DESIGN AND SIMULATION ANTIREFLECTION COATING FOR LASER ND:YAG (1064NM) WAVELENGTH AND HAS MULTIFREQUENCY (532,355NM) ON GLASS SUBSTRATE

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Abstract

In this study, antireflection coatings were designed and simulated, optical reflection values deduced with a matrix formulation via computer program was written in matlab (Ver.7), a five materials were selected to reduce reflection from the surface of glass optical system which is using in single , double and triple frequency of laser Nd-YAG .

The results show, In single layer antireflection coating, the reflection have been reduced but only one or two minima reflection, In double layer antireflection coating, two zero reflection were found at wavelengths of the laser Nd-YAG, In three layer antireflection coating the best results were found, two minima reflection were found at (532,1064 nm) and zero reflection at (355 nm) it is agreement with condition design.

Introduction

Antireflection (AR) optical coatings have long been developed for a variety of applications in all aspects of use; for optical and electro-optical systems in telecommunications, medicine, military products and consumer products. AR coatings have been widely used in many applications including glass lenses, eyeglasses, lasers, mirrors, solar cells, IR diodes, multipurpose broad and narrow band-pass filters, architectural and automotive glass and displays such as cathode ray tubes, as well as plasma, liquid crystal and flat panel displays. In addition to reduce damage of optical device by high power laser [1-5].

The low reflection index of glass causes important reflection loss from its surface, even in thin film form. Therefore, its surface should be coated with an antireflection coating to reduce the reflectance or to increase the transmittance. The principle of the single and multilayer antireflection coatings is based on the destructive interference of light reflected from the interfaces of the coating layers [11].

The aim of this study we have designed several different forms of antireflection coatings on BK7 glass substrate which has broadband transmittance wavelengths between range (300nm-3000nm) [17], these forms are optimized by varying the refractive index , optical thickness and angle incidence to produce optimum antireflection on glass optical system such as lenses , prism and plat which is using in high power laser Nd-YAG wavelength and has double and triple frequency .

Theory and Numerical Design of Antireflection coatings

The optical matrix approach was employed for *N*-layer design of antireflection coating. The main idea of this method is matching the *E* and *H* fields of the incident light on the interfaces of multilayer optical coatings. The matrix relation defining the *N*-layer antireflection coating problem is given by [12]

$$\begin{bmatrix} B \\ C \end{bmatrix} = \left\{ \prod_{j=1}^{N} \begin{pmatrix} \cos\delta_j & i\sin\delta_j/n_j \\ i n_j \sin\delta_j & \cos\delta_j \end{pmatrix} \right\} \begin{pmatrix} 1 \\ n_s \end{pmatrix} \quad \text{...(1)}$$

where B and C are total electric and magnetic field amplitudes of the light propagating in the medium and j=1,2,3,………N-layer, ns refractive index of substrate, n_j refractive index for each layer and δ_j =phase thickness. Thus optical admittance is given by the ratio

$$Y=C/B \quad \text{..(2)}$$

Characteristic matrices are usually used to calculate the reflectance of an assembly of thin film layers. The characteristic matrix at a wavelength λ for the assembly of N layers is given by

$$M = M1M2 \ldots M_N \quad (3)$$

Thus, each layer is represented by a 2X2 matrix M, of the form

$$Mj = \begin{pmatrix} \cos\delta_j & i\sin\delta_j/n_j \\ in_j\sin\delta_j & \cos\delta_j \end{pmatrix} \quad (4)$$

The phase thickness δ_j given by [7]

$$\delta_j = 2\pi n d_j \cos\varphi/\lambda \quad (5)$$

where φ angle of incident light on top surface layer with the physical thickness of the layer being d_j ,then the reflection coefficient r and the reflectance R are, respectively, given

$$r = \frac{n_0 - Y}{n_0 + Y} \quad (6)$$

$$R = \left(\frac{n_0 - Y}{n_0 + Y}\right)\left(\frac{n_0 - Y}{n_0 + Y}\right)^* \quad (7)$$

where

$$R = r x r^* \quad (8)$$

and n_o= refractive index of air.

