Optical properties of double-layer MgF_2 thin films as anti-reflective coating for optical lens

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Abstract

MgF_2 thin films deposited by thermal evaporation are vastly applied onto glass lenses because of its transparency in the UV-Vis spectrum. In the present work, single, double and triple layers of MgF_2 nanostructure have been grown on glass substrates by thermal evaporation method. The optical properties of MgF_2 films in the UV-Visible spectrum has been investigated using the Metertech SP8001 UV-Vis spectrophotometer. The Morphology and topography analysis has been investigated using atomic force microscope (AFM). Atomic force microscopy analysis has detected that the double layer MgF_2 has the lowest root mean square (1.91) nm, lowest surface roughness average (1.49) nm and the smallest grain size (21.63) nm. The optical measurements have observed that the double layer MgF_2 revealed the highest transmittance in the visible region (93.3 %) at 550 nm wavelength and the lowest absorbance (0.029) and reflectance (0.066). The absorption coefficient (3395) cm^{-1}, extinction coefficient (0.0171) and refractive index (1.31) at 550 nm wavelength for the double layer MgF_2 were also the lowest among the other films. These results have proved that the double layer MgF_2 film was the best among the three films for antireflection application.

Keywords: MgF_2, thin film, anti-reflective, thermal evaporation, optical lenses.

الخواص البصرية لاغشية رقيقة من طبقة مزدوجة من فلوريد المغنيسيوم كمضاد للانعكاس للعدسات البصرية

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الخلاصة

تستخدم الاغشية الرقيقة لفلوريد المغنيسيوم على نحو واسع كمضاد للانعكاس على زجاج العدسات البصرية وذلك كونها ذات شفافية عالية للطيف المرئي وفوق البنفسجي. في هذا البحث تم ترسيب فلوريد المغنيسيوم ذي التركيب النانوي بطبقة واحدة وطبقتين وثلاث طبقات على الزجاج باستخدام طريقة التبخير الحراري. وقد تم دراسة الخواص البصرية للاغشة ضمن حدود الطيف المرئي وفوق البنفسجي باستخدام جهاز مطياف (Metertech SP8001 UV-Vis spectrophotometer). كذلك تم دراسة التضاريس والخواص السطحية للاغشية باستخدام مجهر القوة الذرية. ومن خلال النتائج التي تم الحصول عليها في هذه الدراسة تبين ان الغشاء ثنائي الطبقة يمتلك أعلى نفاذية وأقل انعكاسية بين بقية الاغشية لذا فانه الاكثر ملائمة لاستخدامه كطلاء مضاد للانعكاس على العدسات البصرية.

الكلمات المفتاحية: فلوريد المغنيسيوم، غشاء رقيق، مضاد الانعكاس، التبخير الحراري، العدسات البصرية.

Introduction

The antireflective coatings (ARCs) are widely applied on the films in order to minimize the reflection of incident light on their surface and therefore increase the transmission [1]. Moreover; the reflectivity (r) is a very significant parameter in optical materials because of its relationship with the absorbance and transmittance [2]. Two essential fields for the application of antireflective coatings: the first field in which the antireflective coating is applied for aesthetic uses and the second field in which the antireflective coating is applied to enhance the efficiency of the devices [1]. Presently there are many methods of formation of antireflective films like vacuum evaporation, spin coating, chemical vapor deposition (CVD), spray coating, screen printing, and so on [3]. In this work single, double and triple layer of MgF_2 will be applied on glass as antireflective layers using thermal evaporation technique that is competitive in the cost and has a simpler procedure. The antireflective nanocoating thin film is prepared for naturally incidence contains a single quarter wave layer of a material having refractive index near to the geometrical average amount of the refractive index of the two neighboring medium. If no appropriate ambience for a single layer coating can be got, multilayer antireflective coatings with three or more layers can be applied. This can as well be utilized for antireflective characteristics which are desired for a very wide range of wavelength [4]. MgF_2 is an attractive material for optical applications because it has a good stability in the hostile ambiences and has a low refractive index [5]. Magnesium fluoride thin films deposited using thermal evaporation contains a pored vertical microstructure, so they probably have low packing densities, leading to extreme sensitivity to the moisture existing in the room air [6]. The monolayer antireflective coating is possible to can be non reflective only at single wavelength, ordinary at the midst of the visible region spectrum. whereas the double layer antireflective coatings are more efficient onto all the visible region spectrum [7].

