Simulation of Multilayer Layer Antireflection Coating for Visible and Near IR Region on Silicon Substrate Using Matlab Program

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ABSTRACT

In this work , double layer and three antireflection coating were designed and simulated , optical reflection values were deduced with a matrix formulation via a personal computer using matlab program, six materials has been selected to investigated of the reflection as function of wavelength in visible region and near IR between (400-1200nm) on silicon substrate and central wavelength at 900nm the result show double layer quarter-quarter wave optical thickness has good preference antireflection has been reduced reflection from 32% for silicon surface to 3% and for three layer coatings , the results obtained broadband antireflection spectra and several form antireflection that have zero reflection in double and three layer antireflection coating . The refractive index and the optical thickness of each layer are adjusting to optimum antireflection coatings on silicon solar cells .

Keywords: antireflection,thin film,matlab,simulation, reflection .

محاكاة متعدد الطبقات لطلاء مضاد للانعكاس بالنسبة للمنطقة المرئية وتحت الحمراء القريبة على قاعدة من السليكون باستخدام برمجة الماتلاب

الخلاصة

في هذا البحث تم دراسة طلاء مضاد للانعكاس مكون من طبقتين و ثلاثة طبقات باستحداث تصميمو نظام محاكاة،تم حساب القيم البصرية للانعكاس باستخدام نظم المصفوفات باستخدام الحاسب

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و باستخدام برنامج الماتلاب ، تم استخدام ستة مواد بصرية لدراسة انعكاسيتها في المنطقة المرئية وتحت الحمراء القريبة بين (400-1200nm)على قاعدة من السليكون عند طول موجة تصميم 900nm النتائج التي تم الحصول عليها في طلاء طبقتين لسمك بصري ربع-ربع طول موجة تم الحصول على أفضل مضاد للانعكاس حيث قلت الانعكاسية من 32% بالنسبة لسطح السليكون إلى 3% أما في الطلاء ثلاث طبقات فقد تم تقليل الانعكاسية بمدى طيفي أوسع ،وتم الحصول على عدم انعكاس لكلا الطبقتين وثلاث طبقات في عدة أشكال . معامل الانكسار والسمك البصري لكل طبقة ينظم لافضل طبقة طلاء مضادة للانعكاس على الخلايا الشمسية السليكونية.

INTRODUCTION

In an attempt to reduce the surface reflectance, silicon (Si) surfaces were textured, which could reduce the surface reflectance to about 11 % [1]. Since a mirror-polished Si surface reflects about 36 % of the incident light beams, a surface texturing improves surface reflectance by 30.6 %. However, the reflectance of a textured surface is still high for solar-cell application, so single crystal Si substrates were investigated antireflection (AR) coatings [2,3].

Conventional single layer AR (Antireflection) coatings with minimum reflectance are not enough to cover the broad rage of the solar spectrum, many research groups have investigated double and more layer AR coatings [4].

Antireflection (AR) coatings for the visible and the infrared regions have long been the subject of much research and development because they are very important and useful in the solar cell [2].

Silicon is a semiconductor optical material with relatively high refractive index [3]. It is used in infrared devices as windows, lenses and transmission filters 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 [2,4]. In addition, highly reflecting dielectric mirrors have been developed to be used in gas lasers and in Fabry-Perot interferometers [5]. The most important application of silicon in the visible near IR region is photovoltaic solar cells [6].

Conversion of solar energy into other energy forms is more effective if the reflectance of light- receiving surface of solar device is minimal in the solar spectrum range [4]. Efficiency of a solar cell and its lifetime can be raised by coating the light sensitive surface of the cell with an antireflection coating [7-8].

This coating reduces the reflectance of the light incident on the cell surface and also protects it from radiations and atmospheric effects [7].

The high reflection index of silicon 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 [9].

The aim of this study is to present an computational process for the numerical design and simulated of antireflection coatings.

