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Comparative Study for Designing Two Optical Multilayers Stacks ThF_4/AlF_3 and ThF_4/LiF

Zainab I. Al-Assadi*, Murtadha Faaiz Sultan

Department of Physics, College of science, Mustansiriyah University, Baghdad, IRAQ.

*Correspondent contact: dr.zainab_rhm@uomustansiriyah.edu.iq

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ABSTRACT

The dielectric materials ThF_4, AlF_3 and LiF and with refract index n=1.5143 n=1.36 and n=1.393 respectively had been used for the optical design Glass/L/H/Air and for two cases Glass/AlF_3/ThF_4/Air and Glass/LiF/ThF_4/Air for 30 layers and for design wavelength λ_o=550 nm and quarterwave thicknesses. The results of this comparative study explain the peak of the gaussian curves. It will increase with increasing the layers but this increase is higher for Glass/AlF_3/ThF_4/Air and the width of the curves will decrease with increasing the number of layers for the two cases, this will fix the color of the coating and reflect narrow band in the visible region. All results exhibit the coating with AlF_3/ThF_4 is the best and more efficient for coloration and thermal gain than LiF/ThF_4 coating. This study is considered as a modern idea by comparing two multi-layer optical designs and exhibiting which one is better than the other in terms of the solar transmittance ($\tau_{sol.}$), solar reflectance ($\rho_{sol.}$), visible reflectance ($\rho_{vis.}$) and coloring efficiency (M), and employ it in the field of building elements for façade solar collectors cladding.

KEYWORDS: Multi-layers stick; Thin films; Facades collectors; Colored glazing.

الخلاصة

تم استخدام المواد العازلة ThF_4 و AlF_3 و LiF ذوات معامل الانكسار n = 1.5143 و n =1.36 و n = 1.393 على التوالي للتصميم البصري Glass/L/H/Air ولحالتين Glass / AlF_3/ThF_4/Air و Glass/LiF/ThF_4/Air لـ 30 طبقة ولطول موجة التصميم λ_o = 550 نانومتر وسمك ربع طول موجي. توضح نتائج هذه الدراسة المقارنة أن قمة المنحنيات الكاوسية ستزداد مع زيادة الطبقات ولكن هذه الزيادة أعلى بالنسبة Glass/AlF_3/ThF_4/Air وسيقل عرض المنحنيات مع زيادة عدد الطبقات للحالتين ، سيؤدي ذلك إلى تثبيت لون الطلاء وانعكاس حزمة ضيقة في المنطقة المرئية. تظهر جميع النتائج أن الطلاء باستخدام AlF3/ThF_4 هو الأفضل والأكثر كفاءة للتلوين والكسب الحراري من الطلاء LiF/ThF_4. تعتبر هذه الدراسة فكرة حديثة من خلال مقارنة تصميمين بصريين متعددي الطبقات واظهار ايهما أفضل من الآخر من حيث النفاذية الشمسية ($\tau_{sol.}$) ، الانعكاسية الشمسية ($\rho_{sol.}$) ، الانعكاسية المرئية ($\rho_{vis.}$) وكفاءة التلوين (M) ، وتوظيفها في مجال عناصر البناء لطلاء واجهات مجمعات الطاقة الشمسية.

INTRODUCTION

The basic of interference filters are the multilayered thin films coatings, the thickness of every layer must be least than the coherence length of the reference wavelength that used. By taking into consideration at the interfaces the alteration of electric and magnetic field components, we can calculate the optical properties of the multilayer stack [1]. If the materials of the thin film offer a low refractive index it has been introduce special benefit for solar collector glazing coatings [2-7]. Antireflection coating should be active on solar thermal collectors glazing for full spectral bands of terrestrial solar radiation [8], it plays an important role in reducing reflectance and increasing transmittance [9]. By employing ThF_4 (n=1.5143) and other materials have low refractive indices than ThF_4 like AlF_3 (n=1.36) and LiF (n=1.393), we can obtain for the low value of the visible reflectance a high solar transmittance through a partial antireflection in neighboring spectral regions for the visible reflectance peak.

