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# Design of non-polarizing Antireflection Coating in visible Range 300-800 nm

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**Abstract**— We demonstrate a special construction stacks that produce design non-polarizing AR coating. This stacks allowing design tilted V-type AR coating and tilted broadband AR coating. In this paper, designed non-polarized broadband anti-reflection coating that have the same reflection for both S-and P-polarizations for a specific range of incidence angles, can be achieved. With the aid of a matrix formula design a double layer and multilayer non-polarizing anti-reflection coatings in visible range (300-800 nm) illustrated.

**Key words** — Non-polarizing coatings, Multilayer design, Anti-reflection coatings, Optical coating design.

## 1 INTRODUCTION

Anti Reflection coating (ARC) is the most used optical coating to suppress undesired wavelengths and enhanced the transmissions in optical components and devices [1]. Antireflection (AR) coatings make up more than 50% of the total optical thin-film market [2]. It is not surprising, therefore, that a great number of publications are devoted to this topic. Reducing the reflection of surfaces is important in many applications [3]. such as telecommunications, medicine, military products, sunglasses sunlight readable displays, architectural windows, display cases, projection port windows & sight glasses [4,5].

At oblique incidence of light, the optical performance is affected because of polarization phenomenon.The polarization is expressed in terms of the two modes, P- and S-polarization, characterized by the electric vector parallel and normal to the plane of incidence respectively.

The optical performance for S- and P-polarized light are different in dielectric thin films because the refractive indices of coating layer have a different function to the angle of incidence thus reflectance of S- and P-polarized light tends to be different [6,7].

It is challenge to achieve non-polarizing antireflection coatings that have the same reflection performance for both S- and P-polarizations at specific rang of incident angles. This which we have achieved and will illustrate in section 3.
We have design several different construction design stacks of non-polarizing antireflection coatings for visible region (300-800 nm).

Also, obtained optimal designs of non-polarizing anti-reflection by using multilayer thin films with different refractive index and controlling thickness of each layer at a specific range of incident angles.

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## 2 THEORY

The general formulation of calculating the spectral reflectance profile for thin films structures based on a characteristic matrix .The characteristic matrix approach was employed for q-layer design of antireflection coating, the main idea of this approach is matching the E- and H-fields of the incident light on the interfaces of multilayer. simply is the product of individual matrices for the individual layers of assembly taken in the correct order, which is given by [8,9]:

$$\begin{bmatrix} C \\ B \end{bmatrix} = \left( \prod_{r=1}^{q} \begin{bmatrix} \cos\delta_r & (i\sin\delta_r)/n_r \\ in_r\sin\delta_r & \cos\delta_r \end{bmatrix} \right)$$

where, C and B are normalized total tangential electric and magnetic fields respectively at the input surface.
q is the number of layers next to substrate
$\delta r = 2\pi\, n_r\, d_r \cos\theta o / \lambda o$
$n_r$, $d_r$ are refractive index and physical thickness of layer
($\theta_o$) is angle of incident
$\lambda_o$ is design wavelength
$n_S$ is the refractive index of the substrate

$\begin{bmatrix} B \\ C \end{bmatrix}$ is defined as the characteristic matrix of the assembly.

As it is mentioned previously that at oblique incidence there are two modes of wave, S-polarization and P-polarization so the refractive index should be modified as following [6,10]:

$\eta_p = n / \cos\theta$ the effective refractive index for P-polarization (3)

$\eta_s = n^* \cos\theta$ the effective refractive index for S-polarization (4)

The reflectance of the multilayer system is obtained by following:

$$R=\left(\frac{\eta_o B-C}{\eta_o B+C}\right)\left(\frac{\eta_o B-C}{\eta_o B+C}\right)^* \quad (5)$$

$\eta_o$ effective index of incident medium

The necessary and sufficient conditions to produce zero reflectance are calculated as following [8,9]:

For a double layer
$n_1^4 = n_o^3$ , $n_2^4 = n_o n_S^3$ (6)

For a three layer
$n_1^8 = n_o^7$ ; $n2^8 = n_o^4 n_S^4$ ; $n_3^8 = n_o n_S^7$ (7)

$n_o$, the refractive index of the incident medium
$n_1$, $n_2$, $n_3$, refractive indices of the 1st,2nd and 3rd coating layer.

