Program "FILMS"

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The compiled version of this program cannot be acceded from an hyperlink as the others because it needs an auxiliary data structure. It is necessary to download it from the web and install in a particular machine decompressing the file "unzipfilms.exe", to be found in the page of contents http://www.ecampitelli.com.ar/Ingles/Contents.htm

It is necessary to create a new folder. ***It must be "C:\films"****. On executing "unzipfilms.exe", a place where to decompress will be asked for, showing "unzip to folder", and a space to select the folder. Select folder "films", click "unzip" and the program "films.exe" will be ready to use in this folder.*

The program was written in collaboration and the source code is not available.

Neither is available an English version of it, but the words used are very similar to their English counterparts. A list of some words is shown later.

It is assumed that is at hand Chapter 2, "Interference by division of amplitude" and chapter 5, "Applications", of "Astronomical Optics"

It is an application of the method of Abeles-Herpin, and permits to obtain the graphs of Figs. 5.4, 5.5, 5.6, 5.7, and also those of Figs. 1.5, 2.2, 2.3, but from a more general algorithm.

The evaluation section show the reflectivity, transmissivity, phase on reflection, phase on transmission and absorption of a pile of films of complex index, deposited on a sustrate of complex index. The incident medium must have real index.

These quantities may be functions of the wavelength (spectral response) or of the incidence angle (angular response), and for oblique incidence there are computed all for both TE and TM polarizations.

The complex indices of refraction of the sustances may be taken explicitly as fixed or may be considered depending on λ, with a value linearly interpolated from filed data.

When a multilayer is analyzed before saving, all results of analysis are saved too.

The optimization section is based on the method of Lagrange multipliers and permits to refine a prescription varying the thicknesses in order that any of the functions evaluated approach another given as target.

An example of optimization is the prescription of Tab. 5.1, that was obtained from a periodic multilayer by setting as target the suppression of the oscillations of reflectivity in the short wave side of a dielectric mirror. Figure 5.6 is the final result and the left part of Fig 5.4 is the starting point.

Description of the program for the user.

(First a brief introduction: A poetic quotation and the colors of a soap bubble fairly well rendered. Enter!)

Evaluation section (or analysis).

The visible options appear highlighted as blinking, and generally is clear what they mean

The first ones are **M**-ulticapa **S**-ustancia (**M**-ultilayer **S**-ustance)

Let it be **M**-ulticapa

It is requested the name of the multilayer, that may be defined or retrieved from a file one defined before.

At this point on entering a * appears a listing of multilayers filed.

When retrieving a multilayer from a file it brings with it all data generated in the last analysis and may be viewed directly without a further **A**-nalysis

On defining a multilayer its name must begin with a number followed by a dash.

The number sets the quantity of layers, and on entering them, first appear I: Initial medium and last F: Final medium. Thicknesses are in angstroms.

If the name of a sustance begins with @, is means that the index is constant and explicitly given. If not, the index is not requested and its values interpolated from the file.

In the screen **A**-nalizar (**A**-nalyze) there ought to be entered two numbers that are proposed as general and particular options to define the conditions of an analysis calculation.

This screen may be somewhat strange at first, so it will be explained in detail and in English, although it appears in Spanish

1 – Data for the calculation

1 – Spectral or Angular response [S/A] = S
2 – Steps of calculation = 128
3 – Angle of entrance = 0.00

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2 – Data for the graphic

ABSCISAS:	1 – Lower	= 4000 A
	2 – Higher	= 9000 A
	3 – Interval	= 500 A
ORDINATES R,T,A	4 – Lower	= 0.D+00%
	5 – Upper	= 1.D+02%
	6 – Interval	= 1.D+01%
ORDINATES PHASE	7 – Lower	= 0
	8 – Upper	= 360
	9 – Interval	= 45

Enter Section # and Line # **C**ontinue **X**: End

The quantities shown are default values and if one is changed others may change in turn.

