Institute of Applied Physics
Friedrich-Schiller-Universität Jena

Optical Design with Zemax for PhD

Lecture 16: Coatings

2016-05-13

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Preliminary Schedule

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No	Date	Subject	Detailed content
1	11.11.	Introduction	Zemax interface, menus, system description, editors,, coordinate systems, aperture, field, wavelength, layouts, raytrace, stop and pupil, solves, ray fans, paraxial optics
2	02.12.	Basic Zemax handling	surface types, quick focus, catalogs, vignetting, footprints, system insertion, scaling, component reversal
3	09.12.	Properties of optical systems	aspheres, gradient media, gratings and diffractive surfaces, special types of surfaces, telecentricity, ray aiming, afocal systems
4	16.12.	Aberrations I	representations, spot, Seidel, transverse aberration curves, Zernike wave aberrations
5	06.01.	Aberrations II	PSF, MTF, ESF
6	13.01.	Optimization I	algorithms, merit function, variables, pick up's
7	20.01.	Optimization II	methodology, correction process, special requirements, examples
8	27.01.	Advanced handling	slider, universal plot, I/O of data, material index fit, multi configuration, macro language
9	03.02.	Correction I	simple and medium examples
10	10.02.	Correction II	advanced examples
11	02.03.	Illumination	simple illumination calculations, non-sequential option
12	23.03.	Physical optical modelling	Gaussian beams, POP propagation
13	08.04	Tolerancing I	Sensitivities, Tolerancing
14	15.04.	Tolerancing II	Adjustment, thermal loading
15	22.04.	Scattering	Introduction, surface scattering, diffraction and empirical, optical, systems, volume scattering, models, tissue, scattering in Zemax
16	13.05.	Coatings	Introduction, matrix calculus, properties, single and double layer, miscellaneous, coatings in Zemax

Contents

Fresnel Formulas

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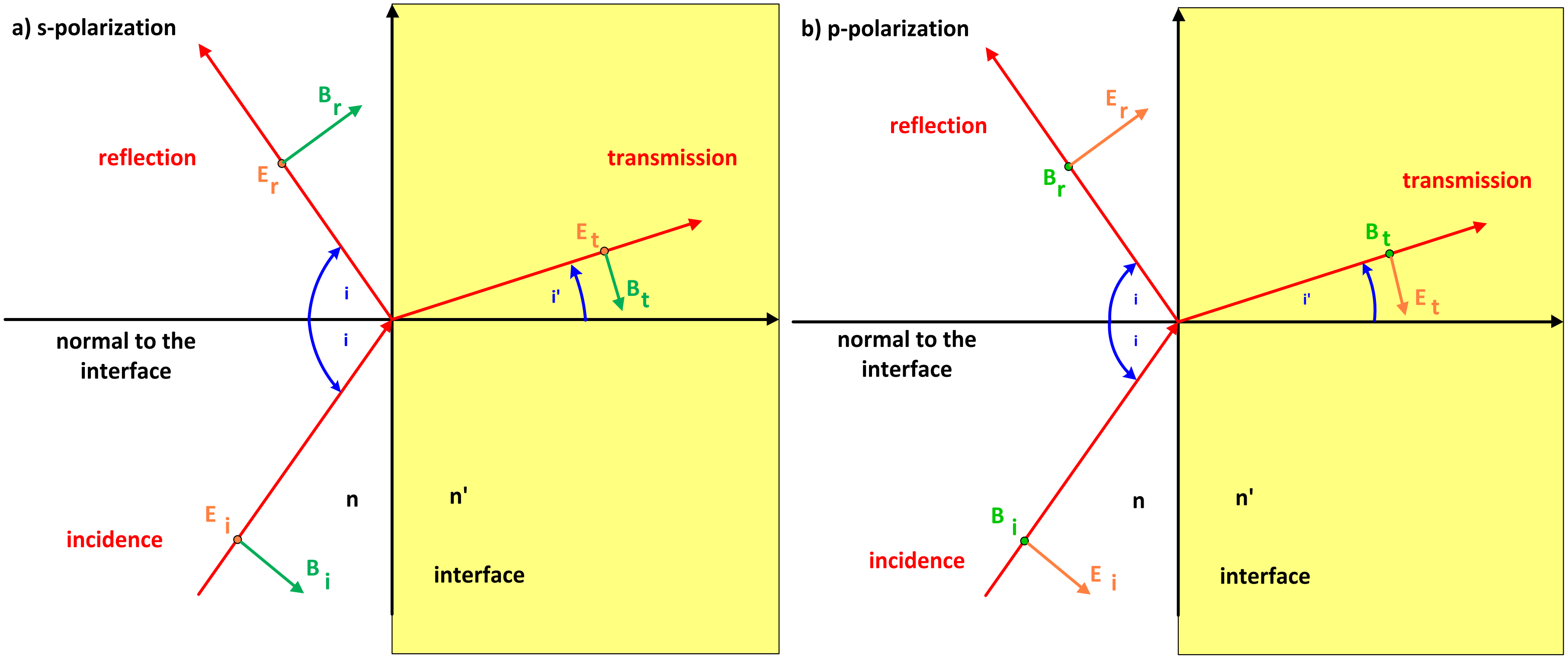
- Schematical illustration of the ray refraction (reflection at an interface
- The cases of s- and p-polarization must be distinguished



Fresnel Formulas

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- Electrical transverse polarization
  TE, s- or σ-polarization, E perpendicular to incidence plane $\perp$

- Magnetical transverse polarization
  TM, p- or p-polarization, E in incidence plane $\parallel$

- Boundary condition of Maxwell equations
  at a dielectric interface:
  continuous tangential component of E-field

$$\varepsilon_1 \cdot E_{1n} = \varepsilon_2 \cdot E_{2n}$$

$$E_{1t} = E_{2t}$$

- Amplitude coefficients for
  reflected field

$$r_{TE} = \left. \frac{E_r}{E_e} \right|_{TE} \qquad r_{TM} = \left. \frac{E_r}{E_e} \right|_{TM}$$

  transmitted field

$$t_{TE} = \left. \frac{E_t}{E_e} \right|_{TE} = r_{TE} + 1 \qquad t_{TM} = \frac{n}{n'} \cdot \left(r_{TM} + 1 \right)$$

- Reflectivity and transmission
  of light power

$$R = \frac{P_r}{P_e} = \left| r^2 \right| \qquad T = \frac{P_t}{P_e} = \frac{n' \cdot \cos i'}{n \cdot \cos i} \cdot \left| t^2 \right|$$

Fresnel Formulas: Stokes Relations

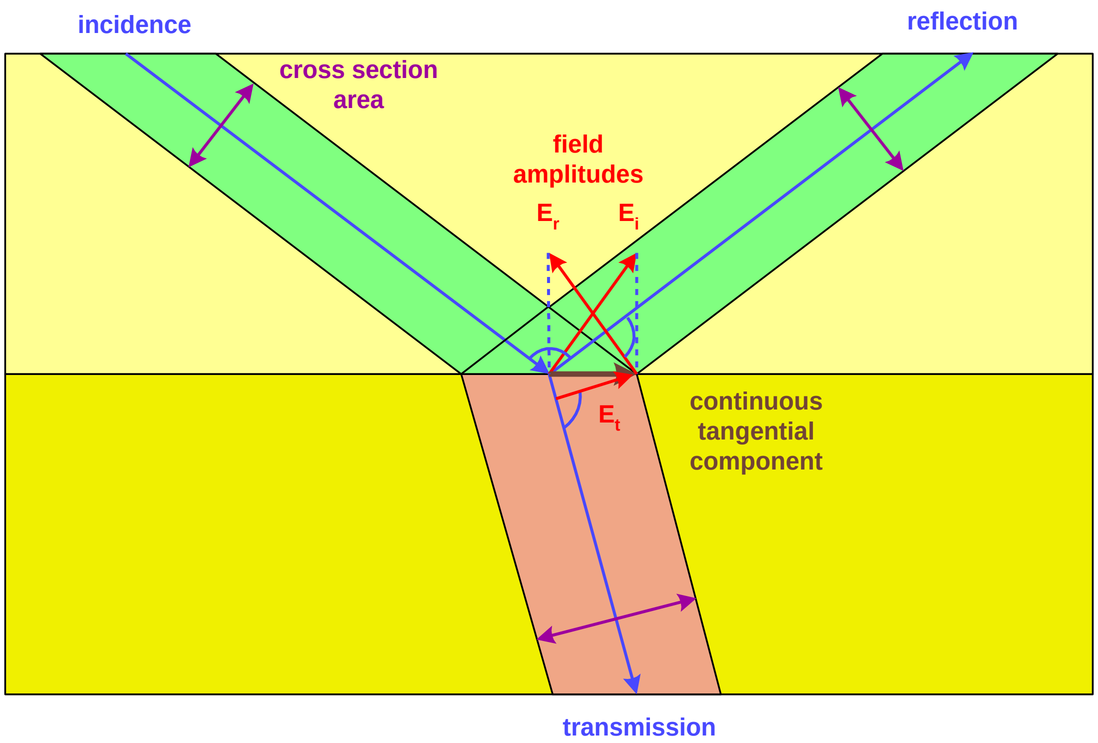
- Relation between the amplitude coefficients for reflection/transmission:

1. s-components:
   field components additive
   minus sign due to phase jump

$$t_{\perp} - r_{\perp} = 1$$

2. p-components:
   energy preservation but change of area size due to projection, correction factor, no additivity of intensities

$$t_{\parallel} \cdot \frac{\cos i'}{\cos i} + r_{\parallel} = 1$$



Fresnel Formulas

- Coefficients of amplitude for reflected rays, s and p

$$r_{E\perp} = -\frac{\sin(i-i')}{\sin(i+i')} = \frac{n\cdot\cos i - \sqrt{n'^2 - n^2\cdot\sin^2 i}}{n\cdot\cos i + \sqrt{n'^2 - n^2\cdot\sin^2 i}} = \frac{n\cdot\cos i - n'\cdot\cos i'}{n\cdot\cos i + n'\cdot\cos i'} = \frac{k_{ez} - k_{tz}}{k_{ez} + k_{tz}}$$

$$r_{E\parallel} = \frac{\tan(i-i')}{\tan(i+i')} = \frac{n'^2\cdot\cos i - n\cdot\sqrt{n'^2 - n^2\cdot\sin^2 i}}{n'^2\cdot\cos i + n\cdot\sqrt{n'^2 - n^2\cdot\sin^2 i}} = \frac{n'\cdot\cos i - n\cdot\cos i'}{n'\cdot\cos i + n\cdot\cos i'} = \frac{n'^2\cdot k_{ez} - n^2\cdot k_{tz}}{n'^2\cdot k_{ez} + n^2\cdot k_{tz}}$$

- Coefficients of amplitude for transmitted rays, s and p

$$t_{E\perp} = \frac{2n\cdot\cos i}{n\cdot\cos i + n'\cdot\cos i'} = \frac{2n\cdot\cos i}{n\cdot\cos i + \sqrt{n'^2 - n^2\cdot\sin^2 i}} = \frac{2n\cdot\cos i}{n\cdot\cos i + n'\cdot\cos i'} = \frac{2k_{ez}}{k_{ez} + k_{tz}}$$

$$t_{E\parallel} = \frac{2n\cdot\cos i}{n'\cdot\cos i + n\cdot\cos i'} = \frac{2n'\cdot n\cdot\cos i}{n'^2\cdot\cos i + n\cdot\sqrt{n'^2 - n^2\cdot\sin^2 i}} = \frac{2n\cdot\cos i}{n'\cdot\cos i + n\cdot\cos i'} = \frac{2n'^2\cdot k_{ez}}{n'^2\cdot k_{ez} + n^2\cdot k_{tz}}$$

Fresnel Formulas

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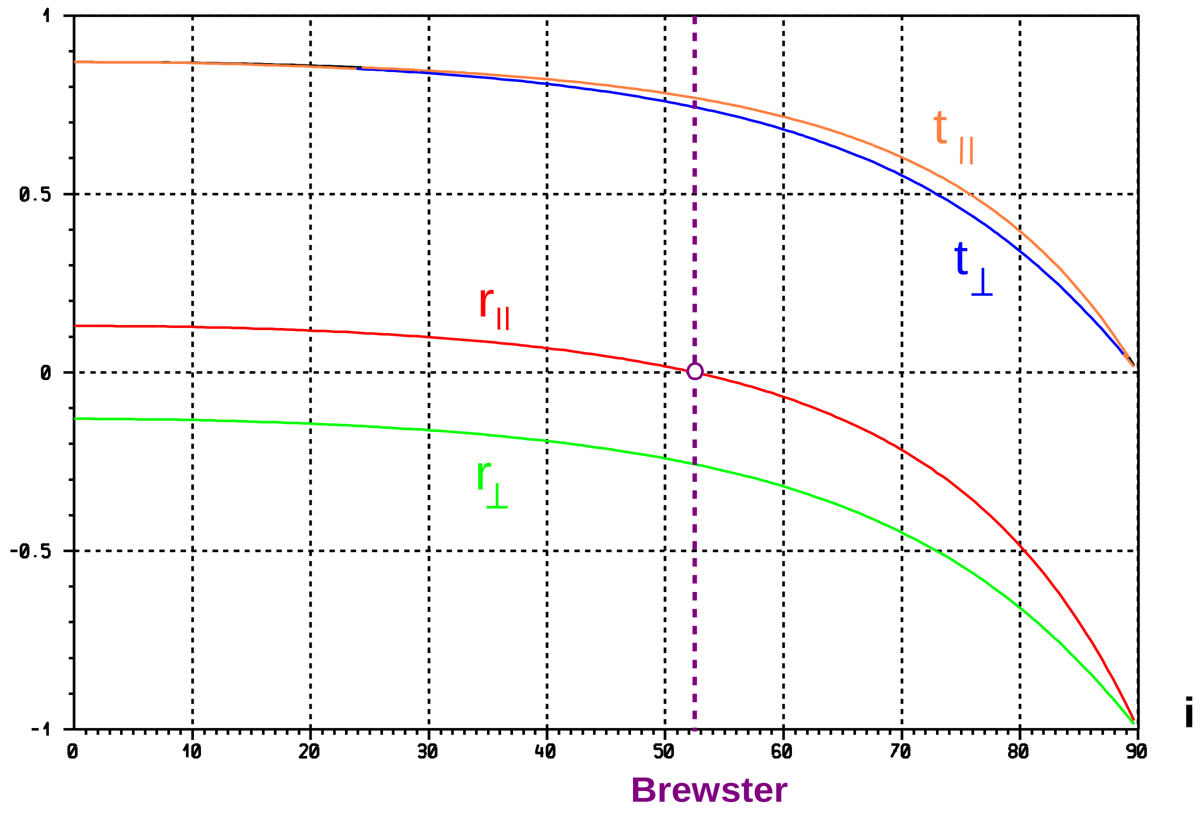
- Typical behavior of the Fresnel amplitude coefficients as a function of the incidence angle for a fixed combination of refractive indices

- i = 0
  Transmission independent on polarization
  Reflected p-rays without phase jump
  Reflected s-rays with phase jump of π (corresponds to r<0)

- i = 90°
  No transmission possible
  Reflected light independent on polarization

- Brewster angle:
  completely s-polarized reflected light



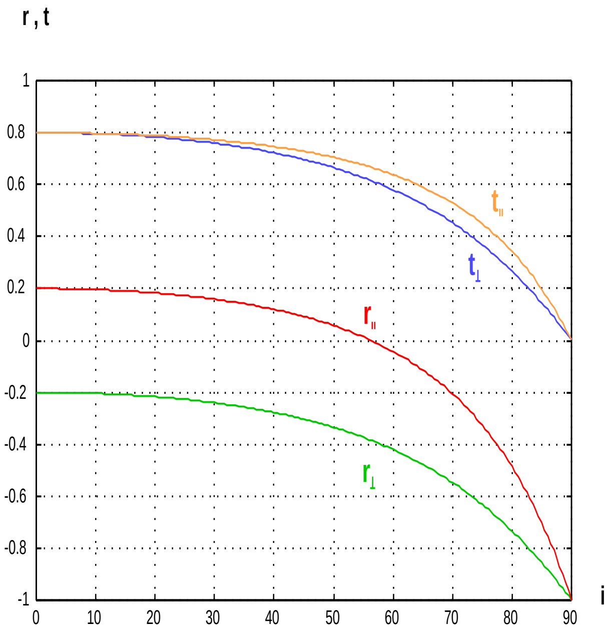
Fresnel Formulas: Energy vs. Intensity

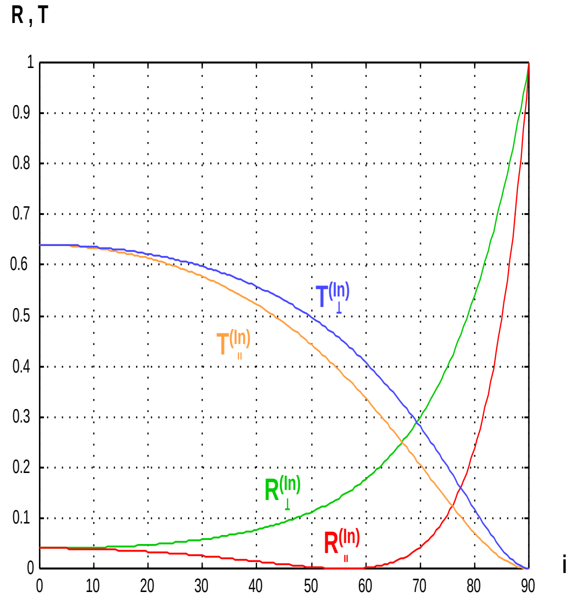
Fresnel formulas, different representations:

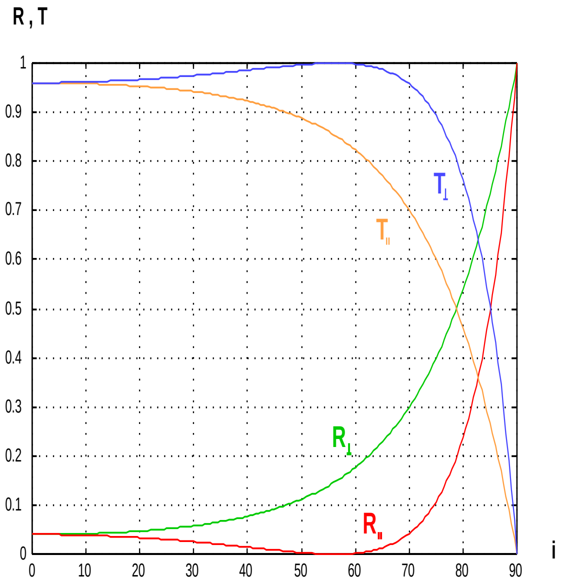
1. Amplitude coefficients, with sign

2. Intensity cefficients: no additivity due to area projection

3. Power coefficients: additivity due to energy preservation







Introduction and Overview

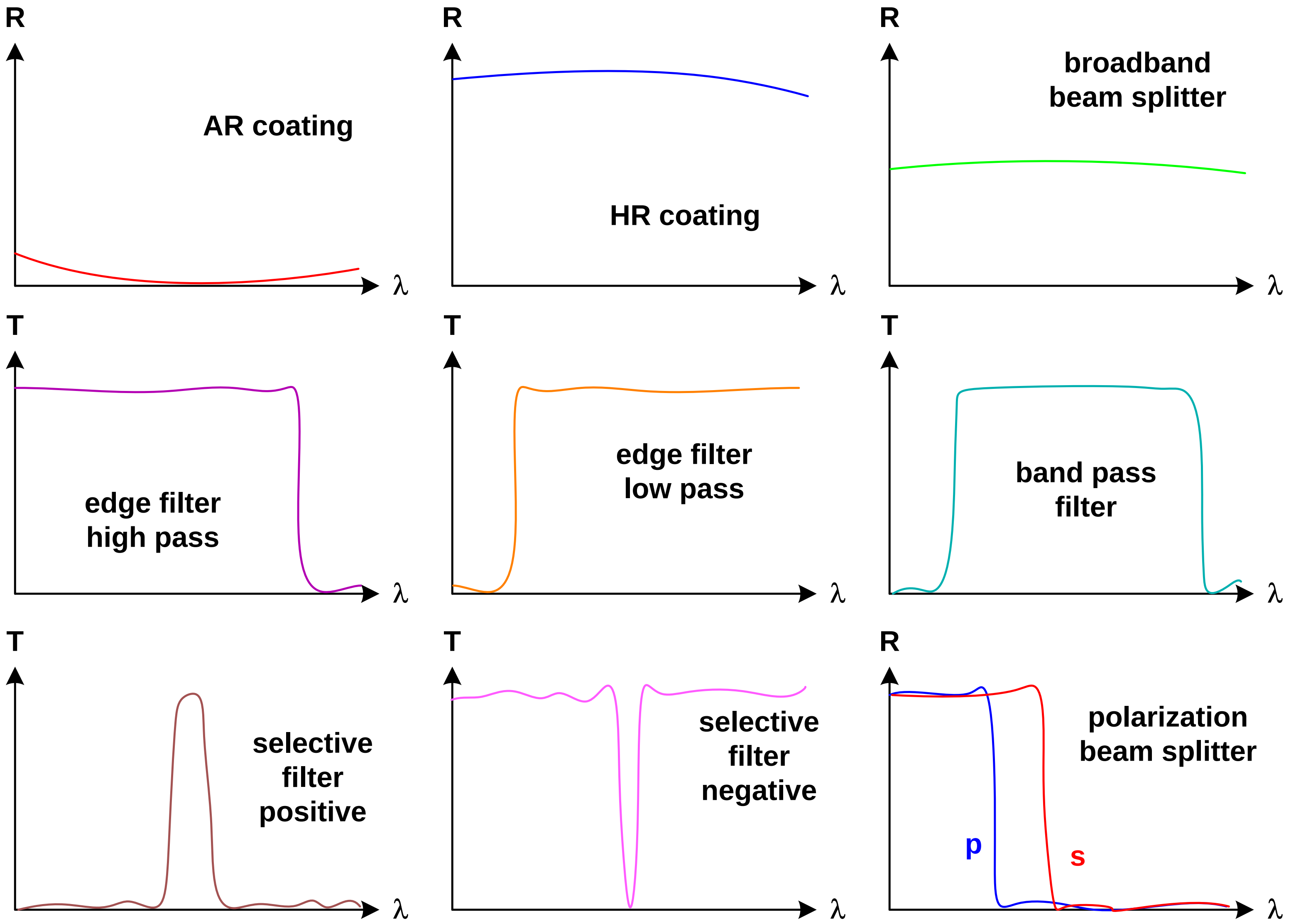
- Optical multi layer systems / thin layers:
  Change of reflection, transpossion, polarization

- Application in optical systems:
  1. improved transmissioin
  2. avoiding false light and ghosts

- Thin layer stacks:
  1. interference at many interface planes
  2. the layer thickness is in the range of the wavelength
  3. calculation is quite complex

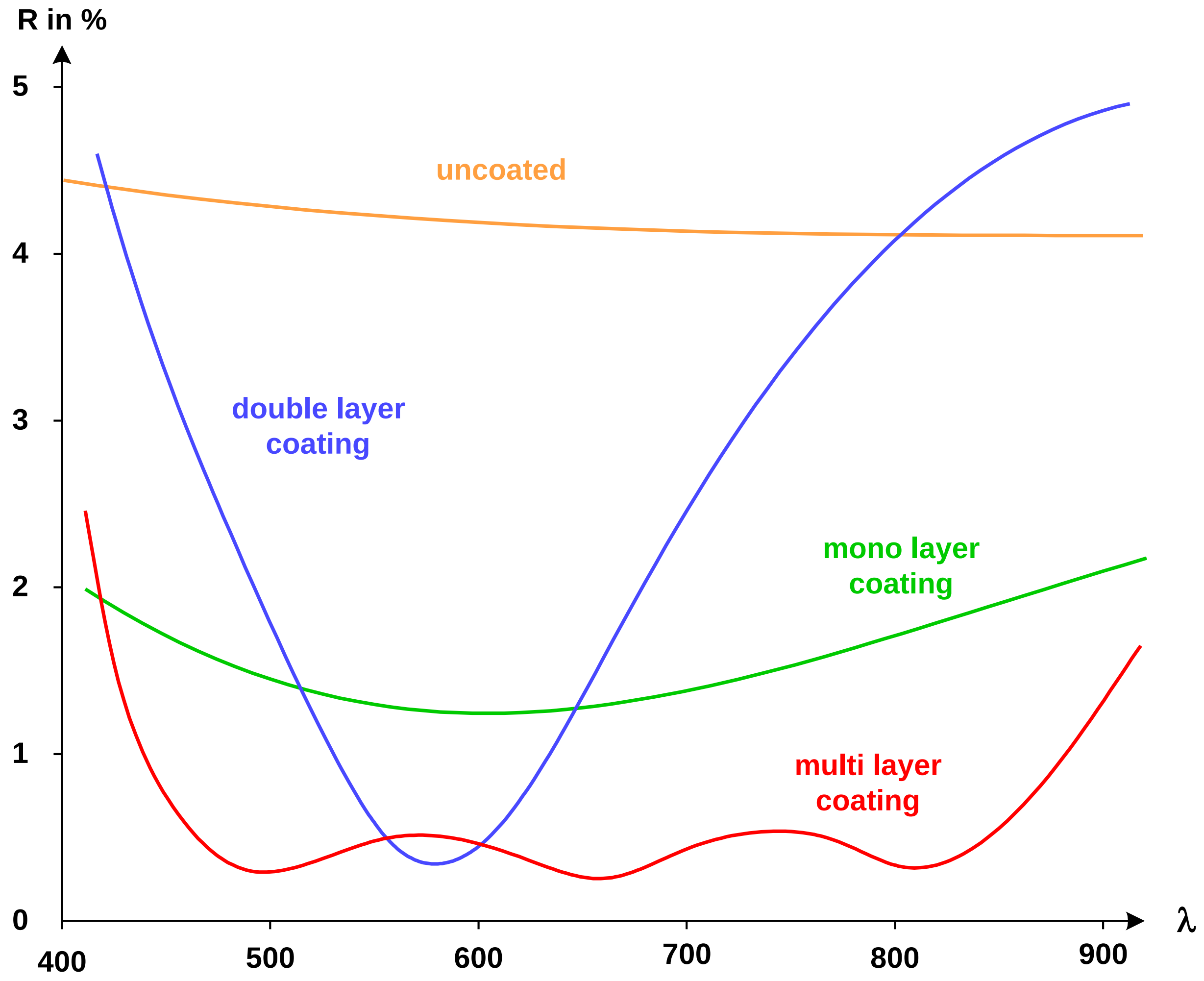
- Types of coatings:
  1. AR coatings
  2. HR coatings (mirrors)
  3. spectral edge filter
  4. spectral band filter
  5. beam splitter
  6. polarizing coatings
  7. color filtering

Types of Coatings



Comparison of Coatings

- Comparison of coatings with different number of layers:
  1. without coating
  2. single layer
  3. double layer
  4. multi-layer

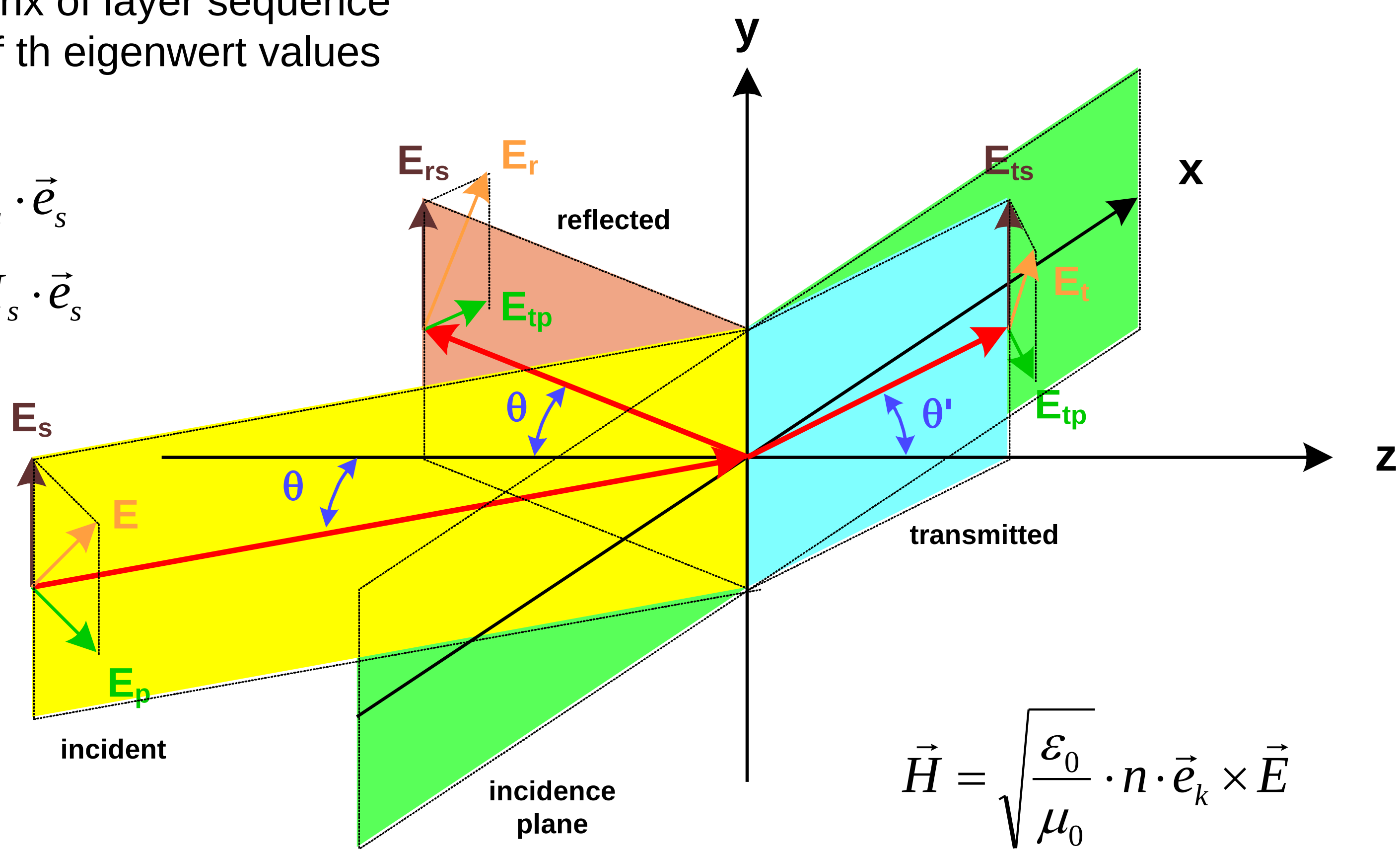


Field Components in Layers

- Principle of calculation of a thin layer system:
  1. decomposition of field components at the plane interfaces
  2. continuity condition of Fresnel equations
  3. resulting matrix of layer sequence
  4. calculation of th eigenwert values

$$\vec{E} = E_p \cdot \vec{e}_p + E_s \cdot \vec{e}_s$$

$$\vec{H} = H_p \cdot \vec{e}_p + H_s \cdot \vec{e}_s$$



$$\vec{H} = \sqrt{\frac{\varepsilon_0}{\mu_0}} \cdot n \cdot \vec{e}_k \times \vec{E}$$

Calculation of Thin Layer Stacks

- Optical impedance in vacuum

$$Z_0 = \sqrt{\frac{\varepsilon_o}{\mu_0}} = \frac{H}{E}$$

- Impedance of a system stack for both polarizations

$$Z_p = \frac{H}{E} = \sqrt{\frac{\varepsilon_0}{\mu_0}} \cdot \frac{n}{\cos\theta} = Z_o \cdot \frac{n}{\cos\theta}$$

$$Z_s = \frac{H}{E} = \sqrt{\frac{\varepsilon_0}{\mu_0}} \cdot n \cdot \cos\theta = Z_o \cdot n \cdot \cos\theta$$

- Equivalent phase delay of a layer for incidence angle θ

$$\delta = \frac{2\pi \cdot n \cdot d \cdot \cos\theta}{\lambda_o}$$

- Reflectivity of amplitude

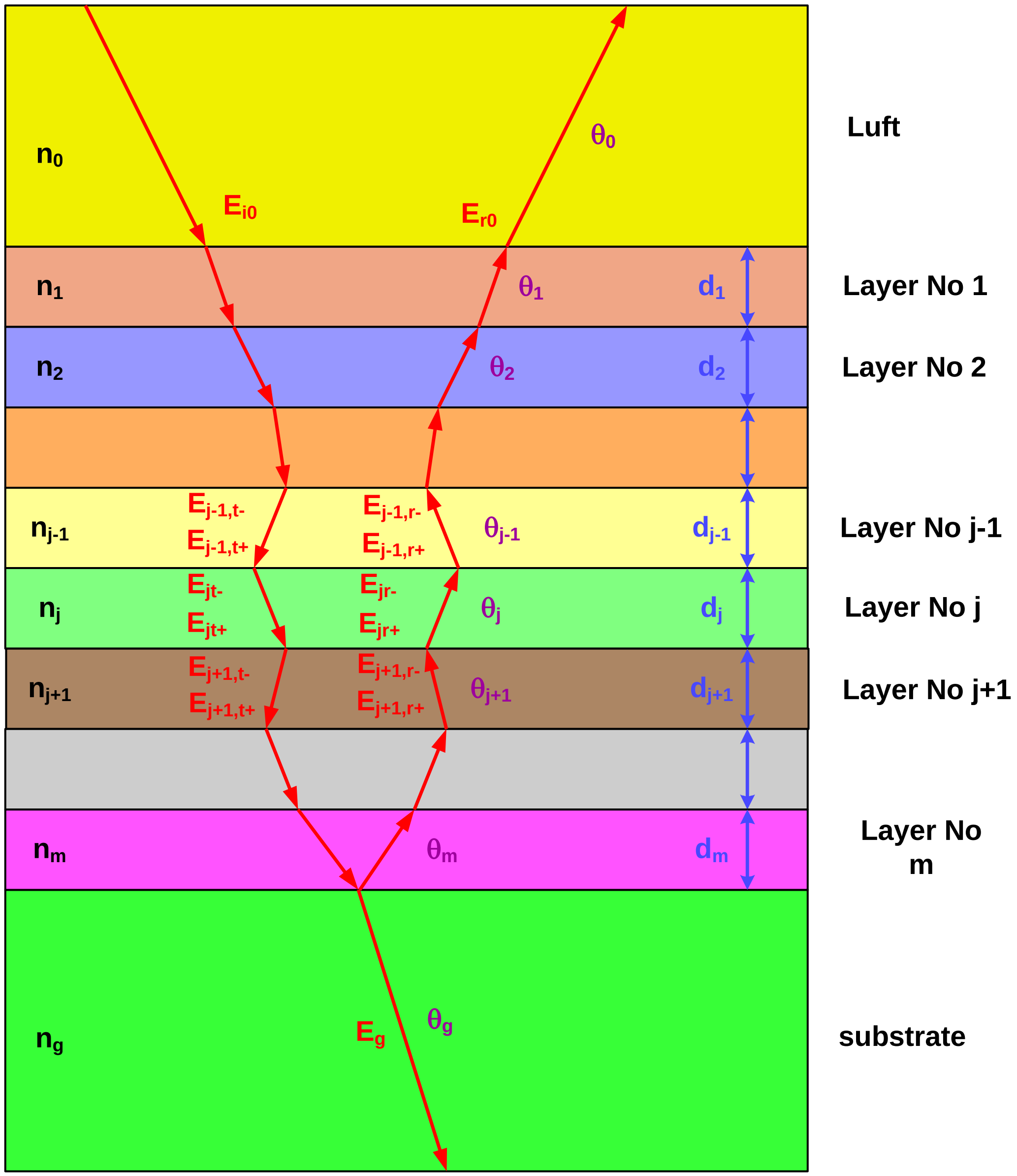
$$r_s = \frac{E_{os}^{ref}}{E_{os}^{inc}} \qquad R_s = \left| \frac{E_{os}^{ref}}{E_{os}^{inc}} \right|^2 = |r_s|^2$$

- Transmission of amplitude

$$t_s = \sqrt{\frac{n_g}{n_o}} \cdot \frac{E_{gs}^{trans}}{E_{os}^{inc}} \qquad T_s = \frac{n_g}{n_o} \left| \frac{E_{gs}^{trans}}{E_{os}^{inc}} \right|^2 = |t_s|^2$$

Matrix Model of Stack Calculation

- Field components:
  1. entrance and exit of a layer
  2. E and H-field
  3. forward and backward propagating wave
  4. both polarization components
- Continuity conditions at the interface planes
- Solution of linear system equations
- Also valid for absorbing media



Transfer Matrices

- Transfer matrices
  - for one layer
  - for both polarizations p and s

$$\begin{pmatrix} E_{j+1,s} \\ H_{j+1,s} \end{pmatrix} = \begin{pmatrix} \cos\delta_j & \dfrac{i}{n_j \cdot \cos\theta_j} \cdot \sin\delta_j \\ i \cdot n_j \cdot \cos\theta_j \cdot \sin\delta_j & \cos\delta_j \end{pmatrix} \cdot \begin{pmatrix} E_{j,s} \\ H_{j,s} \end{pmatrix}$$

$$\begin{pmatrix} E_{j+1,p} \\ H_{j+1,p} \end{pmatrix} = \begin{pmatrix} \cos\delta_j & \dfrac{i \cdot \cos\theta}{n_{j\,j}} \cdot \sin\delta_j \\ i \cdot \dfrac{n_j}{\cos\theta_j} \cdot \sin\delta_j & \cos\delta_j \end{pmatrix} \cdot \begin{pmatrix} E_{j,p} \\ H_{j,p} \end{pmatrix}$$

- Matrix of complete stack (representation with B)

$$\begin{pmatrix} E_j \\ B_j \end{pmatrix} = \underline{M}_{jm} \cdot \begin{pmatrix} E_m \\ B_m \end{pmatrix}$$

$$\underline{M}_{1,m} = \prod \underline{M}_j = \underline{M}_m \cdot \underline{M}_{m-1} \cdot \ldots \cdot \underline{M}_3 \cdot \underline{M}_2 \cdot \underline{M}_1$$

- Impedance of air and substrate must be taken into account

$$Z_{gs} = \sqrt{\frac{\varepsilon_o}{\mu_0}} \cdot n_g \cdot \cos\theta_g \qquad Z_{s0} = \sqrt{\frac{\varepsilon_o}{\mu_0}} \cdot n_0 \cdot \cos\theta$$

Final Calculations Step

- Single layer matrix

$$\underline{M}_j = \begin{pmatrix} \cos\delta_j & \dfrac{i\cdot\sin\delta_j}{Z_j} \\ i\cdot Z_j\cdot\sin\delta_j & \cos\delta_j \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}$$