The optical design Glass/L/H/Air for two cases Glass/AlF_3/ThF_4/Air and Glass/LiF/ThF_4/Air for 30 layers and for design wavelength λ_o=550 nm and quarter wave thicknesses had been designed. Simulation results explain the peak of the gaussian curves will increase with increasing the layers and the width of the curves will reduce with increasing the number of layers for the two cases. This will fix the color of the coating and reflect narrow band in the visible region [10]. The most type use of solar collectors is the flat plate collectors, when the solar radiation pass throw the collector cover glass and hit the black absorber sheet surface which have high absorption, the absorber sheet will absorb a large part of solar radiation energy and transfer it to fluid tubes throw a transport medium to convey for use or for storage. Up to 1008 °C can be obtained this main a good efficiencies of flat plate collector which can be obtained from standard flat plate collectors which have more than 2008 °C stagnancy temperatures [11]. The cost can be saved by using solar collectors substituted by conventional façade element. This will make the solar collectors multifunctional that added to the building [1, 12]. To obtain heat swimming pools and home hot water must thermal solar collectors were installed on the rooftop of the buildings, the issue of the facades integration solar collectors is still infrequent for conventional solar thermal collectors because its own black or dark bluish color, the corrugation of the metal or the absorber sheet, tubes and welding traces. An architect can have complete freedom when the cover glass of the thermal solar collectors associating with color and they integrate them ideally into the building skin [13-16]. The façade collectors integrated buildings has a thermal insulation function and façade element in addition to its function as collector, this multipurpose serve to decrease of costs. In winter, the inclined collectors have been covered with snow while the façade integrated collectors because the method of its setup the irradiation will increase because the reflection from snow will be neglected in large way, this can be considering another function for façade-integrated collectors must add to the previous functions.

The work presented here consider as a modern idea based on the new vision of solar collectors seen as multifunctional building elements for façade cladding and heat collection, by comparing two multi-layer optical designs and it exhibit which one is better than the other in terms of solar transmittance ($\tau_{sol.}$), solar reflectance ($\rho_{sol.}$), visible reflectance ($\rho_{vis.}$) and coloring efficiency (M).

MATERIALS AND METHODS

The optical conduct of thin films multilayer stack is not insignificant because of the multiple reflections throw the different interfaces, Figure 1, the characteristic matrices deal with this stack, that define one matrix M. per individual layer (with number of layers r), these matrices was programed using the Mat Lab program. Equation (1) exhibit the matrix product, which express the total number of layers stack.

$$\left\{\prod_{r=1}^{q} M_r\right\} = \left\{\prod_{r=1}^{q} \begin{bmatrix} \cos\delta r & (i\sin\delta r)/\eta r \\ i\eta r\sin\delta r & \cos\delta r \end{bmatrix}\right\} \quad (1)$$

From this matrix product, transmission and reflection spectra can be computed. Extended calculations are usually carried out by a computer [17, 18].

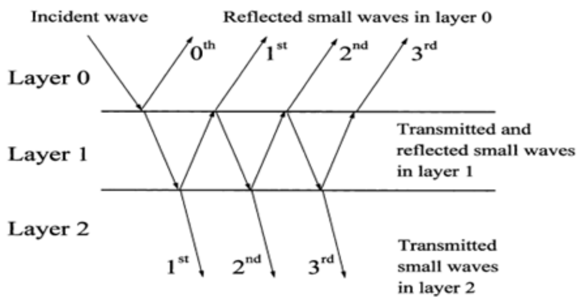

Figure 1. A multilayer system with multiple transmitted and reflected wave[19].

The criterion of the surface brightness as exhibit for human eye under definite illumination condition is known as the visible reflectance $\rho_{vis.}$ Its definition is based on the photopic luminous efficiency function $V(\lambda)$ and rely on the choice of the illuminant $I_{ILL}(\lambda)$:

$$\rho_{VIS} = \frac{\int \rho(\lambda).I_{ILL}(\lambda).V(\lambda)d\lambda}{\int I_{ILL}(\lambda).V(\lambda)d\lambda} \quad (2)$$

Where $\rho(\lambda)$ is the reflectance of the specimen which has simulated or measured [20].