With **C**-ontinuar (**C**-ontinue) the calculation procceeds. The results are retrieved with the options

T-ransmisión **R**-eflexión **A**-bsorción **FT**-ransm. **FR**-eflex

(**F** stands for **P**-hase)

For example, if in screen **A**-nalizar is entered 1 and then 3, the cursor remain at "Angulo de Entrada" (Angle of Entrance), and entering 30 and **C**-ontinuar, the spectral evaluation for 30 degrees is performed. If the angle is different from zero there appear two graphs, the yellow one is for TE and the blue for TM.

In all graphics there is a hidden option, **E**-xtremos (**E**-xtremes), where the maxima and minima of the functions are tabulated. Warning: the place of the extremes depends slightly on the steps of calculation, the default value is 128 and the maximum allowed is 640. (one for each pixel in the screen)

Let be **S**-ustancia. (Name not begining with a number and dash)

The option **I**-ndices show the index of refraction interpolated entering "Lambda" in A.

Examples

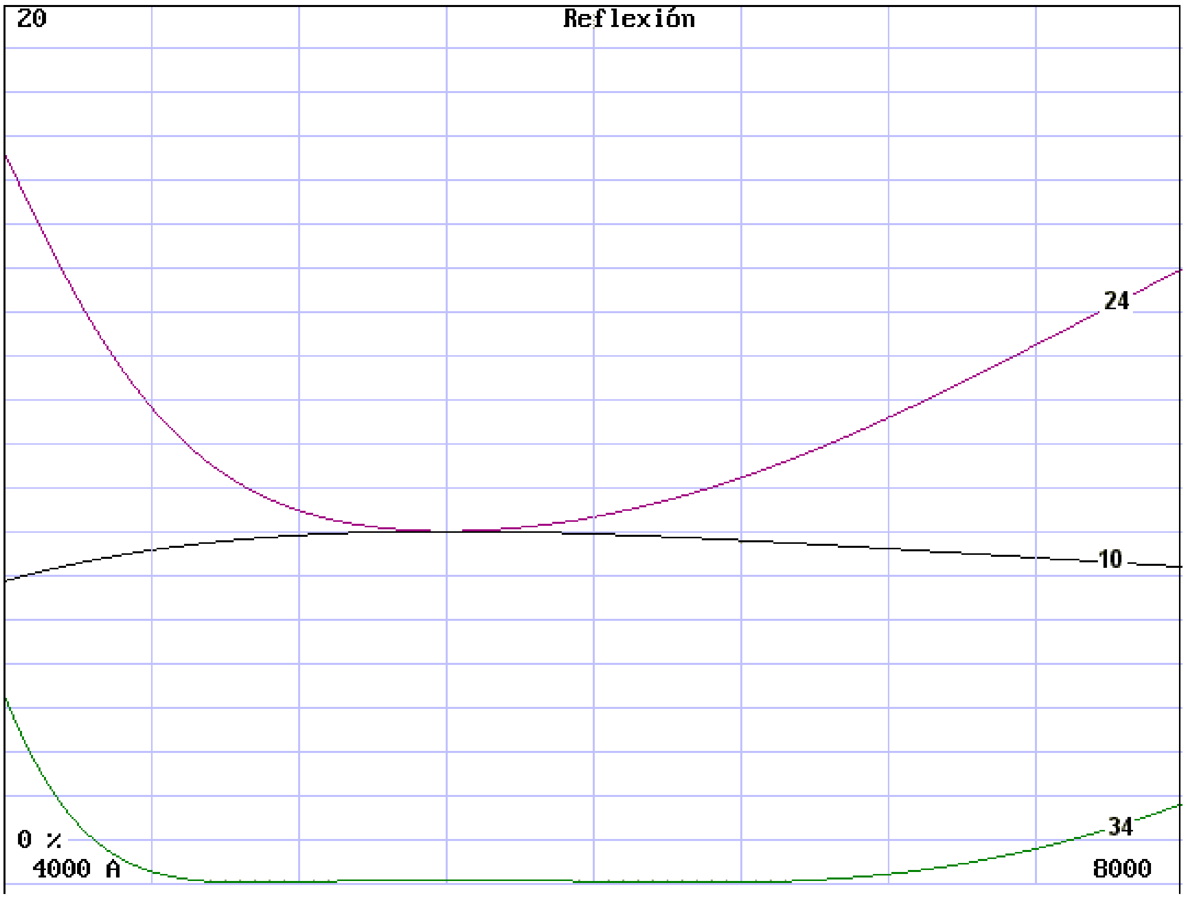
As an example of the practical utility of the evaluation section, in the video "MonitoreoFilmTripeCapa.avi" it is shown the monitoring of the deposition of 3-ar-vis, the three layer antireflectant of Fig 5.7 and Tab. 5.2. This information enables to know when to finish deposition of one sustance and start with another, having a spectrophotometer.

