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OPTIMIZATION MULTI- FUNCTION OF OPTICAL COATING

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ABSTRACT

In this study, non polarized antireflection coating and nonpolarized beam splitter was designed using characteristic matrix method and needle optimization algorithm. Results showed the possibility of using the same coating materials (MgO, MgF_2 and ZrO_2 on a glass substrate), to achieve optimum optical performance for non polarized antireflection and non polarized beam splitters. The results for double and multi-layer designs showed excellent optical performances at 45^o incidence angle for the antireflection coatings and at high incident angle of 85^o for designed beam splitters.

KEY WORDS: Non-polarizing optical coating, multilayer coating, synthesis methods.

INTRODUCTION

Optical interference filters are the most relevant in the advancement of optical coating thin film technology. Their design was based on utilizing interference phenomena to develop efficient optical multilayer system for various applications[1,2]. Optical interference filters were classified according to their optical function whether transmission, reflection, or polarization. They usually consist of thin layers deposited on a substrate, and are used the spectral distribution or the polarization mode of the incident electromagnetic wave to achieve optimized optical performance specifications[3,4]. Interference filters have many applications in optics and optoelectronic such as beam splitters and antireflection coatings [5,6]. In the design of antireflection coatings and beam splitters, it is relatively easer to synthesize normal incidence optical coatings than oblique incidence ones. In normal incidence, the problem of incident beam splitting to s-polarized and p-polarized beams does not exist[7,8]. Oblique incidence highly complicates the matter because of the polarization splitting problem. The effective refractive index divides in two parts η_p for p-modes and η_s for s modes , this adds further complication to the characteristic matrix of the problem because they are two phase shifts related to each of the output beams[3]. A main objective in optical coating design is to optimize the system parameters to achieve a single non polarized output. These objectives not a straight forward task and they can be achieved only for single wavelength or a limited band of wavelength even using well-known optimization techniques. A great deal of research already exists with this respect[9-14]. In this study the optical performance was optimized for two types of optical coatings antireflection coating and Neutral beam splitter based on the same coating materials MgO, Mgf_2 and ZrO_2 on a glass substrate. Double layer non-polarize antireflection coating was designed at working wavelength (632.8nm) at incident angle of (45^o), also a wide band three layers antireflection coating was designed at the same incident angle . Using the same basic coating materials, a high incident angle (85^o) beam splitters was designed using two and three layers. This work uses matrix theory and needle algorithm for optimization procedure.

Analytical Theory

For an oblique incident ray on a thin film configuration, there are two linearly polarized reflected (Refracted) components, one for the (TE) or s mode and the other for (TM) or p mode. Thus, there are two effective refractive indices $\eta s_{\text{and}}\ \eta_{p\ [3]}$

For the s mode

$\eta_s = n \cos\theta$ __1-a

and for the p mode

$\eta_{p\ .=}\ n / \cos\theta$ --------1-b

Where n is the layer refractive index, and θ is the refraction angle.

For one layer the characteristic matrix is defined by the following

$$\begin{bmatrix} c \\ b \end{bmatrix} = M_{s,p} \begin{bmatrix} 1 \\ ng \end{bmatrix}$$

Where $\frac{c}{b}$ is the admittance, ng is the refractive index of substrate

$$M_{s,p} = \begin{bmatrix} \cos\delta\, s,p & i/\eta s,p\ sin\delta s,p \\ i\eta s,p & \cos\delta\, s,p \end{bmatrix}$$

Where each of s and p polarization components has its own characteristic omit of matrix, M_s for the s component and M_p for the p component. The $\delta s,p$ is the effective phase thickness which is given by $\delta s,p = 2\pi/\lambda\ \eta s,p$ d cosθ, Where d is the physical thickness of layer.

