Open Filters: For optimum design wideband ARC's at oblique incidence of light and effect dispersion of material coating

Dr.Alaa Nazar

Baghdad University/ science for women

تقديـــــم البحث 2010/11/10
قبول نشر البحث 3/ 1 /2011

ABSTRACT

Open Filter software was used to devote the optimum design for normal and oblique incidence of wide band antireflection coating taking into account the effect of dispersion for the used materials and substrate.
The reflectance of the system were taking over a wide range of wavelength (300- 1000) nm.
Result show dispersion effect of materials coatings appear clearly on the spectral characteristic in the region near UV. Also estimate the results of using off-normal
(0-89º) incident radiation. Were the reflection performance of AR coating interference filter in collimated light for two polarization modes R_P and R_S show different characteristic.

Key words: antireflection coating, optimization methods, needle optimization methods

1- Introduction

The Antireflection (AR) optical coating have long been used for a variety of application for electro-optical system in telecommunication , medicine and consumer products , thus achieve high quality AR coating is a need in the optical system [1,2] .

AR coating is not an easy task to be done for oblique incidence, since of the limitation in the optical materials to be used in practice to be realized in order to obtain the lowers reflectivity.
The design of an optical (AR) can be studied either analytically or numerically [3-5].The analytical design start from solving equation describing the reflection factor various wavelength. In numerical design appeals to optimized, one can quasi-continuously vary the optical thicknesses of each layer are iterated, in turn to minimize a specified merit function, to satisfy the decrease of the reflection on an imposed spectral range [6,7].Therefore we design high performance AR coating with effect dispersion of the materials and substrate coating for two system combination materials coating using needle optimization method in the frame of Open Filter software[8-10].
Also this paper describes the modes of S-polarization and P- polarization for range of incidence angles.

2- Theory

The optic matrix and characteristic matrix approach was employed for q-layer design of antireflection coatings. The main idea of this method is matching the E- and H- fields of the incident light on the boundary of layer coating. The matrix is calculated at each boundary throughout the multilayer as the magnitude of the electric , magnetic field vectors alter with the properties of the layer [7,11], i.e.

$$\begin{pmatrix} B \\ C \end{pmatrix} = \left(\prod_{m-1}^{q} \begin{bmatrix} \cos\delta_m & (i\sin\delta_m)/\eta_m \\ i\eta_m \sin\delta_m & \cos\delta_m \end{bmatrix} \right) \begin{pmatrix} 1 \\ \eta_s \end{pmatrix} \qquad , \qquad i = \sqrt{-1}$$

Where $B/C= E_a/H_a$, were E_a and H_a are the electric field vector magnetic field vector incident boundary of a film. B and C were the normalized electric field magnetic field amplitude, respectively. The phase thickness $\delta_m = 2\pi\, n_m d_m \cos\theta_m / \lambda$,where n_m ,
d_m ,θ_m and λ are refractive index , physical thickness, incident angle and light beam wavelength, respectively, of the m^{th} thin film layer.
When the radiation incident at oblique incidence there two mode of polarization line TE(s) - and TM (p) mode wave, therefore effecting mode for S- and P – polarization are:

$\eta_m = n_m \cos\theta_m$ TE mode

$\eta_s = n_s \cos\theta_s$

$\eta_m = n_m / \cos\theta_m$ TM mode

$\eta_s = n_s / \cos\theta_s$

The suffix s in above equations used to define the substrate or exit medium η_s and η_m are effective refractive index for the substrate, m[th] layer respectively.

From Snell's law, the reflectance R can be calculated for oblique as follows,

$$R_q = \left(\frac{\eta_0 B - C}{\eta_0 B + C}\right)\left(\frac{\eta_0 B - C}{\eta_0 B + C}\right)^*$$

.

η_0 effective index of incident medium, * = complex conjugate

3 - Result and discussion

In this section we present design AR coating taking the dispersion effect for the multilayer and substrate coating, for two system combinations of materials coating and compare this designs with design ARC's with dispersion free.
These designees are studied in two cases normal case and oblique incidence case.
The combination of materials is chosen in such a way that the refractive indices are ideal for a three material system. As a rule of thumb, when the refractive index of the intermediate material equals the square root of the product of the refractive indices of the other two materials, the refractive indices are considered optimal [12, 13] .Table (1) show that two systems material in case dispersion free [12] .But the disperse properties of the materials in combinations I and II have been taken into account, which is closest to reality this clear in fingers (3-a-b)[14] .

