Iraqi J. Laser, Part A, Vol.11, pp. 21-28 (2012)

IRAQI JOURNAL OF LASER

Design and Simulation of Optical Element Use in Solid State Blue Laser Source

Aseel A. Shakaty and **Wail Y. Nassir**

Laser and Optoelectronics Eng. Dept., University of Technology, Baghdad, Iraq

(Received 22 May 2012; accepted 18 November 2012)

Abstract: Solid state blue laser source is a solid state laser include generation of IR laser light 1064 nm and companied with other wavelength 810 nm that invented from other active medium (Tm:ZBLAN) and non-linear crystal (CLBO) are used to generate fourth harmonic of the resultant wavelength 1874 nm that is blue laser light of 460nm. Several optical component have been designed by multilayer dielectric structure and anti reflection coating analysis. By using MATLAB soft ware, the simulation done and used the following non linear material (ZrO_2, HfO_2, MgO, SiO, Ta_2O_5 CaF_2) and other linear material (ZnO, MgF_2, GaAs, AlAs, BaF_2, LiF, TiO_2) as coating material. The result showed that as more quarter wave layers are added to the structure, the reflectance spectrum acquires more oscillatory features, and a narrow, flat-topped high-reflectance region grows around the design wavelength, GaAs and MgF_2 represent good choice for the coating material of the front and exit mirror of the system especially produces very narrow wavelength band width and excellent value for R=100 % , LiF_2 and BaF_2 are good choice used to coat non linear crystal. For the polarized dichroic beam splitter, 45^0 represent good choice for the incident angle and BK7 as substrate material and HfO_2 as high refractive index material and ZnO as low index material for coating.

Introduction

A solid state laser system used comprises a gain medium producing a light beam and two mirrors defining a laser cavity around the gain medium to reflect a light beam back and forth through the gain medium. One of the mirrors, the exit mirror, is specially dielectric coated to allow a beam of light, the laser beam, having a predetermined wavelength to pass there through [1]. The gain medium is pumped by a light source, such as a diode or another laser.

The wavelength of the blue light generated by the solid state laser is approximately 460 nm and can be tune over approximately 5 nm, as allowed by the 10 nm gain spectral bandwidth of the Tm:ZBLAN gain medium. The emission wavelength is close to the peak response of the blue receptors in the human eye and is therefore ideal for visual display applications. A nonlinear crystal is used, which operates efficiently when 810 nm and 1064 nm beam are of the same polarization, the 810 nm laser cavity 1 can be co-extensive with the 1064 nm laser cavity 2. Also, while it is preferable to place the nonlinear crystal in both the 1064 nm laser cavity 1 and the 810 nm laser cavity 2, the non linear crystal may be place outside the cavities 1 and 2 and the exit mirror made transparent at both 810 nm and 1064 nm [2].

Theory

A dielectric mirror consists of multiple thin layers of (usually two) different transparent optical materials (dielectric coatings, thin-film coatings, interference coatings). Even if the Fresnel reflection coefficient from a single interface between two materials is small (due to a small difference in refractive indices), the reflections from many interfaces can (in a certain wavelength range) constructively interfere to result in a very high overall reflectivity of the device. The simplest and most common design is the Bragg mirror, where all optical layer thickness values are just one-quarter of the design wavelength. This design leads to the highest possible reflectivity for a given number of layer pairs and given materials. It is also possible to design dichroic mirrors with controlled properties for different wavelengths [3]. The number of thin-film layers required depends on the required function and on the refractive index difference between the coating materials[4].

The resonator mirrors of a laser are almost always dielectric mirrors, because such devices routinely achieve a very high reflectivity of >99.9%, and their limited reflection bandwidth can be convenient because it allows the transmission of pump light (at a shorter wavelength) through a folding mirror of the resonator (dichroic mirrors), so that the dielectric mirrors are often called laser mirrors[4].