The general final matrix for an assembly omits system is product of individual characteristic matrices, *i.e.*

$$\begin{bmatrix} c \\ b \end{bmatrix} = M_l M_{l-1} \ldots M_3 M_2 M_1 \begin{bmatrix} c \\ b \end{bmatrix} = M_{s,p} \begin{bmatrix} 1 \\ ng \end{bmatrix}$$

M is the characteristic of matrix for the $_i$th layer

The reflectance R of the assembly is given by [3,15]

$$R=\left(\frac{\eta o\ c-b}{n0\ c+b}\right)\left(\frac{n0\ c-b}{n0\ c+b}\right)^{*}\text{---------------}2$$

η_o refers to the indices of the incident medium

Needle optimization approach

Starting for the initial coating design, layers having zero thickness are added, then they are grown using local minimum optimization until an optimum design is achieved were no further layers can be allowed to grow[10]. This numerical procedure is assessed by minimizing the merit function which expressed as:

$$MF=\left[\frac{1}{q}\sum_{i=1}^{q}\left[\frac{N_i^{\ T}-N_i^{\ C}}{¢N_i}\right]^2\right]^{1/2}$$

Where q is the number of grid points and $N_i^{\ T}-N_i^{\ C}$ is the difference between the desired and computed reflectance values at a chosen wavelength and mode of polarization. The reciprocal of the tolerance $¢N_i$ is the weight [11].

RESULTS & DISCUSSION

Percentage reflectance (R) of Bk7 glass as a function of incidence angle θ is shown in figure 1. It seen that s and p components are nearly indistinguishable for normal incidence ($\theta \approx 0^0$ with very small R), and grazing angle ($\theta \approx 90^0$ with $R\approx 1$).

The reflectance for the s component increases with θ but for the p component it decreases until it reaches $R \approx 0$ at the "Brewster angle" ($\theta \approx 56.6^0$) then it increases, the rate of increase gets higher near the grazing angle for s and p states .

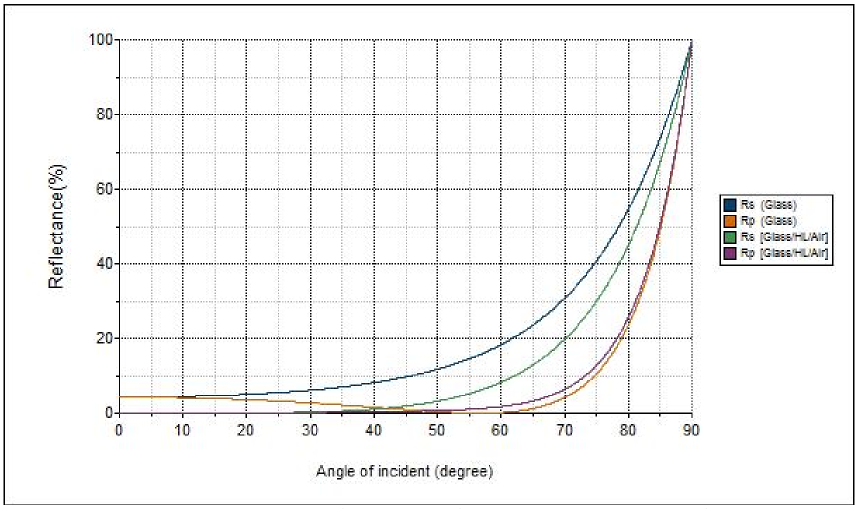


FIGURE 1: Reflectance R_S and R_P versus angle of incidence for substrate(glass)and for double layer as stacks design Glass /HL/ Air