Table 1: two systems material in free dispersion

Combination	n_s refractive index of substrate	n_1 refractive index of 1st layer	n_2 refractive index of 2nd layer	n_3 refractive index of 3rd layer
System I	1.51	1.38	2.10	1.65
System II	1.53	1.47	2.14	1.80

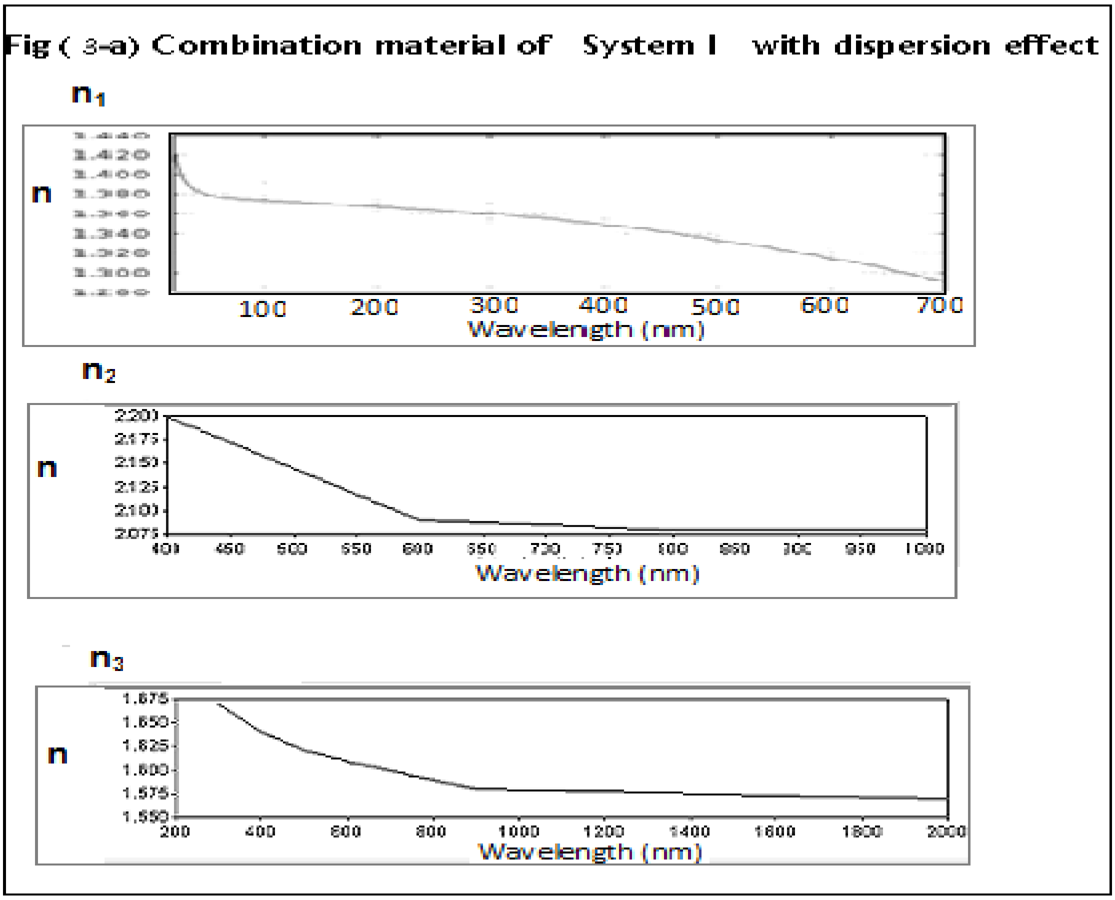

Fig (3-a) Combination material of System I with dispersion effect
Refractive index (n) vs wavelength, of the material coating and substrate of the system I