## 3 DESIGNS AND DISCUSSION

In this work, we designed two kinds of non polarizing AR coating double and multilayer coating, for visible region (300-800 nm) at $\lambda o$=550 nm. Adopted glass as substrate with utilizing coating materials that are shown in Table (1) .

Table (1) coating materials deposited on glass as substrate

| Configuration | Materials | Refractive index |
|---|---|---|
| Double layer | MgF2 | 1.38 |
| | MgO | 1.7 |
| Multilayer | $MgF_2$ | 1.38 |
| | $ZrO_2$ | 2.15 |
| | MgO | 1.7 |

### 3.1 Double Layer Non-polarized Antireflection Coating

Design non-polarized anti-reflection coating with low reflection at specific wavelength (design wavelength 550nm) which have optical performance of V-type shown in Figures (1-4). These Figures appears successfully new stacks for design non polarization anti-reflection coatings that have the same reflection for both S and P-polarizations at range of incident angles.

Where Figure (1) demonstrates the optical performance and design construction stack of non-polarized anti-reflection coating at incident angle $\theta_o$ =30$^o$ , where we got zero reflection at wavelength design with high similarity in optical performance for S and P-polarization.

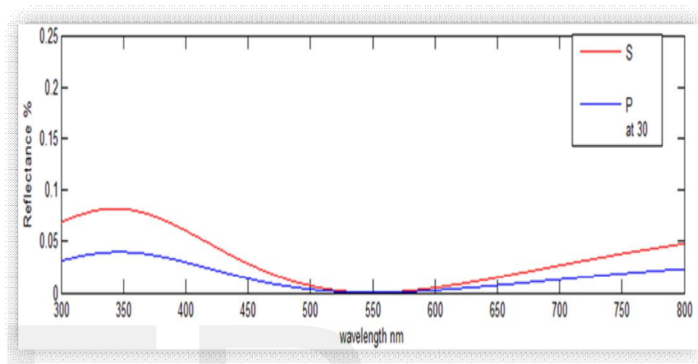


Figure (1) optical performance of non polarization ARC, $\theta_o$=30$^o$ with construction design stack: Air | 1.0729 L | 1.0463 H | Glass

At $\theta_o$ =45$^o$ we obtained design of non-polarized antireflection coating where both S and P approach to zero reflectance at wavelength design as shown in Figure (2). Also, this Figure appears the optical performance and design construction of such design.

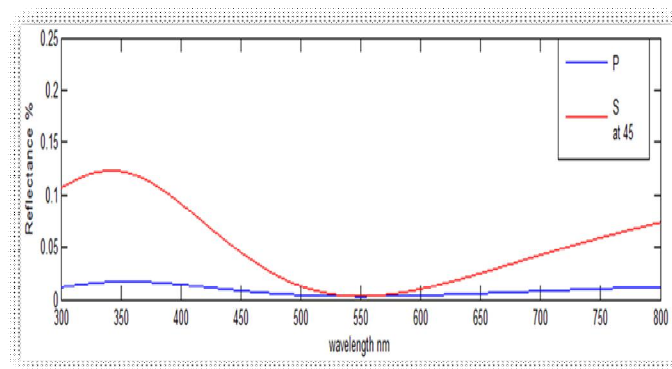


Figure (2) optical performance of non-polarizationantireflection coating at $\theta_o$ =45$^o$ with construction design stack : Air | 1.1645 L | 1.0996 H | Glass

In general when angle of incidence is increased that leads to increase reflectance with shifting toward shorter wavelengths this shifting may be as result of varying the optical thickness of layer due to the oblique incidence of plane electromagnetic wave.

In this work we have submitted new construction stacks design of non-polarized anti-reflection at high incident angles where their optical performance are characterized by very low increasing of the reflection value and overcoming the problem of shifting towards shorter wavelength as shown in Figures (3),(4).

Figures (3) demonstrates the optical performance and construction design of non-polarized anti-reflection at $\theta_o$ =50$^o$ Where we got very low reflection at design wavelength without splitting between S-P polarization and as its obvious that is no shifting.

