J.Thi-Qar Sci. No. (2) Vol.1 Aug./2008

ISSN 1991- 8690 الترقيم الدولي ٨٦٩٠ - ١٩٩١
website: http://jsci.utq.edu.iq Email: utjsci@utq.edu.iq

Design and manufacture (He-Ne) laser windows multiplayer antireflection coating

Alaa j. Ghazai

Thi-qar university - College of Science - physics dept.

Abstract

In this study;the windows of (He-Ne) laser multilayer antireflection coating have been designed from materials MgF_2 as external layer with refractive index (1.38) and ZnS as internal layer with refractive index (2.35) deposited on BK-7 glass that have refractive index (1.52). Five layers with optical path equal quarter wavelength ($\lambda/4$) theoretically and experimentally, and another way, five layers with middle layer ($\lambda/2$) theoretically were used. The all designs are dealing with them in the wavelength less than design of wavelength with clear difference of the theoretical design with middle layer ($\lambda/2$) at design wavelength. The value of minimum reflectance to one about (0.002) at (680) nm theoretically and (0.0081) at (590)nm while experimentally about (0.69) at (650)nm. Another way we obtains on refraction about (0.00٠٤) in a wide range from wavelength (450 - 690)nm when the seven layer with optical path equal quarter wavelength ($\lambda/4$) theoretically were designed .

1. Introduction

Antireflection coating is required in most optical applications to reduce the undesired reflections at the surface of the optical elements. Durable single layer coating of magnesium fluoride (MgF_2) do not satisfy these requirements very well, because can it is only reduce the reflectance of glass from 4 to 1.2 %. Double layer coating can be made which produce one or two zero reflectance minima. However, the reflectance in the first case rises too sharply on both sides of the minimum, and in the second case the reflectance is insufficiently constant over the low reflecting region *Cox and Hass (1962)*. Antireflection coating (ARC) in general can be classified into four types with respect to their spectral features: V-type, W- type, U- type *Negandra at. el., (1985)* and π - type *Rashid at. el, (1999)*. V- type coating have low reflection losses at specific wavelength region whereas in W- type coating the antireflection condition is satisfied at two wavelength regions between those have ripple behavior . The other type is U-type coating in which residual reflection losses are virtually zero over a moderate spectral range *Negandra at. el., (1985)*, and π- type in which the reflectance have minimum value at wavelength and a maximum value at the other *Hussein (2000) & Rashid at. el (1999)*. In all cases where a single layer ARC not satisfactorily result can be achieved, two or more layers have been applied. For applications it is mostly sufficient to reduce the reflection at one specific wavelength this can be done with a double layer ARC as V– coating but when we need to extend the range a multilayer AR- coating must be used.

1-1 Coating Materials

Many of inorganic materials which can be evaporated in high vacuum without comprises many elements are few simple compounds, such as some of fluorides, oxides and sulfides. A further limitation in the range of available material results from other essential requirements such as mechanical and chemical durability. Depending on the applications sometimes very strict specifications has to be fulfilled. For dielectric film materials, the region of high transparency extended from the UV– to the IR absorption bands *Arechi and Schulz (1972)*. The film material used for layer windows should show a large difference in refractive index to obtain low reflectance value with least number of deposited layers. For applications due to the high demands with respect to low losses and high stability, only few film materials have provide practical characteristics for laser windows. The number of layers used depends on the material combination and on the desired reflectance value. If the number of layers is increased the films become quite thick and scattering may occur in this case normally *Chopra (1989)*.

Magnesium Fluoride (MgF_2)

Thin films of Magnesium Fluoride (MgF_2) are widely used in optical coating where a low refractive index layer is required and also for enhancing the reflectance of aluminum mirrors in the vacuum ultraviolet region. Consequently MgF_2 has been extensively studied and some significant advances in the preparation of durable low stress films have been made *Martin et. al., (1987)*. Most MgF_2 films are crystalline *Hass et. al., (1975)* and they are in the form of a white powder and possess melting point (1266) C ^{o} and has density of (2.9 – 3.2) $gm.cm^{-3}$. In the near infrared MgF_2 film is a good material with low index can be used.