The transfer matrix for one double layer of (λ/4) thick coating at normal incidence in the product of the individual film matrices, just as in the case of the double-layer anti reflecting films:

$$m_{HL} = m_L \, m_H . \qquad (1)$$

$$m_{HL} = \begin{bmatrix} 0 & i/\gamma_H \\ i/\gamma_H & 0 \end{bmatrix} \begin{bmatrix} 0 & i/\gamma_L \\ i\gamma_L & 0 \end{bmatrix}$$

$$= \begin{bmatrix} -\gamma_L/\gamma_H & 0 \\ 0 & \gamma_H/\gamma_L \end{bmatrix} \qquad (2)$$

$$m = (m_{H1}\, m_{L1})\,(m_{H2}\, m_{L2})\ldots\ldots$$
$$(m_{HN}\, m_{LN}) = (m_H m_L)^N = (m_{HL})^N \qquad (3)$$

Then the transfer matrix is

$$= \begin{bmatrix} -\gamma_L/\gamma_H & 0 \\ 0 & -\gamma_H/\gamma_L \end{bmatrix}^N$$
$$= \begin{bmatrix} (-\gamma_L/\gamma_H)^N & 0 \\ 0 & -\gamma_H/\gamma_L{}^N \end{bmatrix} \qquad (4)$$

For normal incidence

$$\frac{\gamma_L}{\gamma_H} = \frac{n_L}{n_H} \quad \text{and} \quad \frac{\gamma_H}{\gamma_L} = \frac{n_H}{n_L} \qquad (5)$$

so that

$$\frac{\gamma_H}{\gamma_L} = \begin{bmatrix} (-n_L/n_H)^N & 0 \\ 0 & (-n_H/n_L)^N \end{bmatrix} \qquad (6)$$

the matrix representing N high –low double layers of λ/4 thick coating in series are thus.

$$m_{11} = \left(\frac{-n_L}{n_H}\right)^N , \quad m_{22} = \left(\frac{-n_H}{n_L}\right)^N , \; m_{12} = m_{21} = 0 \qquad (7)$$

Using these matrix elements in the expression for the reflection coefficient that is :

$$R = \frac{n_{o}(-n_L/n_H)^N - n_s(-n_H/n_L)^N}{n_{o}(-n_L/n_H)^N + n_s(-n_H/n_L)^N} \qquad (8)$$

When numerator of eq. (8) are next multiplied by the factor $\left(\frac{-n_H/n_L)^N}{n_s}\right)$ and the result is squared to give reflectance:

$$R_{max} = \left[\frac{(-n_0/n_s)(n_L/n_H)^{2N} - 1}{(-n_0/n_s)(n_L/n_H)^{2N} + 1}\right]^2 \qquad (9)$$

Simulation and Result Proposed on Optical Component

In Figure 1 a block diagram of solid state fourth harmonic laser source shows the Nd:YVO4 gain medium 10 output a light beam of 1064 nm and is putting the laser cavity 11 extending between mirror 16 and 18. such active medium are pumped by using a laser diode 810 nm. A Tm doped ZBLAN fluoride glass 12 is positioning in the 1064 nm laser cavity Nd:YVO4 gain medium 10. Tm doped ZBLAN fluoride glass serve as gain medium pumped by Nd:YVO4, ZBLAN (ZrF4-BaF2-LaF3-AlF3-NaF), considered as the most stable heavy metal fluoride glass and the excellent host for rare-earth ions, has been extensively used for efficient and compact ultraviolet, visible, and infrared fiber lasers due to its low intrinsic loss, wide transparency window, and small phonon energy [9]. An 810 nm laser action is achieved in the Tm: ZBLAN glass 12 by creating 810 nm laser cavity 19 extending between mirror 17 and 18, which does not interfere with the operation of the Nd:YAG gain medium 10 using dichroic polarized beam splitter 20 and mirror 17 and this is the idea of our design. In order to generate fourth harmonic (blue laser) having a wavelength near 460 nm, a nonlinear crystal CLBO 14 is placed at a position which is intra cavity for both the 1064 nm and 810 nm .