- Reflectivity of complete system
  for s and p polarization

$$r_s = \frac{Z_{so}M_{11} + Z_{so}Z_{sg}M_{12} - M_{21} - Z_{sg}M_{22}}{Z_{so}M_{11} + Z_{so}Z_{sg}M_{12} + M_{21} + Z_{sg}M_{22}}$$

- Transmission of complete system
  for s and p polarization

$$t_s = \frac{2Z_{so}}{Z_{so}M_{11} + Z_{so}Z_{sg}M_{12} + M_{21} + Z_{sg}M_{22}}$$

- Matrix approach:
  - analysis method
  - optimization by NLSQ-algorithms
  - problem: periodicity of phase

- In principle solution only for
  1. one wavelength
  2. one incidence angle

- Typically the spectral performance is shown as a function of λ_o / λ

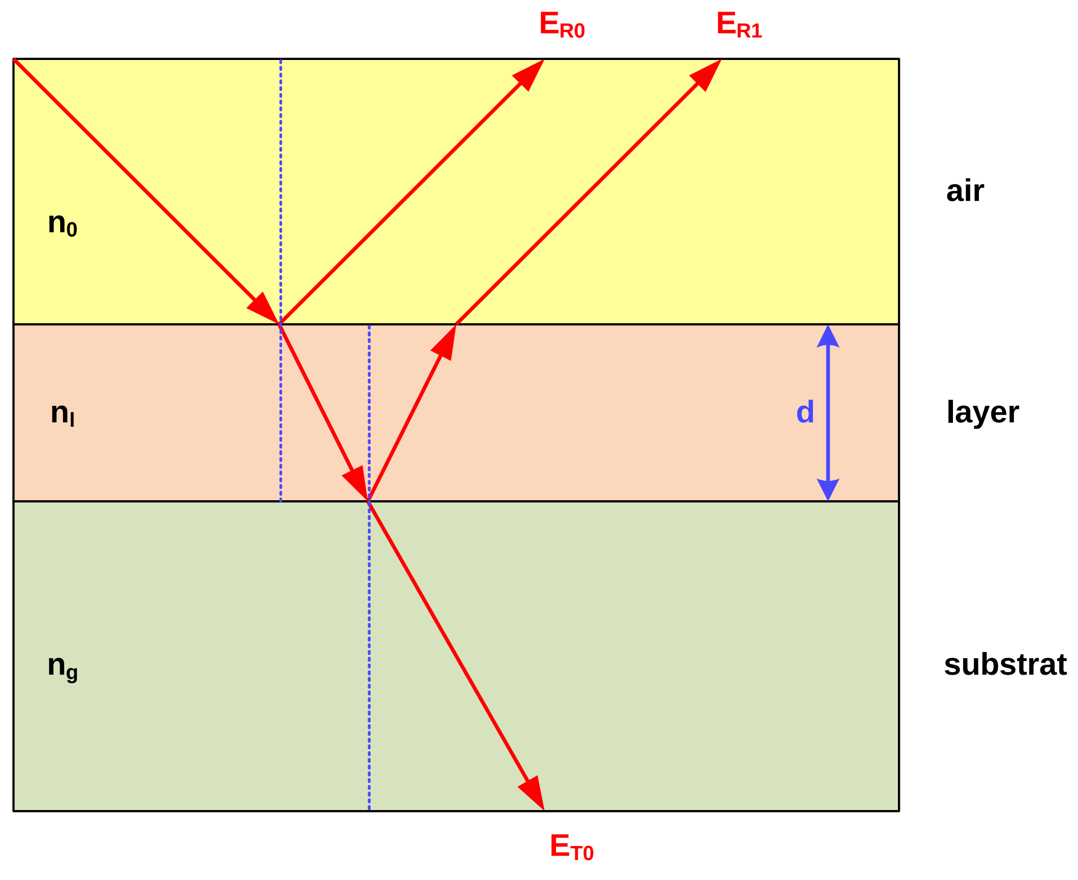
Single λ/4 Layer

- Single layer with thickness λ/4

- Matrix

$$\underline{M}_{\lambda/4} = \begin{pmatrix} 0 & \dfrac{i}{Z_0 n_l} \\ i Z_o n_l & 0 \end{pmatrix}$$

- Destructive interference of the two backwards propagating waves: no reflected light



Single λ/4 Layer

- Reflectivity of amplitude

$$r = \frac{n_l \cdot (n_o - n_g) \cdot \cos\delta + (n_o n_g - n_l^2) \cdot i \cdot \sin\delta}{n_l \cdot (n_o + n_g) \cdot \cos\delta + (n_o n_g + n_l^2) \cdot i \cdot \sin\delta}$$

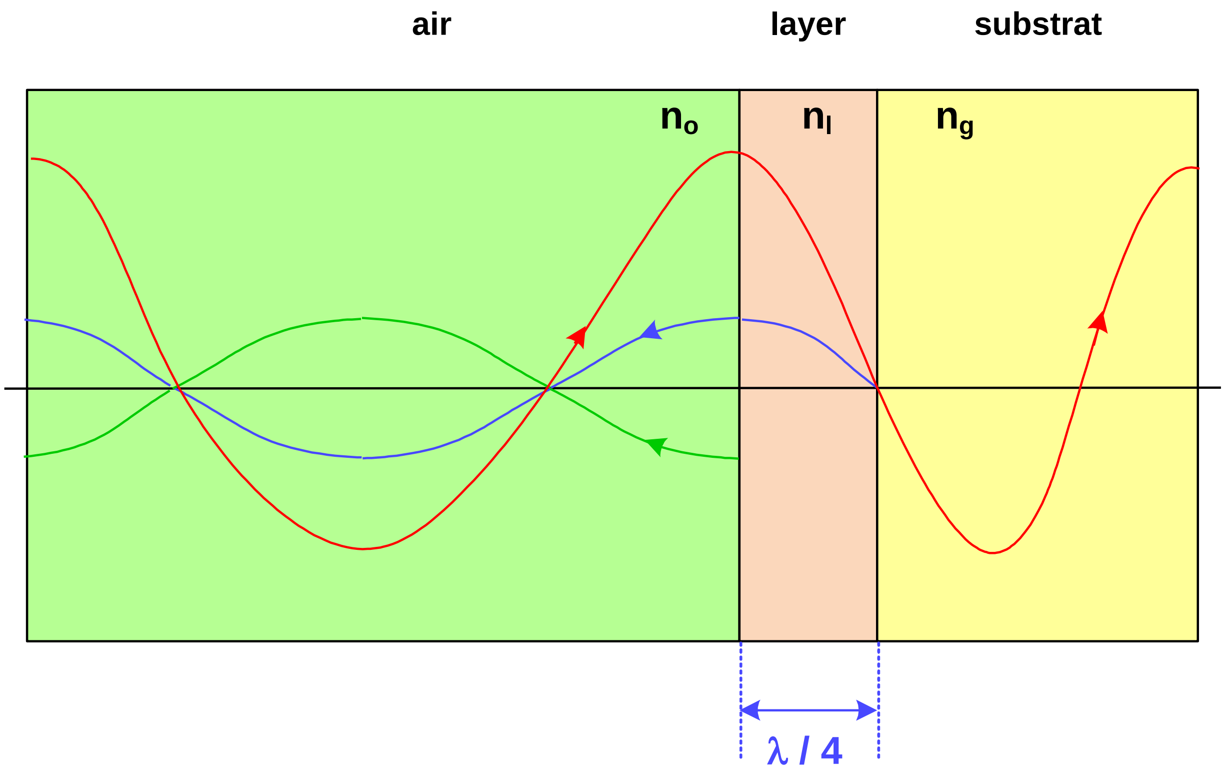
- Phase condition corresponds to λ/4

$$d = \frac{\lambda}{4 \cdot n_l}$$

- Amplitude condition: identical amplitude

$$n_l = \sqrt{n_o \cdot n_g}$$

- Problem:
  on a glass with n = 1.5
  a layermaterial of
  n=1.23 is needed



Single λ/4 Layer

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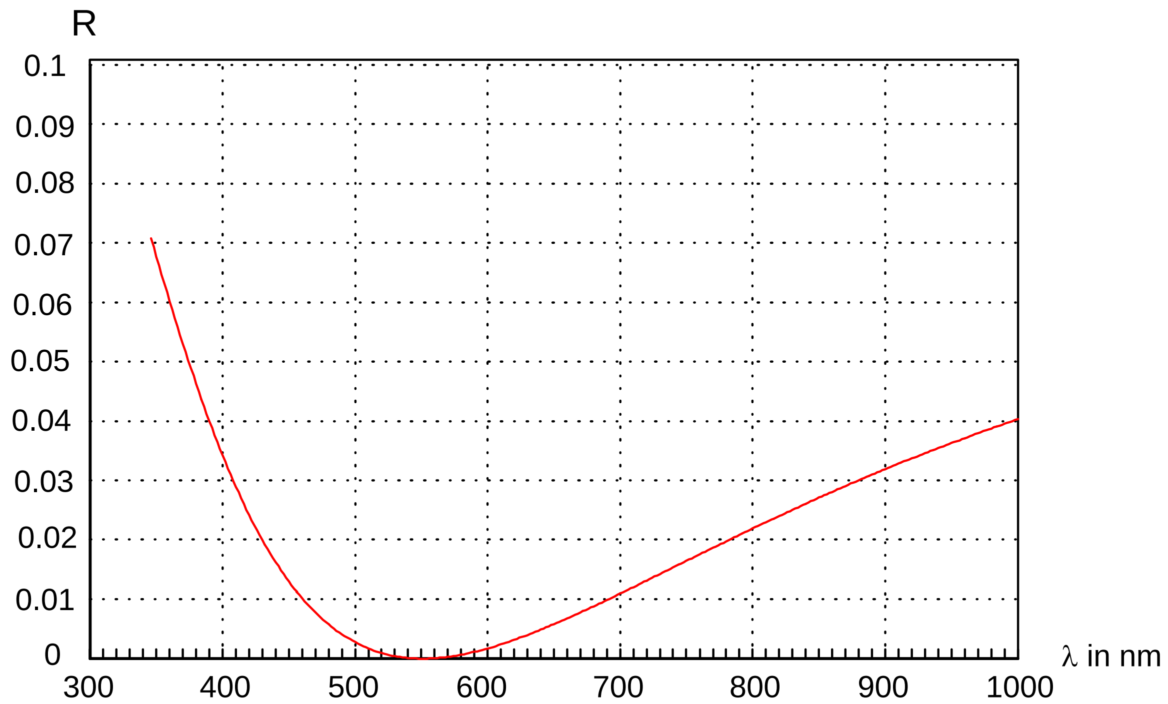
- Spectral behavior:
  single zero of reflectivity at the desired design wavelength



- Residual reflectivity for violation of the amplitude condition
  (non-ideal refractive index)

$$R_{single} = \left(\frac{n_o \cdot n_s - n_l^2}{n_o \cdot n_s + n_l^2} \right)^2$$

Double Layer

- Double layer: several solutions possible
- One simple solution: thickness

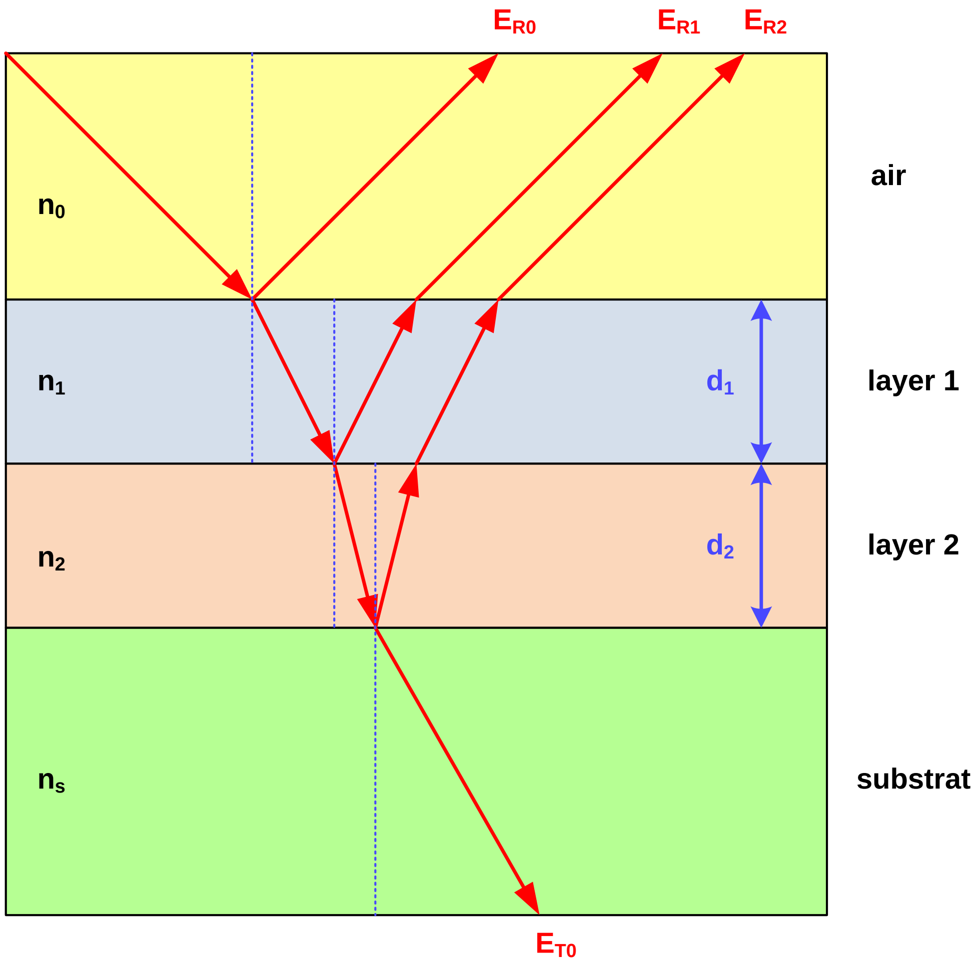
$$n_1 d_1 = n_2 d_2 = \lambda / 4$$

- Corresponding amplitude condition

$$\frac{n_1}{n_2} = \sqrt{\frac{n_o}{n_g}}$$

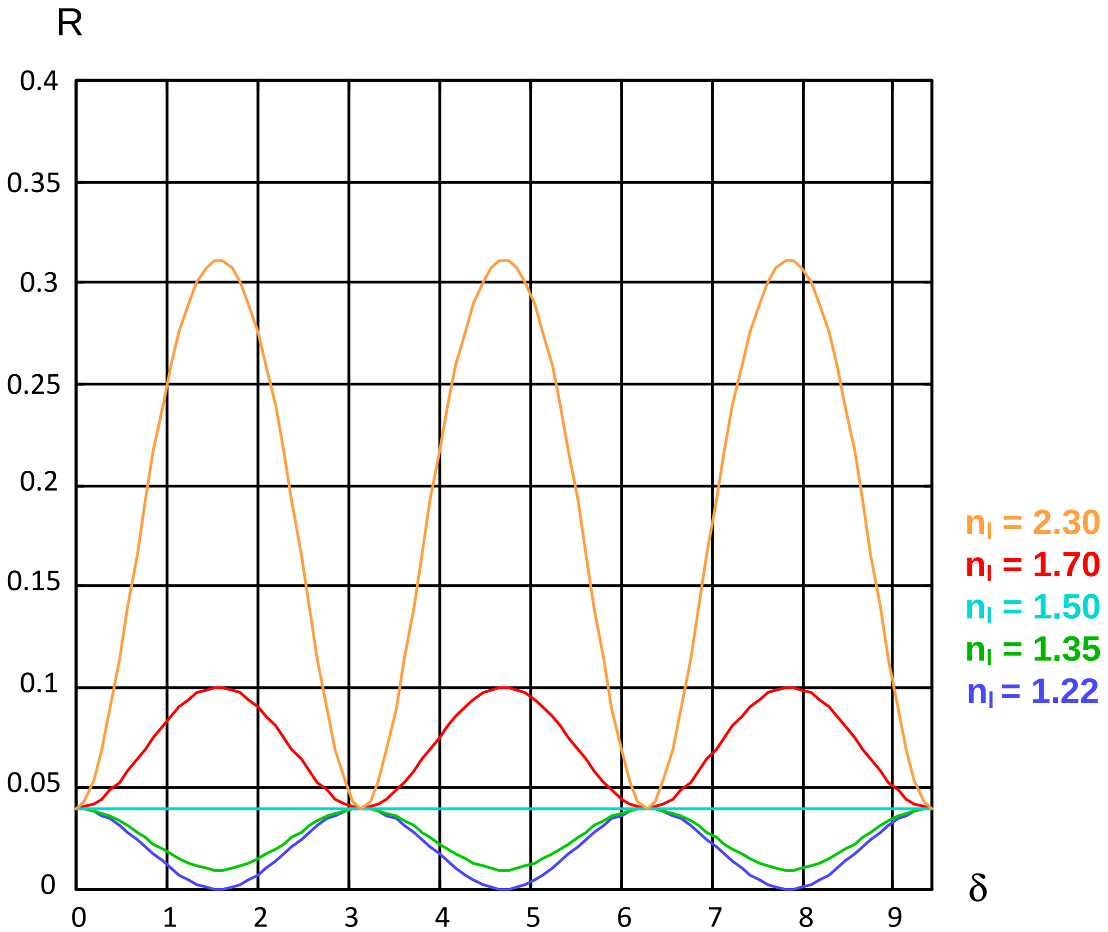
- Residual reflectivity

$$R_{double} = \left(\frac{n_0 \cdot n_2^2 - n_g \cdot n_1^2}{n_0 \cdot n_2^2 + n_g \cdot n_1^2} \right)^2$$



Influence of the Layer Thickness

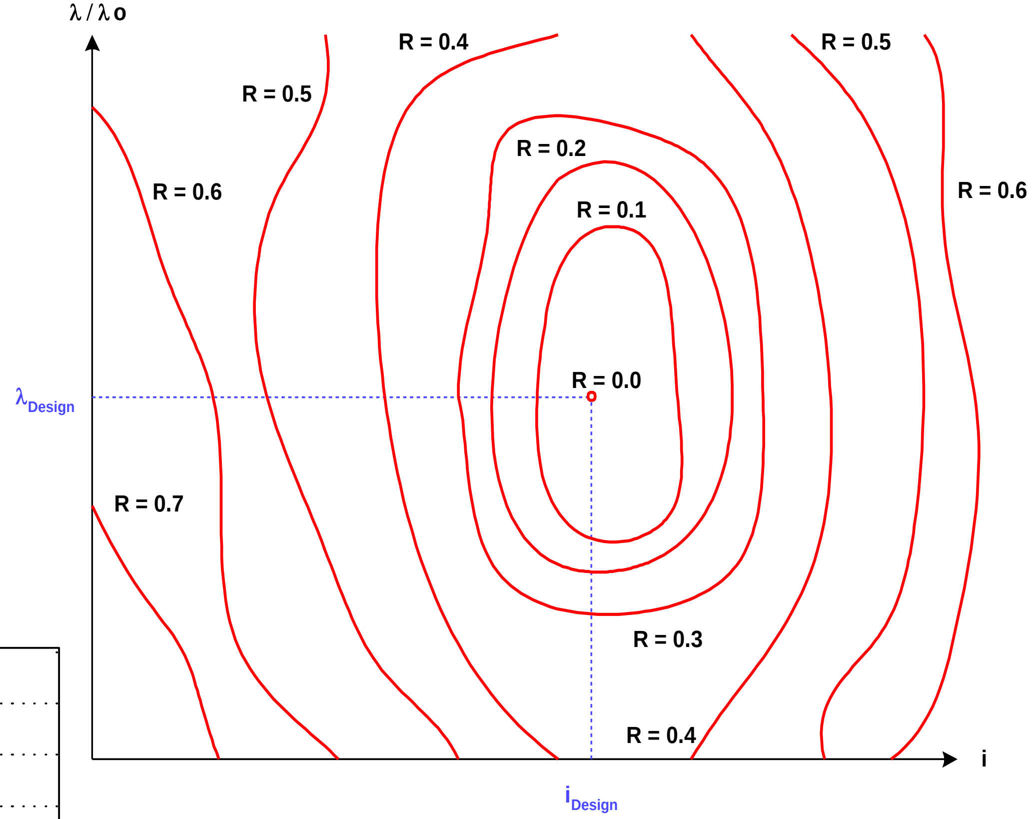
- Periodicity of phase:
  dependence of performance on thickness
- Period is the wavelength
- Special thicknesses:
  waves in phase,
  no effect of the thin layer stack