Sequence of thickness corresponding to curves shown in the video.

Notice that they are larger than those of tab 5.2 by a factor 1.11 because design λ was 5500 A instead of 5000 A.

	air		glass
Frame	thickness MgF_2	thickness ZrO_2	thickness CeF_3
1	0	0	0
2	0	0	100
3	0	0	200
4	0	0	300
5	0	0	400
6	0	0	500
7	0	0	600
8	0	0	700
9	0	0	800
10	0	0	834
11	0	100	834
12	0	200	834
13	0	300	834
14	0	400	834
15	0	500	834
16	0	600	834
17	0	700	834
18	0	800	834
19	0	900	834
20	0	1000	834
21	0	1100	834
22	0	1200	834
23	0	1300	834
24	0	1310	834
25	100	1310	834
26	200	1310	834
27	300	1310	834
28	400	1310	834
29	500	1310	834
30	600	1310	834
31	700	1310	834
32	800	1310	834
33	900	1310	834
34	997	1310	834

In Fig.5.7 there is an amplified graphic of reflectivity of the complete multilayer to compare with reflectivity of bare glass and a single layer of MgF_2

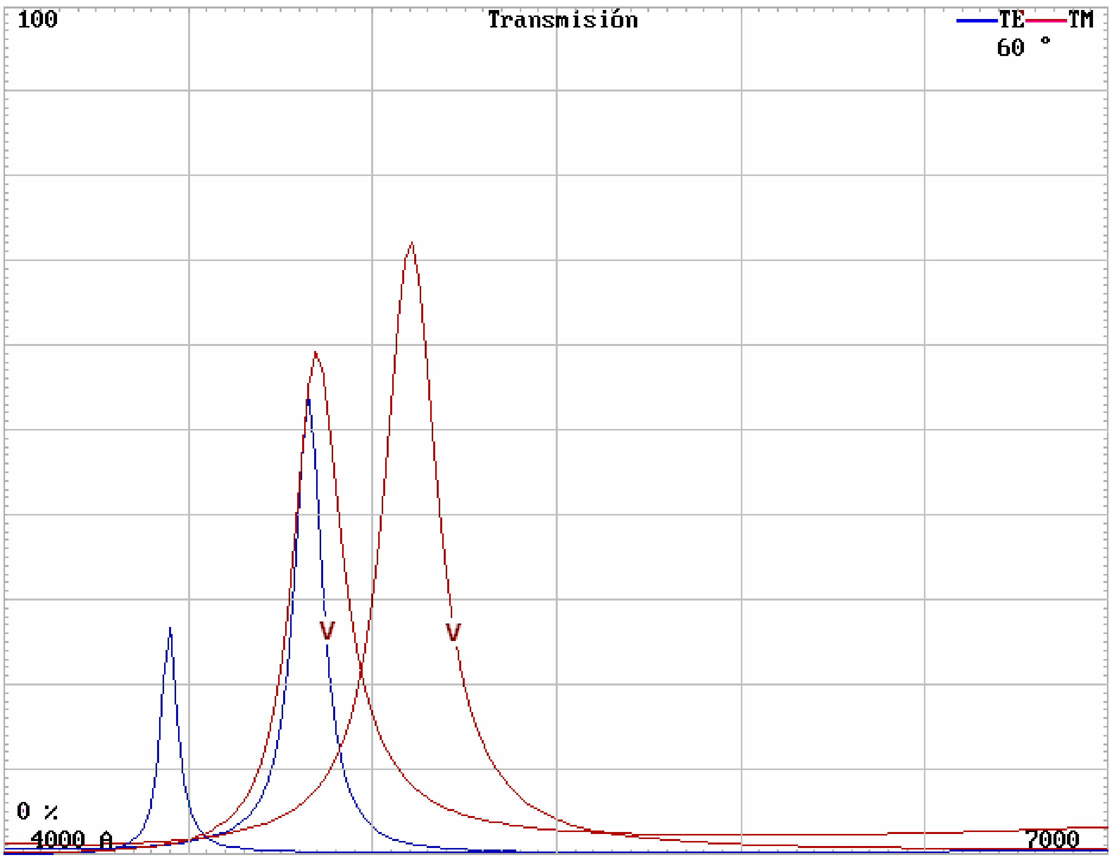


Stages of the deposition of the antirreflectant 3-ar-vis. The numbers indicate the frames of the video where is changed the sustance