THEORY AND NUMERICAL DESIGN OF ANTIREFLECTION COATINGS

The optical matrix approach was employed for *N*-layer design of antireflection coatings. 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 [7]

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

where B and C are total electric and magnetic field amplitudes of the light propagating in the medium. Thus optical admittance is given by the ratio

$$Y=C/B \qquad \ldots\ldots\ldots(2)$$

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

$$M=M_1M_2\ldots\ldots\ldots\ldots\ldots\ldots M_N \qquad \ldots\ldots(3)$$

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

$$Mj= \begin{pmatrix} \cos \delta_j & i\sin \delta_j / n_j \\ i n_i \sin \delta_i & \cos \delta_i \end{pmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where ηj is the refractive index of the layer and δj is its phase thickness given by:

$$\delta j = 2\pi ndj/\lambda \qquad \ldots\ldots\ldots(5)$$

with the physical thickness of the layer being dj ,then the reflection coefficient r and the reflectance R are, respectively, given by

$$r = \frac{n_0 - Y}{n_0 + Y} \qquad \text{.........(6)}$$

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

where $R = r x r^*$

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 [7].

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{pmatrix} \cos\delta_1 & i\sin\delta_1/n_1 \\ in_1\sin\delta_1 & \cos\delta_1 \end{pmatrix} \begin{pmatrix} \cos\delta_2 & i\sin\delta_2/n_2 \\ in_2\sin\delta_2 & \cos\delta_2 \end{pmatrix} \qquad \text{....................(8)}$$

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 [7].

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{pmatrix} \cos\delta_1 & i\sin\delta_1/n_1 \\ in_1\sin\delta_1 & \cos\delta_1 \end{pmatrix} \begin{pmatrix} \cos\delta_2 & i\sin\delta_2/n_2 \\ in_2\sin\delta_2 & \cos\delta_2 \end{pmatrix} \begin{pmatrix} \cos\delta_3 & i\sin\delta_3/n_3 \\ in_3\sin\delta_3 & \cos\delta_3 \end{pmatrix} \begin{bmatrix} 1 \\ n_s \end{bmatrix} \text{....(9)}$$

quarter-wave optical thickness antireflection coating

The reflectance for a quarter wave thickness at normal incidence the matrix equation becomes

$$\begin{pmatrix} 0 & in_j^{-1} \\ in_j & 0 \end{pmatrix} \qquad \ldots\ldots\ldots\ldots(10)$$

HALF- WAVE OPTICAL THICKNESS ANTIREFLECTION COATING

The reflectance for a half wave thickness at normal incidence the matrix equation becomes

$$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \qquad \ldots\ldots\ldots\ldots(11)$$

a half wave thickness called absence layer because it isn't theoretical effect [7].

2.5 Solution of Double-layer antireflection coatings

From (8) ,(7),(10)and(11) The reflectance reduced to zero(R=0) then

n_2/n_1=(nsno)1/2 ……………(12)

or

n_{13}=n02ns ……………(13)

n_{23}=n0ns2 ……………..(14)

where n0=1 for air and ns=3.5 for Si

can be written in n1=(ns)1/3 and n2=(ns)2/3

n1= 1.51

so must be select materials have refractive index about 1.5 ,the materials (SiO2=1.44 , MgF2=1.38) have been selected for top layer antireflection antireflection coating in our program [7,5]

n2 =2.3

so must be select materials have refractive index about 2.3 ,the materials (CeO_2=2.2 , ZnS=2.3) have been selected for bottom layer coating in our program[7]

2.6 Solution of three- layer antireflection coatings

From (9) ,(7),(10)and(11) The reflectance reduced to zero(R=0) then

n_{14}=n03ns So n_1=1.36 ……………(15)

n_{24}=n02ns2 So n_2=1.87 ……………(16)

n_{34}=n0ns3 So n_3=2.5 ……………(17)

for

n1 was selected materials (SiO_2=1.44,MgF_3=1.38)

n2 was selected materials (SiO=1.95,CeF_3=1.7)

n3 was selected materials (ZnS=2.3,CeO_2=2.2) [8].

3. Simulation in Matlab

The simulation of the reflection in matlab have been the main assignment of this work, The reflectivity of the silicon has been simulated with two ,three layers of antireflection coatings the program optimize at λo=900nm central wavelength for visible and near infrared spectral region . the parameters of antireflection

Optical thickness for each layers.

Reflection index for each layer coating and substrate [10].