Zinc sulfide (ZnS)

The easiest material of all to handle is Zinc sulfide (ZnS) , ZnS are sublime rather than , melt , and can deposited from a tantalum and molybdenum boat or else from a howitzer . Although ZnS is not particularly robust, it is so easy to handle especially in the construction of multilayer for visible and near infrared regions. Zinc sulfide ZnS is particularly strong and can be used for infrared windows in high speed aircraft and vacuum applications.

All combination of ZnS or ZnSe with MgF_2 or Na_3ALF_6 should be handled with great care; they should only be cleaned very gently without fluids. Zinc sulfide , Magnesium Fluoride have a greatest resistance to attack by chemicals and moisture, and they hard enough that special cleaning methods are not required *Chopra (1989)*.Table (1) shows some of coating materials and those properties.

Table (1): some coating materials and those properties Macleod (1986).

Materials / Properties	Magnesium Fluoride MgF_2	Silicon Si	Zinc Sulfide ZnS
Refractive Index at λ_{630nm} / λ_{1060nm}	1.377 / 1.3735	3.8892 / 3.555	2.32 / 2.291
Density (gm cm^{-3})	3.177	2.3291	4.09
Melting point (C°)	1225	1420	1500
Hardness	415	1150	240
Molecular weight	62.32	28.09	97.43

2. Theoretical Part:

The reflection of incident radiation on transparent medium at non normal incident is given by Fresnel's equation *Yodals (1980)*

$$\boldsymbol{R} = \frac{1}{2}\left[\frac{\sin^2(\boldsymbol{i}-\boldsymbol{r})}{\sin^2(\boldsymbol{i}+\boldsymbol{r})} + \frac{\tan^2(\boldsymbol{i}-\boldsymbol{r})}{\tan^2(\boldsymbol{i}+\boldsymbol{r})}\right] \quad .... (1)$$

Where i is the angle of incident and r is the angle of refraction. For normal incidence in air eq. (1) becomes

$$R = \left(\frac{n_s - n_o}{n_s + n_o} \right)^2 \quad \text{.............. (2)}$$

Where n_o , n_s are refractive indices of incident , emergent The coating of surface with a non-absorbing film is one way of eliminating the reflectance. For a coated surface, the minimum reflection at the designed wavelength λ_o with quarter- wave optical thickness is given by:-

$$R = \left(\frac{n_o n_s - n_f^{\,2}}{n_o n_s + n_f^{\,2}} \right)^2 \quad \text{.............. (3)}$$

n_f is film refractive index .To obtain zero conditions reflectance, two condition must be satisfied:-

1- Film index condition: $n_f \sqrt{n_o n_s}$

2- Optical thickness of the film must be quarter wavelength or multiple of it

i.e: $nd = m\frac{\lambda_o}{4}$

Where (m = 1, 3, 5……) is the order of interference. This means that an antireflection film on glass, having refractive index (1.52) must becomes have refractive index ≈ 1.23 . This low index requirement practically impossible make it to design a single layer antireflection film for glass *Yodals (1980)*. Since MgF_2 has an index of refraction (1.38), which would reduce the maximum reflectance to ≈ 1.2 %. At the other wavelength the reflectance can be computed with the aid of the characteristic matrix *Abels (1950)* and it' s modification *Rashid (1996)*. For the r^{th} layer it was given by:

$$\begin{pmatrix} B \\ C \end{pmatrix} = \begin{pmatrix} \cos\delta_r & i n_r^{-1}\sin\delta_r \\ i n_r \sin\delta_r & \cos\delta_r \end{pmatrix} \begin{pmatrix} 1 \\ n_s \end{pmatrix} \quad \text{................ (4)}$$