Metal dielectric filter

This filter was used to test the program because it has all features and is one of the earliest references to this kind of programs, made by the originator of the method. The prescription is from Ref. 2. The multilayer 3-mdm has the indices constant (@) and 3-mdmv has the indices variables with λ. The only difference in the prescription is that 3-mdmv has not the @, as was explained, and the indices are interpolated from a table

	3-mdm	n	k	d
I	@BK7	1.52	-	-
01	@Ag	0.057	3.443	360
02	@ZnS	2.363	0	1900
03	@Ag	0.057	3.443	360
F	@BK7	1.52	-	-



3-mdm and 3-mdmv

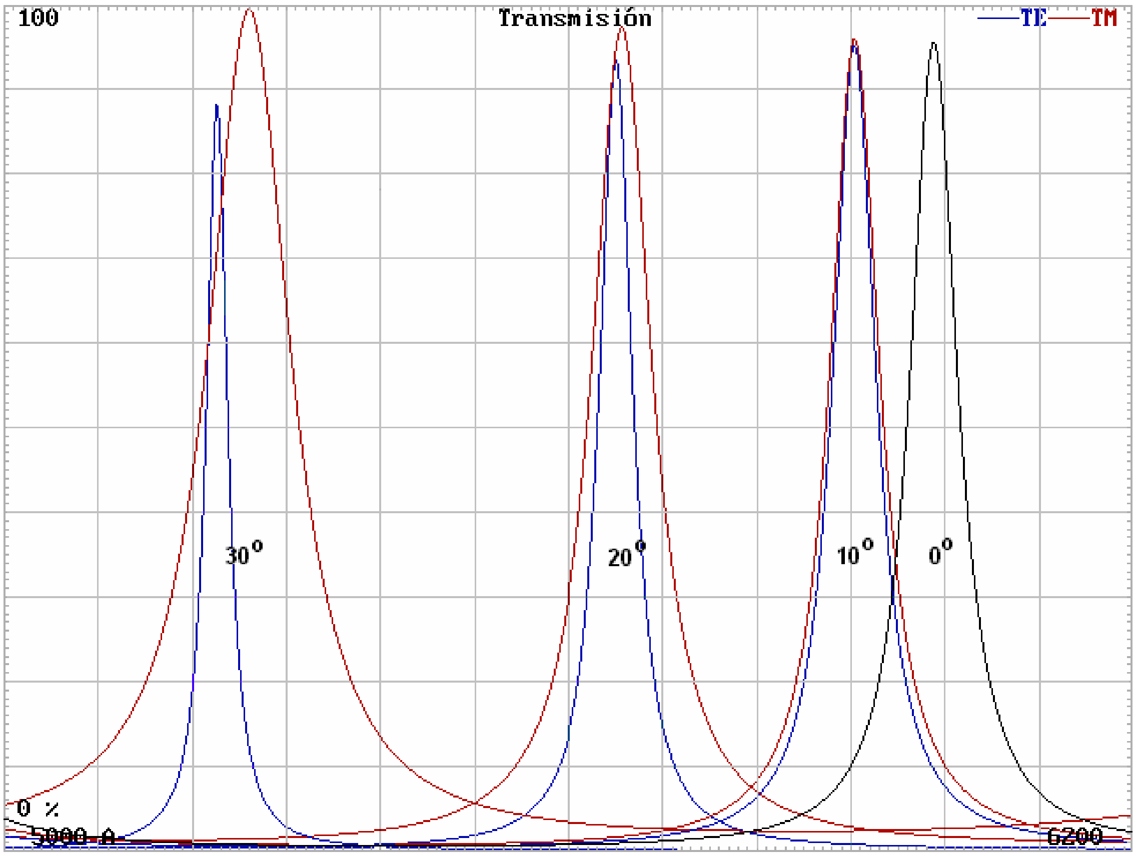
The angle of incidence is 60 deg., and this is an inconsistency because implies infinite medium incident and transmitted, otherwise there is total reflection at the glass boundaries. This error was recognized by Abeles itself, but is no harm to the accuracy of the calculation.