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.[11]

RESULTS AND DISCUSSION

Double-layer antireflection coating

The refractive index ns of silicon in the region between (400-1200nm) is 3.5 [9], therefore when the surrounding medium is air no=1 the reflective index of the first layer should have coating materials value about 2.3 according to the condition in equation.(13) and (14) so the first layer (SiO_2,MgF_2) and second layer (CeO_2,ZnS) materials was selected, the Figs. (1-4) show reflectance spectra of double-layer coating for four dielectric materials with variety optical thickness .

The figure (1) show the reflectance spectra as a function of wavelength for quarter-quarter antireflection coating on silicon and uncoated silicon surface , all curves in the figure have nearly the same behavior , the silicon reflectance surface reduced from 32% to less than 5% in range between (700-1200nm) and zero reflection at 700nm and the best curve antireflection is (d) illuminated in the figure.

The higher reflection values at the shorter wavelengths particularly in the region between (400-700nm) are attributed to small variation in thickness and refractive index of the materials leading to higher reflection value .This is form its suitable for antireflection coating on silicon and can be used in silicon solar cells [6].

The multilayer antireflection coatings are based on the destructive interference of beams reflected from the interfaces of the layers [4].

figures (2)and(3) show the reflectance spectra of quarter-half for figure (2)and half-quarter for fig.(3) wave optical thickness of bauble layer coating. These figures have nearly the same behavior and have broadband antireflection spectral region in range between (580-1200nm) but there is no zero reflection because the different thickness compared with figure(1) , they good application in silicon solar cells , they would be increase quantum efficiency of optoelectronic device [12] .

Fig.4 show reflectance spectra of half-half wave optical thickness of double –layer coating the figure. show failure to reduce reflection particularly between 700-1200nm but only range between 550-700nm was reduced reflection . this form couldn't be use in antireflection on silicon solar cells but they may be capability use antireflection coating in green and red light detector or as filter application [3] .

Three-layer antireflection coating

Figure (5) show reflectance spectra of three-layer coating for six dielectric materials, the form antireflection coating was shown below of figure, in this figure(5) , two dielectric materials have been changed in each layer according to paragraph (2-6). Figure.5 show the reflectance spectra of quarter- quarter- quarter layer coating on silicon all curves exhibit the same behavior , the figure obvious the antireflection coating reduce the reflection from 32% to less than 10% . In this figure there are two zero reflection , the first at 600nm and the second at 900nm due to high transmittance in these regions [8].

Fig.6 show reflectance spectra of three-layer coating with the form antireflection coating was shown below of figure , this figure has broadband antireflection if compare with figure (5) its has reduce reflectance in range between 540-1200nm . The two figures. above Just suitable use in silicon solar cells [3].

The figures 7and 8 show reflectance spectra ,the form of the antireflection coating was shown below of figures. The figures aren't different in form it exhibit same behavior the two figures. have maxima reflectance 17% for broadband spectra , this form may be unsuitable or ineffective in silicon solar cells [9].

The figures (9) and (11) show reflectance spectra ,the form of the antireflection coating was shown below of figure , the figures . exhibit the same behavior, the antireflection reduce the reflection from 32% to less than 15% this figures. have broadband spectra antireflection coating this form may be suitable use in silicon solar cells .

The figure (10) exhibit the same behavior of the figure (4) this form couldn't be use in antireflection on silicon solar cells.

CONCLUSIONS

In this work, we have presented the optical matrix approach method to design and simulated multilayer antireflection coatings in visible and near IR region using matlab program starting from double-layer up to three layer at central wavelength λ=900nm ,The refractive index and the optical thickness of each layer are adjusting to optimum antireflection coatings on silicon solar cells.

Since the refractive index of silicon is relatively high, its surface reflects a high portion of the incident radiation throughout the spectral range between 400 and 1200 nm. The way to reduce this reflectance is to coat the surface of silicon with at least a single layer, in this work design and simulated antireflection coating of silicon with double and three layer . In the Double-layer antireflection coating, the form (d) in figure (1) is illuminated the best antireflection its reduce reflection less than 3%

between 700-1200nm A more effective reflectance reduction in a broad spectral region can be obtained with quarter-half-quarter wave optical thickness coatings, in narrow band antireflection spectra can be use (such as figure (4)) as filter application.