Where B and C are the matrix elements represents electric and magnetic field and $\delta_r = \frac{2\pi n_r d_r}{\lambda}$ represents the phase thickness of the film. The characteristic matrix for two layers can be written as: *Abels (1950)*

$$\begin{pmatrix} B \\ C \end{pmatrix} = \begin{pmatrix} \cos\delta_1 & i n_1^{-1}\sin\delta_1 \\ i n_1 \sin\delta_1 & \cos\delta_1 \end{pmatrix} \begin{pmatrix} \cos\delta_2 & i n_2^{-1}\sin\delta_2 \\ i n_2 \sin\delta_2 & \cos\delta_2 \end{pmatrix} \begin{pmatrix} 1 \\ n_s \end{pmatrix} \quad \text{.......... (5)}$$

In general from (m) layers: *Abels (1950)*

$$\begin{pmatrix} B \\ C \end{pmatrix} = \left\{ \Pi_{r=1}^{m} \begin{pmatrix} \cos\delta_1 & in_1^{-1}\sin\delta_1 \\ in_1\sin\delta_1 & \cos\delta_1 \end{pmatrix} \right\} \begin{pmatrix} 1 \\ n_s \end{pmatrix} \quad \text{................ (6)}$$

3. Experimental Part:

The multilayer coating of MgF_2 and ZnS deposited on glass (n_s=1.52) by thermal evaporation technique under high vacuum by using Laybold Hearaeus coating unit to prepare the samples. The samples are prepared and experimental measurements are done in the technology and science ministry. The system is capable of a achieving pressure down to (10^{-5}) mbar. Crystal thickness monitor was used to control the thickness of the layer MgF_2 and ZnS were evaporated from Molybdenum or Tankistan boat, to produce hard and durable coating. The substrate was heated to (100) C^o under vacuum, reflectance measurement in air at room temperature within the wavelength range (400-900)nm by using UV-Visible recording spectrophotometer UV/160.

4. Result and Discussion

Figure (1) can be divided into three parts: The first one shows two theoretical curves ($n_it_i=\lambda/4$ where i=1,2,3,4,…) and ($n_it_i=\lambda/4$ where i=1,2,3,4,…) , ($n_jt_j=\lambda/2$ where j=3) and the experimental curve ($n_it_i=\lambda/4$ where i=1,2,3,4,…) shows the same behavior where the lowest reflection value is about 0.09 in the wavelength (λ=500 nm). The reasons of this behavior is due to the materials are dealing with them and with the substrate in physical and chemical properties and the conditions of the zero reflection were satisfied. The second part where two theoretical curve shows opposite behavior where the reflection value about (R= 0.0034) at the wavelength(λ= 650) nm in curve (a) which show the same behavior comparing with experimental curves and the reflection value about (R= 0.0696) at the same wavelength in curve (b) this case obtains when the design contains middle layer with optical path (nd=λ/2) this layer called absent layer which show opposite behavior with experimental curve also (curve c) .The third part shows shift between the low reflection in curve (a) and (b) and experimental curve(curve c) where (R= 0.002) at (λ= 680) nm in theoretical curve (a) while (R=0.012) at (λ=490) nm and (R=0.012) at (λ=760)nm in theoretical curve (b) and Figure (2) can be show that the low reflection value extended a long wide range from wavelength, since(R= 0.002) from (λ= 450) nm to (λ=690)nm this case satisfies the zero reflectance conditions and it is the best choice to design this applications which obtain because the best selection to suitable materials to this region from the electromagnetic spectral. Table (2) shows the theoretical and experimental reflectance values of multilayer antireflection coating design which contains five and seven layers .

Table (2): The theoretical and experimental reflectance values of multilayer antireflection coating design which contains five and seven layers

Design	No. of layer	Optical thickness (nd)	Theoretical		Experimental	
			R %	λ (nm)	R %	λ (nm)
Air/MgF_2/ZnS/Glass	5	$\lambda_0/4$	0.002	680	0.0081	590
Air/MgF_2/ZnS/Glass	5	$\lambda_0/2$	0.08	490		
			0.012	760		
Air/MgF_2/ZnS/Glass	7	$\lambda_0/4$	0.0004	450-690		