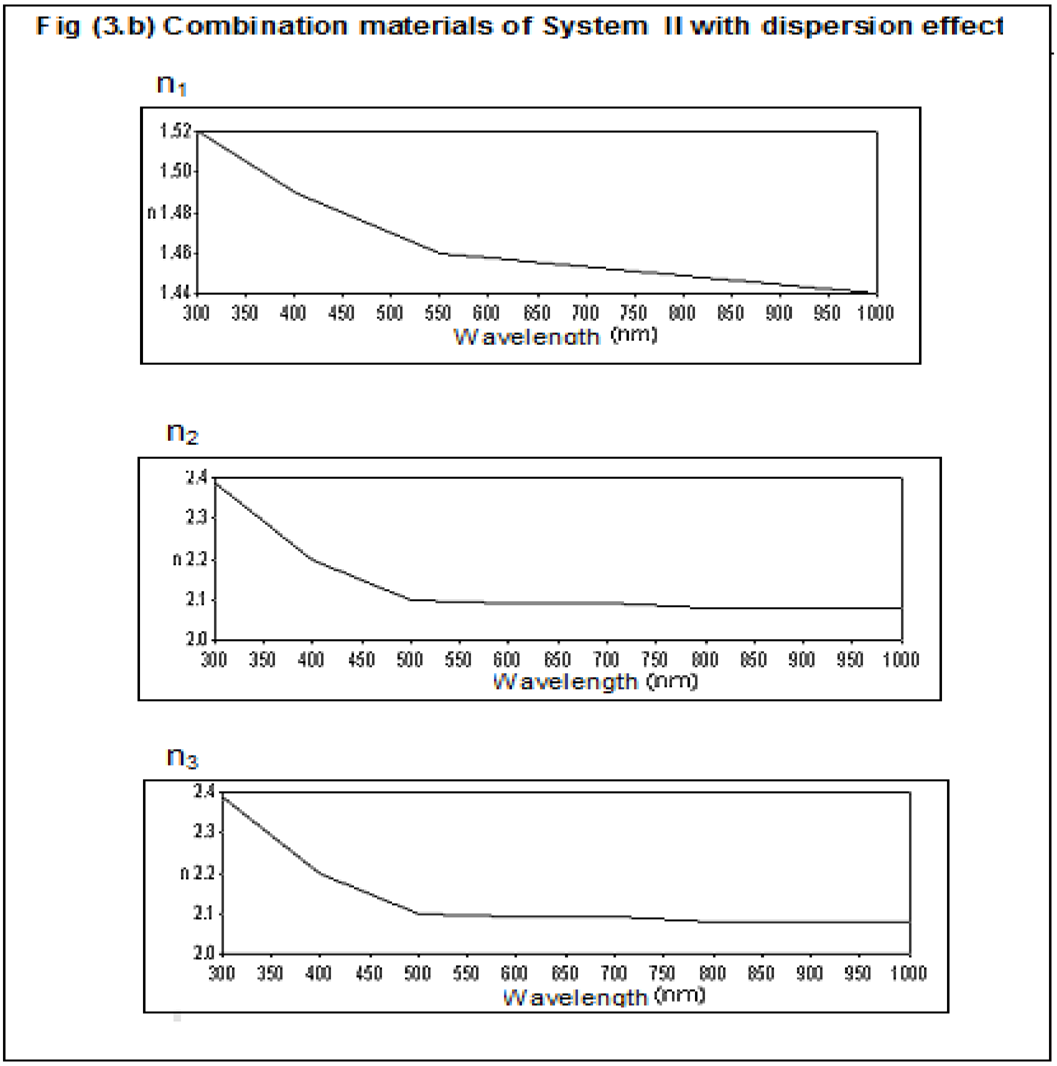

Fig (3-b) Combination material of System II with dispersion effect
Refractive index (n) vs wavelength, of the material coating and substrate of the system II

3-1 normal case

we report the design of an ARC's, for the optical material of system I , for free dispersion of these materials at normal incidence in fig (3-a) and design this filter in same system of materials but with taken the dispersion effect of the optical materials this shown in fig (3- b).
Fig (3 –c) show the design of ARC's using combination material of system II without using dispersion effect of the material coating at normal incidence , but fig (3- d) shows design ARC's for the same system II , but with taken the dispersion effect of materials coating also at normal incidence

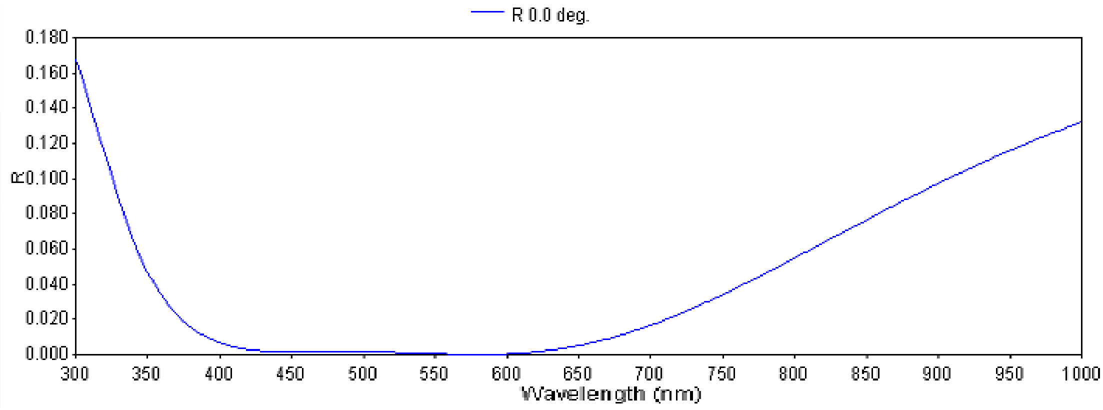

Fig (3-1.a) Reflection R vs. wavelength at normal incidence for system I with dispersion free

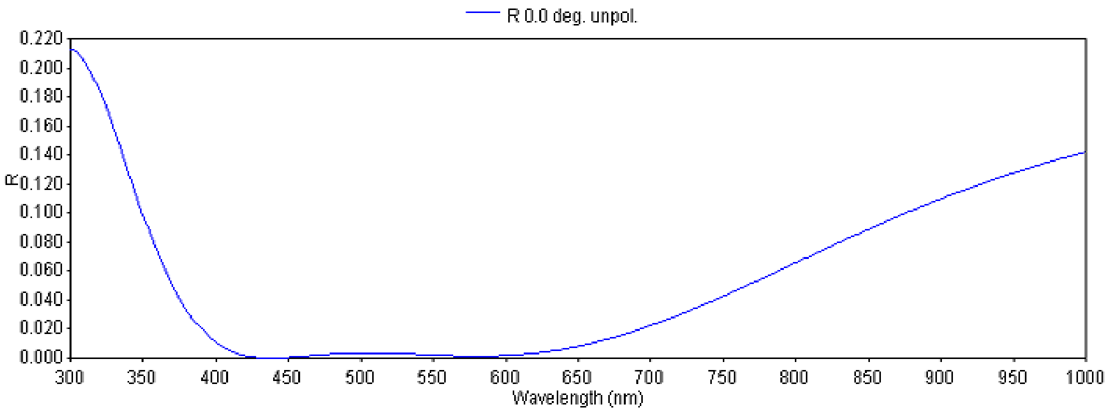

Fig (3-1.b) Reflection R vs. wavelength at normal incidence for system I using dispersion effect