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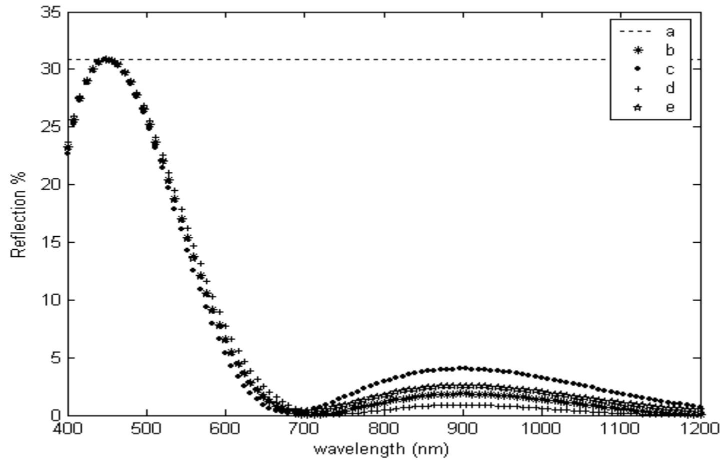


Figure (1) Reflectance spectra of (a) an uncoated Silicon surface and double-layer coating for four dielectric materials with optical thickness arranged below (b) SiO_2(1/4)+ZnS(1/4)/Si, (c)SiO_2(1/4)+CeO_2 (1/4)/Si, (d)MgF_2(1/4)+ CeO_2(1/4)/Si, (e) MgF_2(1/4)+CeO_2(1/4)/Si.

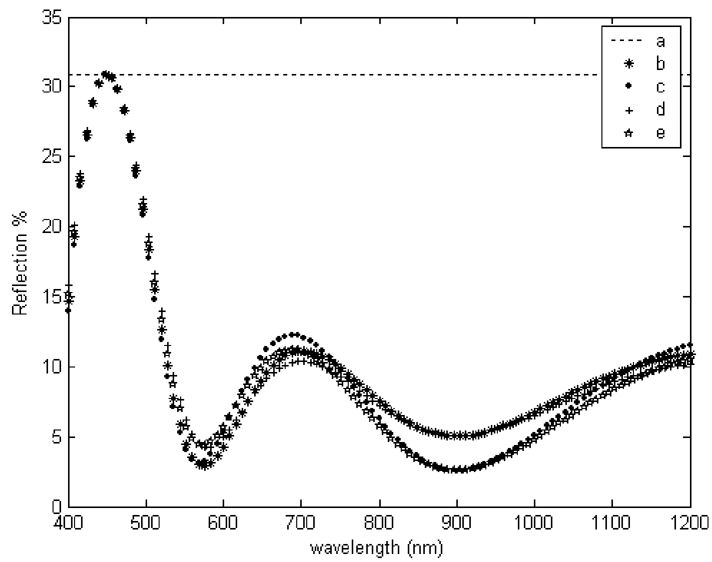


Figure (2) Reflectance spectra of (a) an uncoated Silicon surface and double-layer coating for four dielectric materials with optical thickness arranged below (b) SiO_2(1/4)+ZnS(1/2)/Si, (c)SiO_2(1/4)+CeO_2 (1/2)/Si, (d)MgF_2(1/4)+ ZnS(1/2)/Si, (e) MgF_2(1/4)+CeO_2(1/2)/Si.