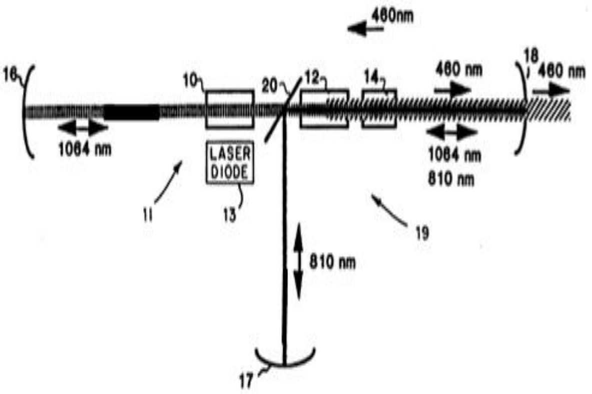

Fig. (1) Schematic diagram of design setup**.**

The dichroic beam splitter must have near zero percent reflectivity selectivily at 1064 nm and near one handerd percent reflectivity at 810 the mirror 16 and the exit mirror 18 are one handered percent reflectivity at wavelength equel to 810 nm and mirror 18 has near zero percent reflectivity at wavelengths equel to 460 nm. So, to maximize the pumped intensity, the Tm ZBLAN glass 12 is placed in the 1064 nm cavity where the beam waist is at minimum, and such glass is anti-reflective coating for the 1064 nm to minimize cavity loss.

The crystal 14 used is new nonlinear crystal Cesium Lithium Borate ($CsLiB_6O_{10}$ or CLBO) suits well for UV applications and generates the 4th and 5th harmonics of the Nd:YVO4 fundamental laser wavelength [8]. CLBO is transparent down to 190 nm and can be phase matched for type-II SHG to 640 nm and type-I to 477 nm. CLBO has excellent nonlinear optical properties with larger angular and spectral bandwidths. It also has a lower nonlinear coefficient d_{eff} , but a smaller walk-off angle and high damage threshold (26 GW/cm^2). The as-cut blanks, as well as optical elements were used and its main properties shown in Table 1.

Table (1) Main properties of CLBO crystal [8].

Transparency range, nm	180 - 2750
Symmetry	tetragonal, point group 4*m*2
Cell parameters	a = 10.494, c = 8. 939 Å
M hardness	4
Refractive indexes:	
at 1064 nm	n_o= 1.4852; n_e = 1.4353
at 532 nm	n_o = 1.4985; n_e = 1.4462
Non-linear coefficient at 1064 nm, pm/V	d_{36} = 0.86
Optical damage threshold, GW/cm^2	25 (1064 nm; 1,1 ns pulses)
Work off	532 nm - 1.83°; 488 nm - 0.98°
Cut off SHG	471 nm
Chemical properties	slightly hygroscopic
Max. size of element, mm^3	7 x 7 x 15

Simulation Work

A dichroic beam splitter that's used as a main optical component in blue laser source to obtain zero percent reflectivity selectivily at 1064 nm and near one handerd percent reflectivity at 810 have been don by using BK7 Glass as substrate, and different dichroic material are used to take simulated one by using MAT LAB programming as shown in figurs below. Figure 1 shows a diagram of the design setup. In all Figures the simulation was taken for two case with diffrent number of stack layer N and with angle of incident for the beam splitter (45^0) and transverse electric (TE) where “transverse” is meant here with respect to the z-axis. The TE case has an electric field transverse to z which has been taken as the case of polarization for simulated beam splitter. In the case of N=12, Figure 2 shows the asymptotic edges of the required reflecting band are calculated to obtain λ1 = 610 nm and λ2 = 1100 nm, the width of Δλ must be equal to 490 nm and exhibit more ripple as number of stack layer of our simulated element increased .

In Figure 2 the value of reflectivity at 810 nm is 100% but at 1064 nm it has also 100% which is far from the required value therefore it must find other material for the simulated polarized beam splitter.

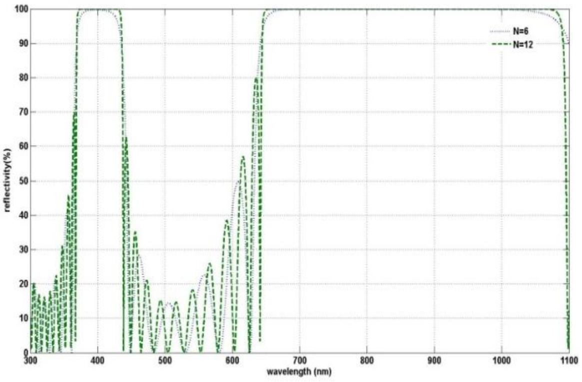

Fig. (2) The reflectivity versus wavelength with different number of layer for ZrO_2 .