Experimental Work

Single, double and triple layer MgF_2 thin films have been deposited on glass substrates using thermal evaporation technique, which is illustrated in the schematic in figure 1. MgF_2 powder has been provided by (Sigma-Aldrich, USA) with high purity (99.99%) has been used as a source material for deposition.

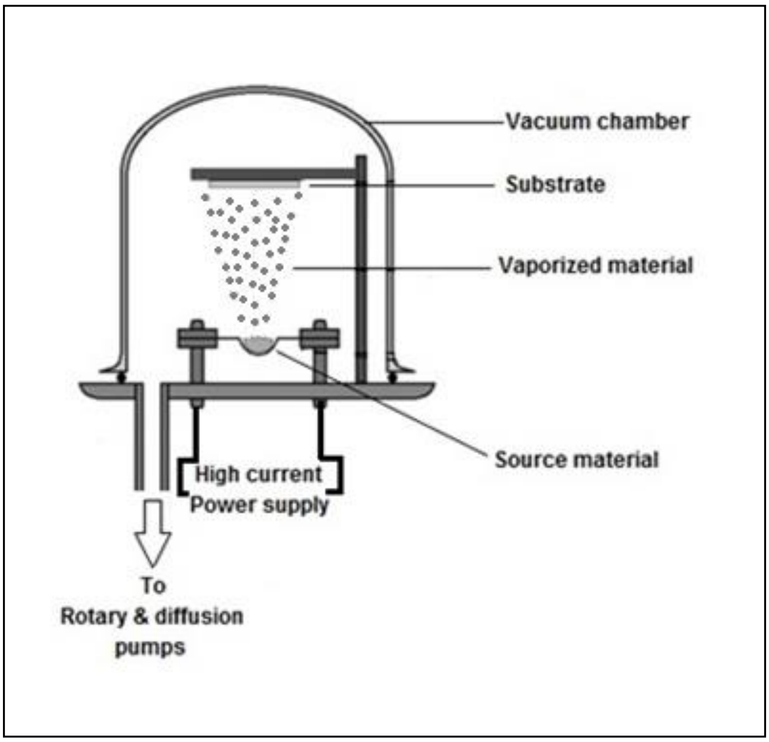

Figure 1. A schematic diagram of Thermal Evaporation system

Glass substrates have been well Cleaned using double distilled water and ethanol solution, then dried for a few minutes and then placed 17 cm over MgF_2 powder which has been placed onto molybdenum boat inside vacuum chamber. High current power supply has been used for heating the boat. When the powder riches to the sublimation temperature it evaporates and then deposits on the glass substrates. The process has been done under high vacuum (15×10^{-6} mbar) using rotary and diffusion pumps. The pressure inside the vacuum chamber has been controlled using pirani and penning gauges. The films thicknesses have been measured using laser light interference and found to be (98,145 and 195) nm for single, double and triple layer respectively. The morphological and topographical properties have been studied using (Angstrom AA 3000 SPM), whereas the optical properties have been analyzed using (Metertech SP-8001) UV-Vis spectrophotometer.

Results and Discussions

Topography and Morphology analysis

Topography and morphology characterization of the films have been studied using atomic force microscope (AFM). Fig. 2 shows the results of AFM analysis for the three films.