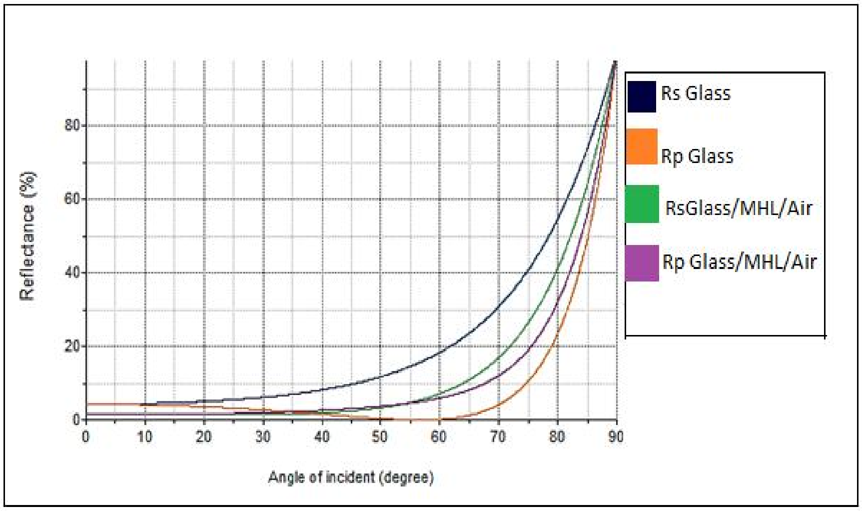
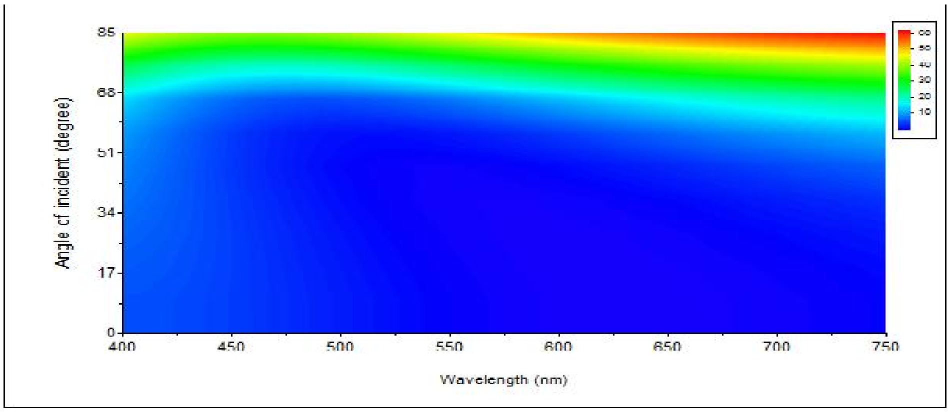


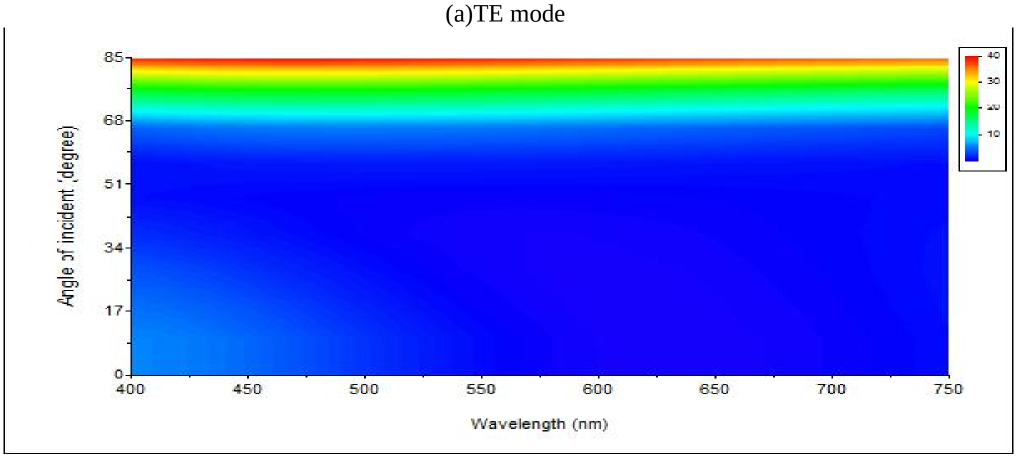
FIGURE 2: Reflectance R_S and R_P versus with angle of incidence for substrate (glass)and multilayers design stack Glass /MHL / Air

Also in figure 4.1 is shown the results for the double layer design Glass /HL/ Air, where H and L represent high and low index materials respectively, MgO (n_H=2.58) and MgF_2 (n_L=1.38)[16] at λ_0 =632.8 nm deposited on glass substrate (n_s=1.52). The s and p mode reflectance is ≈0 for incident angle θ ≈(0–40^o) where there behavior become distinguished in a less noticeable manner compared to the glass results then the reflectance starts to increase for ≥ 40^o until reaching unity at θ ≈90^o. The Reflection (R) of three layer coating as a function of incident angle for stacks Glass /HML/Air is shown in figure (4.2). ZrO_2 (n_H=2.58), MgF_2 (n_L=1.38) and MgO (n_M=1.73) as material coatings [16], where M is the quarter wave optical thickness of medium value for the refractive index. A nearly similar behavior to the double layer system was found but the s and p modes are more distinguished.