$\tau_{sol.}$ is the solar transmittance which can occurred by integration process with the solar spectrum $I_{sol.}(\lambda)$:

$$\tau_{sol.} = \frac{\int \tau(\lambda).I_{sol}(\lambda)d\lambda}{\int I_{sol}(\lambda)d\lambda} \quad (3)$$

Generally the solar spectrum at air mass 1.5 (Am 1.5) has been utilized as intensity $I_{sol.}(\lambda)$. The solar reflectance $\rho_{sol.}$, which is identical to the losses of the solar energy, was expressed in eq. (4)

$$\rho_{sol.} = \frac{\int \rho(\lambda).I_{sol}(\lambda)d\lambda}{\int \rho_{sol}(\lambda)d\lambda} \quad (4)$$

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In the case of transparent thin film and substrate materials, absorption is absent and energy is conserved:

$$T(\lambda) + \rho(\lambda) = 1 \ and \ T_{sol.} + \rho_{sol.} = 1 \qquad (5)$$

The large spectral regions are invisible which represented by the ultraviolet and infrared regions, the human eye can only sense the visible spectrum which occupy small part from solar spectrum, then for produce colored solar collector the essential idea is make a surface which reflect only a narrow frequency band in the visible region, thus lead to colored aspect, while the non-reflected solar spectrum part will be altogether transmit and transform to thermal energy [19, 20]. Because of the difference in films morphology the optical reflection will change [21].

The ratio of the visible reflectance $\rho_{vis.}$ under daylight illumination D65 and the solar reflectance $\rho_{sol.}$ (based on the solar spectrum AM 1.5 global) defined as merit factor M [19, 20, 22]:

$$M = \frac{(\rho_{VIS} \ under \ daylight \ illumination \ D65)}{(\rho_{sol} \ for \ AM \ 1.5 \ global)} \qquad (6)$$

When a visible reflectance being high or low solar reflectance $\rho_{sol.}$, the merit factor will be considerable, this factor represents the energy efficiency of the visual perception.

RESULTS AND DISCUSSION

The dielectric materials ThF_4, AlF_3 and LiF and with refract index n=1.5143, n=1.36 and n=1.393 respectively had been used in this research and with the optical design Glass/L/H/Air for two cases Glass/AlF_3/ThF_4/Air and Glass/LiF/ThF_4/ Air for 30 layers for two cases and for design wave length λ_o=550 nm and quarterwave thicknesses. Simulation results explain the peak of the Gaussian curves will raise with increasing the number of layers and the width of the curves will reduce with increasing the number of layers for the two cases, this will fix the color of the coating and reflect narrow band in the visible region. Figure 2a, b, c) below explain the peak curves of reflectance versus wavelengths for 10, 20, 30 layers which appear for Glass/AlF_3/ThF_4 coating is higher than the peak curves for Glass/LiF/ThF_4 coating, the peak of the color reflectance curve will increase gradually from 2, 4, 6 until 30 layers and reach to 90% for Glass/AlF_3/ThF_4 coating and 80% for Glass/LiF/ThF_4.