Single-layer antireflection coatings

According to the double layer AR coating theory for nonabsorbing films and for normal incidence of light, the matrix equation becomes [7],

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{pmatrix} \cos\delta_1 & i\sin\delta_1/n_1 \\ in_1\sin\delta_1 & \cos\delta_1 \end{pmatrix} \quad (9)$$

Double-layer antireflection coatings

According to the double layer AR coating theory for nonabsorbing films and for normal incidence of light, the matrix equation becomes [12],

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{pmatrix} \cos\delta_1 & i\sin\delta_1/n_1 \\ in_1\sin\delta_1 & \cos\delta_1 \end{pmatrix} \begin{pmatrix} \cos\delta_2 & i\sin\delta_2/n_2 \\ in_2\sin\delta_2 & \cos\delta_2 \end{pmatrix} \quad (10)$$

Three-layer antireflection coatings

According to the double layer AR coating theory for nonabsorbing films and for normal incidence of light, the matrix equation becomes [12],

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{pmatrix} \cos\delta_1 & i\sin\delta_1/_1 \\ in_1\sin\delta_1 & \cos\delta_1 \end{pmatrix} \begin{pmatrix} \cos\delta_2 & i\sin\delta_2/n_2 \\ in_2\sin\delta_2 & \cos\delta_2 \end{pmatrix} \begin{pmatrix} \cos\delta_3 & i\sin\delta_3/n_3 \\ in_3\sin\delta_3 & \cos\delta_3 \end{pmatrix} \begin{bmatrix} 1 \\ n_s \end{bmatrix} \quad (11)$$

Solution of single-layer antireflection coatings

From (5), (7),(9) The reflectance reduced to zero R=0 and at normal incident then equation became

$n_1 = (n_s n_o)^{1/}$ ....(12)

where $n_0=1$ for air and $n_s=1.53$ for BK7glass

$n_1=1.23$, so the materials ($MgF_2=1.38$) have been selected for top layer antireflection antireflection coating in our program [14].

Solution of Double-layer antireflection coatings

From (5), (7), (10) The reflectance reduced to zero R=0 and at normal incident then equation became

$n_2/n_1 = (n_s n_o)^{1/2}$ ....(13)

where $n_0=1$ for air and $n_s=1.53$ for glass

$n_1 = 1.38$

so must be select materials have refractive index about 1.5, the materials ($MgF_2=1.38$) have been selected for top layer antireflection antireflection coating in our program [12].

$n_2 = 1.7$

so must be select materials have refractive index about 1.7 ,the materials ($CeF_3=1.7$, $SiO_2=1.44$) have been selected for bottom layer coating in our program [15].

Solution of three-layer antireflection coatings

From (5), (7), (11). The reflectance reduced to zero R=0 then

$n_1 n_3 = n_2 (n_o n_s)^{1/2}$ ....(14)

for n_1 was selected materials ($MgF_3=1.38$) n_2 was selected materials ($TiO_2=2.2$)[14].

n_3 was selected materials (La_2O_3=1.95) [15].

Simulation by Matlab

The simulation of the reflection in matlab have been the main assignment of this work, The reflectivity of the glass has been simulated with one two, three layers of antireflection coatings the program optimize at λo=550nm central wavelength for double and three layer coating.

The parameters of antireflection

1- Optical thickness for each layers.
2- Reflection index for each layer coating and substrate.
3- Angle incidence of light .[13].

The materials must be select that Low wave absorption, Homogeneity, High packing density, Good adhesion, Low stress, Hardness and ability to survive in deferent environmental, Low cost and easy preparation. [10, 11].

Result and Discussion

The reflectance of the light from the glass surface is 4.2% to reduce the reflectance must be coating the glass with optical materials.