In the case of (N=12) asymptotic edges of the required reflecting band are obtain λ1 = 742 nm and λ2 = 910 nm, the width of Δλ must be equal to 162 nm and exhibit more ripple as number of stack layer of our simulated element increased. Also, the value of reflectivity at 810 nm is nearly 100% but at 1064 nm it has nearly 12% which is very closed to the required value as shown in Figure 3.

For (N=10) Figure 4 shows the of asymptotic edges of the required reflecting band are obtain λ1 = 650 nm and λ2 = 1065 nm, the width of Δλ must be equal to 415 nm and exhibit more ripple as number of stack layer of our simulated element increased, and the value of reflectivity at 810 nm is 100% and at 1064 nm it has nearly 0% which is required but it must be find other

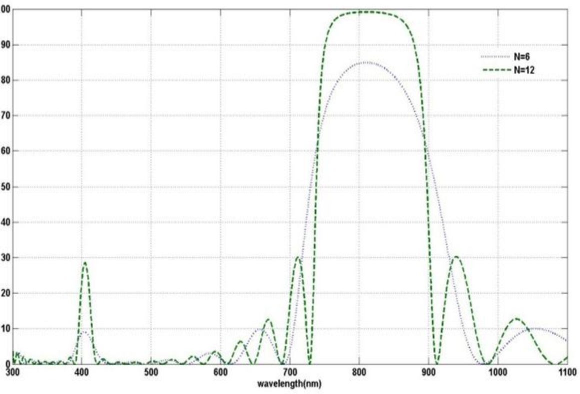

Fig. (3) The reflectivity versus wavelength with different number of layer for TiO2.

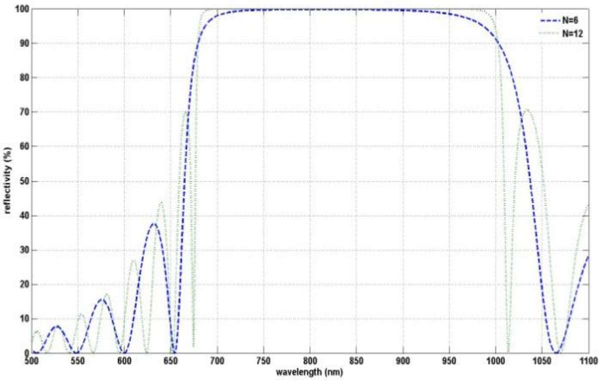

Fig. (4) The reflectivity versus wavelength with different number of layer for Se.

Figure 5 shows that the reflectivity increased as number of stack layer increased with decreasing of the width Δλ, asymptotic edges of the reflecting band (for N=16) are obtain λ1 = 750 nm and λ2 = 880 nm, the width of Δλ must be equal to 130 nm and exhibit more ripple as number of stack layer of our simulated element increased, moreover, the value of reflectivity at 810 nm is approached to 100% while at 1064 nm there is no reflectivity observed.

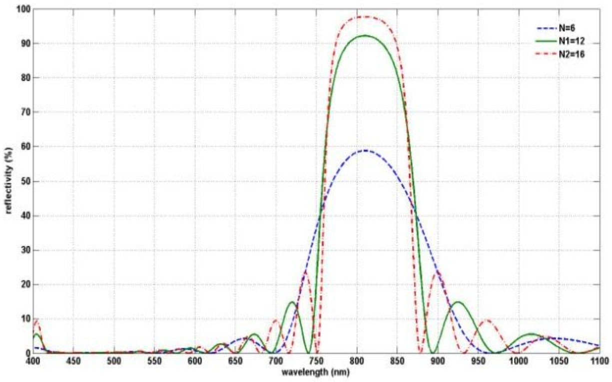

Fig. (5) The reflectivity versus wavelength with different number of layer for HfO_2.

For the same parameter, it can be shown that the value of reflectivity =100% as the number of stack layer (N=20) as shown in Figure 6 below with smallest band.

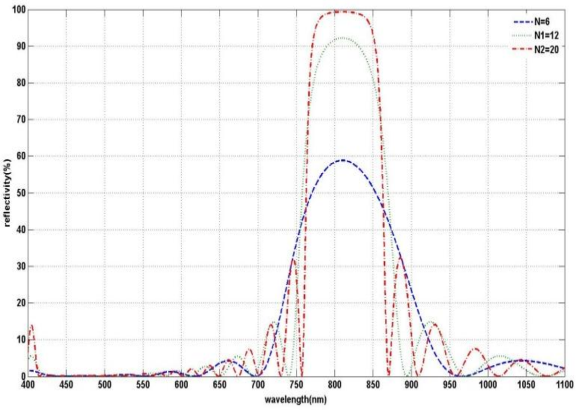

Fig. (6) The reflectivity versus wavelength with different number of layer for HfO_2.