Reflection at oblique incident for stakes Glass /HL/ Air and Glass /HML/ Air computed with aid matrix method and result shown in figures 4.3, 4.4 respectively , using Teraplot [17].

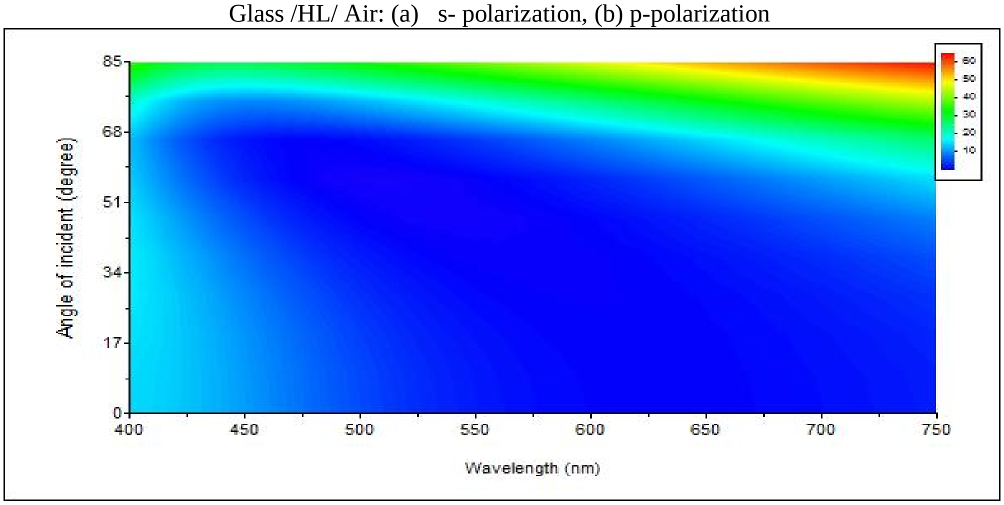


(a)TE mode

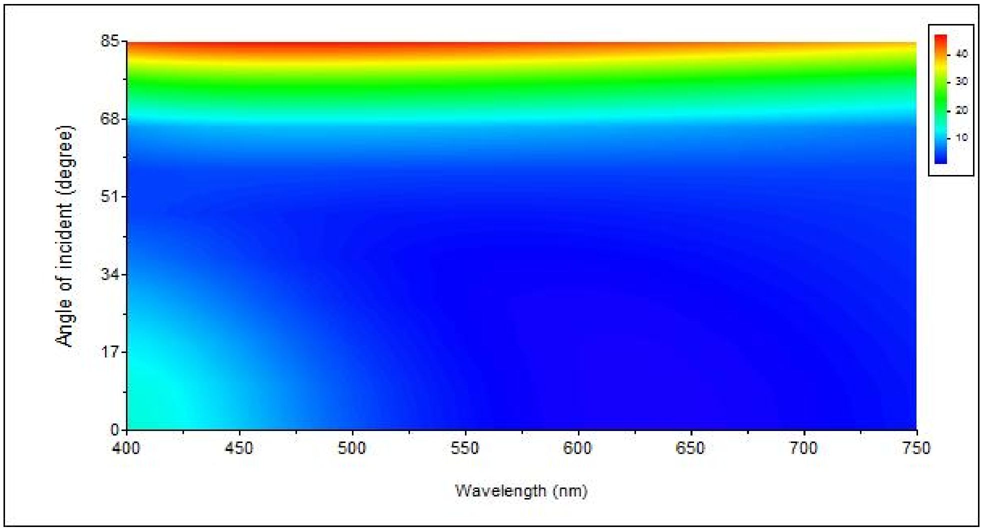


(b) TM mod

FIGURE 3: Reflectance vs. wavelength and angle of incident, for the design Glass /HL/ Air: (a) s- polarization, (b) p-polarization



(a) TE Mode



(b) TM mode

FIGURE 4: Reflectance *vs*. wavelength and angle of incident, for the design Glass /MH L/ Air: (a) s- polarization , (b) p-polarization

For graphs figures 3 and 4 show the variation of angle of incidence with wavelength also depicting the reflectance levels using Teraplot. For the figure 4 double layer design (glass/HL/air) .The reflectance is relatively lower for the TM mode for all incident angle value (θ= 0-85^o). It is also seen that there is a trend toward higher reflectance value at the same θ when the wavelength increases for TE mode, while there appears a reverse behavior for the TM mode but in ales noticeable fashion .In figure 4.4 a similar trend appears for the three layer design (glass /MHL/air) with minute difference towards relatively more sensitive dependence of the reflectance on wavelength .