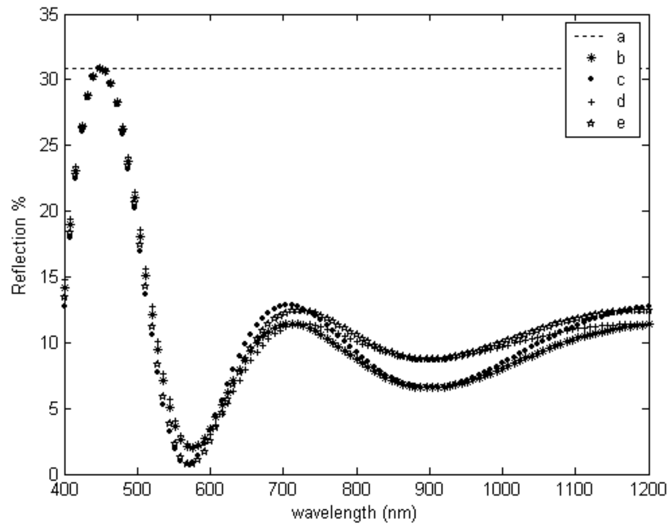


Figure (3) Reflectance spectra of (a) an uncoated Silicon surface and double-layer coating for four dielectric materials with optical thickness arranged below (b) SiO_2(1/2)+ZnS(1/4)/Si, (c)SiO_2(1/2)+CeO_2 (1/4)/Si, (d)MgF2(1/2)+ ZnS(1/4)/Si, (e) MgF_2(1/2)+CeO_2(1/4)/Si.

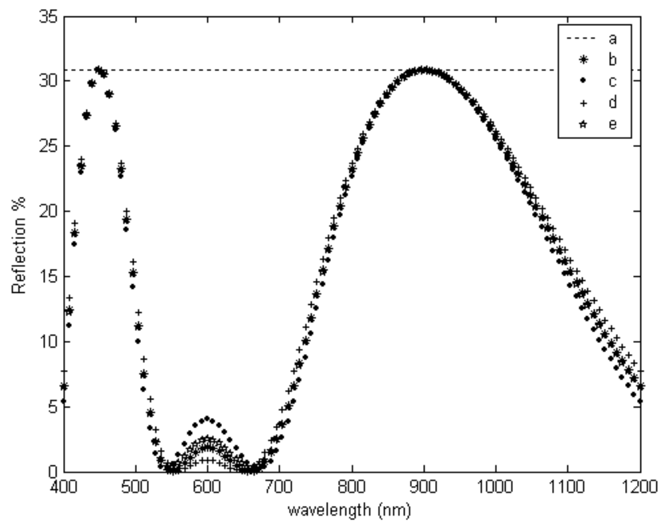
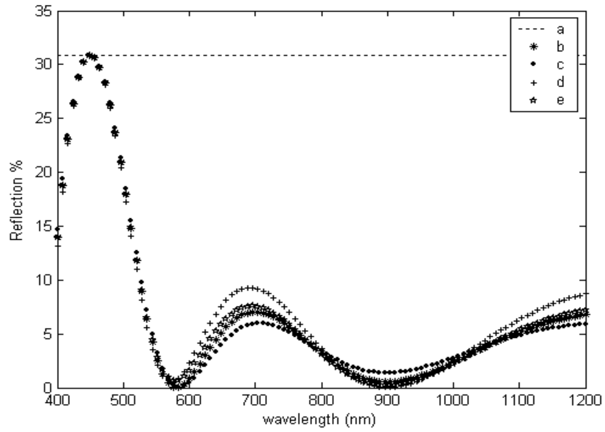


Figure (4) Reflectance spectra of (a) an uncoated Silicon surface and double-layer coating for five dielectric materials with optical thickness arranged below (b) SiO_2(1/2)+ZnS(1/2)/Si, (c)SiO_2(1/2)+CeO_2 (1/2)/Si, (d)MgF_2(1/2)+ ZnS(1/2)/Si, (e) MgF_2(1/2)+CeO_2(1/2)/Si.



Figure(5) Reflectance spectra of (a) an uncoated Silicon surface and three-layer coating for six dielectric materials with optical thickness arranged below (b) SiO_2(1/4)+SiO(1/4)+ZnS(1/4)/Si, (c)MgF_3(1/4)+SiO(1/4)+ZnS(1/4)/Si, (d) SiO_2(1/4)+CeF_2(1/4)+CeO_2(1/4)/Si(e)MgF_3(1/4)+CeF_2(1/4)+CeO_2(1/4)/Si