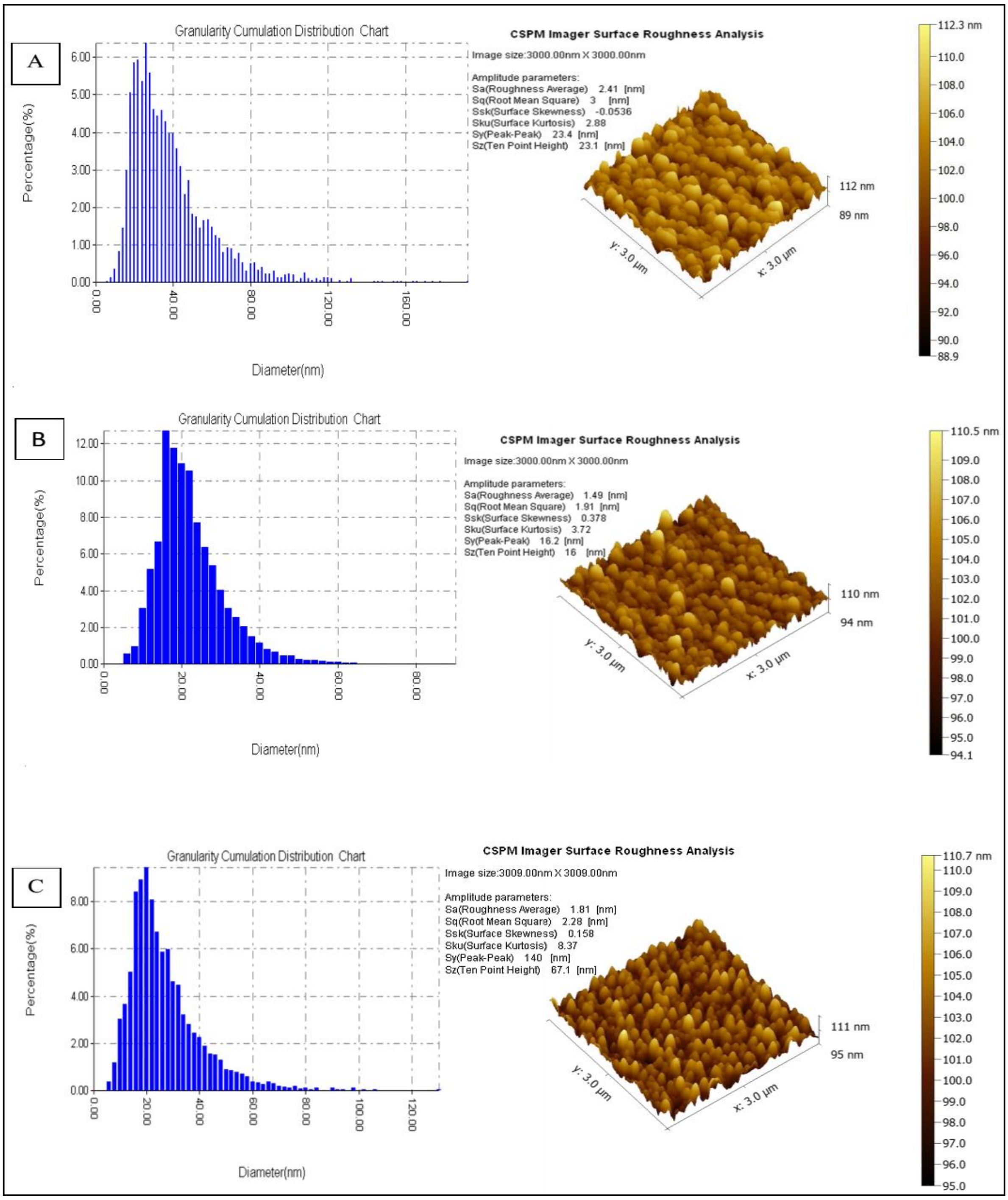

Figure 2. AFM micrographs and grain size distribution of (A) Single layer MgF_2, (B) Double layer MgF_2 and (C) Triple layer MgF_2 thin films

From Fig. 2 it can be seen that the surfaces of the films are dense, uniform, and smooth and there are no cracks observed in the films.