Single layer antireflection coating:

The Fig.(1) show reflectance spectra of single layer coating with MgF_2 dielectric material

Fig.(1) show reflectance spectra as function of wavelength for the single layer antireflection a quarter wave optical thickness at central wavelength λ_o=550nm, the MgF_2 coating which is shown in the figure decreased the reflectance of the glass surface from 4.2% to 1.2% at wavelength 532nm which is double frequency of the laser Nd-YAG , the thickness of the MgF_2 coating must be 96.3nm corroding to equation(5)

$$nd = \lambda/4 \qquad (15)$$

where d= thickness of the coating, n refractive index of the coating.

Fig.(2) show reflectance spectra as function of wavelength for the single layer antireflection a quarter wave optical thickness at central wavelength λ_o=350 nm , the MgF_2 coating which is shown in the figure decreased the reflectance of the glass surface from 4.2% to 1.2% at wavelength 355 which is triple frequency of the laser Nd-YAG , the thickness of the MgF_2 coating must be 64.3 nm corroding to equation (5).

Fig.(3) show reflectance spectra as function of wavelength for the single layer antireflection a quarter wave optical thickness at central wavelength λ_o=1050 nm , the MgF_2 coating which is shown in the figure decreased the reflectance of the glass surface at two wavelength the first at 335 nm the reflectance is reduced from 4.2% to 1.2% and second at 1046nm the reflectance is reduced from 4.2% to 1.2% which is wavelength of the laser Nd-YAG , the thickness of the MgF2 coating must be 192.7 nm corroding to equation (5).

The Figs.(1, 2, 3) is good agreement with condition (12) and suitable to coat the optical system (such as lenses , prism, plate , …..etc) which are made by the glass , but the problem of those form is reduced the reflectance only at one and two wavelength and there wasn't zero reflectance.

Double layer antireflection coating

The single layer coating couldn't achieve zero reflectance and only one or two minima reflectance, so that high index material layer placed next to the substrate might make it appear to have higher index so a subsequent layer of low index material would more effective.

Fig.(4) show reflectance spectra as function of wavelength, double layer antireflection coating. Four forms are designed by changed optical thickness.

a-curve that illustrated in Fig.(4) uncoated glass , the reflectance of the glass is 4.2%.

b-curve that illustrated in Fig.(4) has zero reflectance only at central wavelength and the curve as V-form. It is useful only to coat glass optical system surface that using in double frequency of Nd-YAG.

c-curve half-quarter optical thickness the figure are illustrated , two minima reflectance the first at 355 nm is 1.2% and at 1064 nm is 0.5% , this form antireflection is suitable to coat glass optical system only at single and triple frequency of laser Nd-YAG.

d-curve has broadband antireflection in range between wavelength (400-900 nm), this curve.

e-curve that illustrated in figure has two zero reflectance in two region, the first at 355nm and the other at 1064nm this form antireflection is just suitable to reduce the reflection of glass optical system which is using only in single and triple of laser Nd-YAG .

Fig.(5) show reflectance spectra as function of wavelength , in this figure , the second layer are charged with SiO_2 (n_2=1.44) it has refractive index lower than of substrate , the zero reflection have not been found in this figure but broadband antireflection , the curves b,c,d (shown in Fig.(5)) isn't good form to coat the glass optical system.

The c-curve is illustrated in the figure is the best form of antireflection because has three minima reflection the first at 355 nm the reflection reduced to 1.5% and the second at 532 nm reduced to 2.5% and the third at 1064 nm reduced to 2.2% this form is just suitable using to coat glass optical system for single and double and triple frequency of laser Nd-YAG, this form may be accomplished the aim of this work.

Three layer antireflection coating

The designing three layer antireflection coating surface the reflectance is minima at two or three wavelength and low over wider range than in the two layer coating.

The Fig.(6) show reflection spectra as function of wavelength, In this figure insert layer between second layer and substrate which has refractive index 1.95 the La_2O_3 dielectric material have been selected.

The b-curve illustrated in the figure has two minima reflection the first at 400 nm and the second between range (800-1100 nm), this form isn't useful to coat glass optical system.

