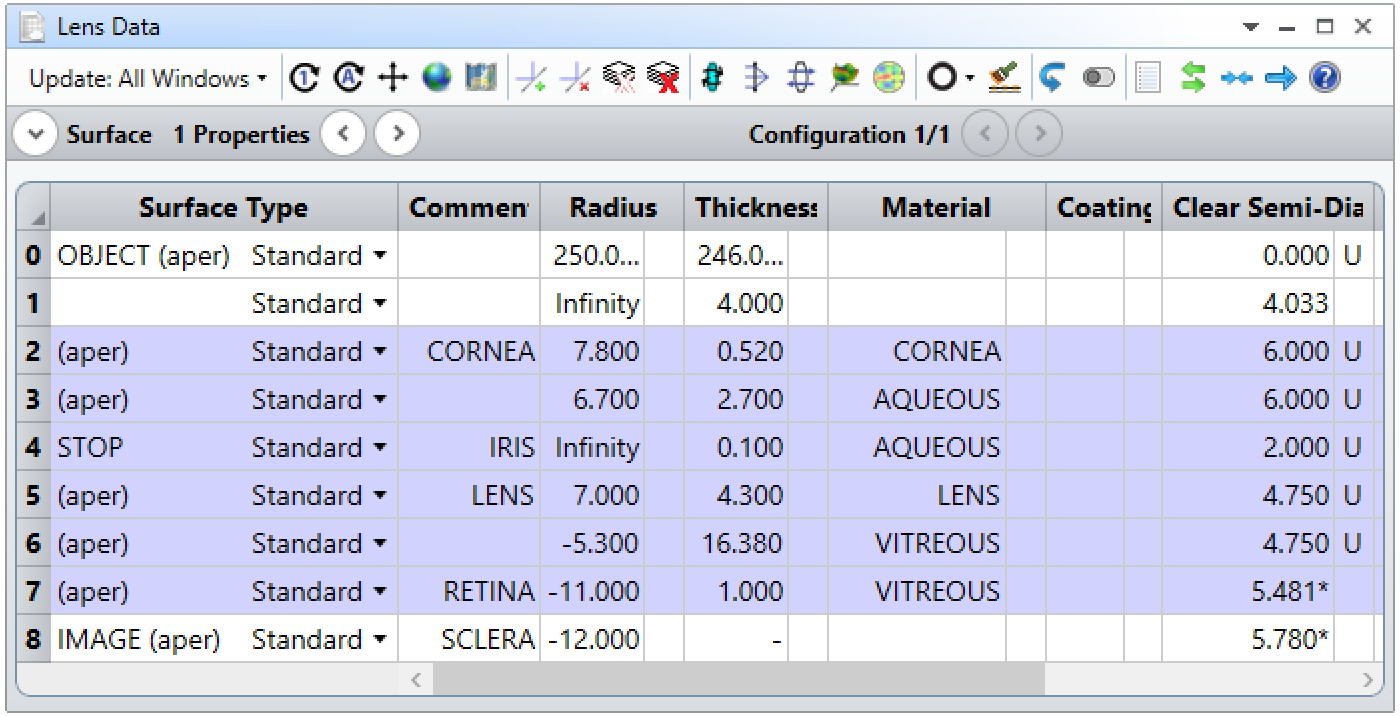
Surf:Type		Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		0.000	0.000
STO	Standard		Infinity	10.000		10.000	0.000
2	Standard		100.000	8.000	MYGLASS.ZTG	10.000	0.000
3	Standard		-80.000	87.623		9.844	0.000
IMA	Standard		Infinity	-		4.064	0.000