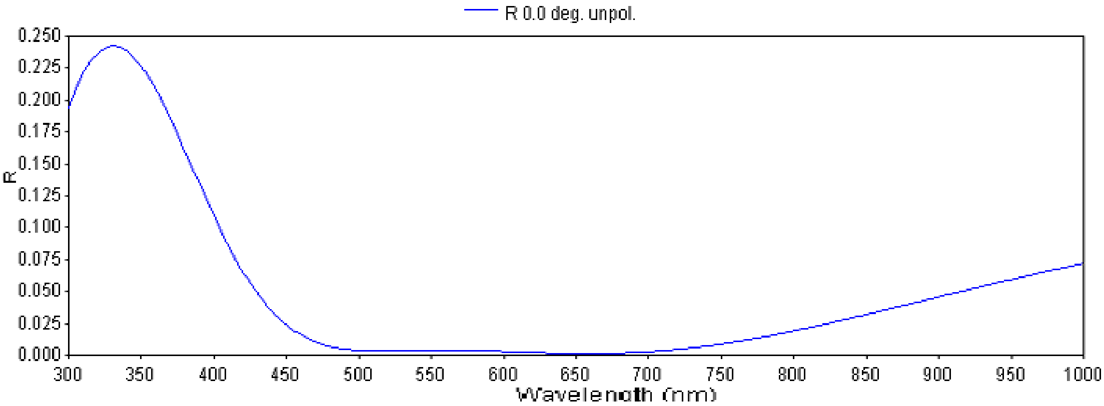

Fig (3-1.c) Reflection R vs. wavelength at normal incidence for system II with dispersion free

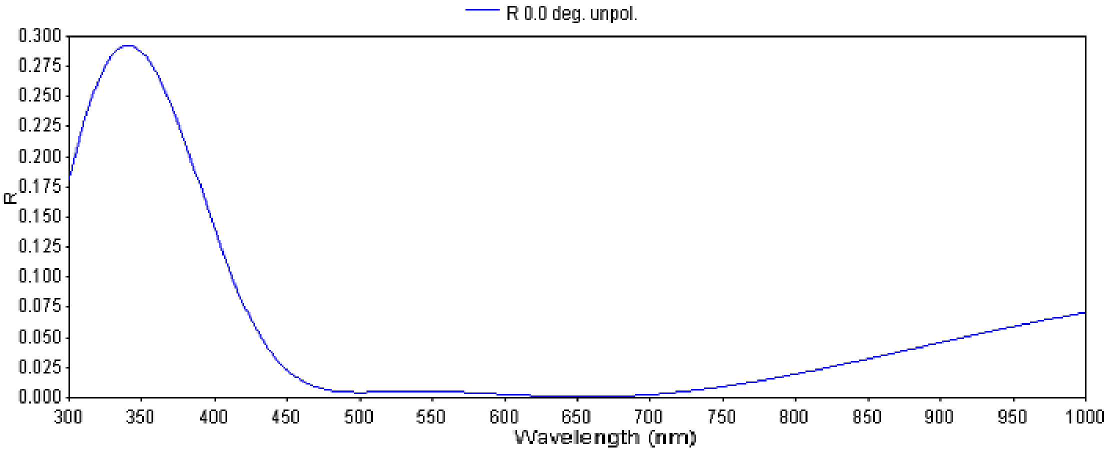

Fig (3-1.d) Reflection R vs. wavelength at normal incidence for system II with dispersion effect

The figure (3-1.b) and figure (3-1.d) shows the effect dispersion of the materials coating for two systems appears clearly in the zone near UV, was the reflection peak increase clearly near the UV region

3-2 oblique case with dispersion free

In many applications, normal incidence radiation is not practical or even possible. So we can, however, estimate the results of using off-normal (0-89º) incident radiation. The reflection performance of AR coating interference filter in collimated light for two polarization modes over a wide range of incident angles was studied. The R_P and R_S show different characteristic was shown in Figures (3-2.a-b) for system material I and figures (3-2.c-d) for system materials II. All figures (3-2) taken for dispersion free for materials coating.

As the angle of incidence increase various phenomenon may appears, the reflection peak were split into two distinguishable peaks, R_S ,reflection for S-polarization mode and R_P, reflection for P- polarization mode . For S-polarization mode when it compare with normal incident for system I with dispersion free R_S increase with angles of incidences increase in the region near IR but decrease in the zone near UV region this done until the angle of incident become 50^0 the reflection increase in two regions visible and near IR also the shape of antireflection coating change from U shape to W shape this depicted in Figure(3-2.a) .