The curves for constant and variable indices are plotted together to show the influence of dispersion. The tables of indices are in the corresponding file in the program.

Band shift due to tilt in a dielectric filter.

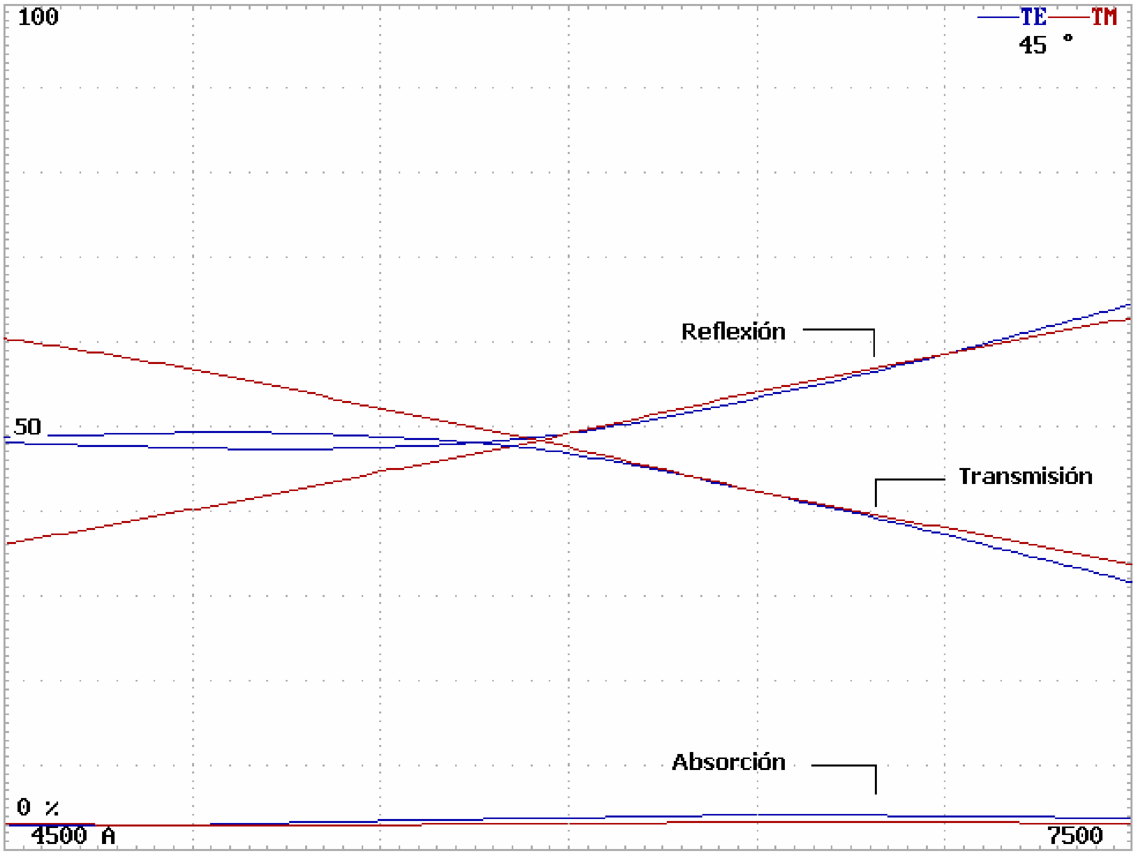
Starting with the band pass filter obtained by thickening to double the layer 9 of the multilayer 17-mulpe, Fig.5.5. It may be verified that the band shift is prorpotional to the square of the angle.