The root mean square (RMS), Surface roughness average and the average grain size of the three films are shown in table 1.

Table 1: The topography and average grain size of single, double and Triple layer MgF_2 thin films.

Sample	Root mean square RMS (nm)	Surface roughness average (nm)	Average grain size (nm)
Single layer MgF_2	3	2.41	37.63
Double layer MgF_2	1.91	1.49	21.34
Triple layer MgF_2	2.28	1.81	26.19

As it is observed in the table, the double layer MgF_2 thin film is the smallest grain size (21.63 nm), lowest root mean square (1.91 nm) and lowest surface roughness average (1.49 nm). These results made the double layer MgF_2 thin film candidate to be the optimum anti reflective thin film.

Optical properties

As shown in Fig. 3, MgF_2 coating has improved the optical transmittance of the glass, whereas, in the most of the visible region, the double layer MgF_2 has given the highest transmittance reached to 93.3 % at 550 nm wavelength, while the transmittance of the single layer thin film was 91.36 % as compared to glass which has 89.7 % transmittance at the same wavelength, however in the case of triple layer MgF_2, the transmittance has tumbled to 91.7 %. These results strongly indicated that the double layer MgF_2 is the best for using as an anti reflective coating on glass for the visible spectrum. The increasing in transmittance has happened because of the decreasing in the surface roughness, which is in agreement with the previous report [8].

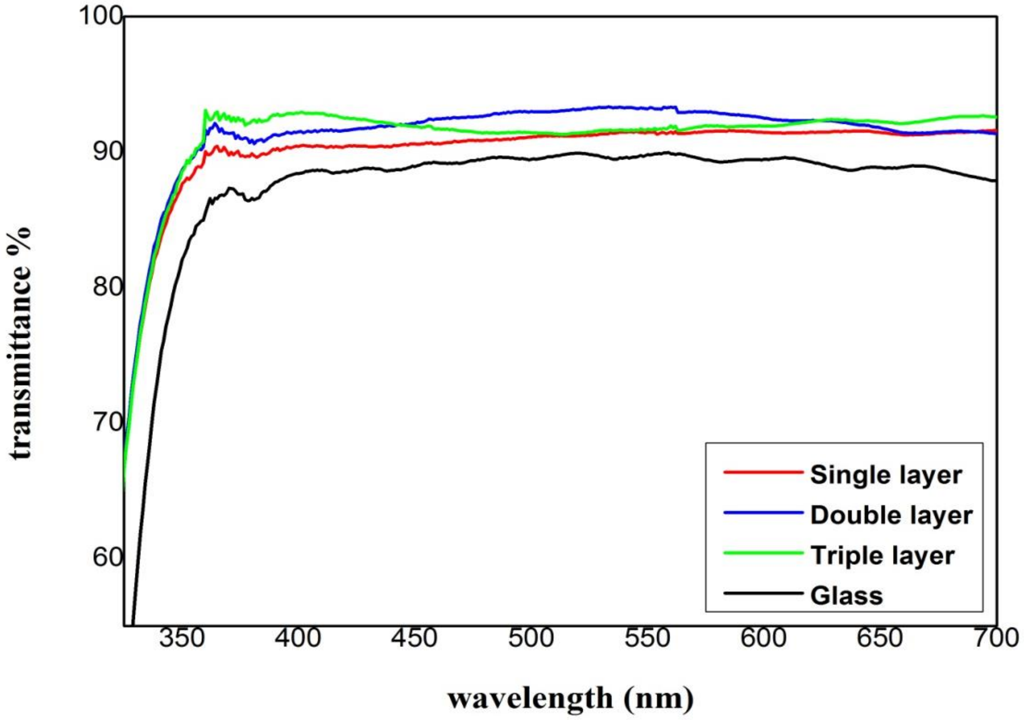

Figure 3. Transmittance spectrum for glass, glass coated with single, double and triple layer MgF_2 thin films

The absorption spectrum of the coated films is shown in fig. 4. As it is seen from the figure, generally the absorbance of the films is very low, but the double layer MgF_2 revealed the lowest value of the absorbance (0.029) at 550 nm wavelength as compared to the uncoated glass which revealed (0.050) absorbance at the same wavelength while the single and triple layer MgF_2 have (0.038) and (0.037) absorbance respectively.