In our system, the design of the front mirror 16 and the exit mirror 18 are such that one handered percent reflectivity at wavelength 810 nm and mirror 18 has near zero percent reflectivity at wavelengths equel to 460 nm, as shown in Figures 7.

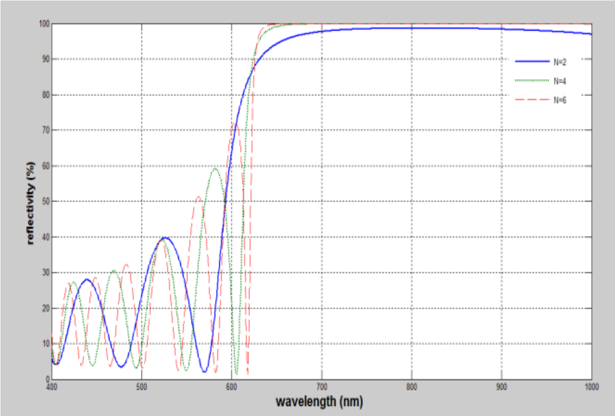

Fig. (7) The reflectivity versus wavelength with different number of layer for GaAs.

In Figure 8 reflectivity has required design value (100%) at required 810 nm but it and 2% for 410 nm but it has very large bandwidth beginning from 615 nm for (N=6) up to 1200 nm. The asymptotic edges of the reflecting band are calculated from Eq. (13). In which ρ is elementary reflection coefficients, both λ_1 and λ_2 equations are :

$$\lambda_1=\frac{\pi(n_H\, l_H+n_L l_L}{\mathrm{acos}(-\rho)}\ ,\ \lambda_2=\frac{\pi(n_H\, l_H+n_L l_L}{\mathrm{acos}(\rho)},$$
$$\Delta\lambda=\lambda_2-\lambda_1 \qquad (10)$$

for obtain λ1 = 915 nm and λ2 =735 nm and the width of Δλ must be equal to 180 nm for the case of N=6, from such figure the width Δλ is narrower as N increased and also the design parameter here nearly closed to the required value for reflectivity that is 94% for N=6 and 810 nm and 3% for the same value of stack layer and with λ=410 nm but still the values far from required therefore number of stack layer must increased as shown in Figure 9.

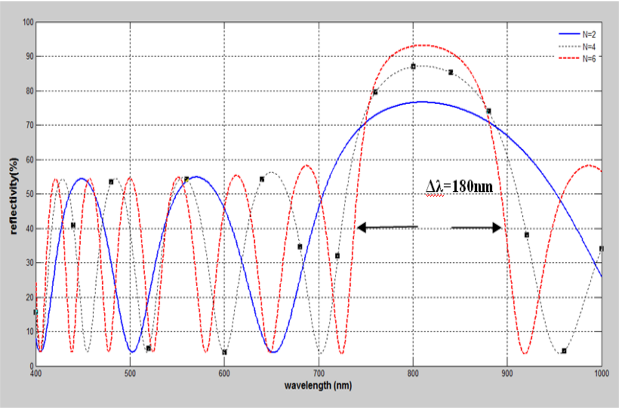

Fig. (8) The reflectivity (%) as function of wavelength with different number of layer for GaAs.

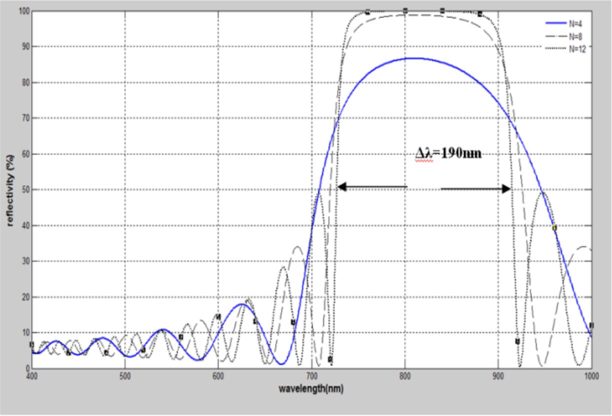

Fig. (9) The reflectivity against wavelength with different number of layer for GaAs.