All the above results are obtained using analytical expressions where quarter optical thickness of thin film is assumed. For optimized design optical coating we use the needle technique for design two type of non polarized interference filters at design wave length 632.8nm

Figures 5 and 6 showed the non polarization antireflection coating design for double layer and multilayers respectively. The best optimized results using needle method are obtained for non quarter thickness stacks designs (glass/1.099H 1.16L/Air) for double layer design and (glass/1.17M 2.06H 1.11L/Air) for triple layer design. In figure 4-5 the separation between the s and p modes is minute at the single working wavelength of 632.8 nm while for the triple layer design a wide band of ≈ (600-750)nm is achieved as clearly in figure .4.5 .

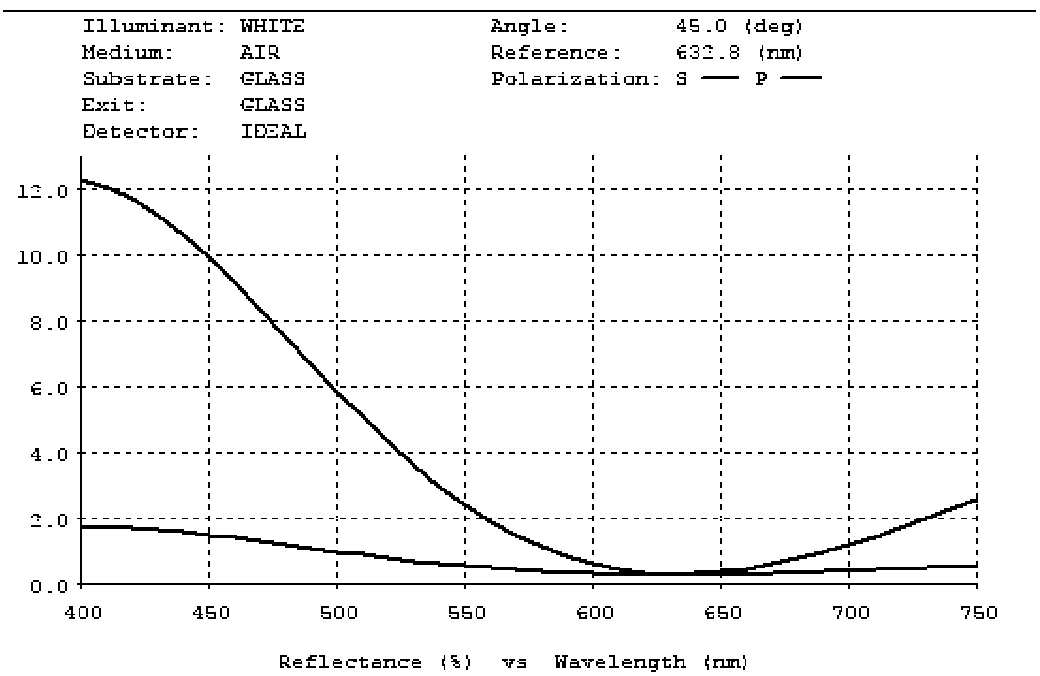


FIGURE 5: optical performance of non polarized double layer antireflection coating for stacks Glass/1.099H 1.16L/Air