Eye Model

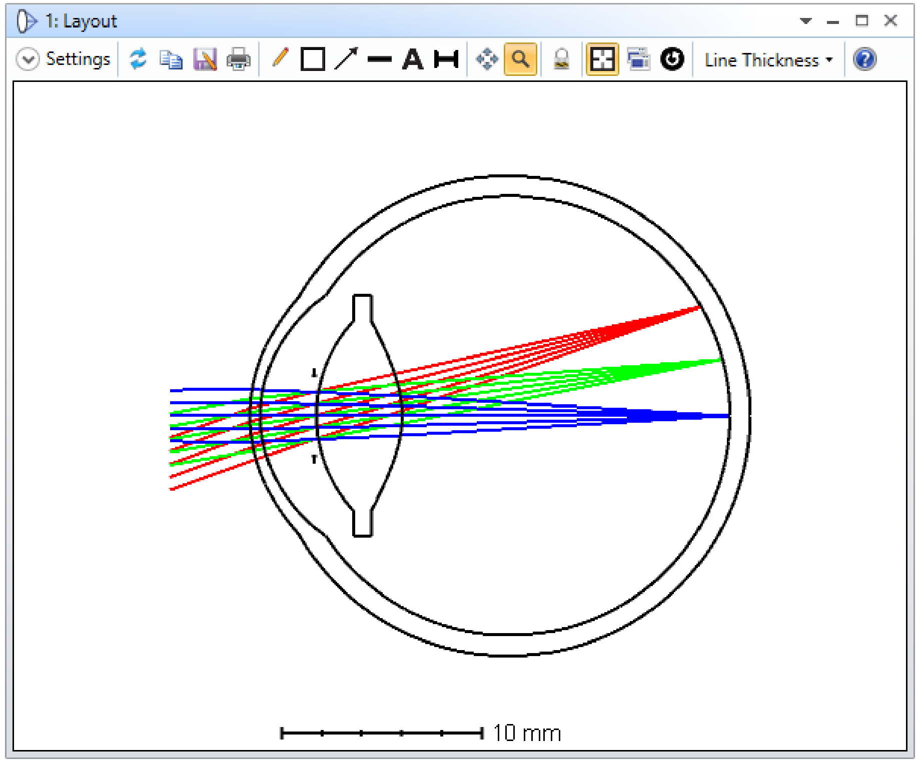
The material file (**`EYE.AGF`**) used in Eye Models are given on the course web page.

See also:

https://support.zemax.com/hc/en-us/articles/1500005575082-OpticStudio-models-of-the-human-eye



	Surface Type		Commen	Radius	Thicknes	Material	Coating	Clear Semi-Dia	
0	OBJECT (aper)	Standard		250.0...	246.0...			0.000	U
1		Standard		Infinity	4.000			4.033	
2	(aper)	Standard	CORNEA	7.800	0.520	CORNEA		6.000	U
3	(aper)	Standard		6.700	2.700	AQUEOUS		6.000	U
4	STOP	Standard	IRIS	Infinity	0.100	AQUEOUS		2.000	U
5	(aper)	Standard	LENS	7.000	4.300	LENS		4.750	U
6	(aper)	Standard		-5.300	16.380	VITREOUS		4.750	U
7	(aper)	Standard	RETINA	-11.000	1.000	VITREOUS		5.481*	
8	IMAGE (aper)	Standard	SCLERA	-12.000	-			5.780*	

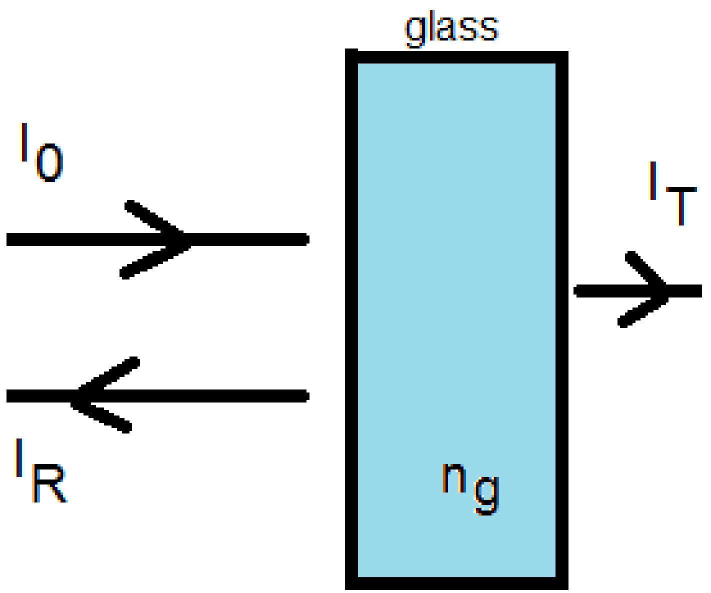


Coating

An optical coating is one or more thin layers of material deposited on an optical component such as a lens or mirror, which alters the way in which the optic reflects and transmits light.