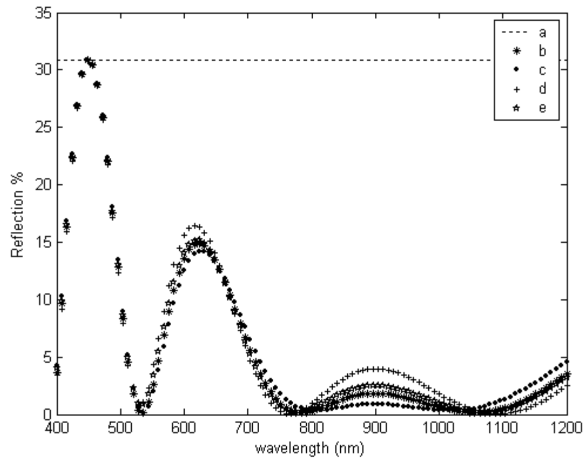


Figure (6) Reflectance spectra of (a) an uncoated Silicon surface and three-layer coating for six dielectric materials with optical thickness arranged below (b) SiO_2(1/4)+SiO(1/2)+ZnS(1/4)/Si(c)MgF_3(1/4)+SiO(1/2)+ZnS (1/4)/Si, (d) SiO_2(1/4)+CeF_2(1/2)+CeO_2(1/4)/Si(e)MgF_3(1/4)+CeF_2(1/2)+CeO_2(1/4)/Si

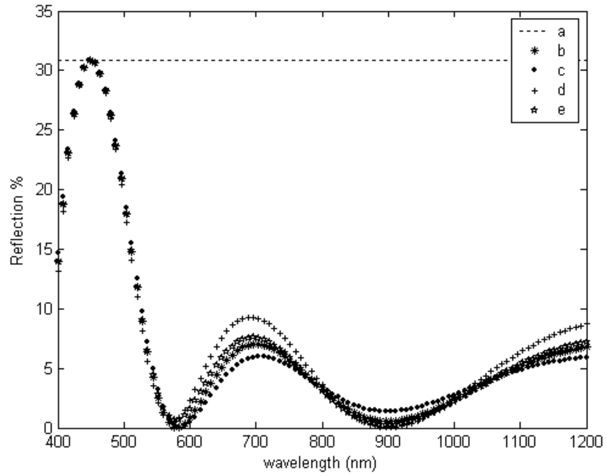


Figure (7) Reflectance spectra of (a) an uncoated Silicon surface and three-layer coating for six dielectric materials with optical thickness arranged below (b) SiO_2(1/2)+SiO(1/4)+ZnS(1/4)/Si(c)MgF_3(1/2)+SiO(1/4)+ZnS (1/4)/Si, (d) SiO_2(1/2)+CeF_2(1/4)+CeO_2(1/4)/Si(e)MgF_3(1/2)+CeF_2(1/4)+CeO_2(1/4)/Si

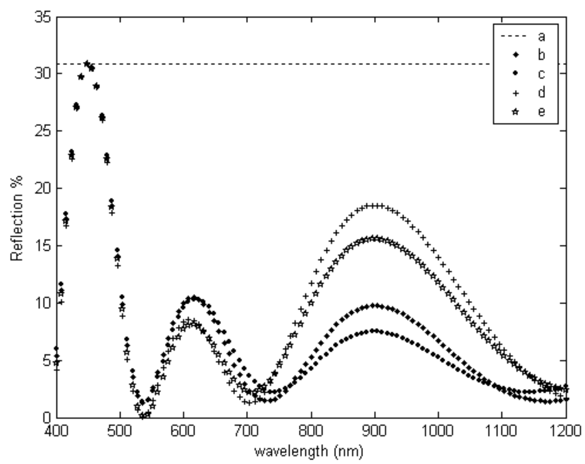
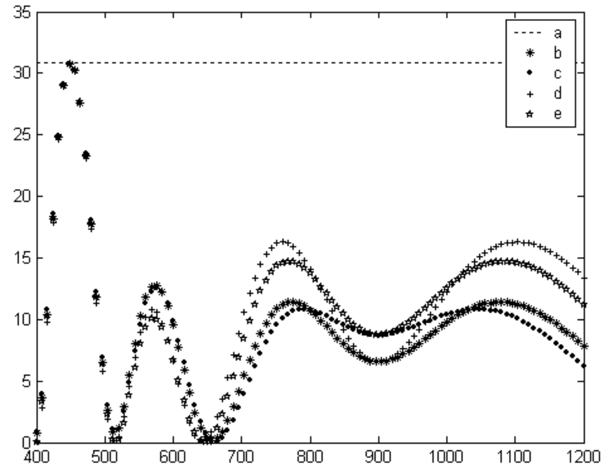