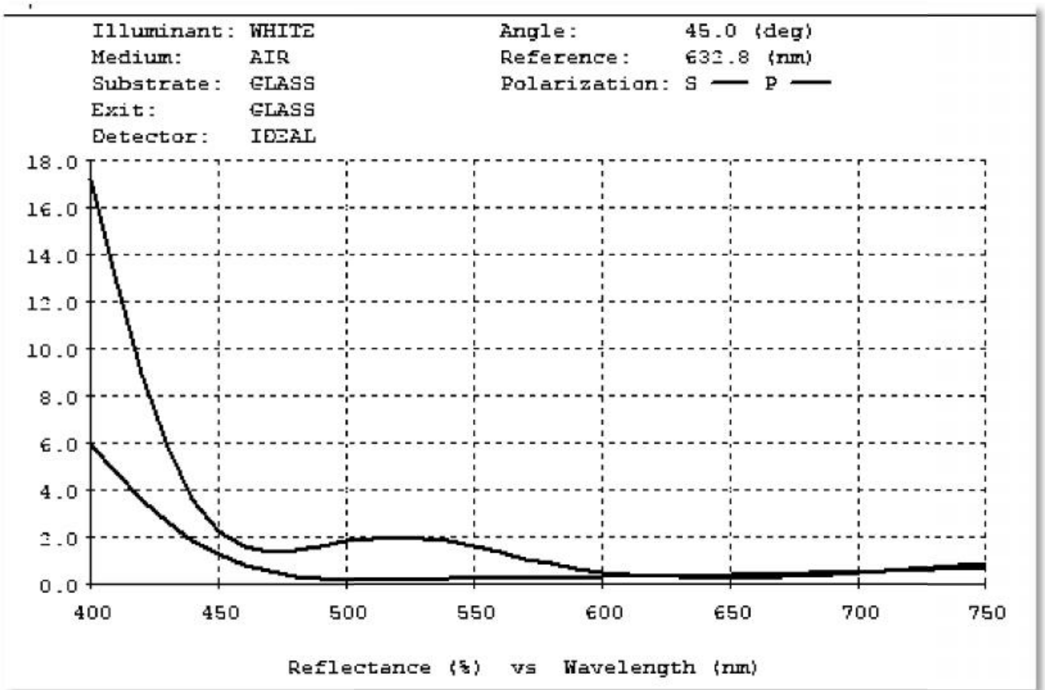


FIGURE 6 :optical performance of non-polarized multi-layer antireflection coating for stacks glass/1.17M 2.06H 1.11L/Air

The results appears non polarize beam splitter design are shown in figures 4.7 and 4.8

For double and triple layers coatings (Glass/1.2341H 1.44L/Air) and (glass/3.3M 0.6H 1.3L/Air) at high incidence angle of 85^{o} respectively. For the double layer non-polarize beam splitter design figure 7 a single wavelength nearly natural (55%) was achieved for the optimized configuration mentioned above.

Figure 4.8 shows the triple layers optimized design non polarize beam splitters where near neutrality (55%) is achieved for a wavelength band of $560\,nm < \lambda > 650\,nm$