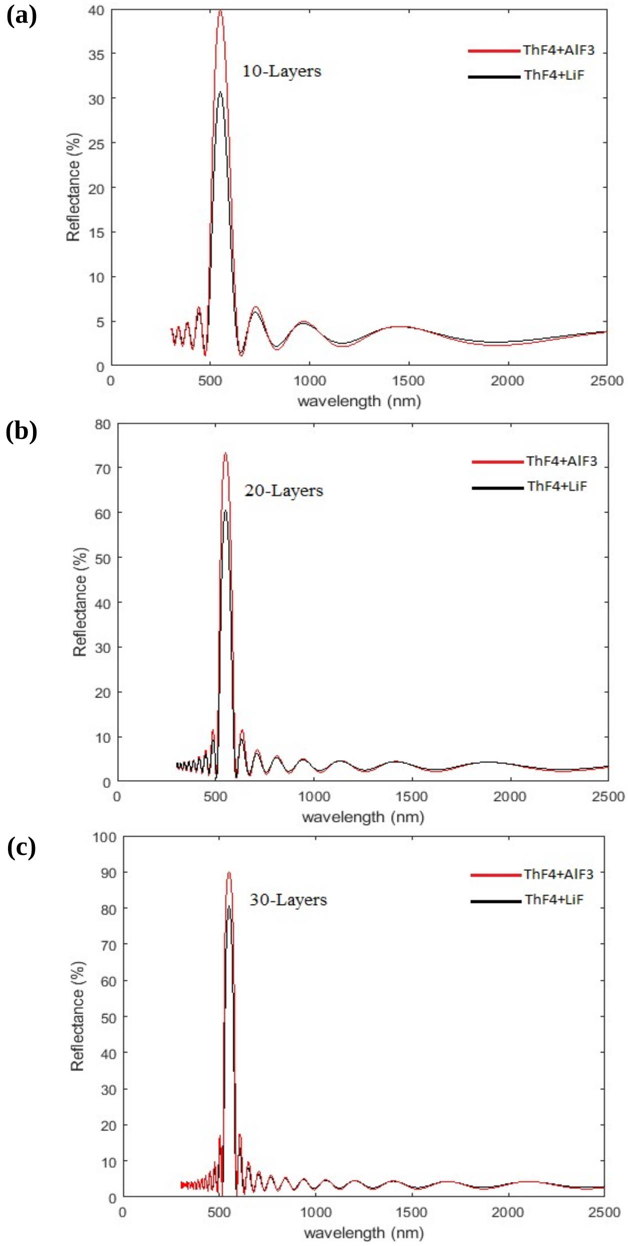


Figure 2. Reflectance versus wavelength for multilayer designs Glass/AlF_3/ThF_4/Air and Glass/LiF/ThF_4/Air, (a) from (2-10), (b) from (2-20), (c) from (2-30) layers.

A visible reflectance of 12%, which is already considerable for a color (since100% match to white) [23], Figure 3 below explain a visible reflectance $\rho_{vis.}$ will increase gradually with number of layer for the two cases for AlF_3/ThF_4 and LiF/ThF_4 but the value of $\rho_{vis.}$ for AlF_3/ThF_4 coating is the high which mean that the efficiency of coloration for this coating is the best.

The two cases of the coating display colored reflection (green), this will add aesthetic appearance to the façade thermal solar collectors, however the infrared region remain antireflection region, this indicate the increasing in solar transmittance ($I_{sol.}$) which is range from (95-97)%, and the solar reflectance very few and varies from (2-4)%, so the colored thermal solar collector efficiency will rise.

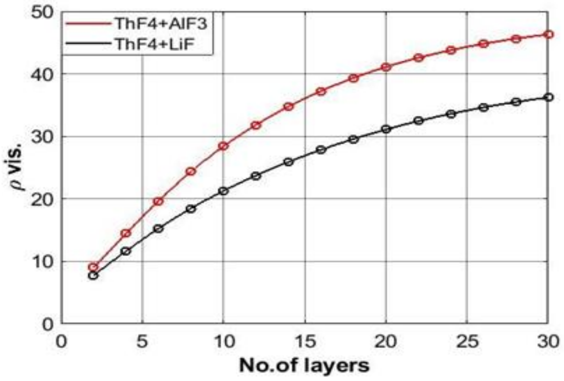
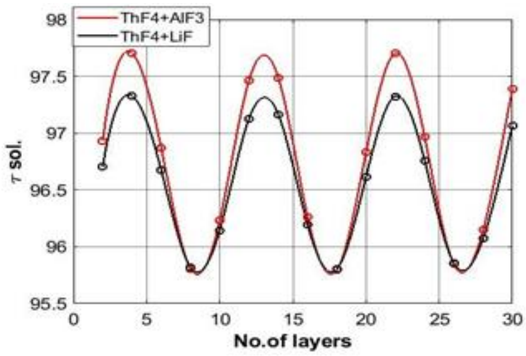


Figure 3. $\rho_{vis.}$ versus No. of layers for Glass/AlF_3/ThF_4/Air and Glass/LiF/ThF_4/Air.