The c-curve has two minima reflectance and one zero reflection , the reflectance at 355 nm was reduced to zero and 532 nm was reduced to 0.8% and at 1064 nm was reduced to 3% this form may be accomplished the aim of this work and agreement with condition (14).

The Fig.(7) show reflectance spectra as function of wavelength , the third layer was changed with La_2O_3 (n_3=1.95) material.

b-curve illustrated in the figure it has two minima reflectance and one zero reflectance .

c-curve illustrate in the figure it has three minima reflectance this form isn't useful to coat glass optical system the Fig.(6, 7) the antireflection is not obey to condition .

Antireflection coating at oblique incidence

The previous antireflection coating are typically designed for normal incidence, as the angle of incidence increase, the antireflection band shift towards lower wavelengths or higher frequencies any designed zero reflection at normal incidence are no longer zeros at oblique incidence in particular angle incidence at 40˚ (shown in Fig.(7)) this angle failure to coat the glass , so the designer of the lens avoid use high curvature of lens.

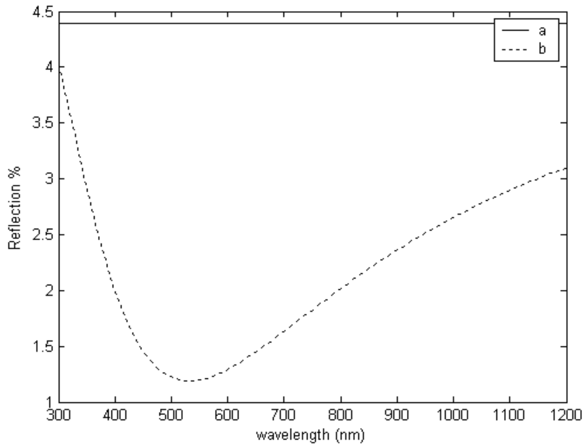

Fig.(1) : Show the reflection as function of wavelength for single layer on glass substrate at λo=532 nm below sequence of layer a-MgF$_2$(1/4)-ns.

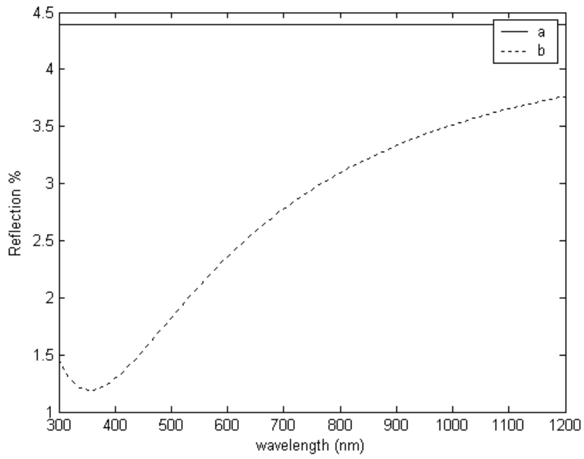

Fig.(2) : Show the reflection as function of wavelength for single layer on glass substrate at λo=355 nm below sequence of layer a-MgF$_2$(1/4)-ns.

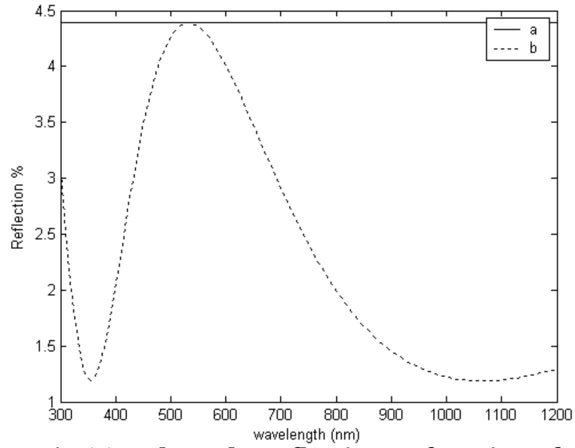

Fig.(3) : Show the reflection as function of wavelength for single layer on glass substrate at λo=1064 nm below sequence of layer a- MgF_2(1/4)-ns.