When N=12 asymptotic edges of the reflecting band are calculated for obtain λ1 = 738 nm and λ2 =928 nm, the width of Δλ which is refer to a value at full width of half maximum and its must be equal to 190 nm and it was increased as number of stack layer decreased as shown in the Figure 9, It can be observed also from Figure 9 that's the value of reflectivity for the case of (N=12) has 100% for λ=810 and 4% for λ=410 nm with flat top but still the band width has wide value that's must be narrower as possible.

In the case (N=12) as in Figure 10 asymptotic edges of the reflecting band are calculated for obtain λ_1 = 782 nm and λ_2 = 862 nm, the width of Δλ must be equal to 80 nm . It can be observed also from figure (10) thats the value of reflectivity for the case of (N=12) has 68% for λ =810 nm which is very far from the value required and for λ=410 nm and the value of R=4% .

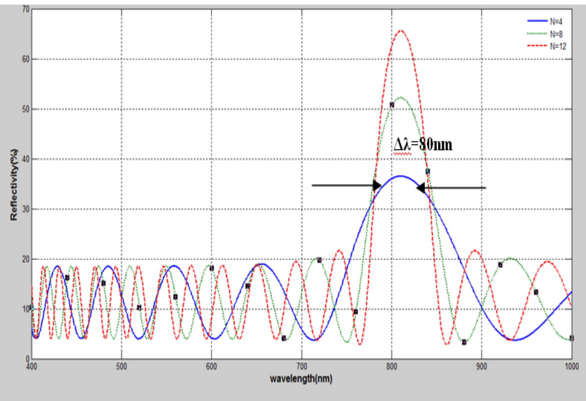

Fig. (10) The Reflectivity as function of wavelength with different number of layer for HfO_2 .

For N=12 Figure 11 asymptotic edges of the reflecting band are calculated for obtain λ_1 = 762 nm and λ_2 = 882nm, the width of Δλ must be equal to 120 nm . It can be observed also from Figure 11 thats the value of reflectivity for the case of (N=12) has 98% for λ =810 nm which is very close to the value required, at λ=410 nm the reflectivity R=4% and this is good at less for the simulated mirror that has been designed .

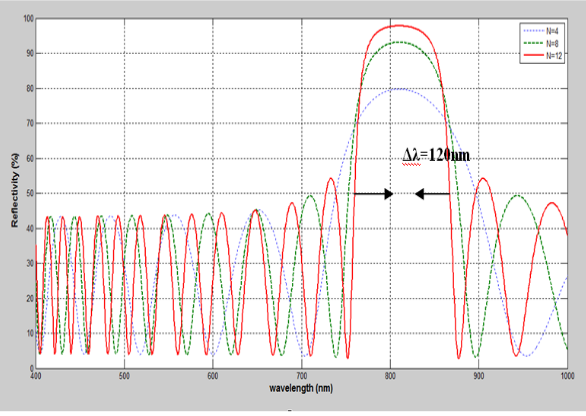

Fig. (11) The reflectivity as function of wavelength with different number of layer for GaAs .

The nonlinear crystal CLBO is design with coated in such way made it transparent for 1064 nm and this is done by making the value of reflectivity approached to zero at the designed wavelength 1064 nm.

In Figure 12 (at N=10) the asymptotic edges of the reflecting band are calculated for obtain λ1 = 995 nm and λ2 = 1146 nm, the width of Δλ must be equal to 151 nm and such value increased as number of stack layer of our simulated element decreased . It can be observed also from figure (12) thats the value of reflectivity for the case of (N=10) is 13.6% for λ =1064 nm which is nearly closed to the required, While in Figure 13 (N=12) the asymptotic edges of the reflecting band are calculated for obtain λ1 = 1000 nm and λ2 = 1130 nm, the width of Δλ must be equal to 130 nm and such value increased as number of stack layer of our simulated element decreased. It can be observed also from figure 13 thats the value of reflectivity for the case of (N=12) is 11.3% for λ =1064 nm which is better than that taken in the brevios case.