There is also a polarization splitting and a difference of heights, as in the former case.



Beam splitter at 45 degrees.

A beam splitter efficient, robust, cheap and easy to make is by means of a film of silver covered by another of magnesium fluoride, with prescription



2-divhaz		n	k	d
I	@vacío	1.52	-	-
01	@MgF2	1.38	0	1118
02	Ag	-	-	186
F	BK7	1.52	-	-

General Brewster angle.

The usual Fresnel formulae are referred to dielectrics, with real refractive index.

Considering only Initial and Final media without any layer it is obtained the reflectivity of a metal with complex index as a function of the incidence angle.

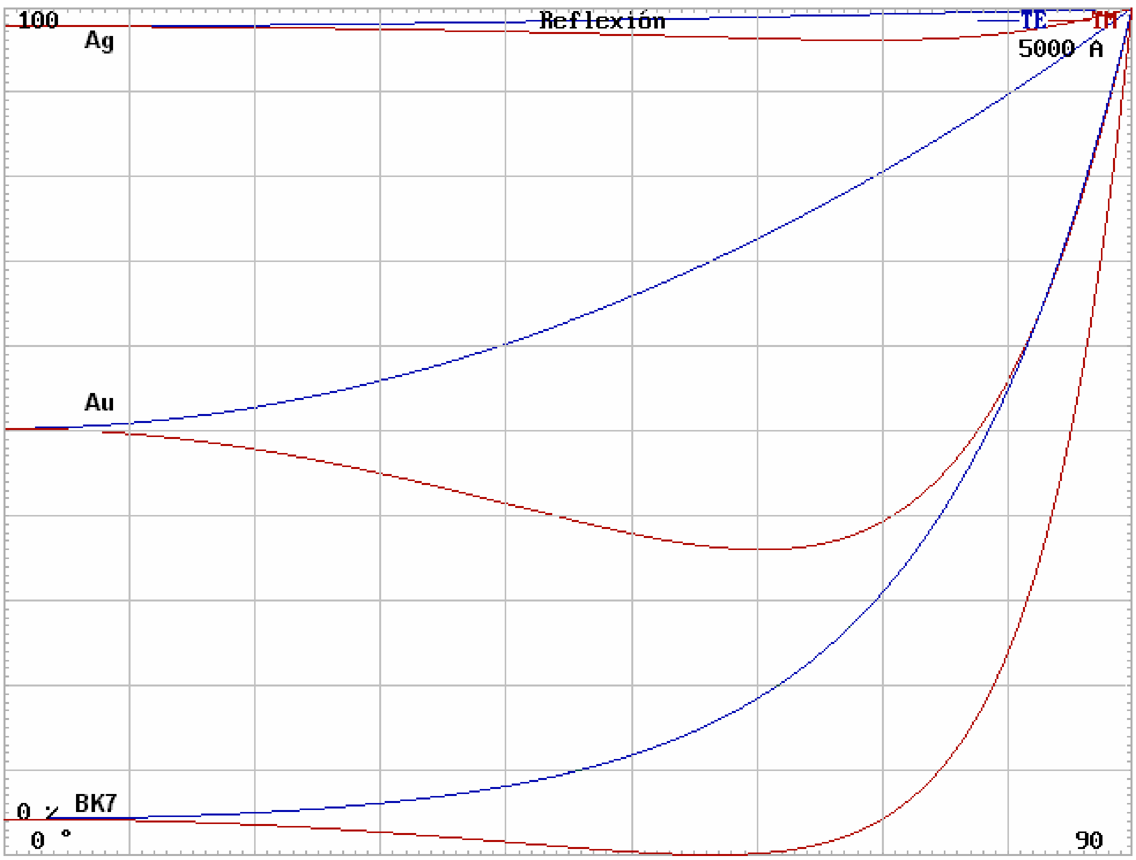
For a glass the Brewster angle yields a zero TM reflection, but for a metal there is a non-zero minimum and depends strongly on the metal.