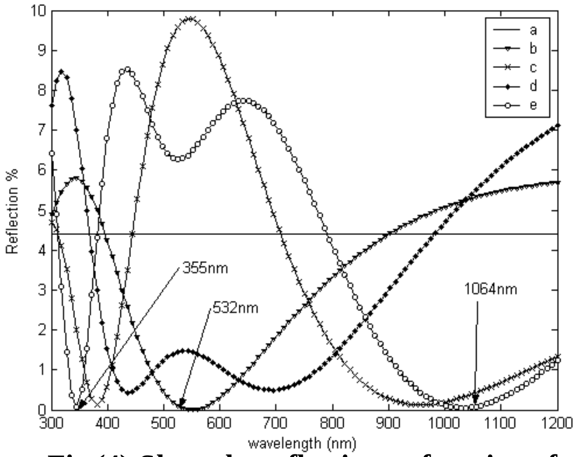

Fig.(4):Show the reflection as function of wavelength for double layer on glass substrate at λo=500nm below sequence of layer : a- uncoated glass , b- MgF_2(1/4)-CeF_3(1/4)-ns , c- MgF_2(1/2)-CeF_3(1/4)-ns, d- MgF_2(1/4)-CeF_3(1/2)-ns , e- MgF_2(1/2)-CeF_3(1/2)-ns.

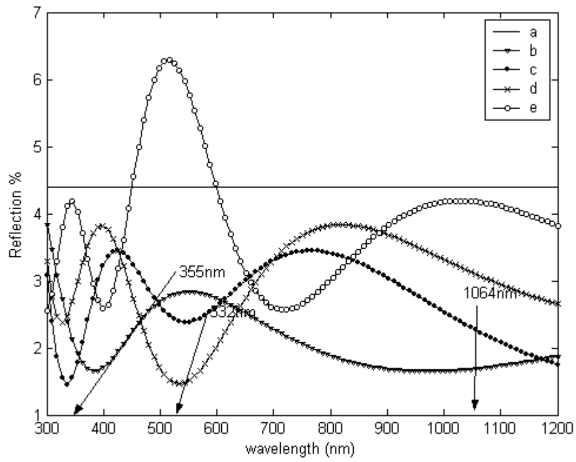

Fig.(5) : Show the reflection as function of wavelength for double layer on glass substrate at λo=500nm below sequence of layer :
a-uncoated glass , b- MgF_2(1/4)- SiO_2(1/4)-ns ,
c- MgF_2(1/2)- SiO_2(1/4)-ns
d- MgF_2(1/4)-SiO_2-ns ,
e- MgF_2(1/2)- SiO_2(1/2)-ns.

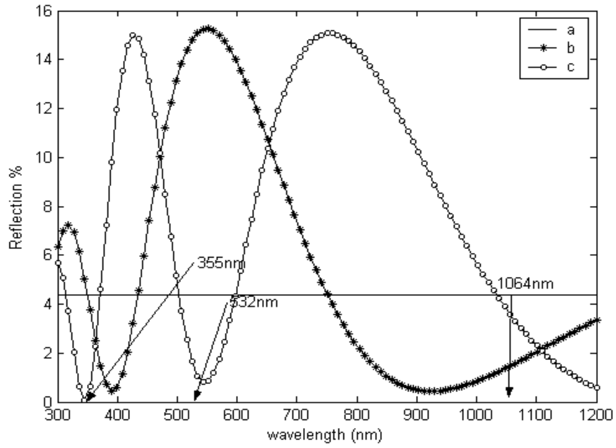

Fig.(6) : S how the reflection as function of wavelength for double layer on glass substrate at λo=550nm below sequence of layer :
a-uncoated glass , b- MgF_2(1/4)- TiO_2(1/4)- La_2O_3(1/4)-ns , c- MgF_2(1/2)- TiO_2(1/4)- La_2O_3(1/4)-ns.