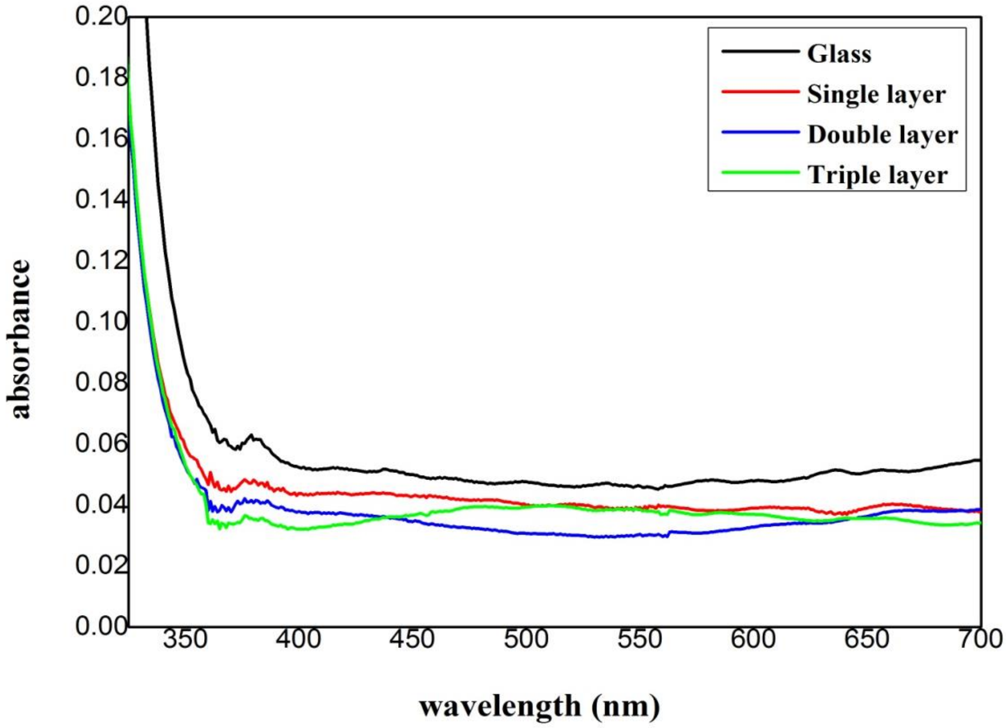

Figure 4. The absorption spectrum for glass and glass coated with single, double and triple layer MgF_2 thin films

The absorption coefficient (α) of the films has been calculated using Eq. (1) [9].

$$\alpha = \frac{1}{d}\ln T \qquad (1)$$

Where d and T are the thickness and transmittance of the films respectively.

Fig. 5 shows the plot of the absorption coefficient versus wavelength for the films. From the figure, it can be seen that the absorption coefficient decreases in the long wavelengths and increases in the short wavelengths for all films because the prospect of the electron's transmission from the valance band to conduction band is very scarce in the law photon energy [10]. Also, it can be shown that the absorption coefficient for double layer film is the lowest among the three films, whereas the double layer MgF_2 film revealed (3395) cm^{-1} absorption coefficient at 550 nm wavelength, while the absorption coefficients for single and triple layer films were (8039) and (4433) cm^{-1} respectively.