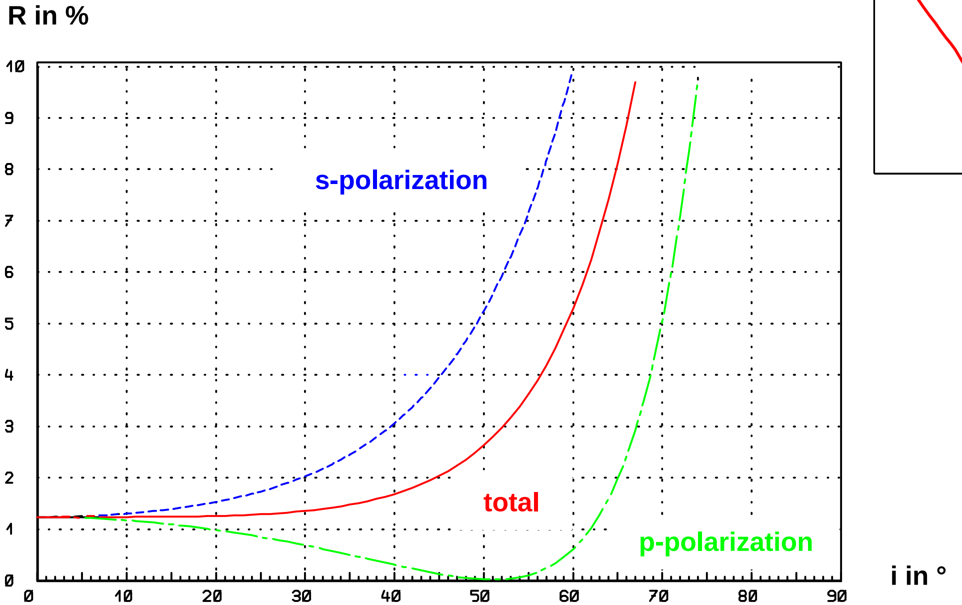


Dependence on Incidence Angle and Polarization

- Fresnel formulas:
  reflectivity in general depends on
  1. incidence angle
  2. polarization

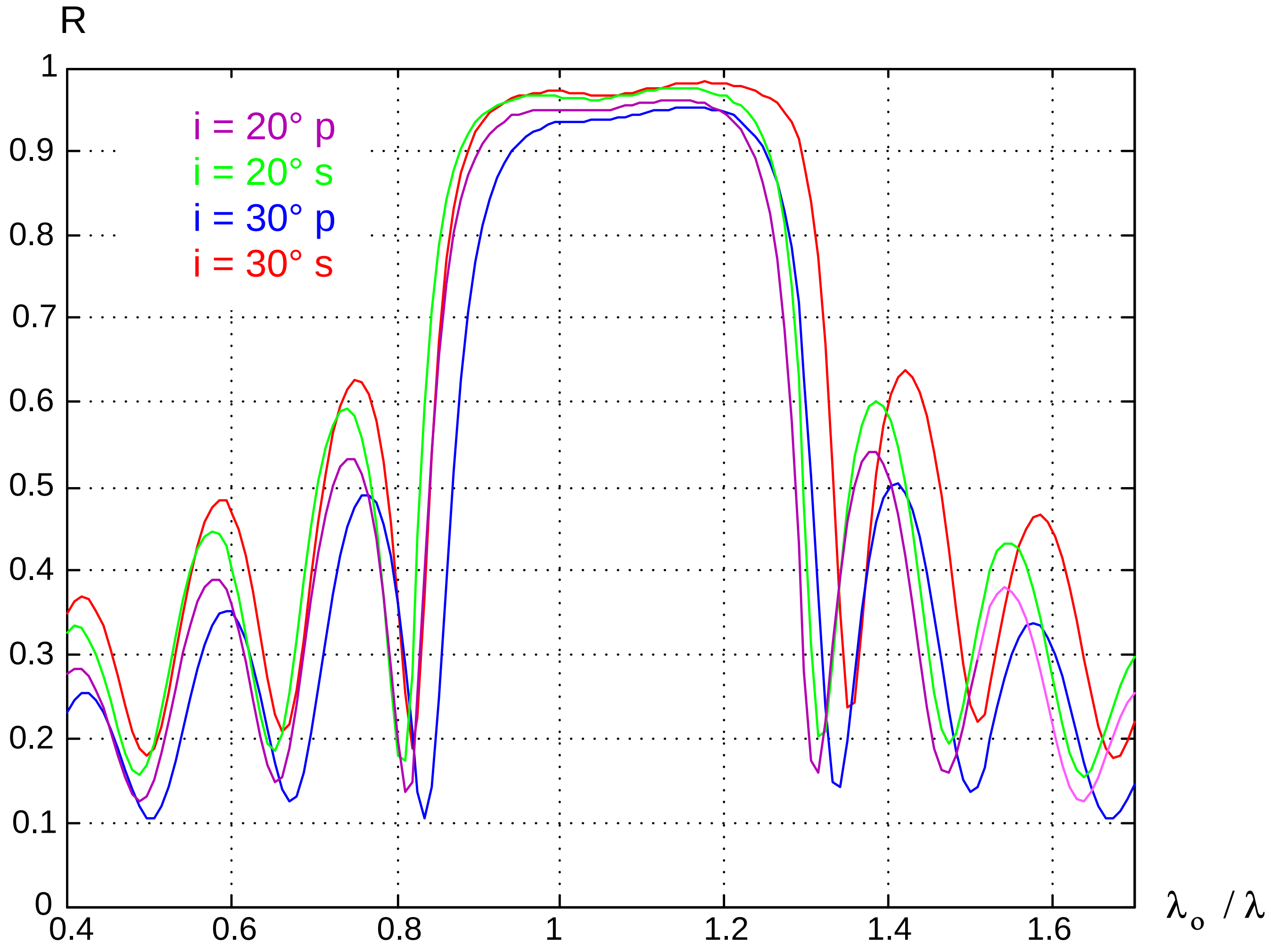
- Degradation for broad band
  and incidence angle interval





Example Coating

- Special example:
  13 layer with
  L : n = 1.45
  H : n = 2.35

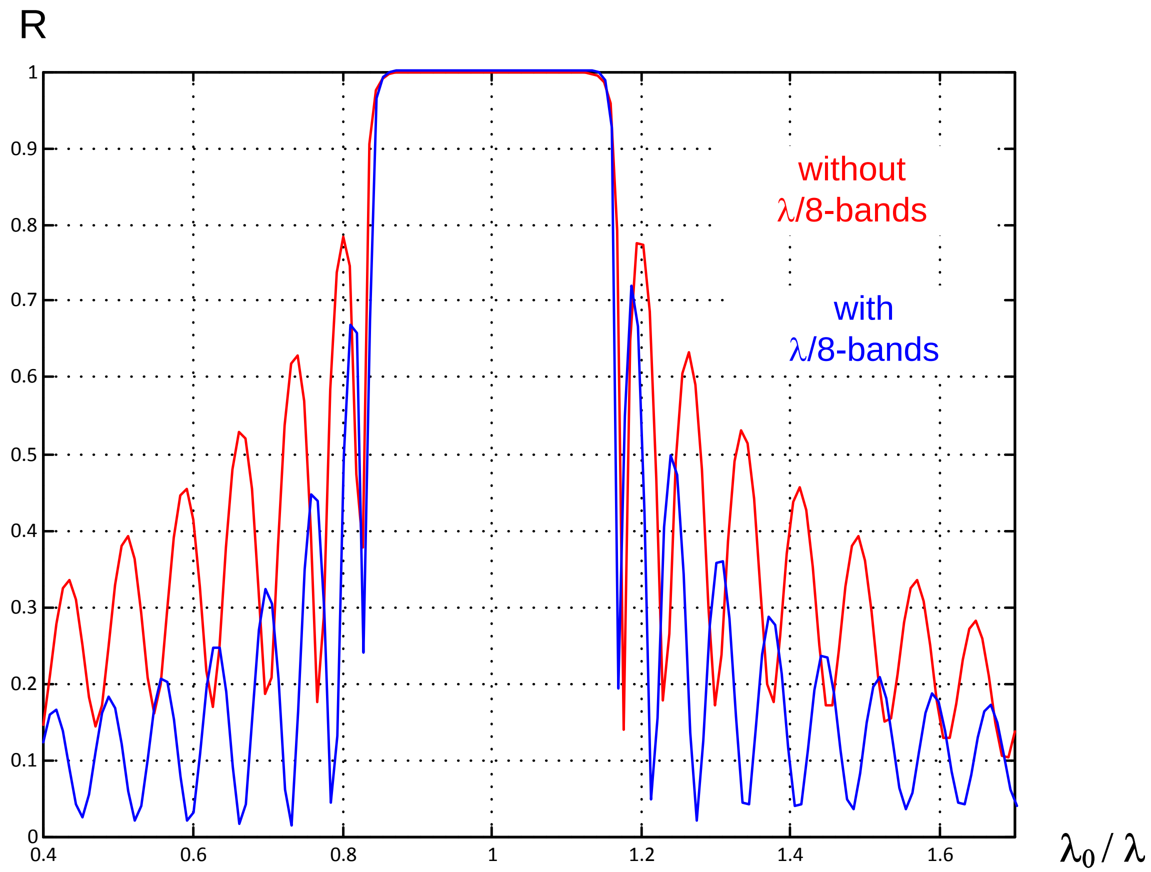


Sidelobs

- Typical coating:
  stack of low-high-materials (LH) with thickness λ / 4

- Remaining sidelobs outside of a centrals spectral interval

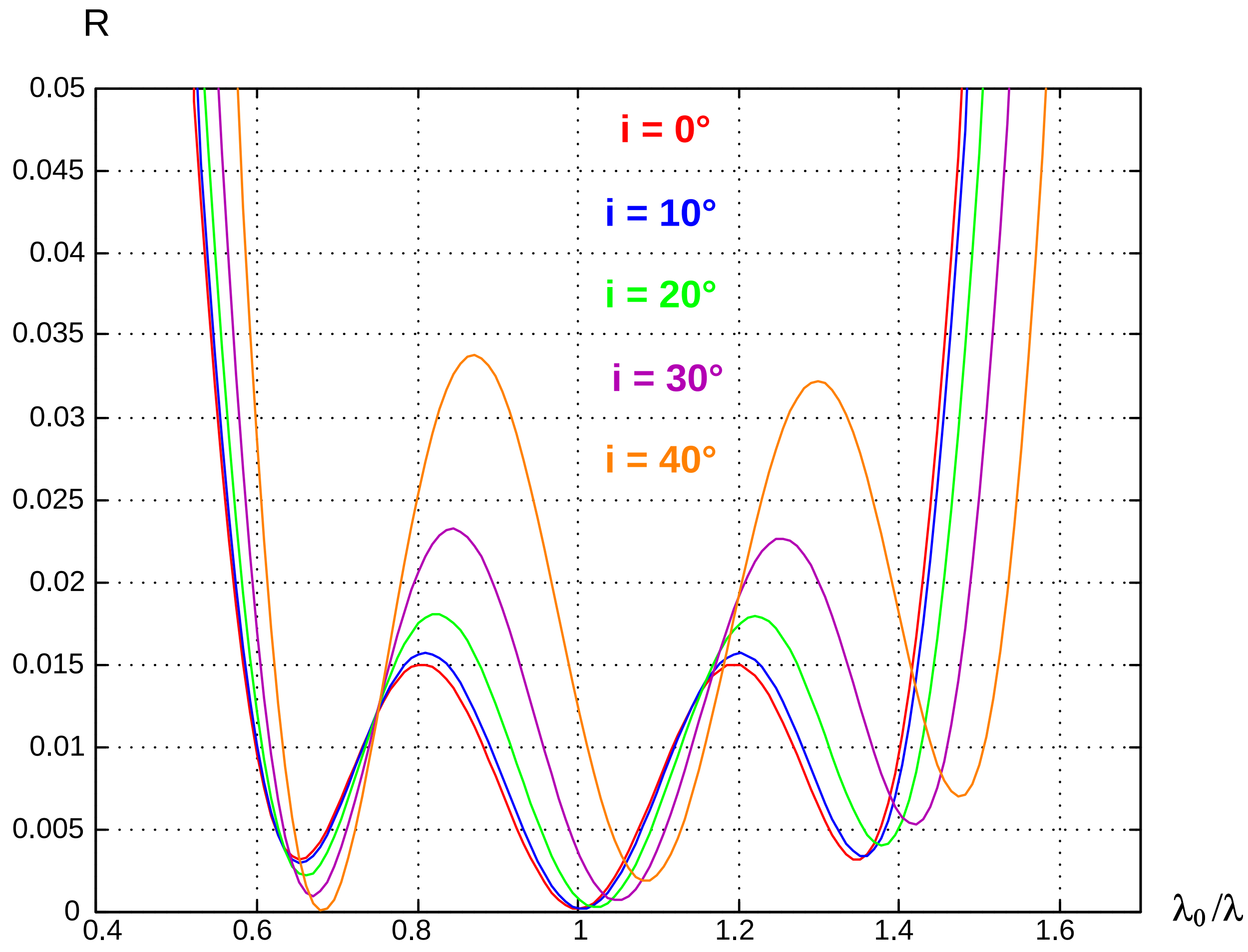
- Suppression of sidelobs:
  additional initial and final layer with λ/8



Example Coating

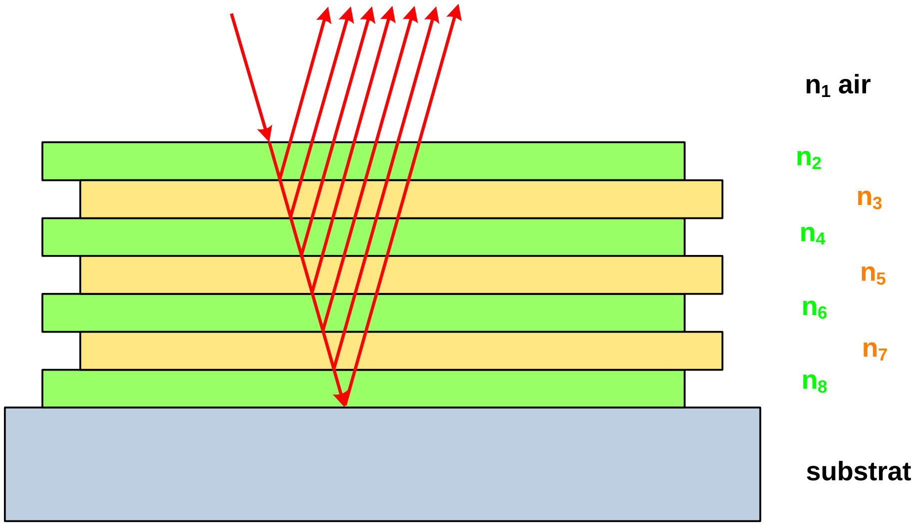
- Special example:
  4 layer with thickness $\lambda/4$
  L : n = 1.45
  H : n = 2.35

- Reflectivity for different incidence angles

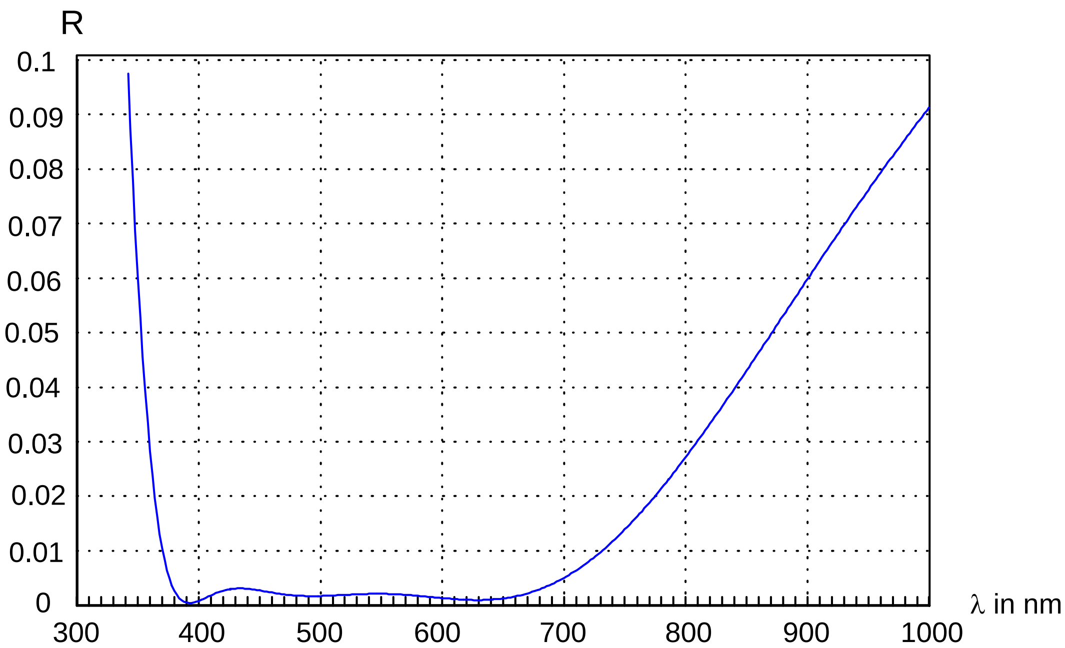


Multi Layer

- Scheme:



- Typical broad spectral performance for reflectivity

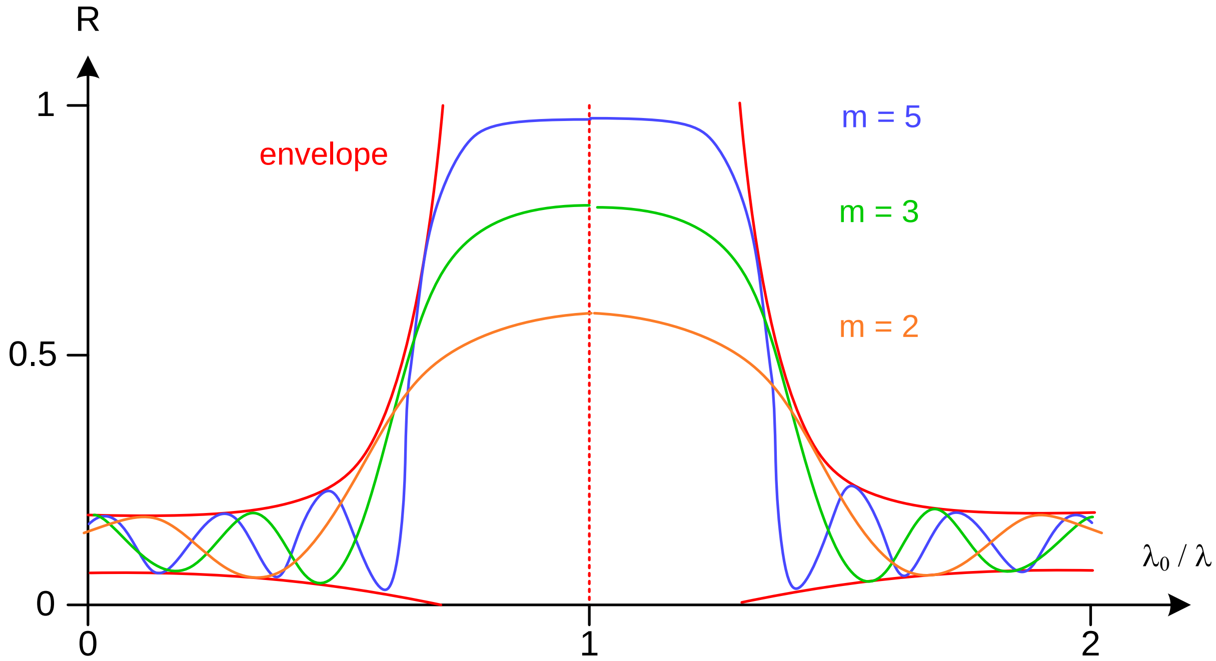


Periodical Layer of 2 Materials

- Especially simple layout: periodical stack with pair of materials

  a(LH)^{m}g

  a : air
  L : low-index material
  H : high-index material
  g : glass substrate
  m : number of pairs



- Approximation of residual reflectivity

$$R \approx 1 - 4 \cdot \frac{n_g}{n_H^2} \cdot \left(\frac{n_L}{n_H} \right)^m$$

- Advantageous:
  1. large ratio of indices
  2. high number of layer pairs

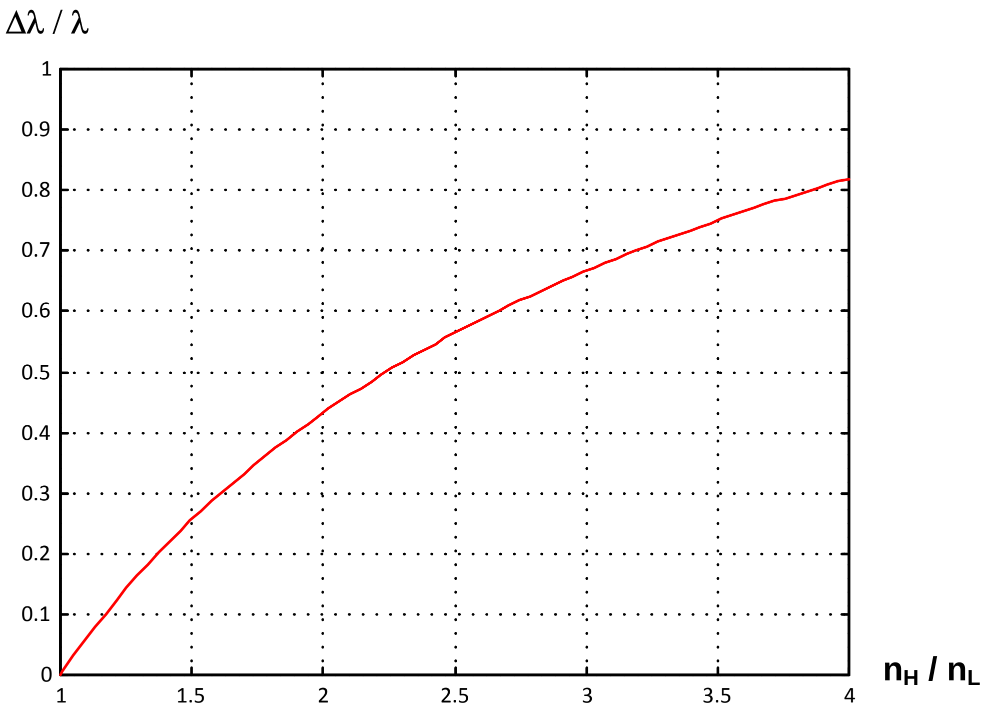
Periodical Layer of 2 Materials

- Comfortable choice:
  layer thickness λ/4

  Peak reflectivity

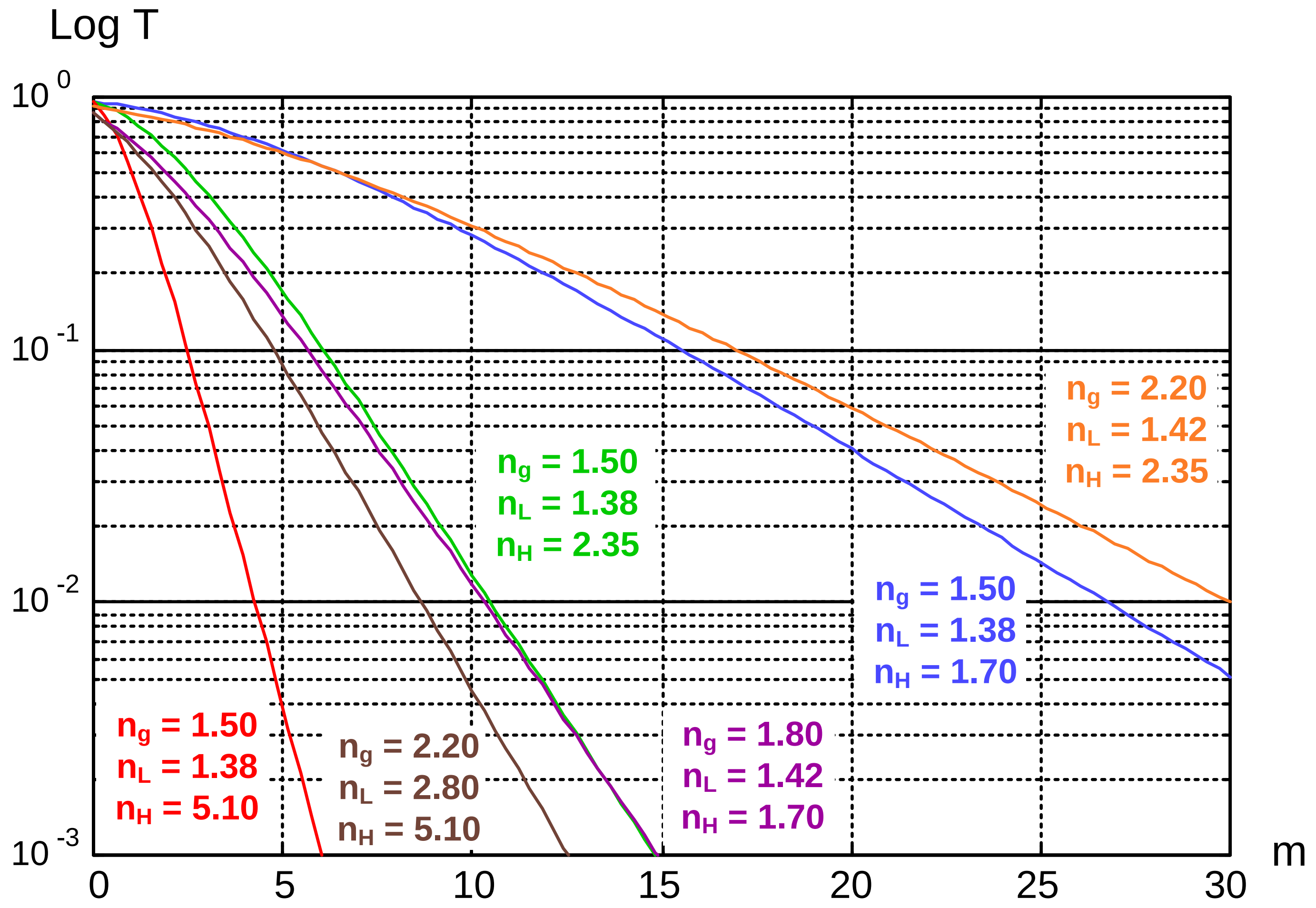
$$R_{\max} = \left[\frac{\frac{n_o}{n_g} - \left(\frac{n_L}{n_H}\right)^{2m}}{\frac{n_o}{n_g} + \left(\frac{n_L}{n_H}\right)^{2m}} \right]^2$$

- Spectral width of the reflectivity interval:
  growing with increased n-ratio



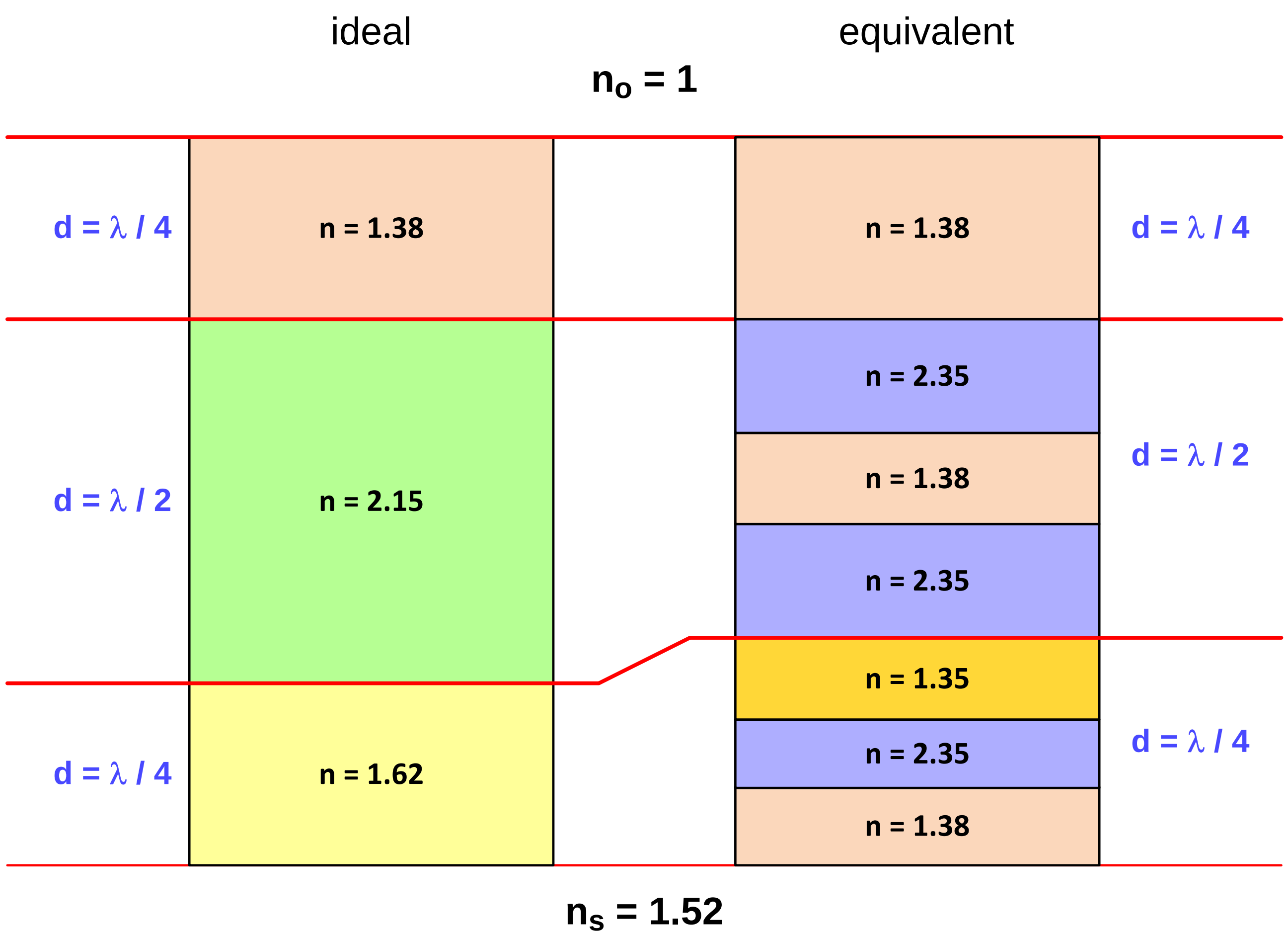
Periodical Layer of 2 Materials

- Performance dependence for different material combinations



Equivalent Layers

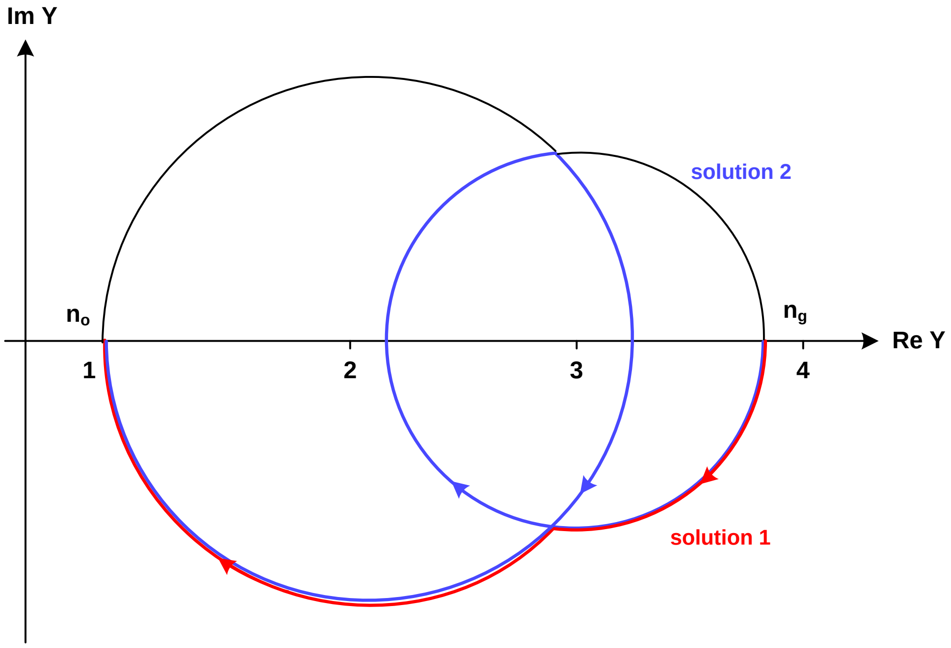
- Combination of layers with real refractive indices can be used to generate arteficial indices

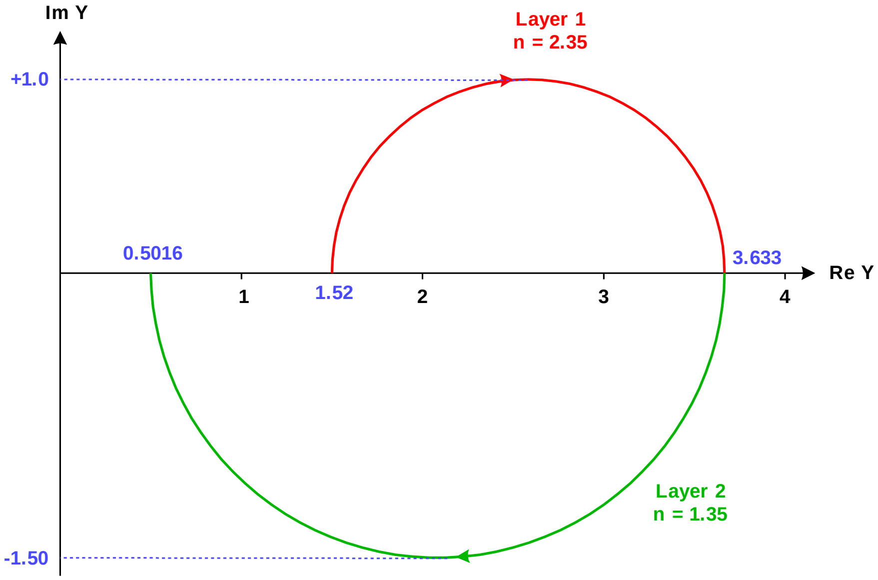


Impedance Diagram

- Graphical visualization of thin layer effects in the complex impedance plane
- Every layer is represented by an arc
- The arc length corresponds to the phase
- Absorbing materilals are represented by spiral curves
- Initial and final point must be on the real axis

  Exception:metals with complex substrate index



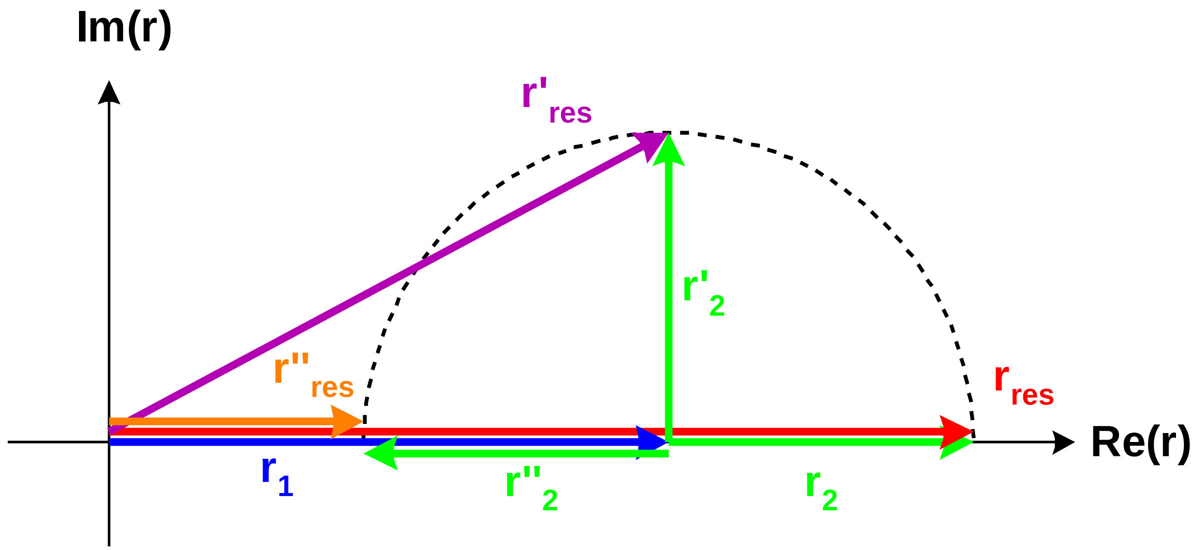


Reflectivity Diagram

- Graphical illustration of layer stacks in the complex plane of the reflectivities
- Every layer is represented by an arrow with