Figure (8) Reflectance spectra of (a) an uncoated Silicon surface and three-layer coating for six dielectric materials with optical thickness arranged below (b) SiO_2(1/4)+SiO(1/4)+ZnS(1/2)/Si, (c)MgF_3(1/4)+SiO(1/4)+ZnS (1/2)/Si, (d) SiO_2(1/4)+CeF_2(1/4)+CeO_2(1/2)/Si(e)MgF_3(1/4)+CeF_2(1/4)+CeO_2(1/2)/Si



Wavelength (nm)

Figure (9) Reflectance spectra of (a) an uncoated Silicon surface and three-layer coating for six dielectric materials with optical thickness arranged below (b) SiO_2(1/4)+SiO(1/2)+ZnS(1/2)/Si, (c)MgF_3(1/4)+SiO(1/2)+ZnS (1/2)/Si, (d) SiO_2(1/4)+CeF_2(1/2)+CeO_2(1/2)/Si(e)MgF_3(1/4)+CeF_2(1/2)+CeO_2(1/2)/Si

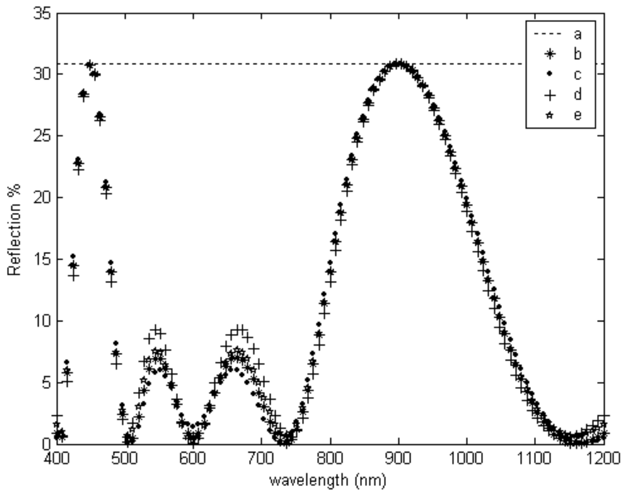


Figure (10) Reflectance spectra of (a) an uncoated Silicon surface and three-layer coating for six dielectric materials with optical thickness arranged below (b) SiO_2(1/4)+SiO(1/2)+ZnS(1/2)/Si, (c)MgF_3(1/4)+SiO(1/2)+ZnS (1/2)/Si, (d) SiO_2(1/4)+CeF_2(1/2)+CeO_2(1/2)/Si(e)MgF_3(1/4)+CeF_2(1/2)+CeO_2(1/2)/Si

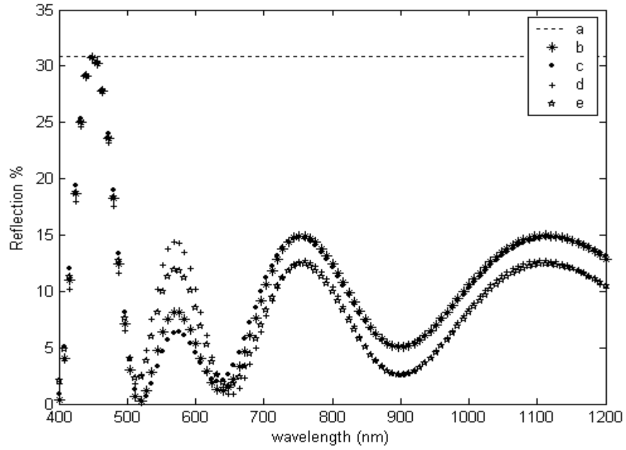


Figure (11) Reflectance spectra of (a) an uncoated Silicon surface and three-layer coating for six dielectric materials with optical thickness arranged below (b) SiO_2(1/2)+SiO(1/2)+ZnS(1/4)/Si(c)MgF_3(1/2)+SiO(1/2)+ZnS (1/4)/Si, (d) SiO_2(1/2)+CeF_2(1/2)+CeO_2(1/4)/Si(e)MgF_3(1/2)+CeF_2(1/2)+CeO_2(1/4)/Si.