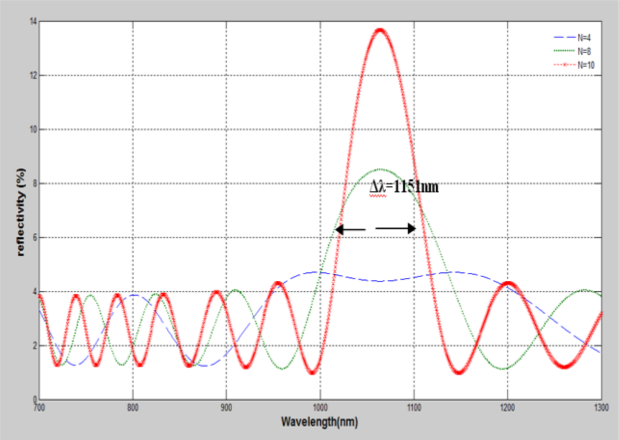

Fig. (12) The reflectivity versus wavelength with different number of layer for LiF.

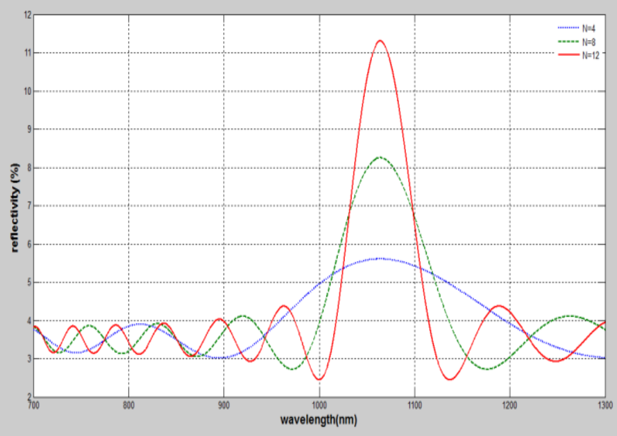

Fig. (13) The reflectivity versus wavelength with different number of layer for LiF2.

Figure 14 shows asymptotic edges of the reflecting band are calculated for obtain λ_1 = 1000 nm and λ_2 = 1130 nm, the width of $\Delta\lambda$ must be equal to 130 nm and such value increased as number of stack layer of our simulated element decreased. It can be observed also from Figure 14 thats the value of reflectivity for the case of N=12 is 11.3% for λ =1064 nm which is not much differerent from that taken in the previous case.

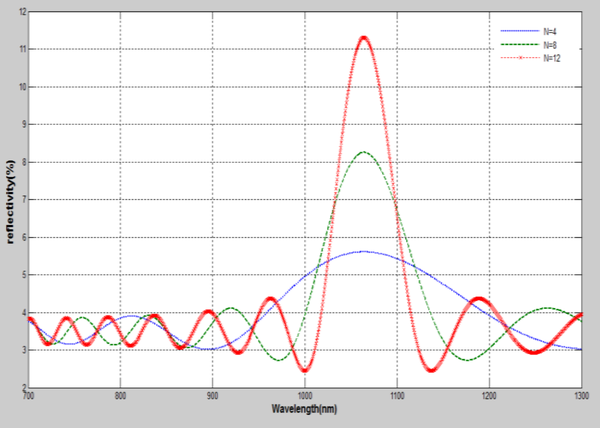

Fig. (14) The reflectivity as function of wavelength with different number of layer for Si3N4 as high refractive index material and ZnO as low index material.

Discussion and Conclusion

Result of simulation shows that for the beam splitter that's simulated one represent by Figure 6 which is perform good design parameter for the suggested system according to its simulated output result. Figure 11 represent good choice for design of mirror 16 and 18 because the simulated result shown in the above figure is very closed to the required value.

From Figures (7-11) we can see that as value[1] of difference (n_H-n_L) be small as value of R and bandwidth reached required value, as shown in figure chosen.

For nonlinear crystal CLBO which was[2] coated to be transmitted for 1064 nm as shown in Figure 12 in which LiF takes as high index of refraction and KF as low index of refraction for the design of multilayer dielectric structure coated such crystal , and the bandwidth here are not imported to be small because the other wavelength here are exist in our system.

From above it can be concluded that the simulated optical component with design parameter chosen can perform the system required with less loses in light photons according to its behavior inside simulation.