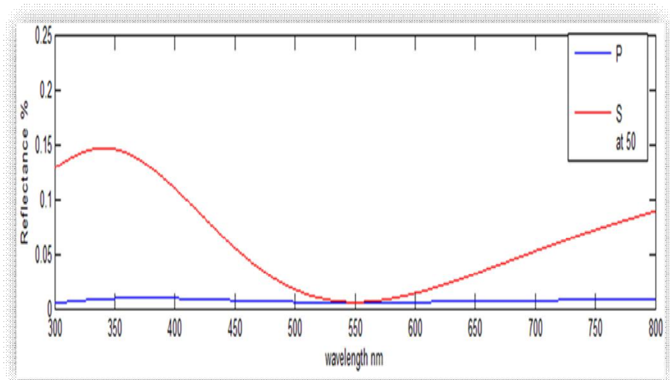


Figure (3) optical performance of non polarizationan antireflection coating at $\theta_o$ =50$^o$ with construction designstack: Air | 1.2022 L | 1.1202 H | Glass

When the incident angle increases to θo =60o the reflection have increased to 0.021 but we still achieved good reducing in reflection of glass surface. Also, it's clear that we have overcome the problem of shifting as shown in Figure (4) with submitting construction design stack of such optical performance.

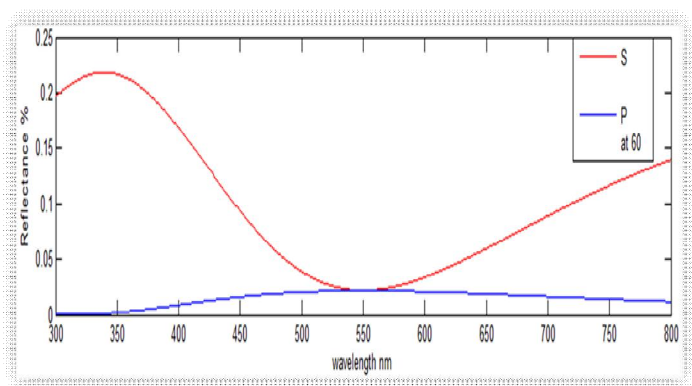


Figure (4) optical performance ofnon polarization an antireflection coating atθo =60o with construction design stack: Air | 1.2844 L | 1.1621H | Glass

### 3.2 Multilayer Non-polarized Anti-reflection Coating

In this part we designed a broadband antireflection in case of oblique incidence for different angles. Adopting glass as substrate with materials coatings utilize in Table (1).

Figures (5-8) appears designs of non- polarized broadband antireflection coating which they have the same reflection for both "S and P-polarizations" at specified angles. Figure (5) present a special construction design stack and the optical performance of non-polarized broadband anti-reflection coating at $\theta_o$ =30$^o$. Where we got zero reflection for both S and P modes over a wide range of wavelengths relatively equal (350 nm).

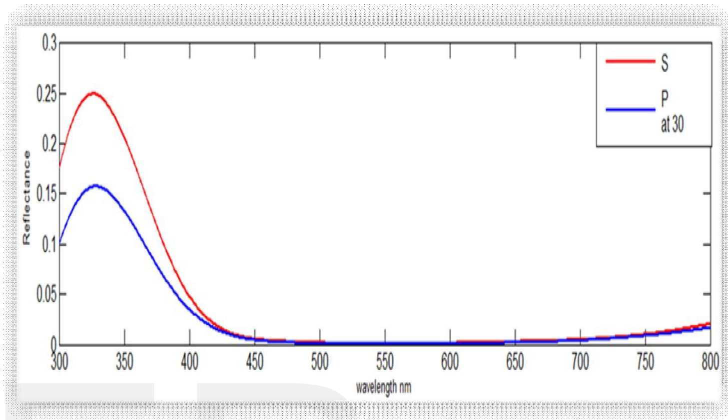


Figure (5) optical performance of non- polarized broadband antireflection coating at $\theta_o$ =30$^o$ with construction design stack :
Air | 1.0729 L | 1.0282 (2H) | 1.0463 M | Glass



At $\theta_o$ =45$^o$ we obtained design of non-polarized antireflection coating where S and P-polarizations are the same low reflection approach zero along wide range of wavelengths as shown in Figure (6) .