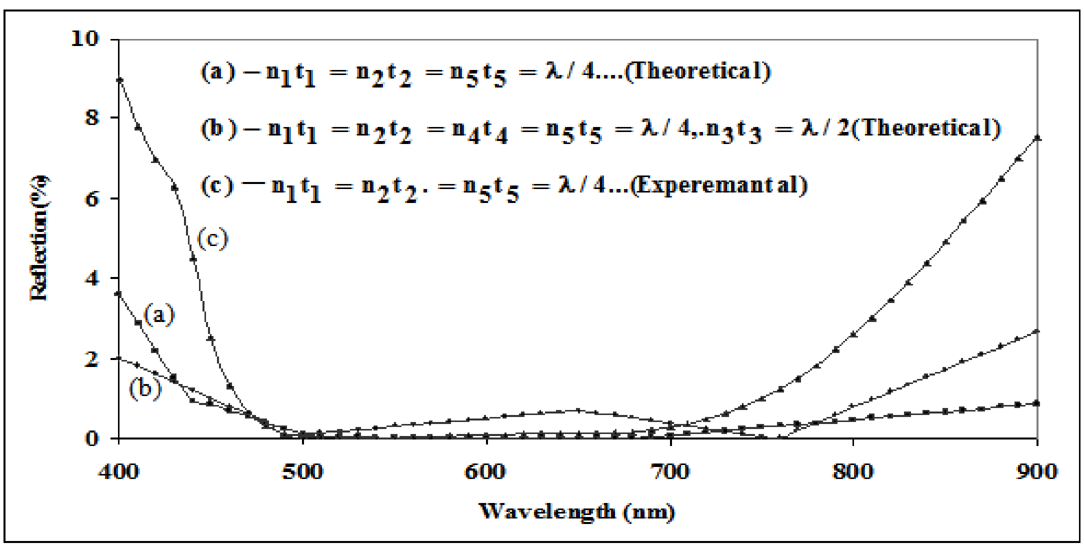

Fig (1) the reflection of multilayer antireflection coating (Five layers) as a function of wavelength

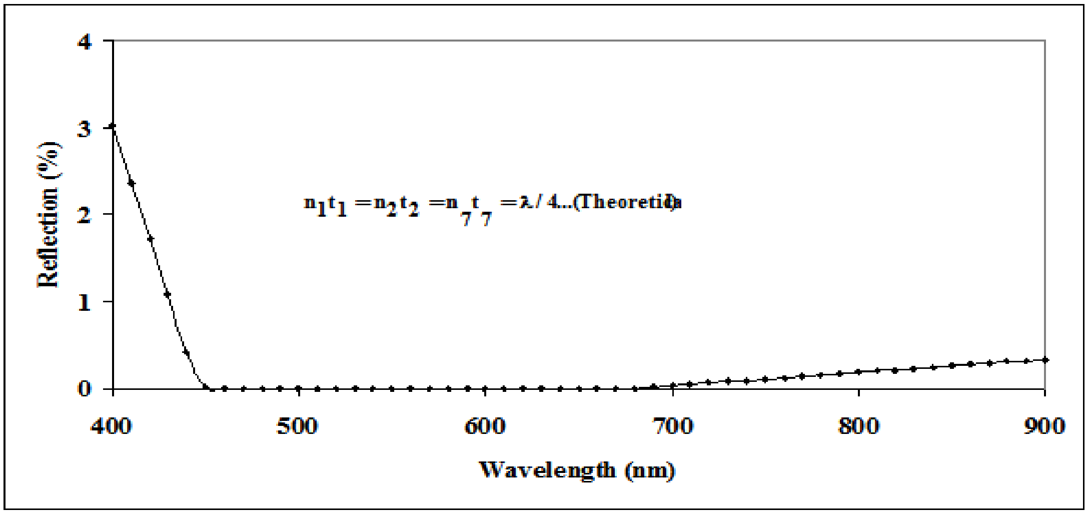

Fig (2) the reflection of multilayer antireflection coating (Seven layers) as a function to wavelength

Conclusion

Increasing the number of layers for multilayer design consist of seven layers lead to wide range wavelength of the minimum reflection which means the suitable design for use in laser windows. A good agreement between experimental and theoretical results for five layers with optical path (nd=λ/4) lead us to suitable corresponding between the used materials and substrate, but the five layers design with middle layer of optical path (nd=λ/2) does not suitable for these applications because of clear increasing on the minimum reflection at wavelength of design, all design are dealing with each other in the wavelength less than design wavelength.