Here it was plotted the reflectivity of silver (Ag), gold (Au) and glass (BK7)

The "multilayer" has a prescription

0-fres		n	k	d
I	@vacío	1	0	
F	Metal	-	-	

That where used the tabulated values for n and k.



Optimization section (or refining)

For clarity, it will be shown the start of the refining process that lead to Fig 5.6 from Fig 5.4

The prescription of multilayer called 17-mulpe (starting periodic multilayer) is

I	@BK7	1.520		
01	@MgF2	1.380	0.000	1085
02	@ZnS	2.300	0.000	651
03	@MgF2	1.380	0.000	1085
04	@ZnS	2.300	0.000	651
05	@MgF2	1.380	0.000	1085
06	@ZnS	2.300	0.000	651
07	@MgF2	1.380	0.000	1085
08	@ZnS	2.300	0.000	651
09	@MgF2	1.380	0.000	1085
10	@ZnS	2.300	0.000	651
11	@MgF2	1.380	0.000	1085
12	@ZnS	2.300	0.000	651
13	@MgF2	1.380	0.000	1085
14	@ZnS	2.300	0.000	651
15	@MgF2	1.380	0.000	1085
16	@ZnS	2.300	0.000	651
17	@MgF2	1.380	0.000	1085
F	@Vacio	1.000	0.000	

Its reflectivity is shown in Fig 5.4. With option **E**-xtremos is obtained

Lambda(A)	Ordenada	Tipo
4078.13	20.7475	MAX.
4273.44	2.8761	mín.
4429.69	29.5546	MAX.
4625.00	1.8866	mín.
4820.31	49.6540	MAX.
4976.56	1.0816	mín.
5992.19	99.8587	MAX.
7515.63	1.3674	mín.
7906.25	49.6543	MAX.
8531.25	1.4241	mín.

Due to rounding errors, these values are exactly reproduced only if the interval is from 4000 to 9000 A and 128 steps of calculation.

The maximum in 5992 A is the reflectivity band. To begin with, the first aim is to suppress the three maxima of the left side. With option **R**-efinar, first is requested "Incremento", with a default value of 5. This quantity is the number of angstroms used as finite increment to calculate certain derivatives. In principle it is left unchanged. Next is asked for "Número de capas de espesor fijo" (Number of layers with fixed thickness), if the problem imposes this restriction. In this case may vary all of them, so that is left as 0. Next appears a table that will be filled until it becomes like this:

REFINACION: REFLEXION

lambda	actual	meta
4078.13	20.7478	0.0000
4429.69	29.5547	0.0000
4820.31	49.6540	0.0000

x

In the first column are entered the λ of the maxima to be suppressed. The second column is filled by the program, and is the actual value of the reflectivity. The third is the desired value.