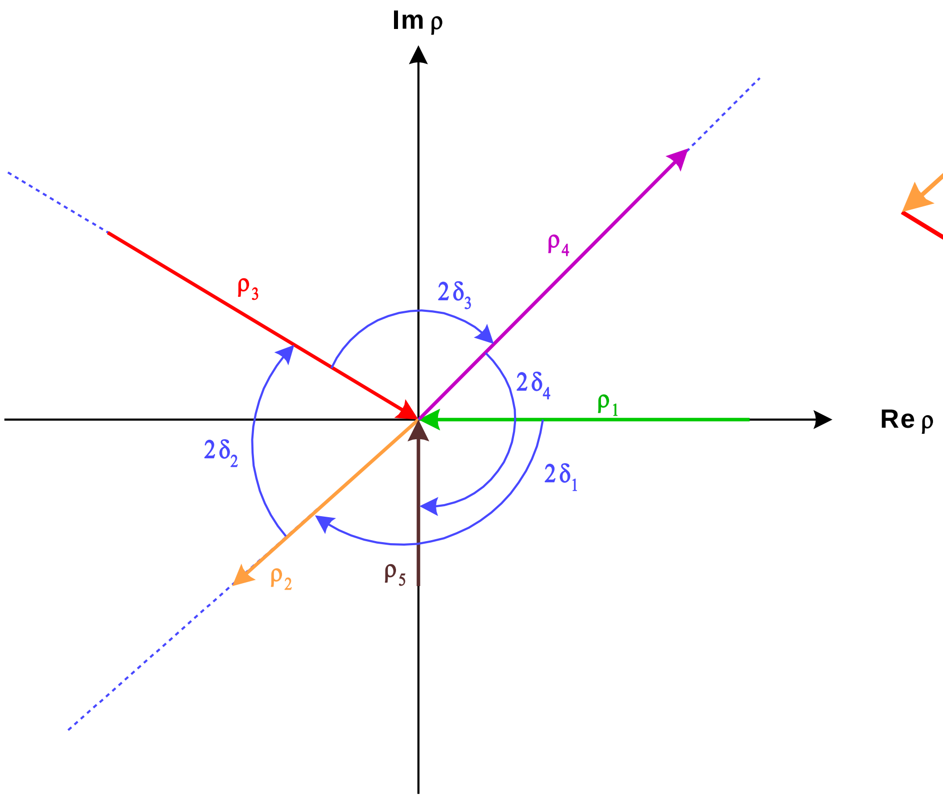
  1. length, corresponds to amplitude

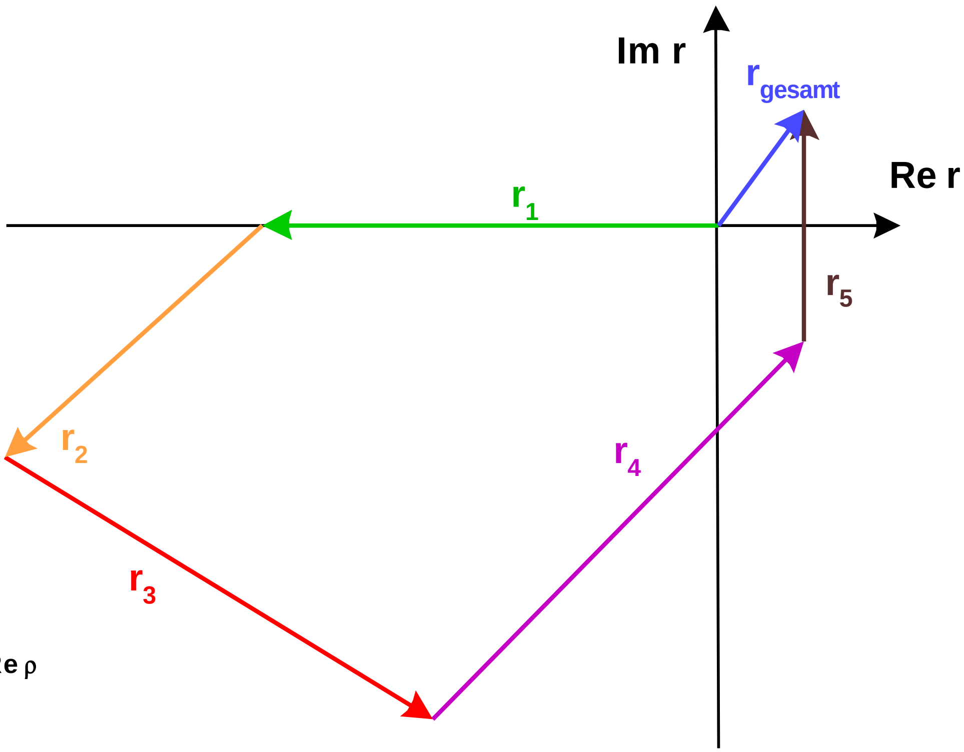
  2. direction, corresponds to phase



Reflectivity Diagram

- AR coating:
  vectorial sum of vectors must vanish





Coating Materials

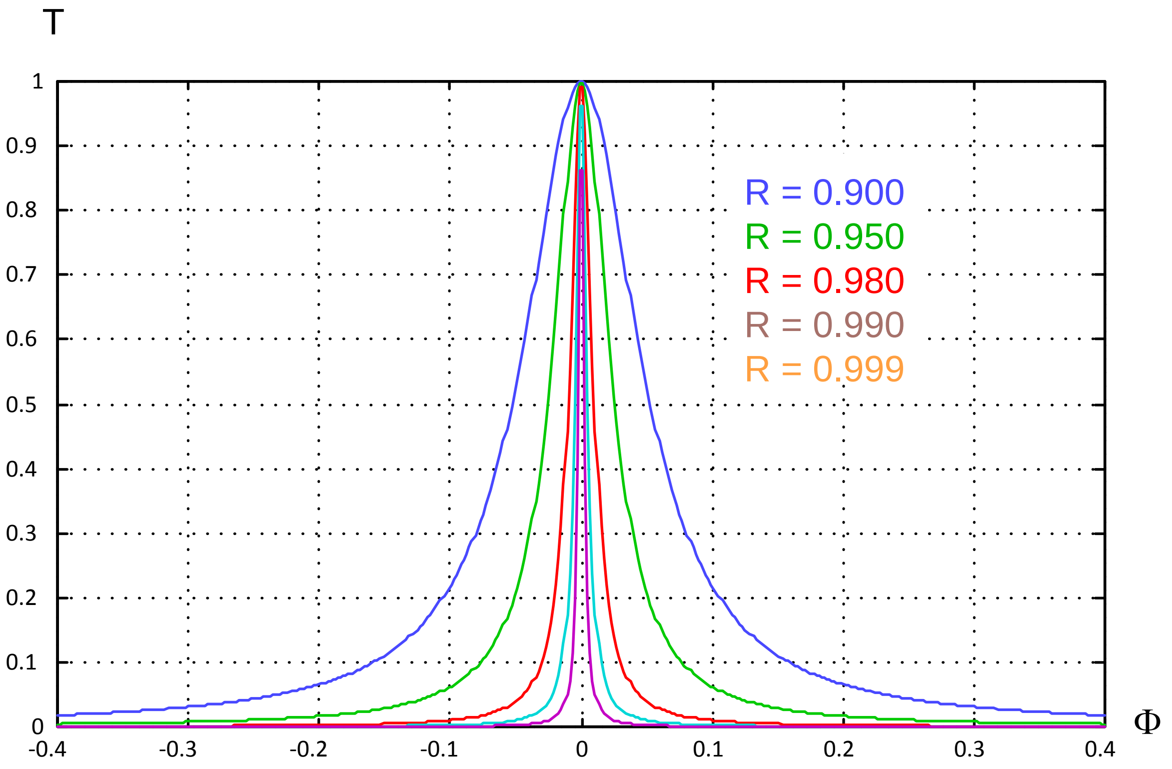
Material	Typ	Refractive index n	Spectral range
Magnesiumfluorid	L	1.38	UV - nIR
Cerfluorid	L	1.62	
Aluminiumoxid		1.62	UV - nIR
Cryolite		1.35	UV - nIR
Siliziumdioxid		1.48	
Magnesiumoxid	L	1.72	
Zirkonium Dioxid	H	2.00	UV - nIR
Hafniumdioxid	H	1.98	
Titandioxid	H	2.45	vis - nIR
Zinksulfid	H	2.30	vis - nIR
Cerdioxid		2.20	vis - nIR
Thoriumfluorid		1.52	UV - nIR
Silizium Monoxid		1.95	vis - nIR
Silizium		3.50	nIR - IR
Germanium		4.20	nIR - IR
Zinkselenid		2.44	nIR - IR
Cadmiumtellurid		2.69	nIR - IR
Bleitellurid		5.5	IR
Tellur	H	4.80	
Lithiumfluorid	L	1.37	

Interference Coating

- Multi-beam interference analogous to the Fabry-Perot
- Extrem narrow spectral transmission
- Calculation of transmission:

Airy formula

$$I_T(\varphi) = \frac{(1-\sqrt{R})^2}{1+R^2-2R\cos\varphi}$$



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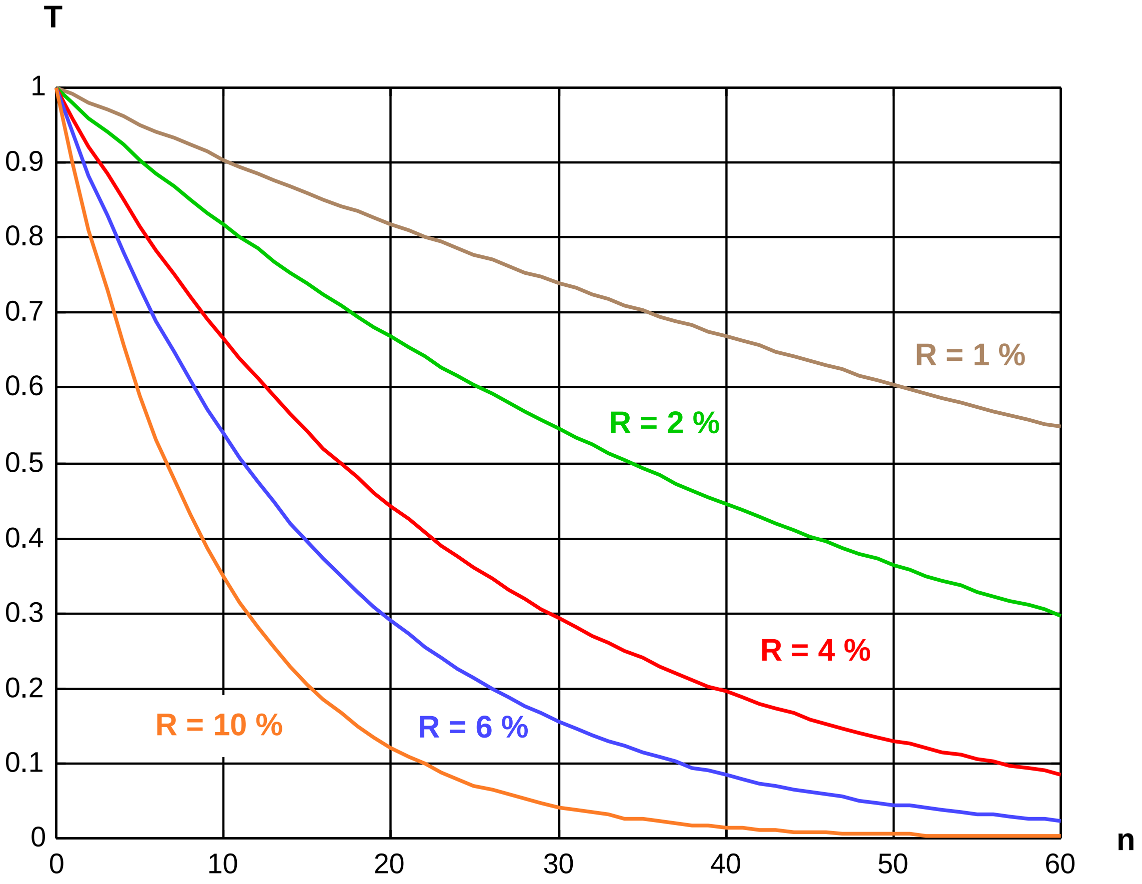
Transmission in Optical Systems

- Residual reflectivity of the (identical) surfaces in an optical system with n surfaces:
  Overall transmission of energy:

$$T_{ges} = (1 - R)^n$$

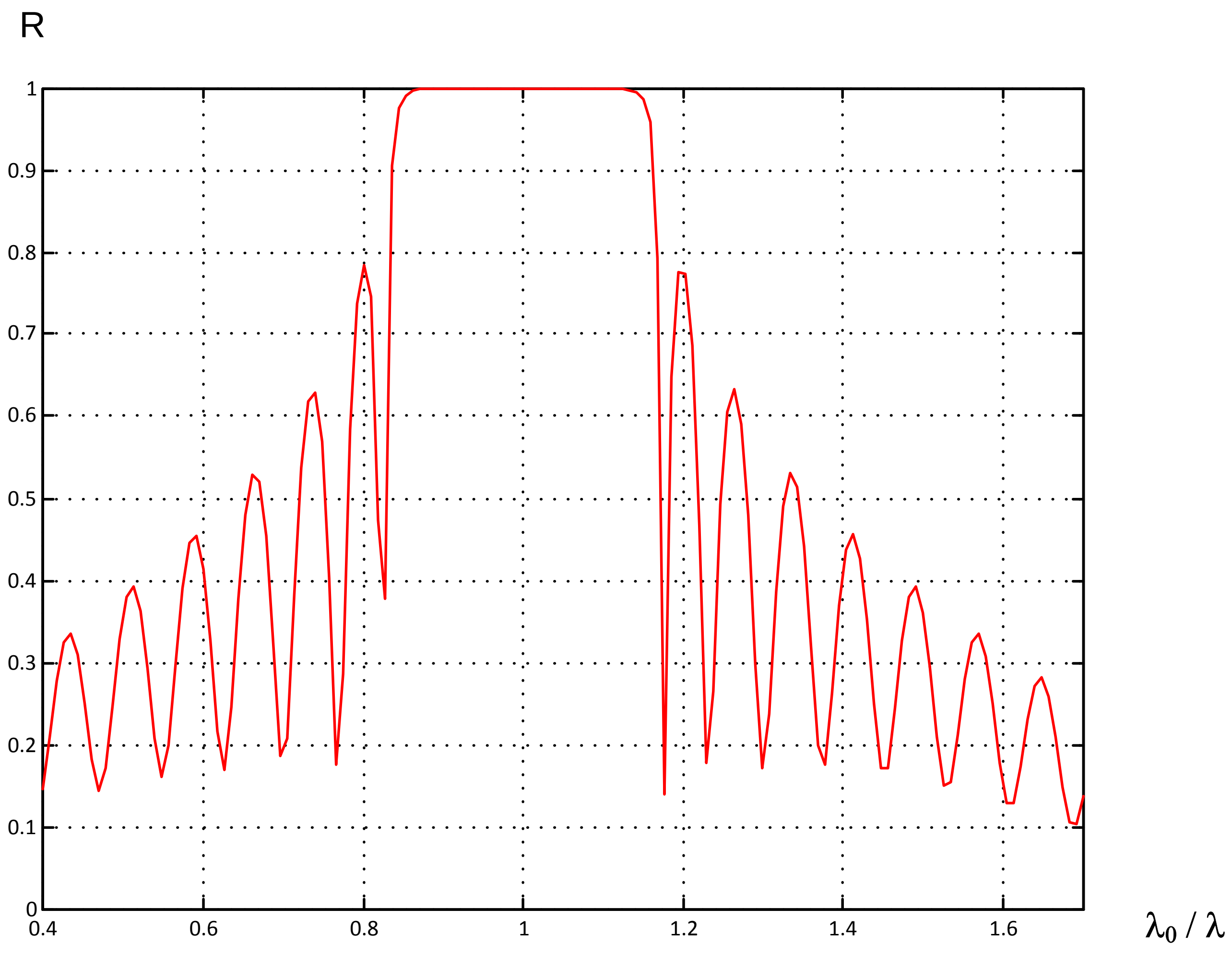
- Transmission decreases nonlinear

- Practical consequences:
  1. loss of signal energy
  2. contrast reduction in case of imaging
  3.occurence of ghost images



Example Coating

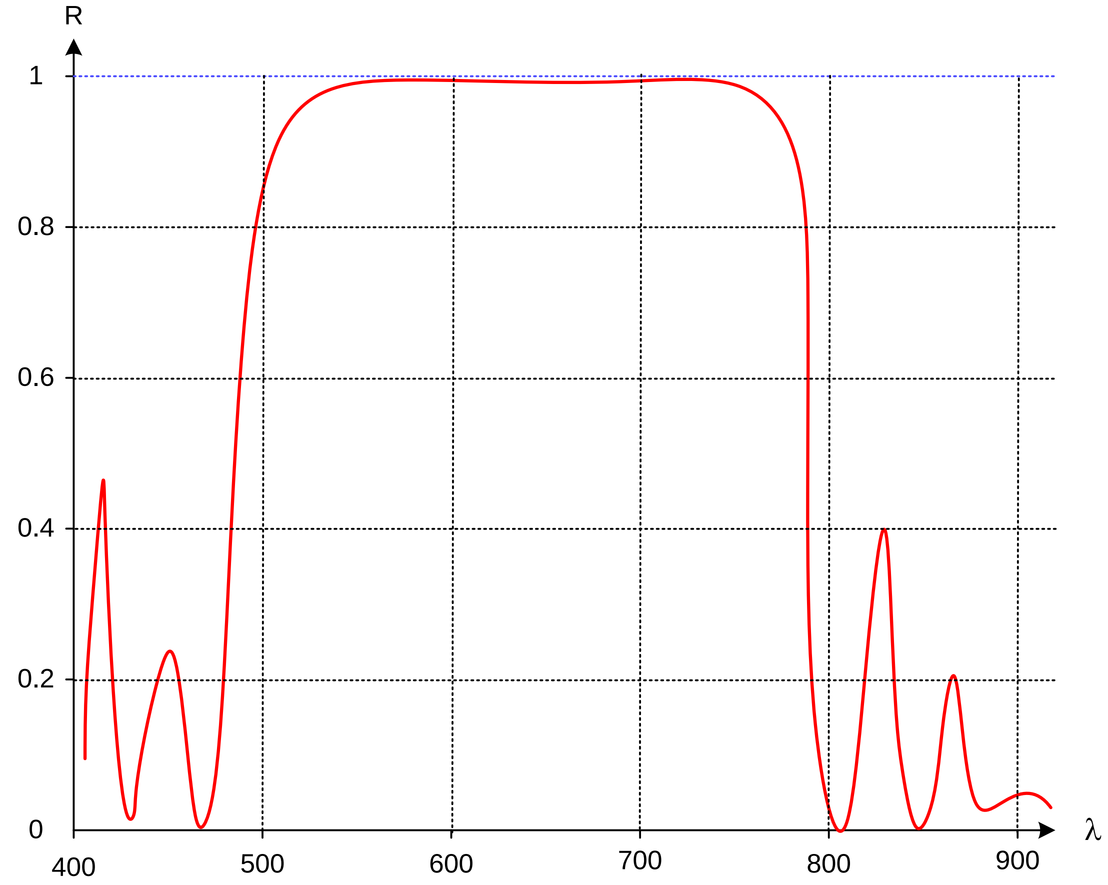
- Example of a concrete multi-layer stack



Example: HR Coating

- Dielectric HR coating
- Problems:

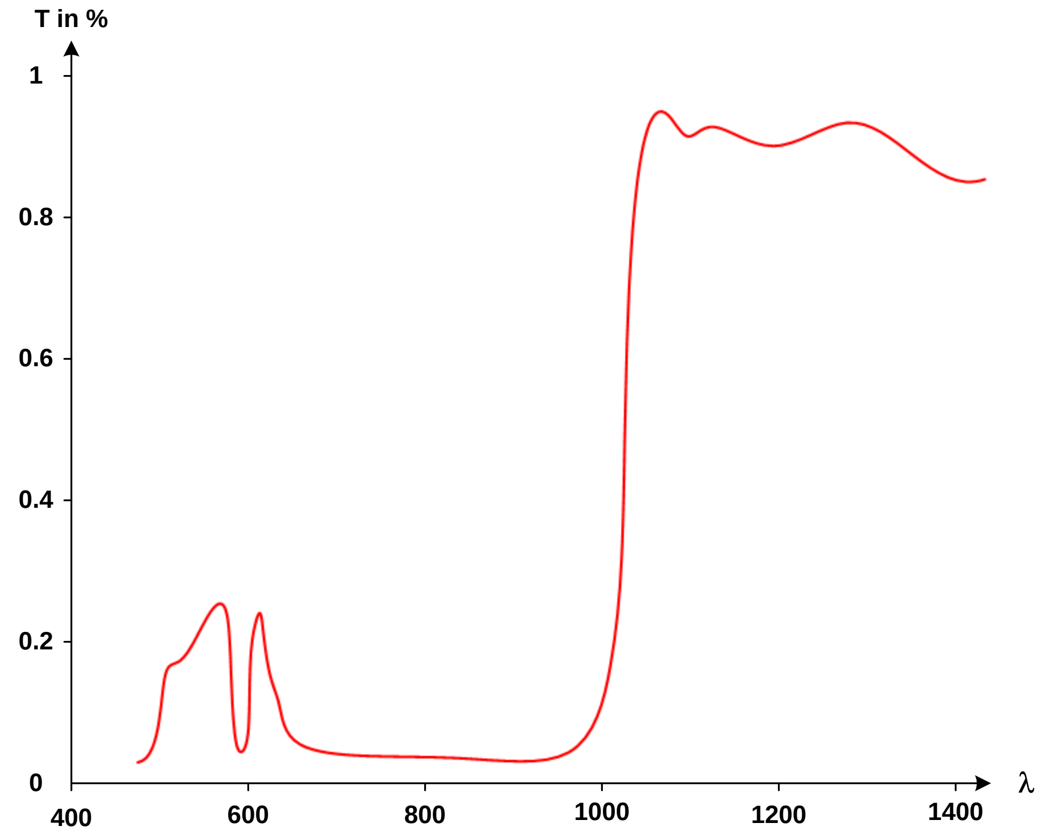
1. absorbing substrates (metal mirrors)
2. Polarization splitting for oblique incidence



Thin Layer as Edge Filter

- Requirements:
  1. steep edge
  2. high reflectivity R on one side
  3. high transmission T on the other side
  4. no oscillations

- Application:
  cold mirror, blocking of infrared light



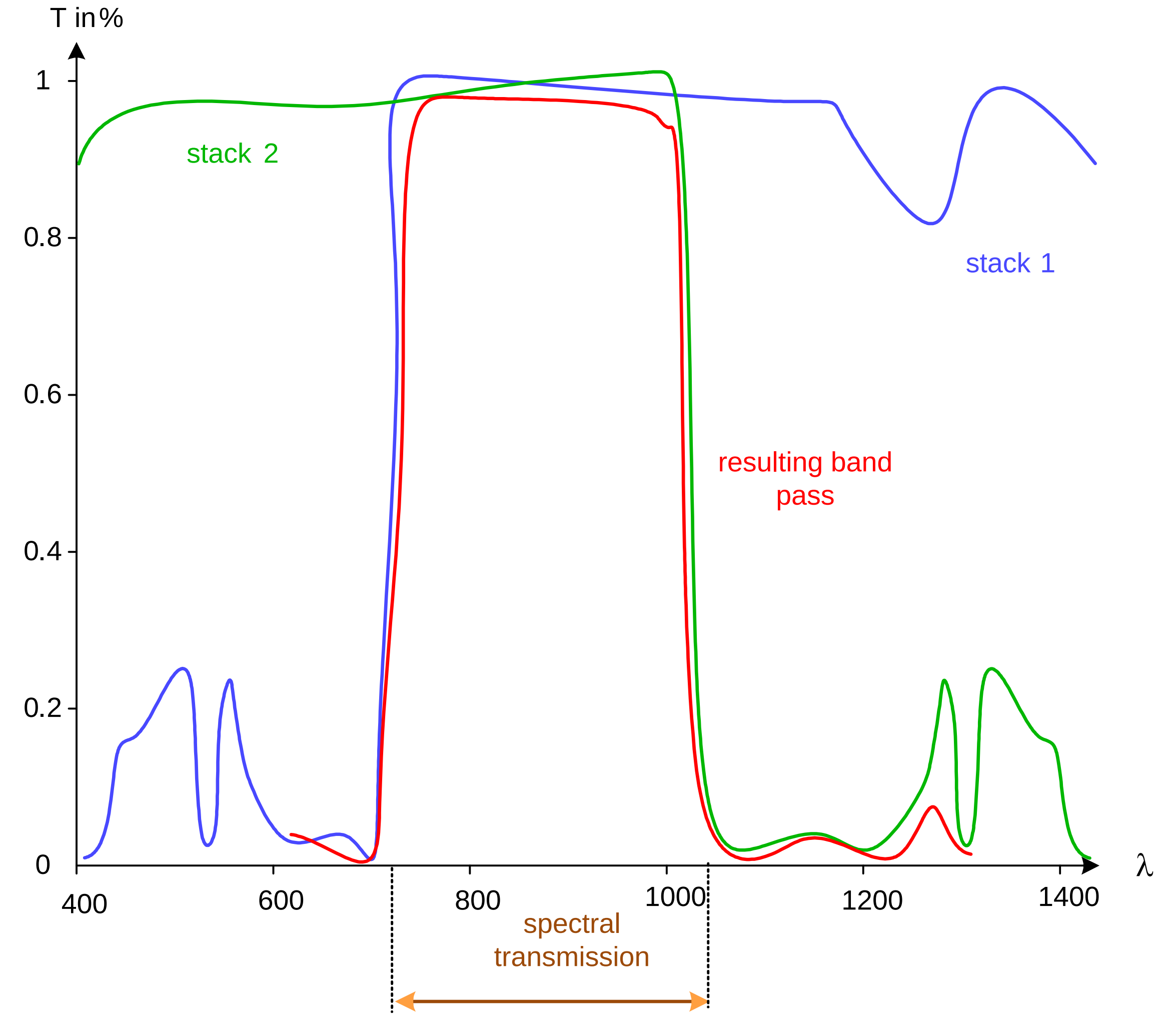
Thin Film Layers for Bandpass Filtering

- Superposition of two edge filters:

  Band pass

- Transmission of a selcted

  spectral range



Color Filtering

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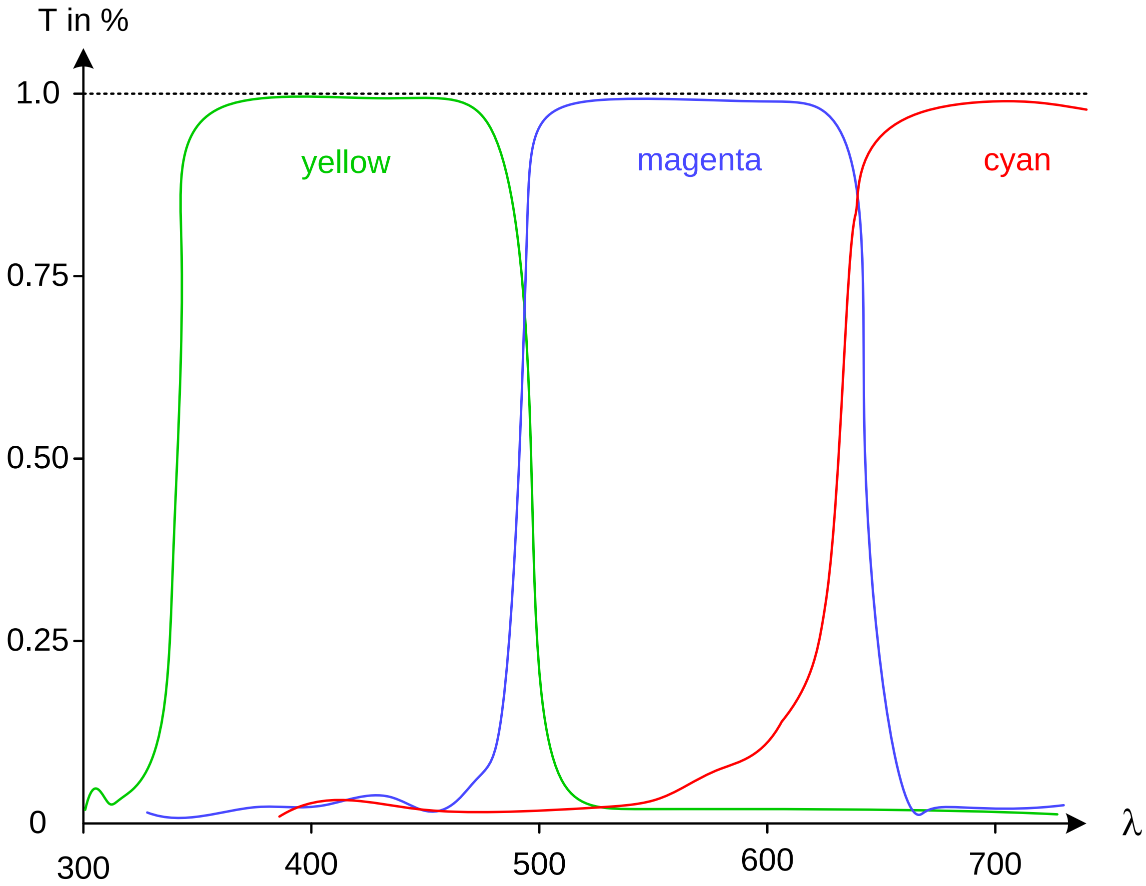
- Special coloring properties by spectral filtering

- Example application:

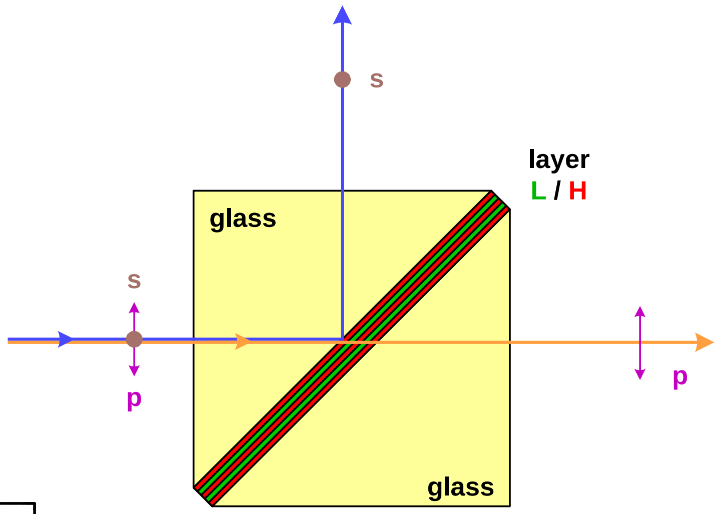
  selective spectral transmission

  for subtractive color printing

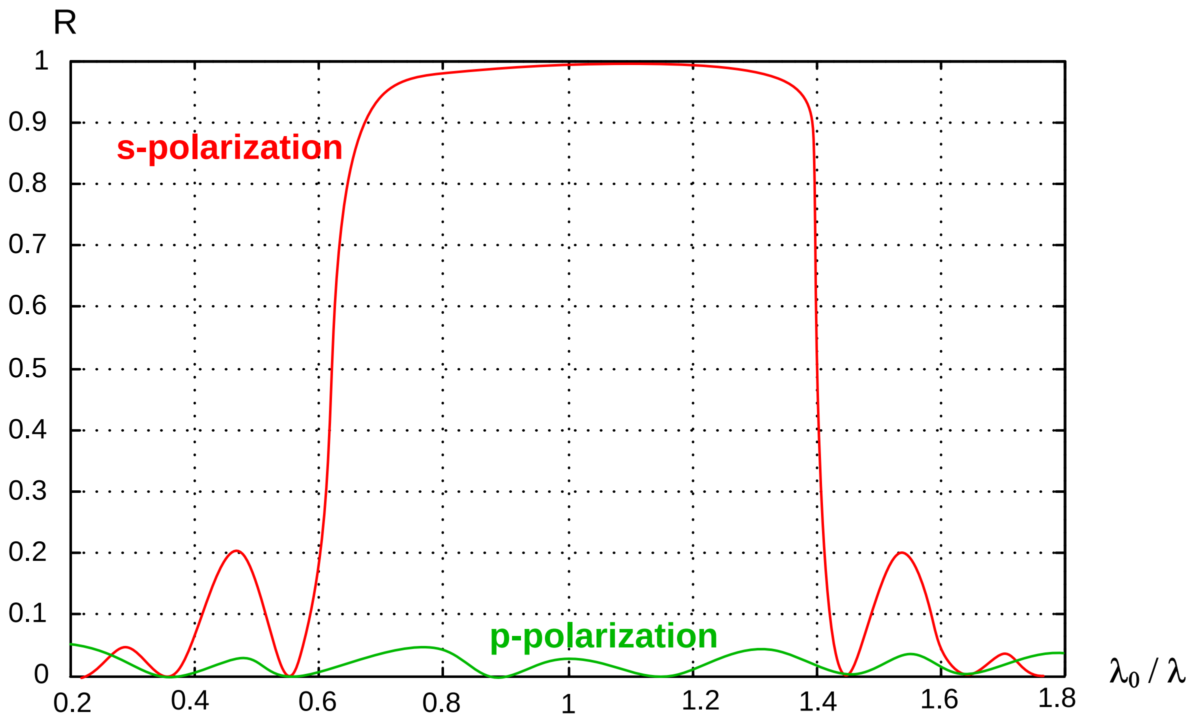


Polarizing Beam Splitting Coating

- Special coating for polarization splitting into s and p

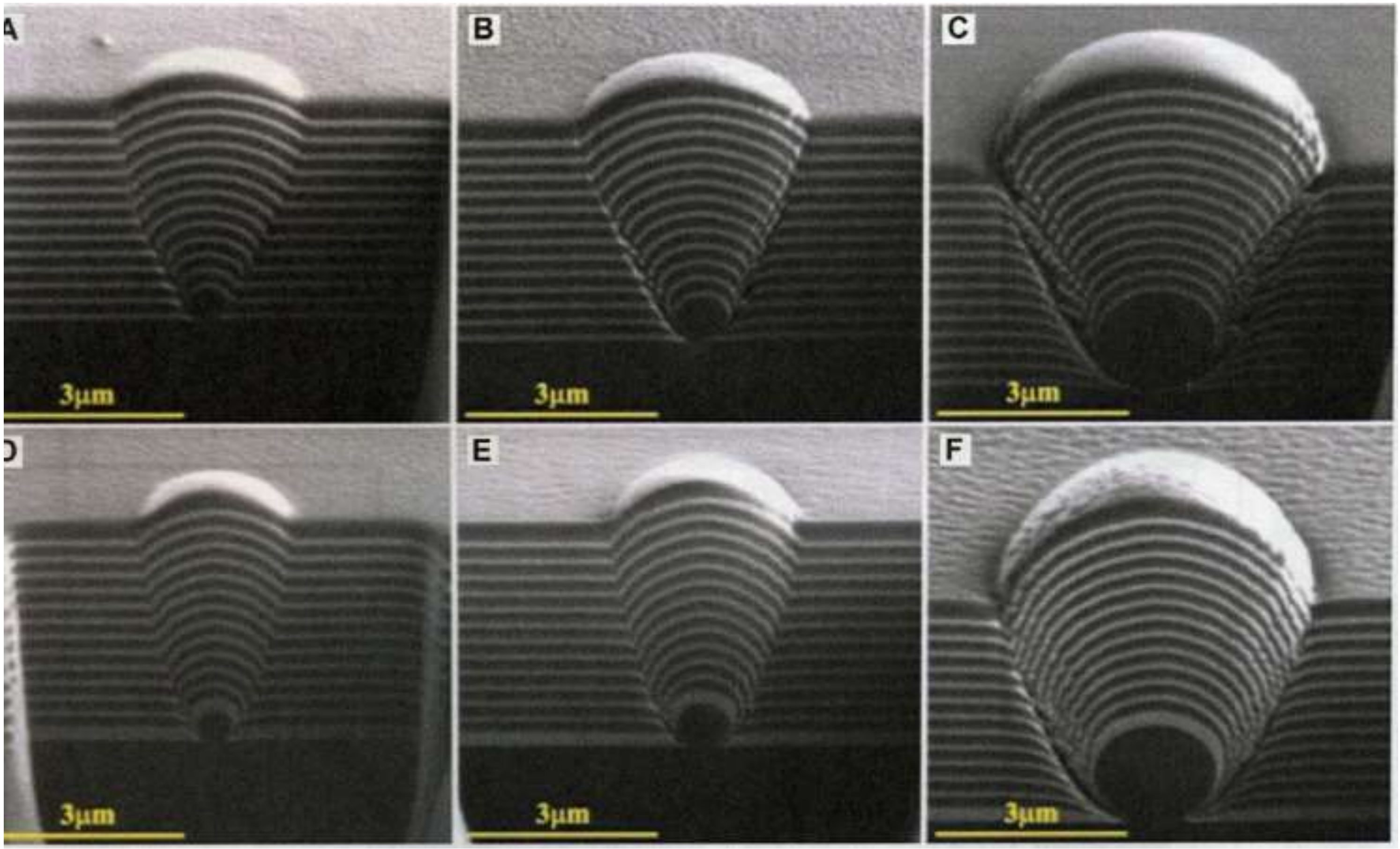


- Application: cubic beam splitter



Coating Defects - Contamination

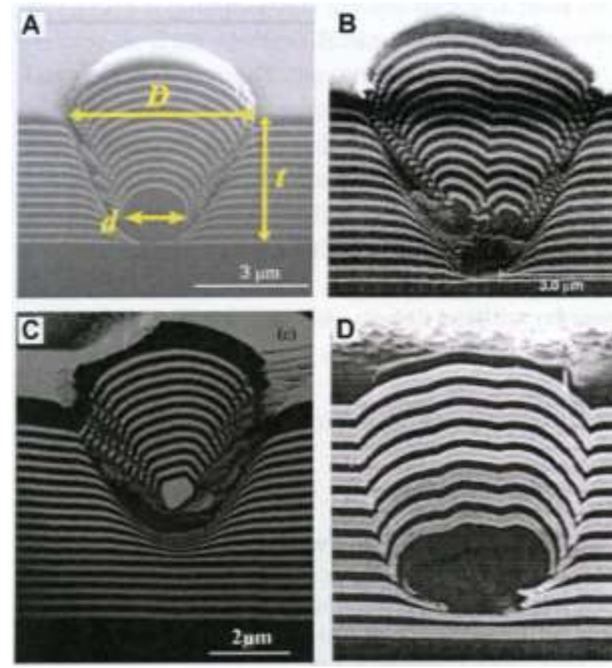
- Calculated coating on a spherical particle of different size