The reflectance between two meadia is given by:

$$R = \left|\frac{n_1 - n_2}{n_1 + n_2}\right|^2 = \frac{I_R}{I_0}$$



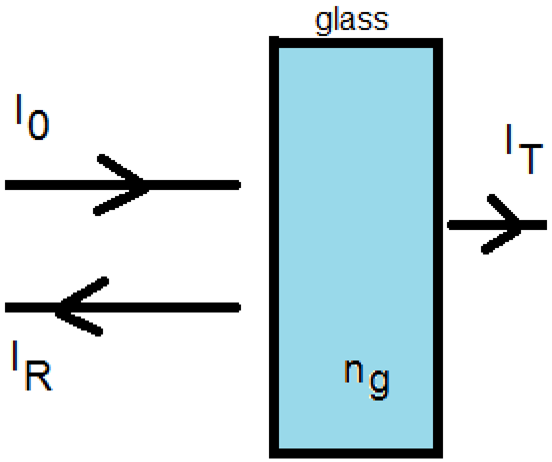
and transmittance after double internal reflections:

$$T = \frac{I_T}{I_0} \approx (1 - R)^2$$

Example 4: Numerical Example

For BK7 at λ= 550 nm index is n_g = 1.52

Then, for BK7 and air (n = 1) interface (no coating)



$$R_0 = (1.52 - 1)^2/(1.52 + 1)^2 = \mathbf{0.0426}$$

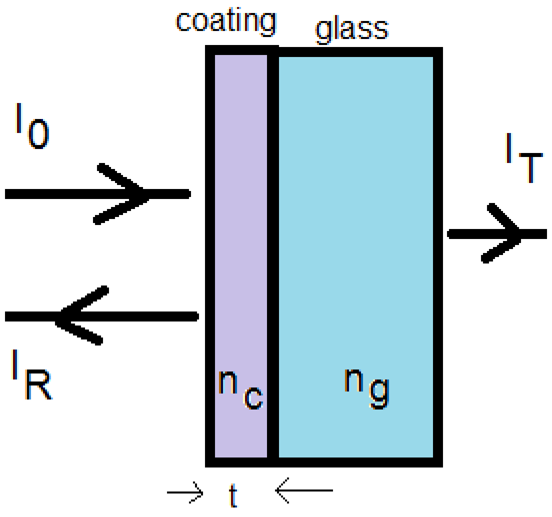
$$T_0 = (1 - R_0)^2 = \mathbf{0.9167}$$

$$\boxed{T_0 = 91.7\%}$$

Now, if we add a coating SiO (n_c = 1.45) with thickness:

$$t = \frac{\lambda}{4n_c} = \frac{550 \text{ nm}}{4(1.45)} = 94.8 \text{ nm}$$

Then, reflectance and transmittance for SiO:



$$R_1 = (1.45 - 1)^2/(1.45 + 1)^2 = \mathbf{0.0337}$$

$$T_1 = (1 - R_1)^2 = \mathbf{0.9337}$$

reflectance and transmittance for BK7:

$$R_2 = (1.45 - 1.52)^2/(1.45 + 1.52)^2 = \mathbf{0.0005}$$

$$T_2 = T_1(1 - R_2)^2 = \mathbf{0.9327}$$

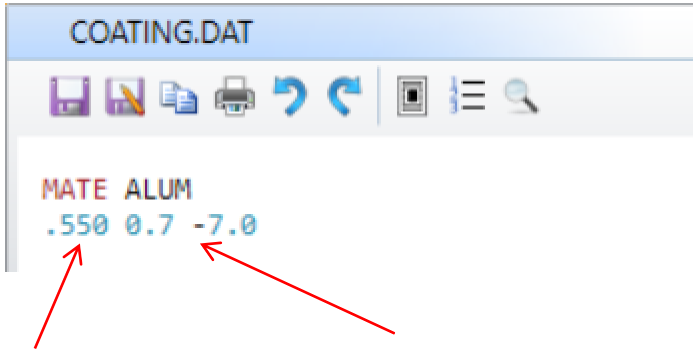
$$\boxed{T_2 = 93.3\%}$$

Coating in Zemax

The default COATING.DAT file supplied with OpticStudio contains several materials and a few common optical coatings.