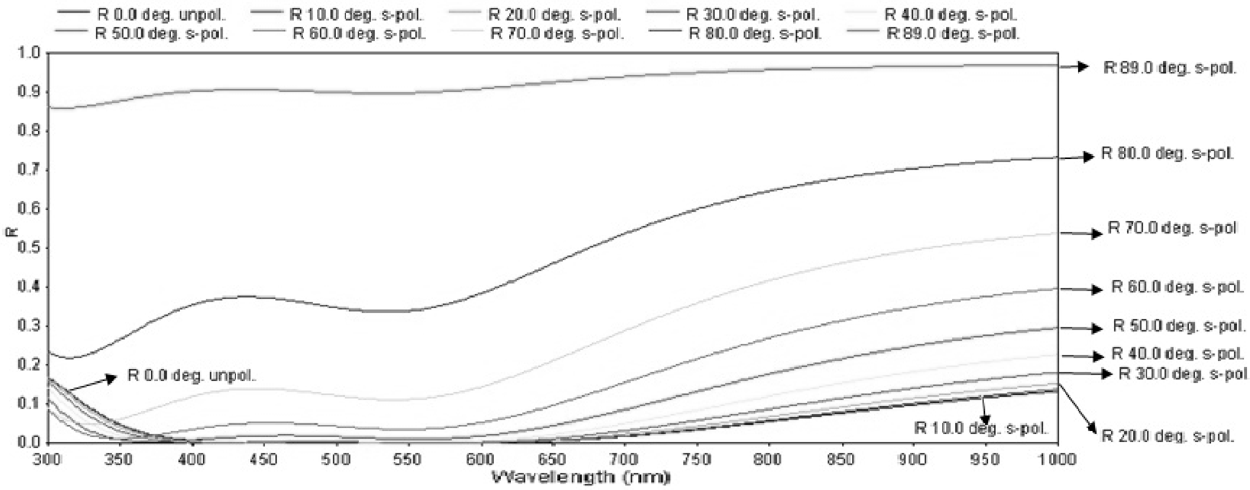

Fig (3-2.a) Reflection R_S vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion free for the optical material system I

The process of R_P of system material I with dispersion free shown in figure (3-2.b) were the reflection decrease with increase incident angles when it compare with normal incident in the two regions near IR and UV but at angles 60° and 70° the R_P became decrease in only region near IR

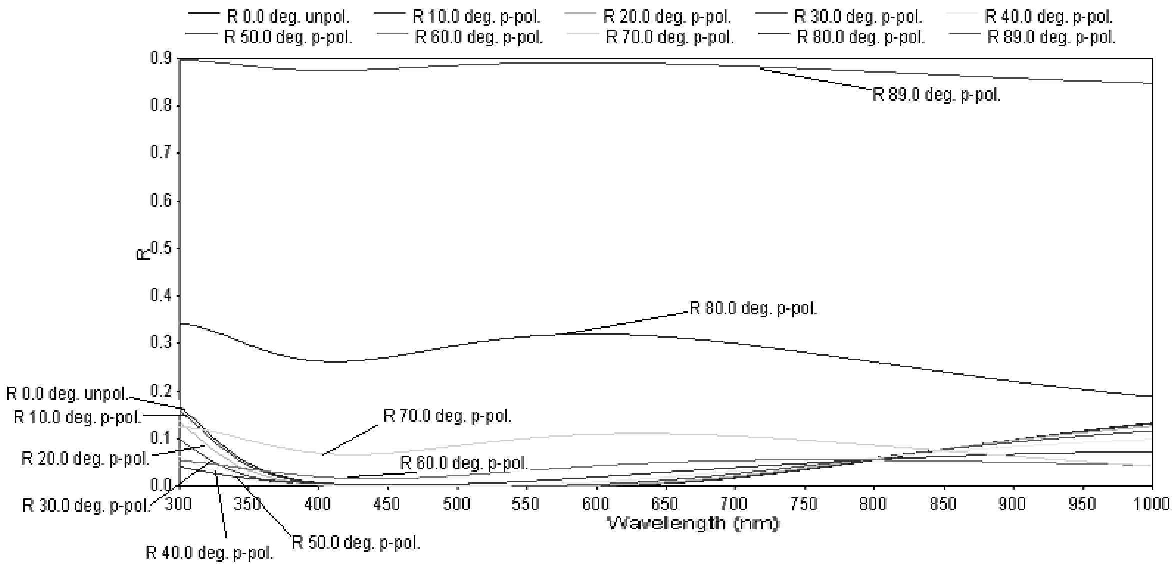

Fig (3-2.b) Reflection R_P vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion free for the optical material system I

Figures (3-2.c-d) shows the behavior reflection for range angles of incident from 10° to 89° compare with normal incident for combination of materials system II with dispersion free .Were R_S increase with increase angles in two regions near IR and UV region until incident angle equal 50^0 the reflection increase for over range of wave length this appear clearly in fig (fig 3-2.c) , but R_P when it compare with normal incident decrease with increase incident angles in two regions IR and UV this presses continue until incident angle became 50 º the R_P increase in the visible region and became increase over all range of wavelength at incident angle 60 º ,this shown in figure (3-2.d)