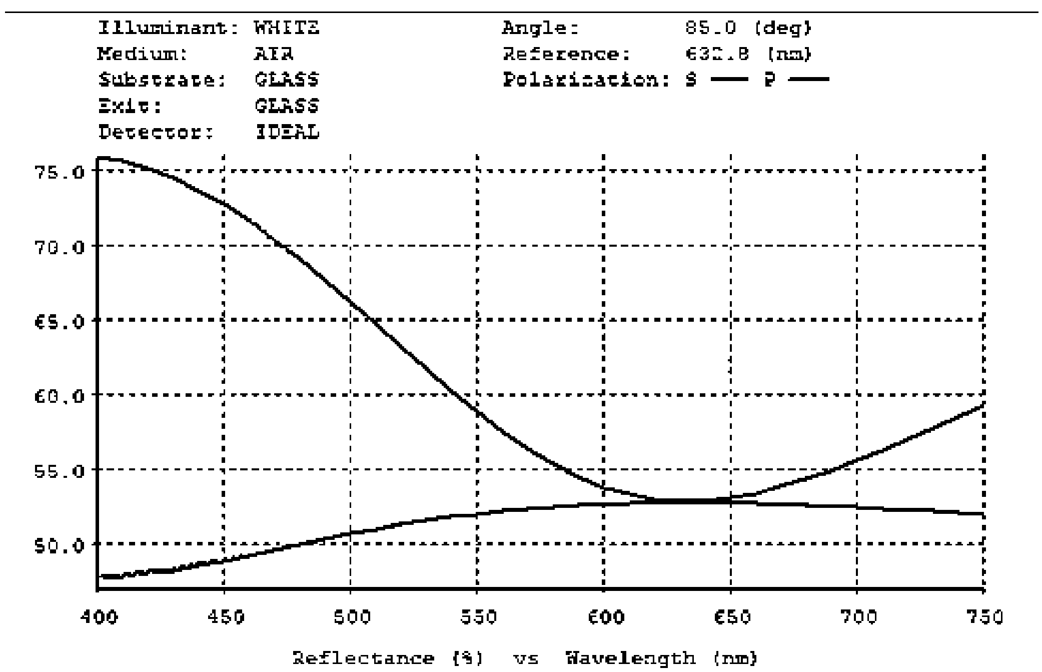


FIGURE 7: optical performance of non-polarized neutral beam splitter for stacks glass/1.2341H 1.44L/Air at incident angle 85^{o}

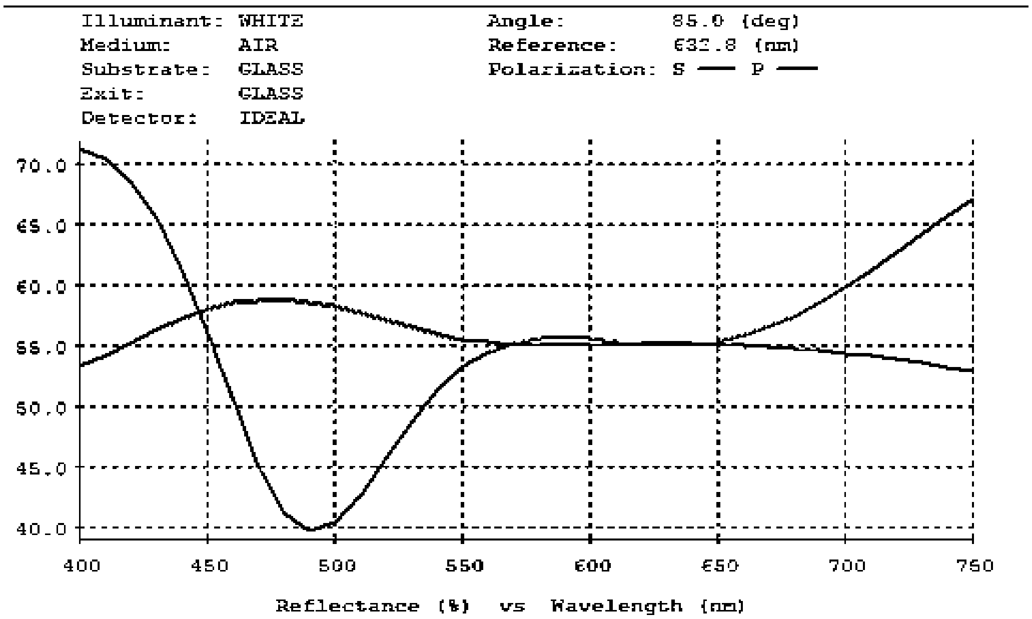


FIGURE 8: optical performance of non-polarized beam splitter for stacks Glass/3.3M 0.6H 1.3L/Air at incident angle 85^o

Figures from 5 to 8 appears improve stacks with few layer coating at incidence angle (45^o)and (85^0) while the reference[5] (Willey) results was done by increase the number of layers or support the configuration system stacks with metal layer to achieve desert performance at specific wave length.

CONCLUSION

In this work we managed to get optimal nonpolarizing designs for antireflection and beam–splitter coating configurations, using small numbers of layers, *i.e.* Double-layer and triple layers designs based on similar materials MgO, MgF_2 and ZrO_2 on glass substrate. For the antireflection coating, the double layer design (Glass/ 1.099H 1.16L/Air) showed no signification splitting between the s and p components at λ_o = 632.8 nm, while the triple design (Glass/1.17M 2.06H 1.11L/Air) showed good optical performance in a broad wavelength range. For the beam splitter a high level of neutrality was achieved for s and p components at the working wavelength for the double layer configuration (Glass/ 1.2341H 1.44L/Air) and for a relatively broad range of wavelengths for the triple layer congregation Glass/ 3.3M 0.6H 1.3L/Air.

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