DEFAULT MATERIALS AND COATINGS

Material	Description
AIR	Unity index, used for including air gaps in coatings
AL2O3	Aluminum Oxide, index 1.59
ALUM	Aluminum, index 0.7-7.0i
ALUM2	An alternate definition for aluminum
CEF3	Cerous Flouride, index 1.63
LA2O3	Lanthanum Oxide, index 1.95
MGF2	Magnesium Fluoride, index 1.38
N15	Imaginary material of index 1.50
THF4	Thorium Fluoride, index 1.52
ZNS	Zinc Sulphide, index 2.35
ZRO2	Zirconium Oxide, index 2.1

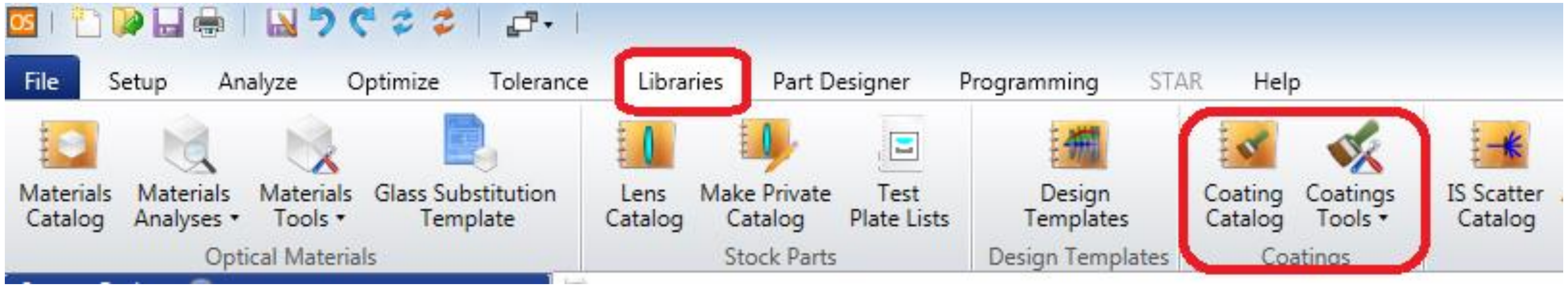


$\lambda = 0.55\ \mu\text{m}$ $n' = 0.7 - 7.0i$

Coating	Description
AR	General anti reflection, defined as a quarter wave of MGF2
GAP	A small gap of air used to show evanescent propagation
HEAR1	High performance anti reflection coating
HEAR2	High performance anti reflection coating
METAL	A thin layer of aluminum used to make beamsplitters
NULL	A zero thickness coating used primarily for debugging
WAR	Anti-reflection "W" coat, defined as a half wave of LA2O3 followed by a quarter wave of MGF2.

Coating

For more information see:



Reflectance of Metals

Metals are used in optical systems as reflective optical components, **optical thin films**, structural elements, and mirror substrates. For metals *n* is complex and it is expressed in Zemax as:

$$n' = n + ik$$

Zemax uses negative value of imaginary part. For example, index of Aluminum is given by:

$$n' = 0.7 - 7.0i$$

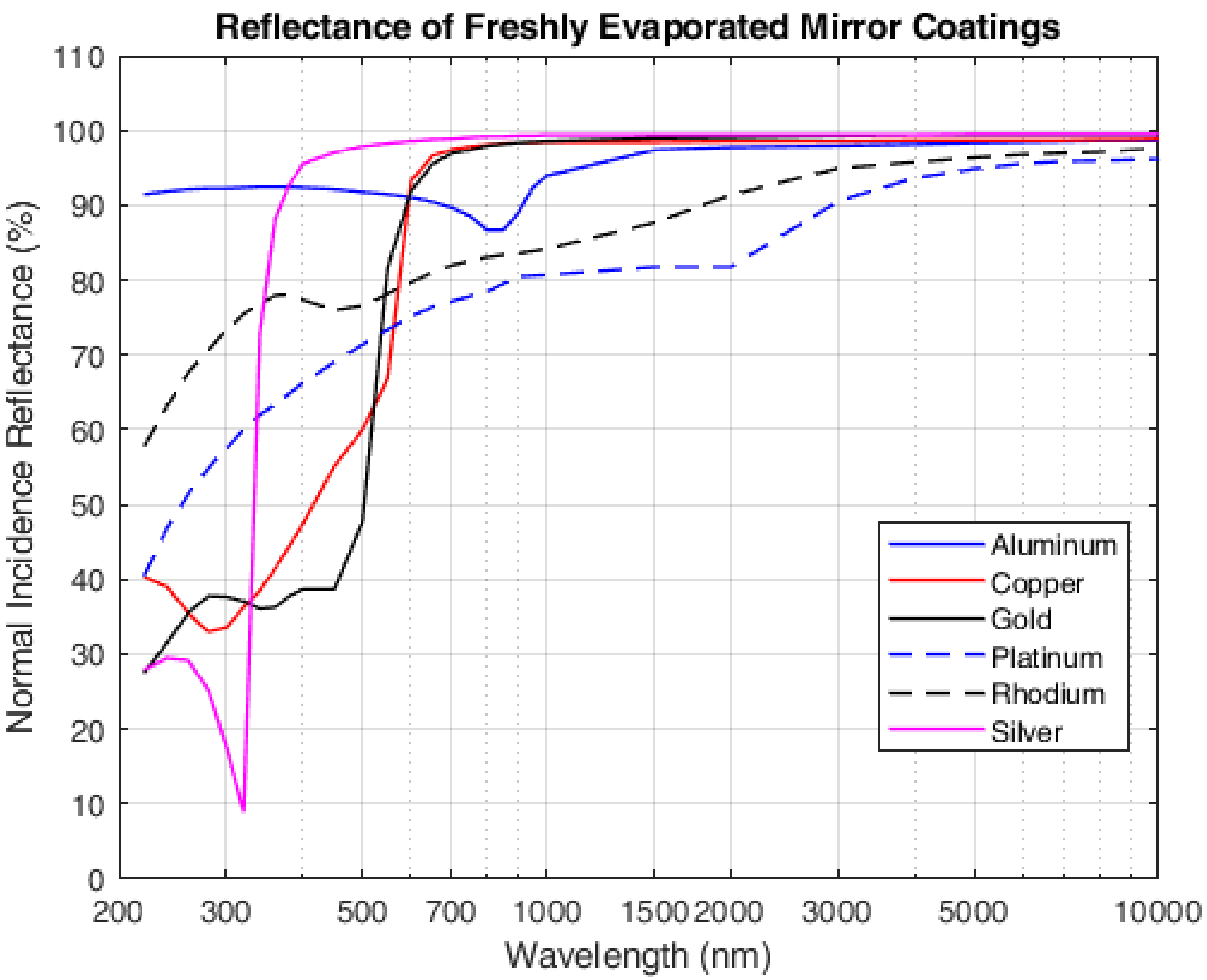
In the ref. Book, index of refraction of Aluminum at λ ≈ 565 nm is given by:

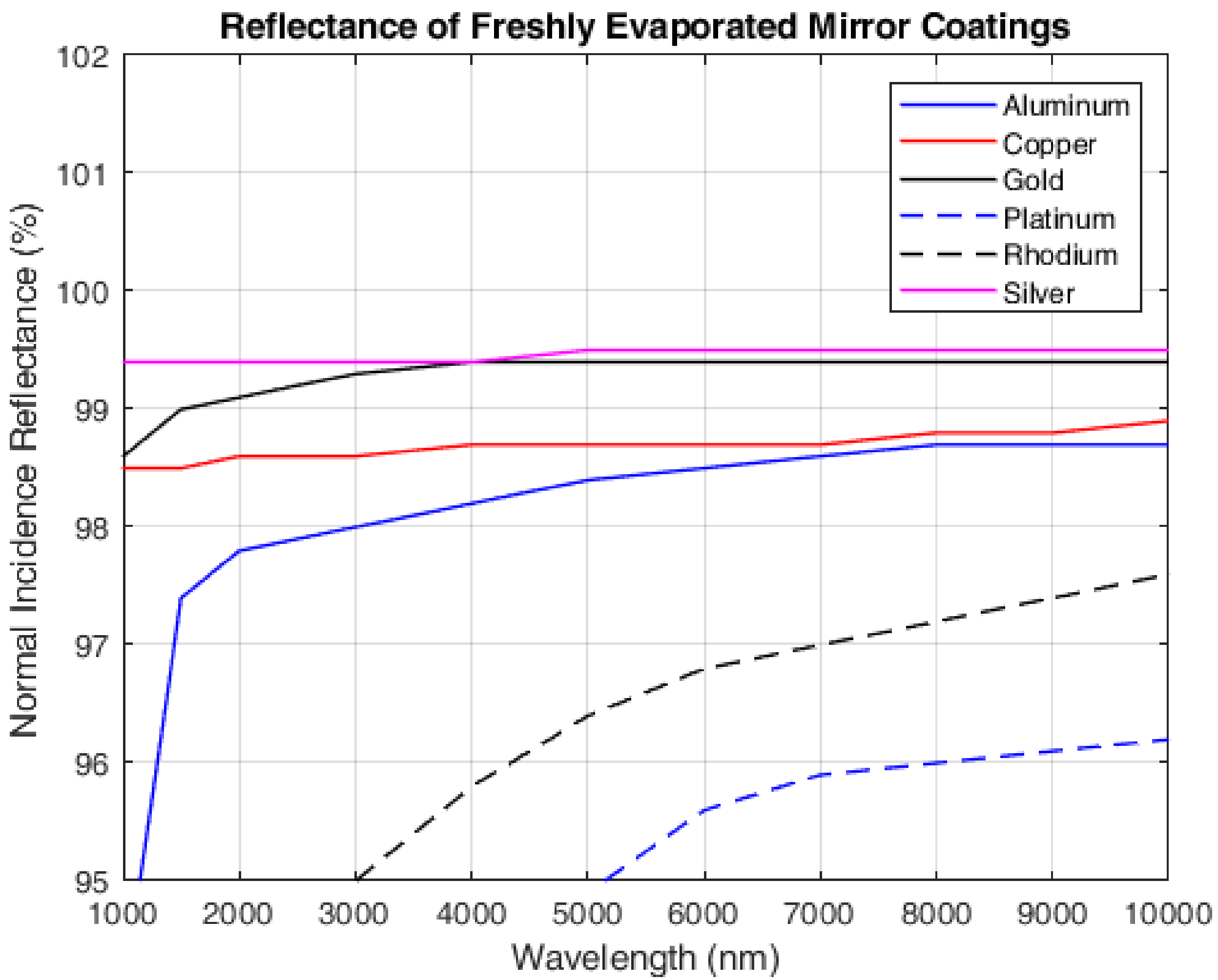
$$n' = 1.018 - 6.846i$$

Then, the reflectance at normal incidence can be computed as follows:

$$R = \left|\frac{n' - 1}{n' + 1}\right|^2 = \left|\frac{1.018 - 6.846i - 1}{1.018 - 6.846i + 1}\right|^2 = 0.92 = 92\%$$

The reflectance is a function of n' and hence the wavelength.


Reflectance of Freshly Evaporated Mirror Coatings
Normal Incidence Reflectance (%)
Wavelength (nm)
Aluminum
Copper
Gold
Platinum
Rhodium
Silver


Reflectance of Freshly Evaporated Mirror Coatings
Normal Incidence Reflectance (%)
Wavelength (nm)
Aluminum
Copper
Gold
Platinum
Rhodium
Silver

Example 5: How to Add new metal coating

There are two ways of accessing the data in the coating file.

- The file can be edited outside of OpticStudio using any text editor.
- “Edit Coating File” option in the Coating Tools group of the Libraries tab.

Edit the default coating file

C:\<Zemax>\Coatings\COATING.DAT

First, add the following lines:

```
MATE  Titanium
0.355 1.30 -2.01
0.414 1.59 -2.17
0.497 1.78 -2.39
0.622 2.11 -2.88
1.24  3.62 -3.52
2.49  4.43 -3.22
12.4  5.03 -23.38
```

Then, define coating as follows:

```
COAT  AR_Ti
Titanium 0.25
```

coating material

coating thickness λ/4

*For more information, search for “**Coating File Data Syntax”** in Zemax help.*

To apply this coating to a sequential surface, go to the Coating section of the Surface Properties in the Lens Data Editor. The new coating will be listed in the drop-down menu. The items in the menu follow the same order as defined in the coating file.