With x (enter) there stop entering λ, and the program modify all the thickness trying to meet the targets. Next show a graph with the reflectivity of the modified multilayer, that is

And has the prescription

I	@BK7	1.520		
01	@MgF2	1.380	0.000	1096
02	@ZnS	2.300	0.000	752
03	@MgF2	1.380	0.000	1136
04	@ZnS	2.300	0.000	661
05	@MgF2	1.380	0.000	1066
06	@ZnS	2.300	0.000	633
07	@MgF2	1.380	0.000	1079
08	@ZnS	2.300	0.000	615
09	@MgF2	1.380	0.000	1056
10	@ZnS	2.300	0.000	626
11	@MgF2	1.380	0.000	1082
12	@ZnS	2.300	0.000	635
13	@MgF2	1.380	0.000	1077
14	@ZnS	2.300	0.000	695
15	@MgF2	1.380	0.000	1145
16	@ZnS	2.300	0.000	719
17	@MgF2	1.380	0.000	1063
F	@Vacio	1.000	0.000	

The lobes at left had been diminished, but those at right had grown higher. This is of no consequence if what matters is a step filter. To continue depressing the lobes of interest, the process is repeated. If a given prescription becomes absurd, it may be discarded with option **U**-ndo, that restores the former.

Any function can be refined in this way, including the double ones for oblique incidence.

The indices do not vary in the refining, and in some cases the method does not lead to any result, but in others, as the one shown, is excellent.

Due to the non linearity of the problem the targets cannot be reached directly. The multilayer 17-fipaa (high pass filter), that is the one of Fig 5.6, resulted from some 40 iterations, including too those discarded. The iterations are far from being automatic. In each one there is need to use "diplomatic and persuasive" strategies to deal with the program. If all is requested from the first time, it yields erratic results. It must be asked for some targets, not all; and for intermediate values, not the ultimate desired. It may be useful to change the increment of the derivatives.

It may be imagined an advanced application of this method in the fabrication of a complex multilayer: If the function resulting in an intermediate step differs from that foreseen due to an error of thickness, to modify the remaining ones in order to achieve the same result.

Some words:

Introduction
"Then, the wise pointed the window and said:
- What do you see?
- I see the world, the people
Next, he took a mirror and repeated the question
- Now only see myself
- That happens whenever a bit of silver lies in between
Said the wise..."

Nombre de la multicapa -> Name of multilayer
Listado de multicapas -> Listing of multilayers
Fin -> End, or next
Archivo no existe, se crea? [S/N] -> file does not exists, create it ? [Y/N]
Corregir -> Modify
Guardar -> Save
Ver -> See
Agregar -> Append
Hoja sig. -> Next page
Salida espectral o angular -> Spectral or angular response
Pasos del cálculo -> Steps of the calculation
Ingrese # de sección y # de línea -> enter section # and line #

List of multilayers

2 – divhaz	Beam splitter at 45 degrees
3 – mdm	(Ref. 1)
3 – mdmv	(Ref. 1)
3 – ar – vis	(Ref. 2)
17 – mulpe	Periodic multilayer
17 – fipaa	High pass filter obtained by refining of 17- mulpe

List of sustances

Ag	Silver. Ref. 3 and 4
Au	Gold. Ref. 3 and 4
Cu	Copper. Ref. 3 and 4
ZnS	Zinc Sulphide. Ref. 5
Al	Aluminum. Ref. 3 y 4
Au2	Gold. Ref. 3 y 4
Si	Silicon. Data from Julio Durán
Pla	Silver. Ref. 3 y 4
Al (MK)	Aluminum. Ref. 6
CdS	Cadmium Sulphide. Ref. 7
SiO	Silicon Oxide. Ref. 8
ALU	Aluminum. Ref. 3 y 4
Al2O3	Aluminum Oxide. Ref. 9
CeO2	Cerium Oxide. Ref. 10
TiO2	Titanium Oxide. Ref. 11

References

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