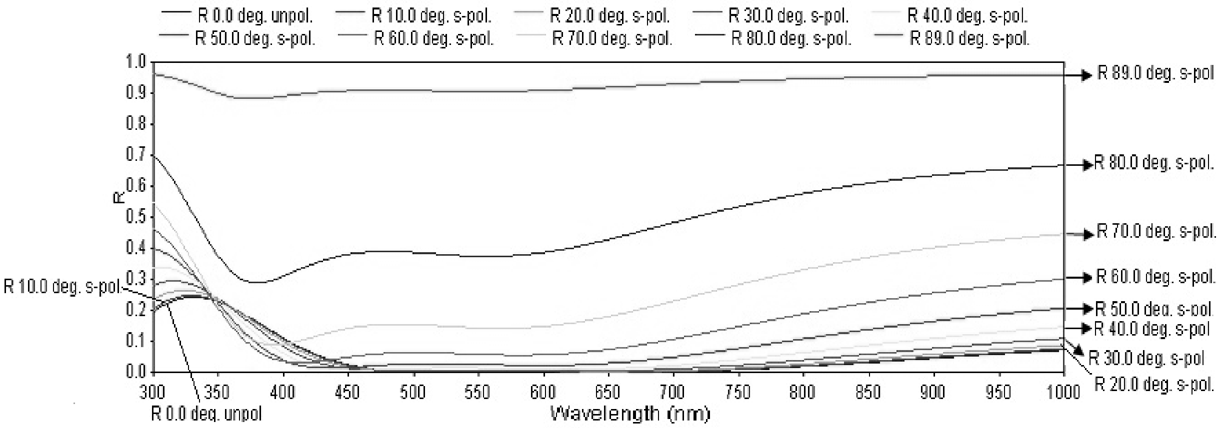

Fig (3-2.c) Reflection R_S vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion free for the optical material system II

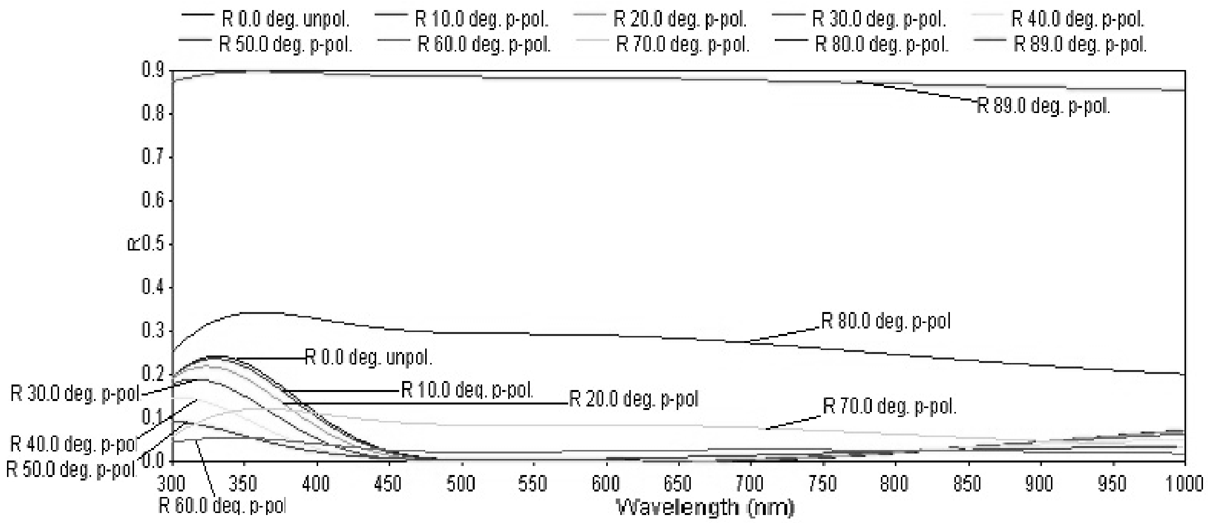

Fig (3-2.d) Reflection R_P vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion free for the optical material system II

3-3 oblique case with dispersion effect

In this section we display the two polarization modes S and P, for wide range of incident angles from 10º to 89º with taking effect dispersion of materials coating for system material I and II. Figure (3-3.a) shown the behavior of R_S of system material I compare with normal incident, were R_S increase with increase incident angles in the region near IR and the shape of antireflection change from U shape to W shape this clear when incident angle equal 50 º, for p- polarization mode we see from fig (3-2b)

R_P compared with normal incident decrease with increase incident angles these clear in two regions near IR and UV but at incident angle equal 80º R_P increase than normal incident over all the range of wavelength.