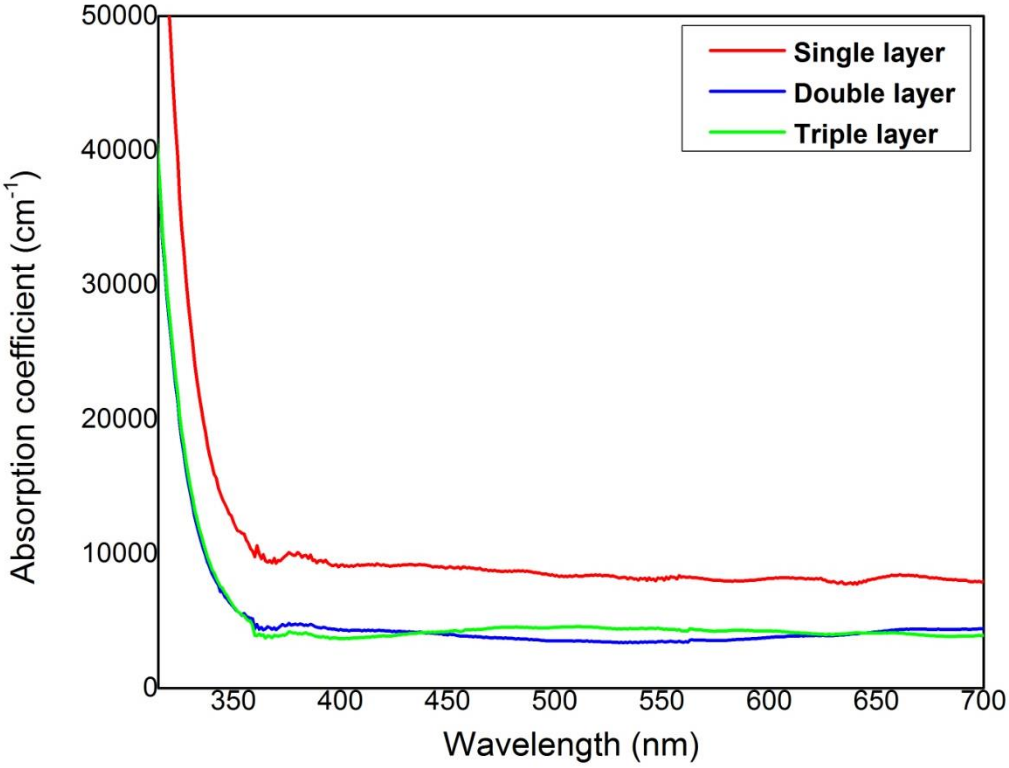

Figure 5. The absorption coefficient vs. wavelength for single, double and triple layer MgF_2 thin films

The extinction coefficient (k) for the films has been calculated using Eq. (2) [11]

$$k = \frac{\alpha\lambda}{4\pi} \quad (2)$$

Where α and λ are the absorption coefficient and wavelength respectively. Fig. 6 shows the extinction coefficient versus wavelength for the three films. As shown in the figure, all the films have very low extinction coefficient, but the double layer MgF_2 film has the lowest value of extinction coefficient as compared to the other films, whereas the extinction coefficients at 550 nm wavelength for the single, double and triple layer MgF_2 thin films were (0.0335), (0.0171) and (0.0227) respectively.