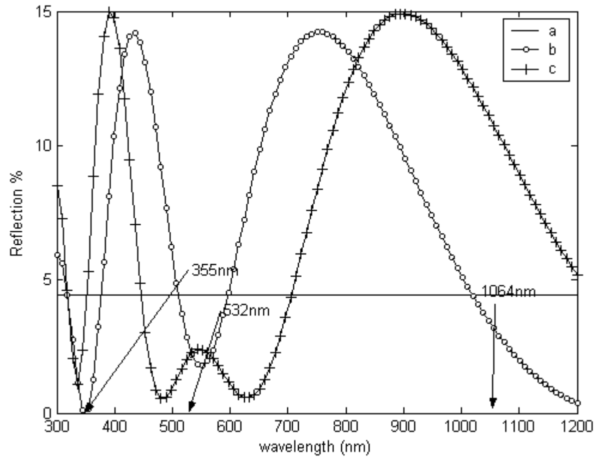

Fig.(7) : Show the reflection as function of wavelength for double layer on glass substrate at λo=550nm below sequence of layer :
a-uncoated glass ,
b- MgF_2(1/4)- TiO_2(1/2)- La_2O_3(1/4)-ns,
c- MgF_2(1/2)- TiO_2(1/4)- La_2O_3(1/2)-ns.

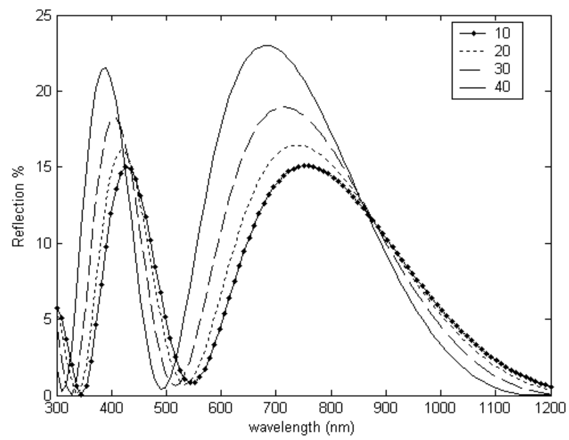

Fig.(8) : Show the reflection as function of angle incidence for the form MgF_2(1/2)- SiO_2(1/4)- SiO(1/4)-ns.

Conclusion

In this study, we have presented the optical matrix approach method to design and simulate antireflection coatings on glass substrate for laser Nd-YAG wavelengths (355, 532, 1064 nm) aid matlab program at central wavelength 550 nm for double and three layer, the results show the best coating with three layer, it has one zero reflection at 355 nm and two minima at 532, 1064 nm.