References

1. Abel's, F., " Recherchés ssur la propagation Des ondes electromague'tigues sinusoidales dans les milieux stratifie's Application aux couches minces , " Ann – dephysigue 5 (1950) 596 .
2. Arechi, F.T. and Schulz-DuBois, E.O., Laser Handbook, North – Holland Publ.Co.Amsterdam 1972
3. Chopra, K.L., Thin –Film Phenomena (McGraw-Hill, Company, New York, 1989)
4. Cox, J. T. and Hass G. "Triple -Layer – Antireflection Coating on Glass for the visible and Near Infrared ". J.Opt.Soc.Am.52 (1962) 965.
5. Hass, G.M., , Francombe, H. and Hoffman, R. W., Physics of Thin Film, Vol. 8, Academic press , U.S.A, (1975).
6. Hussein, R. K., "Computer-Aided method to replace the intermediate ref active index by symmetrical stack with applications on antireflection coating, "M.Sc. Thesis (2000), Al-Mustansiriyah University.
7. Macleod, H. A.,Thin Film Optical Filters (McGraw-Hill, New York, 1986).
8. Martin, P. J. and Other "Influence of ion assistance on the optical properties of MgF_2 " Appl. Opt, Vol.26, No.7, pp. 1235, (1987)
9. Negendra, C.L, Viswanathan, M. and Thutupalli, G.K. " Design and optimization of low wide band antireflection coating for the visible and infrared region : new method Appl. Opt. 24 , (1985) 1156.
10. Rashid, H. G., "Design and Optimization of thin-films optical filters with applications in the visible and infrared regions". Ph. Thesis (1996), Al-Mustansiriyah University.

11. Rashid H. G., Al-Dahan, Z.T. and Ibrahim, H.M., "Design of Dual –Band antireflection coatings", accepted in the first conference on physics and materials research IACE, Baghdad, 1999.
12. Yodals, B. E. "Investigations of porous oxide as an antireflection coating fro glass surface ",Appl. Opt. 19 (1980) 1425.

تصميم وتحضير نوافذ ليزر (He–Ne) من طلاء متعدد الطبقات مضاد للانعكاس

علاء جبار غزاي

جامعة ذي قار – كلية العلوم – قسم الفيزياء

الخلاصة

تم تصميم نوافذ لليزرهليوم–نيون (He-Ne)من طلاء متعدد الطبقات مضاد لانعكاس الضوء من مادة فلوريد المغنسيوم(MgF_2) كطبقة خارجية معامل انكسارها (1.38) ومادة كبريتيد الزنك (ZnS) كطبقة داخلية معامل انكسارها (2.35) مرسبة على أرضية اساس من مادة الزجاج نوع BK-7 معامل انكسارها (1.52) واستخدمت خمسة طبقات جميعها بسمك بصري ربع طول موجة (λ/4) نظريا وعمليا مرة وخمس طبقات مع طبقة وسطية بسمك بصري نصف طول موجة (λ/2) نظريا مرة اخرى وكان هنالك توافق جيد لجميع التصاميم في الاطوال الموجية الاقل من طول موجة التصميم مع اختلاف واضح للتصميم النظري مع طبقة وسطية (λ/2) عند طول موجة التصميم،وكانت القيمة الصغرى للانعكاسية للحالة الاولى بحدود (٠,٠٠٢) عند طول موجة (680) نانومتر نظريا و(٠,٠٠٨١) عند طول موجة (590)نانومتر بينما كانت(٠,٠٦٩) عند طول موجة (650) نانومتر في الحالة الثانية. كذلك استخد مت سبع طبقات بسمك بصري ربع طول موجة وقد تم الحصول على قيمة للانعكاسية بحدود (0.002) لمدى واسع من الاطوال الموجية (690-450) نانومتر.