There is special notes that must be explain which is related to the polarized beam splitter, in which the angle of incident is very important factor because its affected on the result obtained and may caused high loss in the designed system if not carefully chosen.

References

[1] F.W. Sears, M.W. Zemansky, University Physics 6th Ed. H.D. Young, (1991).

[2] Stephen M. Kelly (2000). *Flat Panel Displays: Advanced Organic Materials*. Royal Society of Chemistry. p. 110.

[3] J. A. Dobrowolski and D. G. Lowe, "Optical thin film synthesis program based on the use of Fourier transforms", Appl. Opt. ***17*** (19), 3039 (1978).

[4] J. A. Dobrowolski and R. A. Kemp, "Refinement of optical multilayer systems with different optimization procedures", Appl. Opt. ***29*** (19), 2876 (1990)

[5] S. A. Schelkunoff, Electromagnetic Waves, Van Nostrand, New York, 1943.

[6] J. D. Kraus, Antennas, 2nd ed., McGraw-Hill, New York, 1988.

[7] C. A. Balanis, Antenna Theory, Analysis and Design, 2nd ed., Wiley, New York, 1996.

[8] V. Garnov Sergei, M. Klimentov Sergei,T. V. Kononenko, I. Konov Vitaly, E. N. Lubnin,Dausinger Friedrich, Raiber Armin, Proc. SPIE, **2703**, 442 (1996).

[9] R. S. Elliott, Antenna Theory and Design, Prentice Hall, Upper Saddle River, NJ, 1981.

[10] R. E. Collin and F. J. Zucker, eds., Antenna Theory, parts 1 and 2, McGraw-Hill, New York, 1969. It can be found on http://www.mt-berlin.com/frames_cryst/descriptions/clbo.htm

[11] K. Ohsawa, T. Shibata, K. Nakamura, and S. Yoshida, "Fluorozirconate glasses for infrared transmitting optical fibers," in Proceedings of the 7th European Conference on Optical Communication (ECOC), pp. 111–114, Copenhagen, September 1981

تصميم ومحاكاة استخدام مجزء الحزمة الثنائي في مصدر الليزر الأزرق ذي الحالة الصلبة

أسيل عبد الأمير شغاتي وائل ياس نصير

قسم هندسة الليزر والالكترونيات البصرية ، الجامعة التكنولوجية ، بغداد ، العراق

الخلاصة: مصدر الليزر الازرق ذو الحالة الصلبة يتضمن توليد ضوء ليزر بطول موجي 1064 نانومتر من الوسط الفعال Nd:YVO4 ودمجه مع طول موجي آخر (810 نانومتر) متكون من وسط فعال (Tm:ZBLAN) ضمن نفس المنظومة مضخ بواسطة الأشعة تحت الحمراء، تستخدم البلورة اللاخطية لتوليد الموجة التوافقية الرابعة من الطول الموجي المدمج (1874 نانومتر) وهو الليزر الازرق (460 نانومتر)، يستخدم مجزء الحزمة المزدوج لتمثيل عملية الدمج. وقد استخدمت هيكل متعدد الطبقات العازلة وتحليلات الطلاء المضاد للانعكاس لتصميم مجزء الحزمة المزدوج باستخدام المحاكاة ببرنامج MATLAB، تم استخدام المواد التالية غير الخطية (ZrO2، HfO2، MgO، SiO، Ta2O5، CaF2) كمادة طلاء، وأستخدم الزجاج BK7 كمادة أساس. تظهر النتائج انه كلما أضيفت طبقات ذات سمك ربع طول موجي للتركيب، اكتسب طيف الانعكاسية صفات تذبذبية أكثر وفجوة حزمة اضيق وقمة مستوية وذات قيمة عاليةمتزايدة حمل الطول الموجي المعتمد في التصميم وقد لوحظ ان المواد الثنائية (SiO) الذي يمثل الطبقة ذات الانعكاسية العالية و(ZrO_2) الذي يمثل الطبقة ذات الانعكاسية الواطئة تمثل اختيار جيد للطلاء الخاص لمجزء الحزمة الثنائية والذي يمتلك انعكاسية بحزمة ضيقة للطول الموجي المطلوب والذي يقترب من التصميم المطلوب وكلما زادت عدد طبقات الطلاء اقترب التصميم من قيمته المثالية.