The solar transmittance for the AlF_3/ThF_4 coating is higher than the solar transmittance for the LiF/ThF_4 and the solar reflectance for the AlF_3/ThF_4 coating is less than solar reflectance of the LiF/ThF_4 coating, the best coating exhibit high solar transmittance and low solar reflectance to increase the losses which occur in the thermal solar collectors, this mean the coating with AlF_3/ThF_4 is more efficient compared with LiF/ThF_4.

These results were illustrated in Figure 4a, b below.

(a)



(b)

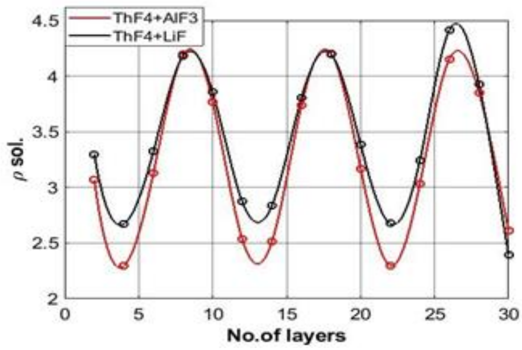


Figure 4. $\tau_{sol.}$ and (b) $\rho_{sol.}$ versus No. of layers for Glass/AlF_3/ThF_4/Air and Glass/LiF/ThF_4/Air.

The figure below shows the merit factor versus the increasing layers number, the values of M is varying from (2.9-17.7) for the Glass/AlF_3/ThF_4/Air design and from (2.3-12.3) for the Glass/AlF_3/ThF_4/Air design. The general potential of colored thermal solar collectors is promising, and can be expressed by merit factor M. The value of six indicates a large potential of coloration. Figure 5 explain a compression between the values of the merit factor for the two design and it show it is the higher for Glass/AlF_3/ThF_4/Air design.

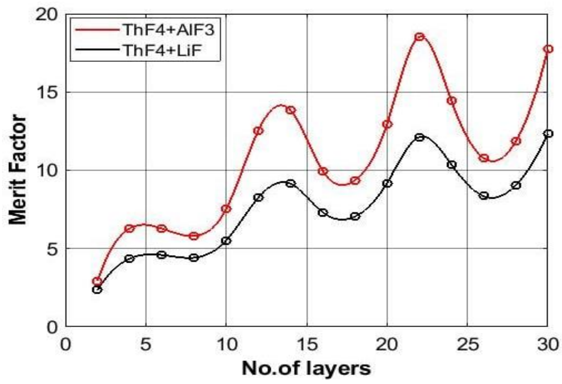


Figure 5. Merit factor Versus No. of layers for Glass/AlF_3/ThF_4/Air and Glass/LiF/ThF_4/Air.

All the previous figures exhibit the coating with AlF_3/ThF_4 is the best and more efficient for coloration and thermal gain than LiF/ThF_4 coating.

CONCLUSION

The best coating exhibit high solar transmittance and low solar reflectance to increase the losses which occur in the thermal solar collectors. All the results of our comparative study explain the coating with AlF_3/ThF_4 is the best and more efficient for coloration and thermal gain than LiF/ThF_4 coating.

The peak of the curves will increase with increasing the layers number but the width of the curves will decrease with increasing the number

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of layers for the two cases, this will fix the color of the coating and reflect narrow band in the visible region , the increasing in the peak height is higher for Glass/AlF_3/ThF_4/Air than Glass/LiF/ThF_4/Air, The two cases of the coating display color reflectance (green), this will add esthetic aspect to the façade thermal solar collectors, however the infrared region still antireflection region.

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