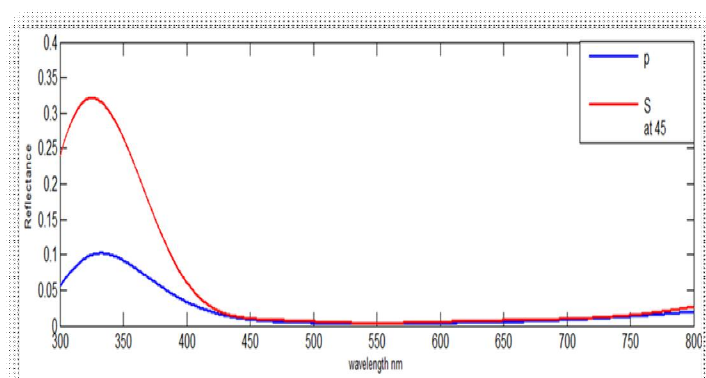


Figure (6) optical performance of non-polarized broadband antireflection coating at $\theta_o$ =45$^o$ with construction design stack: Air | 1.1645L | 1.0589 (2H) | 1.0996 M | Glass

As we mentioned previously that when angle of incidence increase reflectance is increased.We passed this and submitted new construction design stacks of non-polarized broadband anti-reflection coatings at high incident angles with low reflection along wide range of wavelengths as appears in Figures (7),(8).

Figure (7) shows a schematic of the optical performance and construction design stack of non-polarized broadband at $\theta_o$=50°. With a band width extended from 426 to 800 nm. Where we got very low reflection without splitting between S-and P polarization and as its obvious that is no shifting.

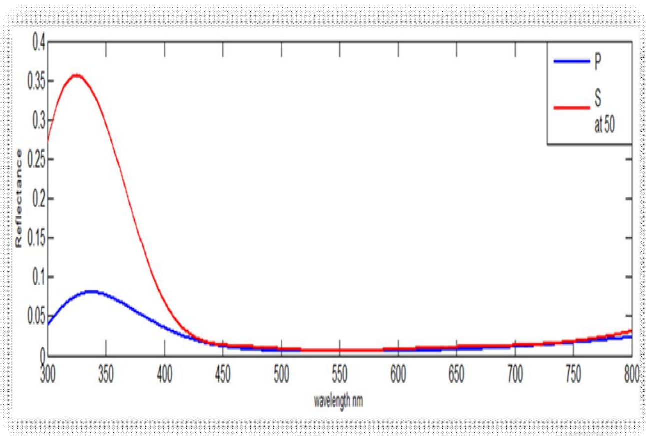


Figure (7) optical performance of ofnon- polarized broadband antireflection coating at $\theta_o$ =50° with construction design stack : Air | 1.2022 L | 1.0702 (2H) | 1.1202 M | Glass

When the incident angle increase to $\theta$o =60o we achieved good optical performance of non- polarized broadband ARC over wide band extended to 800 nm as appears in Figure (8).

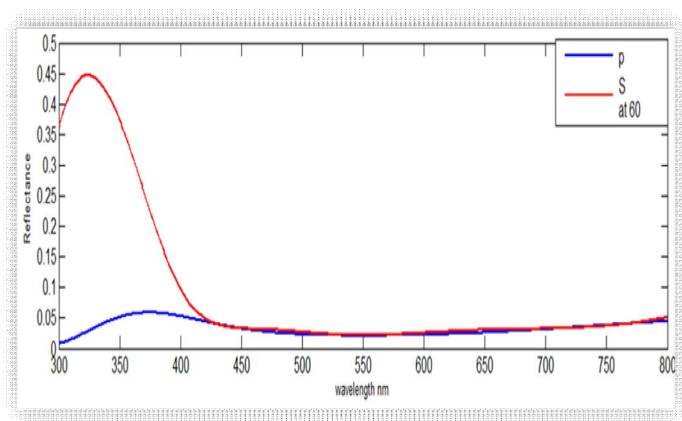


Figure (8) optical performance of ofnon- polarized broadband antireflection coating at $\theta_o$ =60° with construction design stack: Air | 1.2844L | 1.0926 (2H) | 1.1621M | Glass

## 4 CONCLUSION

This study has presented new construction design stacks of nonpolarizing anti-reflection coatings for visible region (300-800 nm). Successfully we got optimal optical performance of non-polarizing (v-coated ) and broadband anti-reflection for different value of incident angles. Result refers that overcome the problem of splitting between S and P-polarization with increasing incident angle. Also, result presented designs of non-polarizing broadband antireflection coatings at higher incident angles.

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