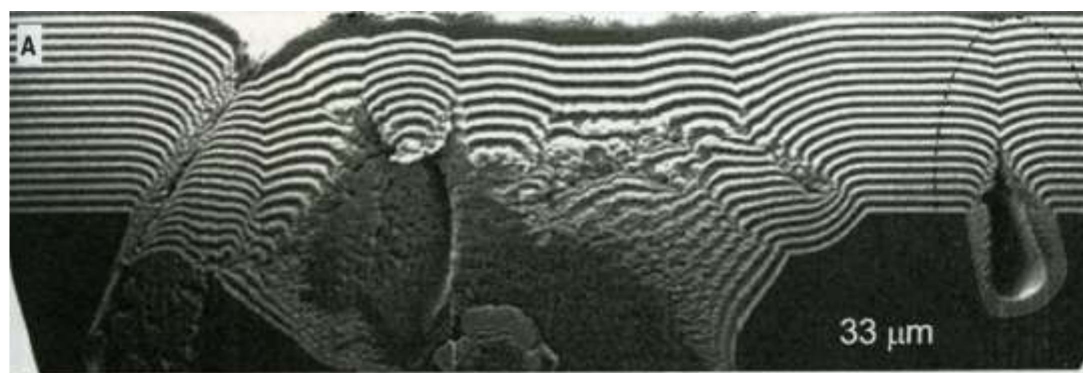
Ref.: X. Cheng et al, AOT 3(2014) p.65

Coating Defects - Contamination

- Coating above a surface defect



- Real coating on a non-smooth surface



Ref.: X. Cheng et al, AOT 3(2014) p.65

Coating Defects - Contamination

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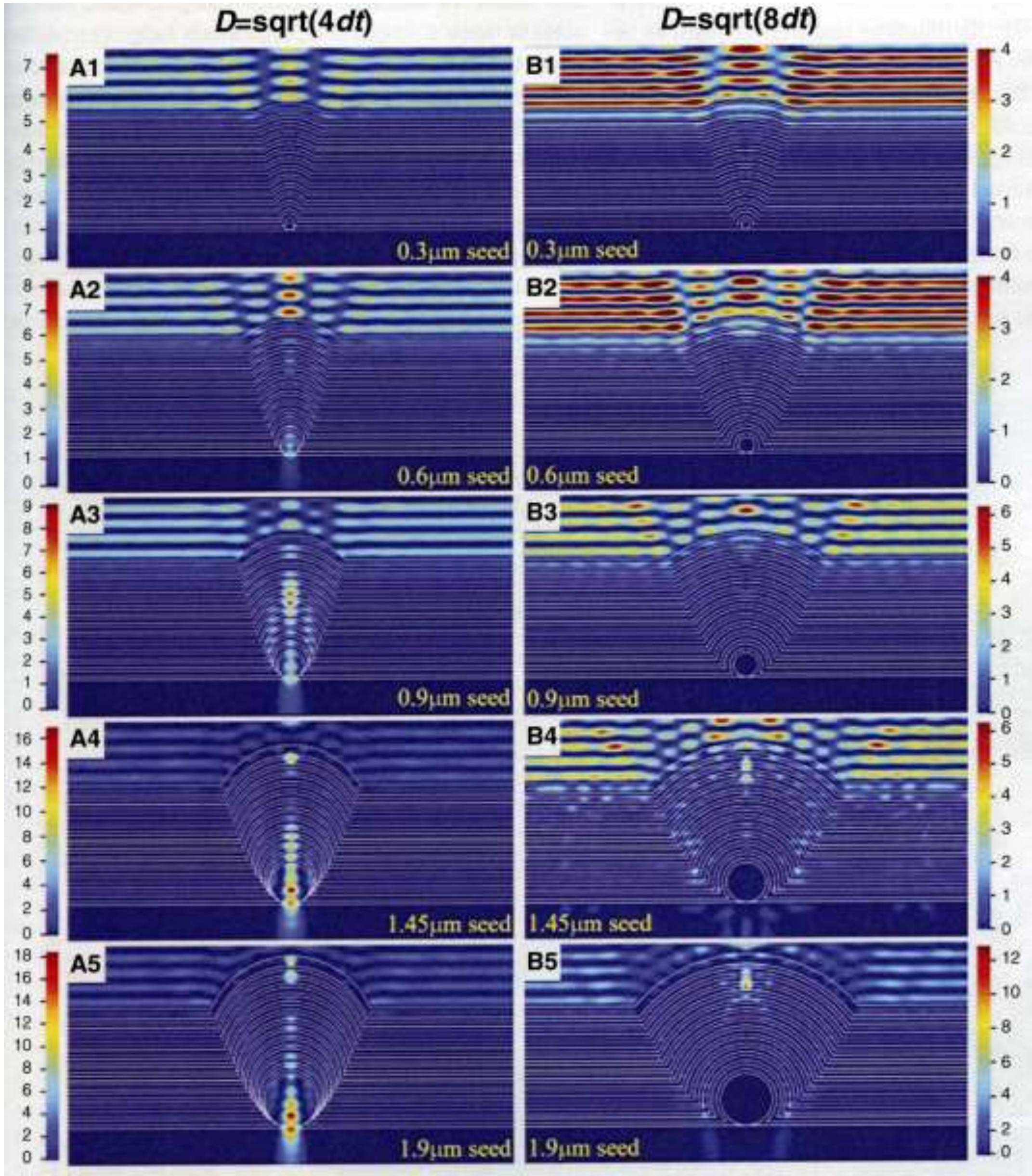
- Modelling a coating on a spherical particle on a surface



Ref.: X. Cheng et al, AOT 3(2014) p.65

Coatings in Zemax

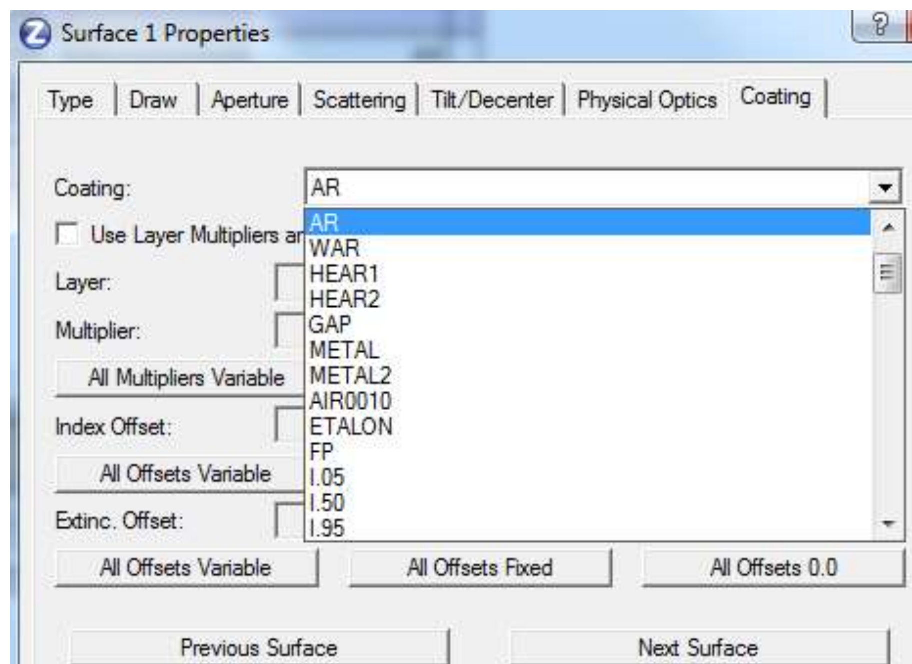
- Last column in the lens data manager:
  coating on the surface

Lens Data Editor

Edit Solves View Help

	Surf:Type	Radius		Thickness		Glass	Semi-Diameter	Coating
OBJ	Standard	Infinity		Infinity			Infinity	
1	Standard	54.1532462	V	8.7466579		SK2	29.2252978	AR
2	Standard	152.521921	V	0.5000000			28.1409540	AR
3	Standard	35.9506245	V	14.0000000		SK16	24.2958124	AR
4	Standard	Infinity		3.7769659		F5	21.2971909	
5	Standard	22.2699246	V	14.2530593			14.9193526	AR
STO	Standard	Infinity		12.4281291			10.2288352	
7	Standard	-25.685033	V	3.7769659		F5	13.1877585	AR
8	Standard	Infinity		10.8339285		SK16	16.4681224	
9	Standard	-36.980221	V	0.5000000			18.9295675	AR
10	Standard	196.417334	V	6.8581749		SK16	21.3107647	AR
11	Standard	-67.147550	V	57.3145379	V		21.6462584	AR
IMA	Standard	Infinity		-			24.5705331	

- One-Step-Coating of the complete system in:
  Tools/Catalogs/
  Add Coatings to all surfaces



- On every surface:
  specification of coating data form ASCII-data file. Sample file:
  coating.dat

- File can be edited in:
  Tools/Catalogs/Edit Coating File

Coatings in Zemax

- Menu Catalogs:
  options for coatings:

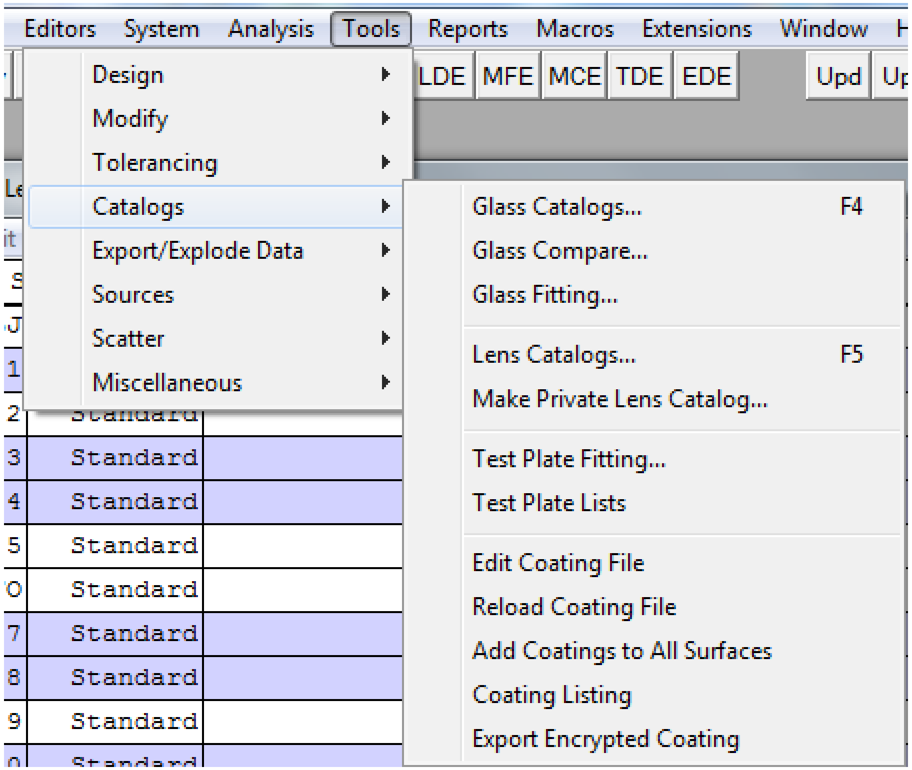
  1. Edit coating file

  2. Reload coating file

  3. Add coating to all surfaces

  4. Coating listing

  5. Export Encrypted coating



- Convention for complex indices of refraction in Zemax:
  $n = n_r + i\, n_i$
  Absorption is optained for negaive values of the imaginary part n_i.

  Example aluminum: $n = 9.7 - 7.0\, i$

Coating Definitions in Zemax

solute
MAT0
thickn
is_ab
solute

- Syntax of the coating file,
  Tools/Catalogs/Coating Listing

1. Material specifications: MATE
   different indices of the substrate:
   MATE name
   lambda nreal nimag
   .....

```
MATE BK7
0.4  1.5308485 0
0.46 1.5244335 0
0.5  1.5214145 0
0.7  1.5130640 0
0.8  1.5107762 0
1.0  1.5075022 0
2.0  1.4945016 0
```

2. Coating data: COAT
   all layers: material, thickness in waves or absolute
   material must be given
   COAT name
   MAT0 thickn is_absolute
   MAT1 thickn is_absolute
   ...
   or effective coatings by transmission:
   COAT I.transm

```
COAT AR
MGF2 .25

COAT HEAR1
MGF2 .25
ZRO2 .50
CEF3 .25
```

```
COAT     CZ2301,45
MGF2_G   0.08450000  1 0
XIV      0.02640000  1 0
MGF2_G   0.01280000  1 0
XIV      0.07600000  1 0
MGF2_G   0.01380000  1 0
XIV      0.02930000  1 0
MGF2_G   0.03260000  1 0
XIV      0.01070000  1 0
```

```
COAT I.05
COAT I.50
COAT I.95
```

Coating Definitions in Zemax

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3. Ideal coatings I: IDEAL
   described by transmission and reflection values
   IDEAL name T R

IDEAL NAME 0.9 0.1

4. Ideal coatings II: IDEAL2
   described by transmission and reflection values for S and P separately
   IDEAL2 name srr sri str sti prr pri ptr pti

IDEAL2 NAME 1.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0

5. Binary coating files: ENCRYPTED
   Encrypted coatings with unknown data
   ENCRYPTED name

ENCRYPTED ZEC_HEA673
ENCRYPTED VISNIR
ENCRYPTED ZEC_UVVIS
ENCRYPTED ZEC_HEA613

Coating Definitions in Zemax

6. Coatings specified by table: TABLE
   explicite values of Rs, Rp, Ts, Tp for each wavelength and incidence angle
   Phase angles of R and T defined by Ars,Arp,Ats and Atp
   Most accurate description in case of unknown data and only availability of empirical data
   $R(\alpha,\lambda)$, $R(\alpha,\lambda)$

```
TABLE NAME
ANGL alfa1
WAVE lambda1  Rs  Rp  Ts  TP  Ars  Arp  Ats  Atp
WAVE lambda2  Rs  Rp  Ts  TP  Ars  Arp  Ats  Atp
...
ANGL alfa2
WAVE lambda1  Rs  Rp  Ts  TP  Ars  Arp  Ats  Atp
WAVE lambda2  Rs  Rp  Ts  TP  Ars  Arp  Ats  Atp
```

```
TABLE PASS45
ANGL 0.0
WAVE 0.55 1.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0
ANGL 45.0
WAVE 0.55 0.0 0.0 1.0 1.0 0.0 0.0 0.0 0.0
ANGL 90.0
WAVE 0.55 1.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0
```

encripted coatings: ENCRYPTED (binary format)

Coating Analysis in Zemax

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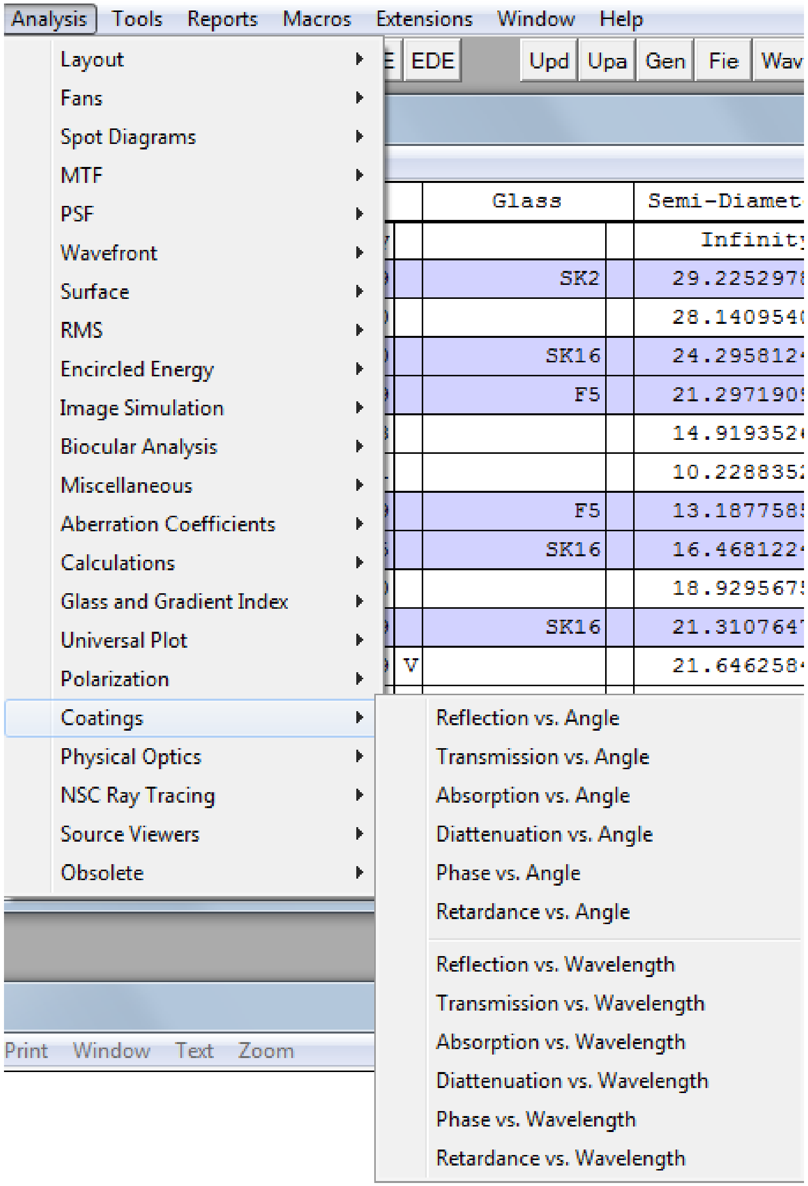
- Selection of coating/polarization analysis at one surface only
- Tapering of coatings is possible: radial polynomial of cosine-shaped spatial thickness variation
- Import of professional coating software data is possible



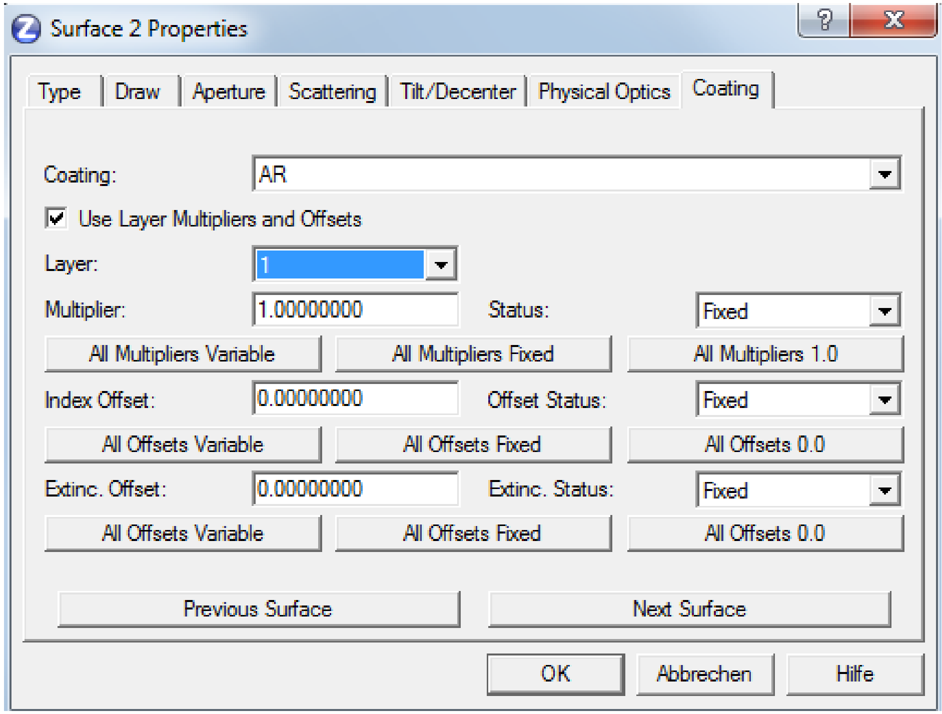
Coating Materials in Zemax

- Supported material for coatings in Zemax

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

- Given coatings can be incorporated into the optimization to a certain flexibility
- Possible variables:
  - thickness scaling
  - offset of refractive index
  - offset of extinction coefficient
- Fixed are number of layers and materials
- Operator in Merit function:
  CODA
  CMGT, CMLT, CMVA constraint multiplier
  CIGT, CILT, CIVA constraint index
  CEGT, CELT, CEVA constraint extinction
- Defaults can be set fast in the surface menue



Coating Analysis in Zemax

- Detailed polarization analyses are possible at the individual surfaces by using the coating menue options for

  1. Reflection
  2. Transmission
  3. Absorption
  4. Diattenuation
  5. Phase
  6. Retardance

  as a function of angle and wavelength