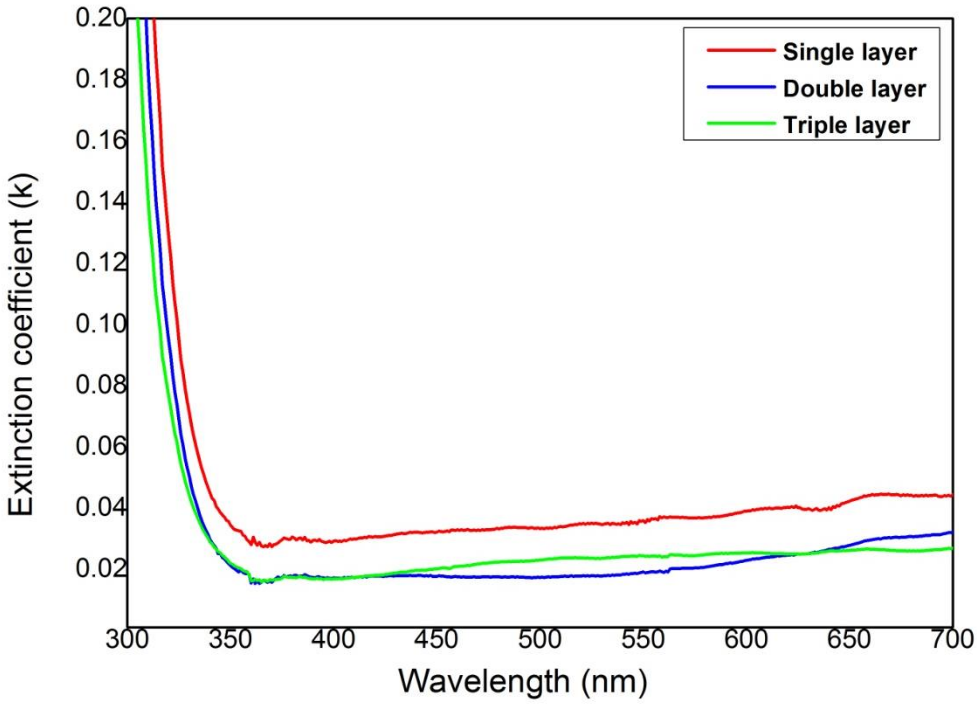

Figure 6. Extinction coefficient vs. wavelength for single, double and triple layer MgF_2 thin films

The refractive index (n) has been determined using Eq. (3) [10].

$$n = [(4R/(R-1)^2) - k^2]^{1/2} - [(R+1)/(R-1)] \quad (3)$$

where R and k are the reflectance and the extinction coefficient for the films respectively.

Fig. 7 shows the refractive index versus wavelength for single, double and triple layer MgF_2. As it is observed in the figure, the double layer MgF_2 film has the lowest value of refractive index as compared to the single and triple layer films, whereas the double layer film has reported (1.31) refractive index, while the single and triple layer films have reported (1.34) and (1.33) refractive index respectively.