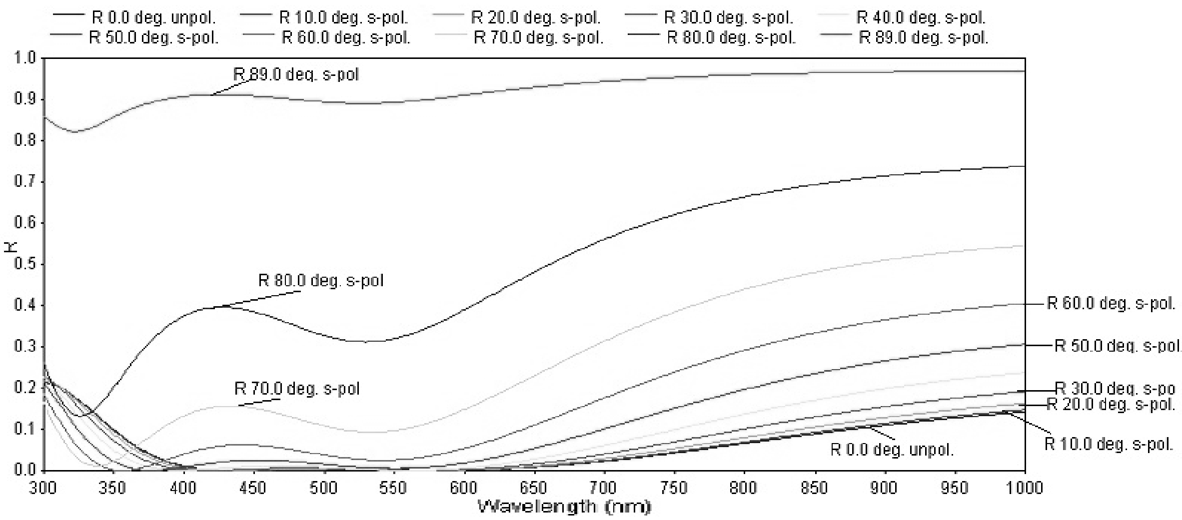

Fig (3-3.a) Reflection R_S vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion effect for the optical material system I

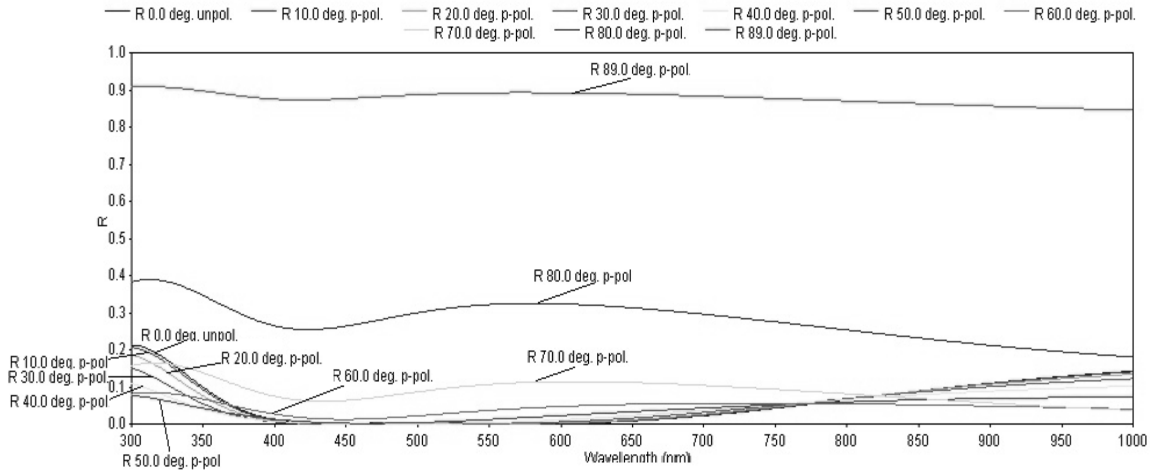

Fig (3-3.b) Reflection R_P vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion effect for the optical material system I

Fig (3-3.c) and Fig (3-3.d) show the demonstrate of R_S and R_P of the optical material system II with dispersion effect of the materials coating. R_S increase with increase incident angles in two regions near IR and UV but at angle equal 50 º the R_S increase

along range of wave length this apparent in fig (3-3.c) this figure also show at incident angles 60º and 70º the form of W antireflection appear clearly. The demeanor R_P of system material II with dispersion effect show in fig(3-3.d) when incident angles increase R_P decrease in two regions near IR and UV region but R_P begin increase along all range chosen of wave length at incident angle equal 70 º

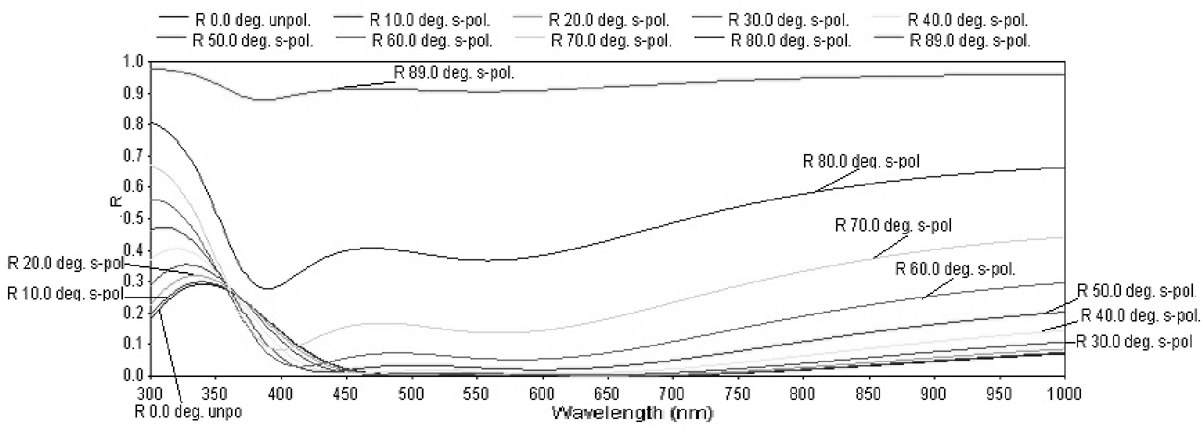

Fig (3-3.c) Reflection R_S vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion effect for the optical material system II