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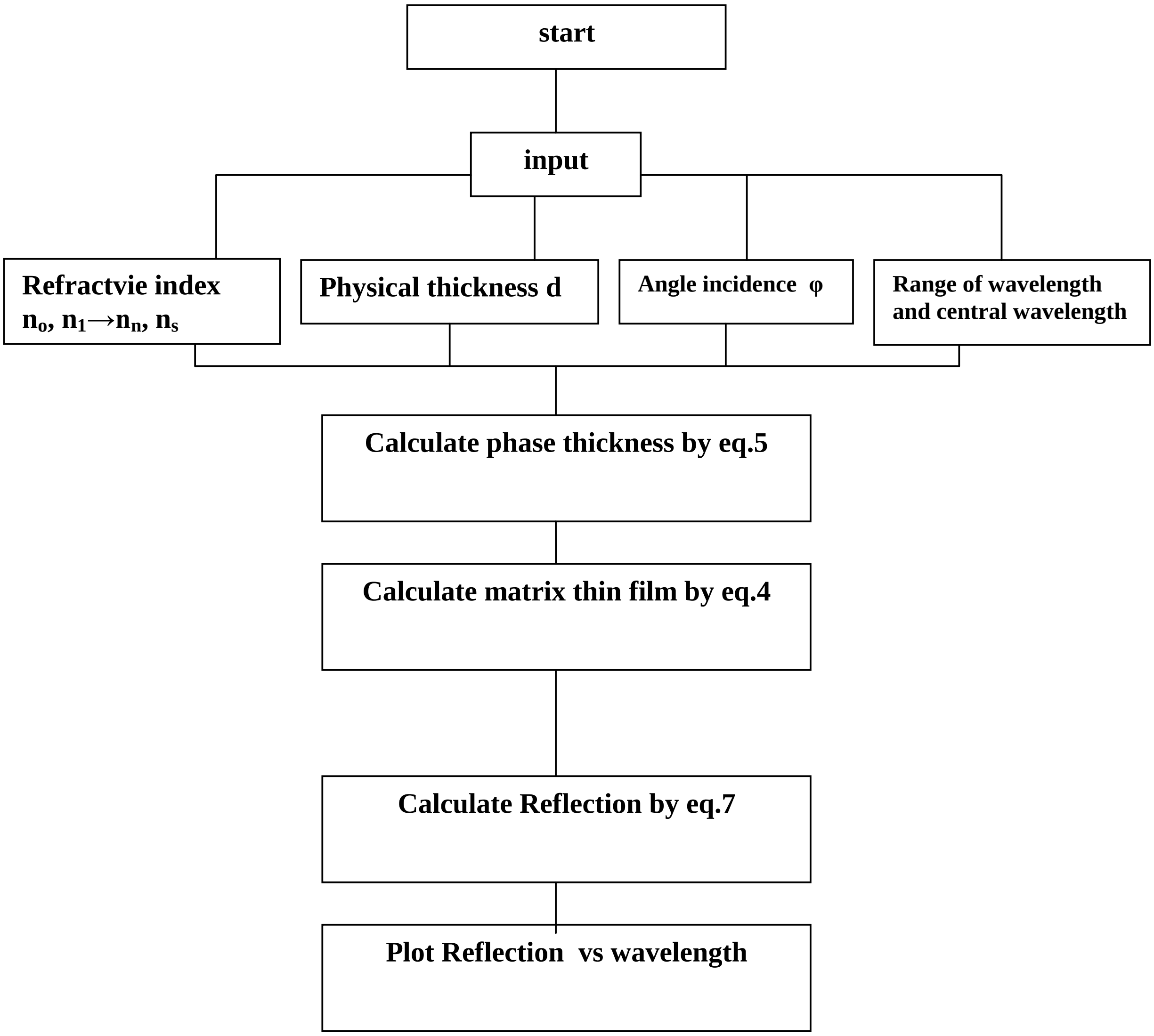
Appendix I



Appendix II

materials	Refractive index at 550nm	Region of transparency	Ref.
MgF_2	1.38	210nm-8µm	14
CeF_3	1.7	300nm-12µm	15
SiO_2	1.44	200nm-8µm	16
TiO_2	2.2	350nm-12µm	14
La_2O_3	1.95	350nm-2µm	15

الخلاصة

في هذا البحث, تم دراسة طلاء مضاد للانعكاس باستحداث تصميم ونظام محاكاة , تم حساب القيم البصرية للانعكاس باستخدام نظم المصفوفات باستخدام الحاسب ببرنامج الماتلاب, استخدمت خمس أغشية بصرية لغرض طلاء الزجاج المستخدم في تصنيع العدسات والمواشير وغيرها من الأجهزة البصرية الزجاجية لتقليل الانعكاس للطول الموجي لليزر النيدميموم-ياك والترددات المضاعفة له, أظهرت النتائج في الطلاء المنفرد ان الانعكاسية قلت الى 1.2% لكن عند طول موجي واحد او اثنين اما الطلاء المزدوج فقد تم الحصول على عدم انعكاس في منطقتين من الأطوال الموجية لليزر النيدميميوم-ياك , اما الطلاء بثلاثة طبقات فقد تم الحصول على أفضل النتائج فقد تم تقليل الانعكاسية بطولين موجين لليزر النيديميوم-ياك (532,1064 nm) مع عدم انعكاس في الطول الموجي (355 nm) وهو مطابق لشرط التصميم.