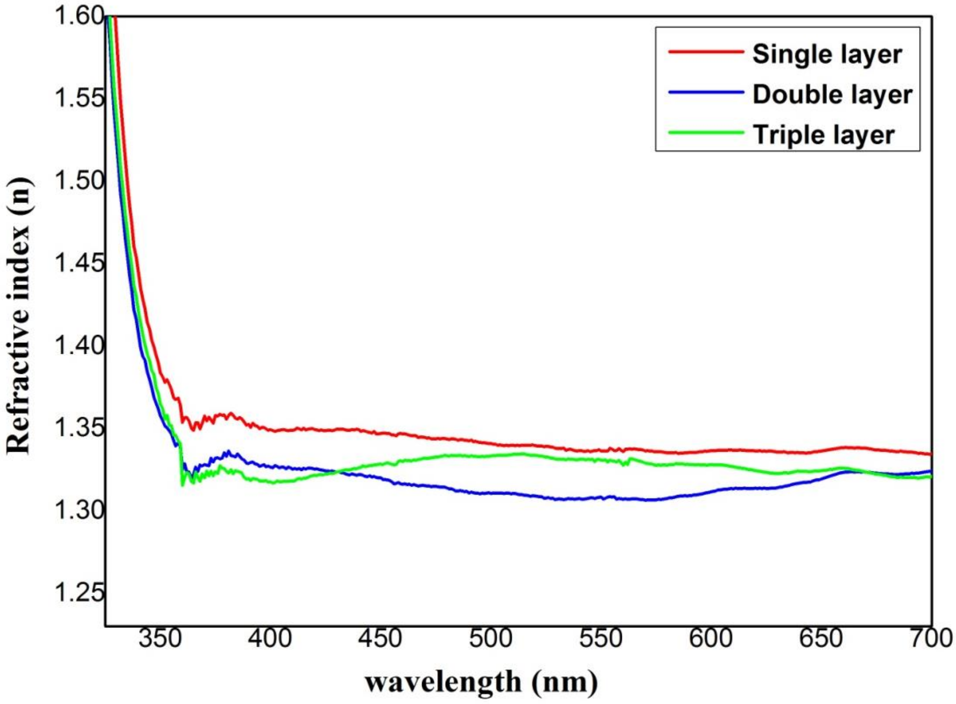

Figure 7. Refractive index vs. wavelength for single, double and triple layer MgF_2 thin films

The reflectance (R) for the films has been calculated using Eq. (4) [12].

$$R = 1 - (A+T) \quad (4)$$

Where A and T are the absorbance and transmittance of the films respectively.

Fig. (8) shows the reflectance of uncoated glass and glass coated with single, double and triple layer MgF_2 as a function of wavelength. As shown in the figure, the double layer MgF_2 film has revealed the lowest value of the reflectance (0.066) at 550 nm wavelength as compared to the uncoated glass which has revealed (0.1023) reflectance and to the single and triple layer MgF_2 films which have given (0. 086) and (0.084) reflectance respectively at the same wavelength.

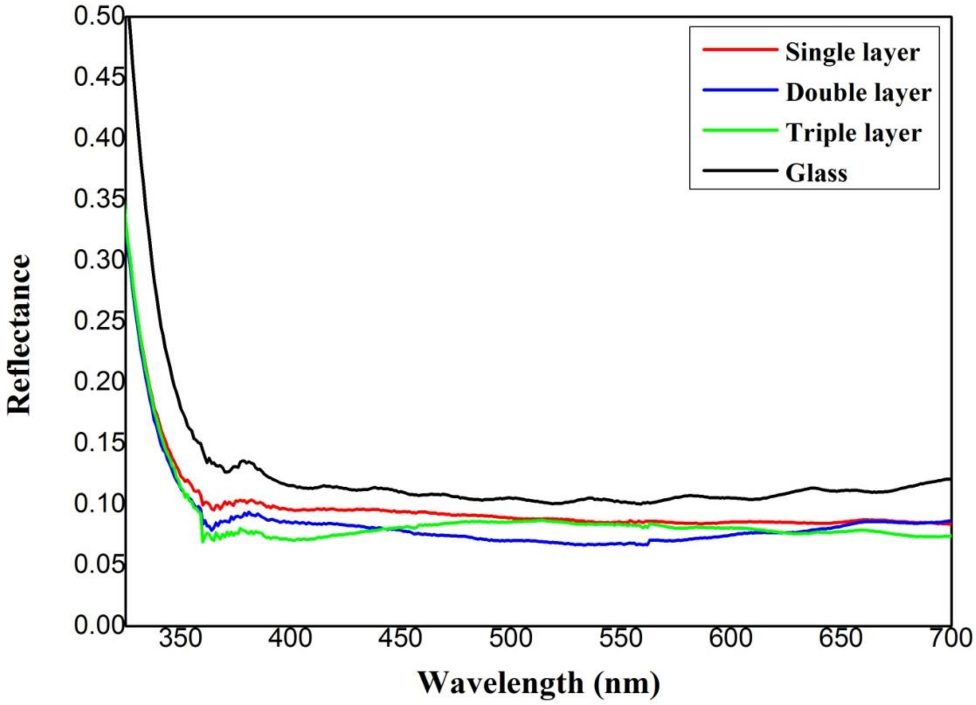

Figure 8. The reflectance spectrum for glass and glass coated with single, double and triple layer MgF_2 thin films

Conclusion

Multilayer MgF_2 thin films have been successfully deposited on glass substrates by thermal evaporation method as a promising inexpensive antireflective coatings for optical lenses. All the results have proved that the double layer MgF_2 thin film deposited on glass substrate was the best among the three films for antireflection application.

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