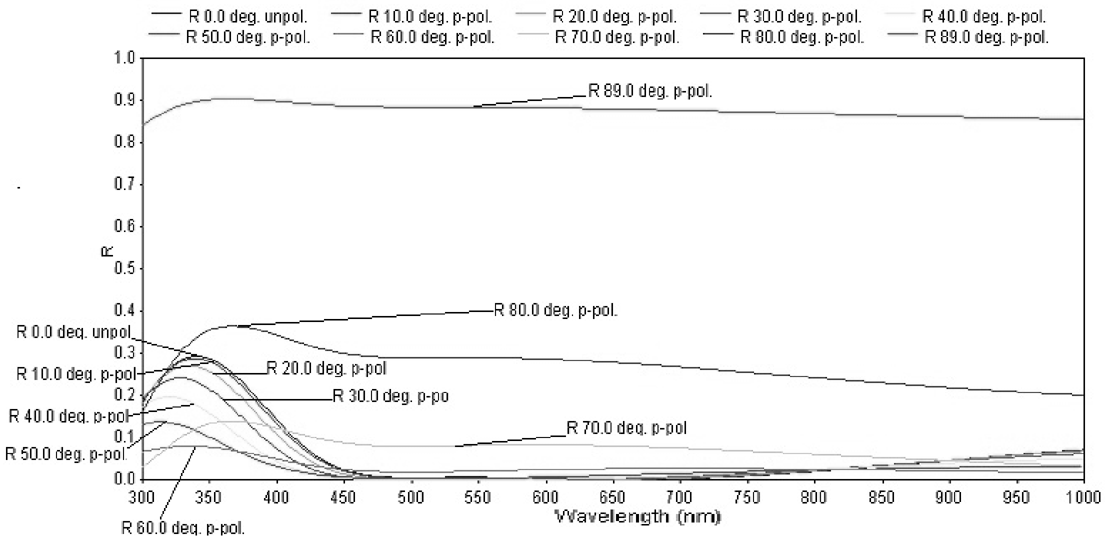

Fig (3-3.d) Reflection R_P vs. wavelength at rang angle of incidence 10º to89º compared with normal incidence, with dispersion effect for the optical material system II

5- CONCLUSION

In this paper, several improvements are introduced for optimizing multilayer antireflection coatings with needle optimization methods using OpenFilters, an open-source program for the design of optical filters.

These results are demonstrate the power of including design ARC's with consideration the effect of dispersion of materials coating in two case normal and oblique light incident. Result presented the effect of dispersion of the materials coating appears clearly in the zone near UV at both oblique and normal incidence this shown for two system materials that chosen, were at normal incidence the reflection peak increases clearly at zone near the UV region . Results mention that the shape of W antireflection appears when we discuss R_s for two systems of materials coating in two case free dispersion and with dispersion effect but been so clarify when we taken the dispersion effect.

References

1- Ozlem Duyar, H¨useyin Zafer Durusoy (2004).Design and Preparation of Antireflection and Reflection Optical Coatings**,** Turk J Phys, 28: 139 -144.
2- Jinn-Moon Yang and Cheng-Yan Kao(2001). Efficient Evolutionary Algorithm for the Thin-Film Synthesis of Inhomogeneous Optical Coatings, Applied Optics,
40: 3256- 3267
3-Dobrowolski. J. A(1995).Optical properties of films and coatings, in Handbook of Optics, M. Bass, ed. ~McGraw-Hill, New York, Chap. 42, pp. 2824–2831

4- Dobrowolski. J. A and Kemp R. A(1990) .Refinement of optical multilayer systems with different optimization procedures,Appl. Opt. **29:** 2876–2893.
5- Li . L and Dobrowolski. J. A(1992). Computation speeds of different optical thin- film synthesis methods, Appl. Opt. **31:** 3790–3799

6- J.A. Hagemana, R. Wehrens a, H.A. van Sprang b(2003). L.M.C. Buydens, Analytica Chimica Acta 490: 211–222.
7- Macleod,H.(2001).Thin -film optical filters,(3rd ed.). Bristol and Philadelphia: Institute of Physics Publication
8- S. Larouche and L. Martinu(2008). OpenFilters: open-source software for the design,optimization, and synthesis of optical filters, Appl. Opt. 47: C219- C230

9- A. V. Tikhonravov, M. K. Trubetskov, and G. W. DeBell(2007).Optical coating design approaches based on the needle optimization technique, Appl. Opt. 46**:** 704–710
10-P. G. Verly(2001).Modified needle method with simultaneous thickness and refractive-index refinement for the synthesis of inhomogeneous and multilayer optical thin films, Appl. Opt. 40**:**5718–5725
11- F. Abelès (1950). Recherches sur la propagation des ondes électromagnetiques sinusoidales dans les milieus stratifies, Ann. Phys. Ser. 12, 5: 706-784.

12-W. G. Driscoll and W. Vaughan (1978). Handbook of Optics (Mc Graw-Hill, New York.

13- A. Thelen, Design of Optical Interference Coatings,McGraw-Hill, New York, 1989.
14-http://www.polymtl.ca/larfis