J. Appl. Environ. Biol. Sci., 5(7S)317-321, 2015

ISSN: 2090-4274
Journal of Applied Environmental
and Biological Sciences
www.textroad.com

Investigating of the Optical Properties of Rugate Filter Stacked Formulas by Using Different Materials

Fatemeh Setareh, Farhad E. Ghodsi

Department of Physics, Faculty of Science, University of Guilan, Rasht, Iran

Received: March 19, 2015
Accepted: May 2, 2015

ABSTRACT

In this paper, the optical properties of the multilayer rugate filter by structure of (HL) ^ 9Hhas been investigated. Here the reflection, optical density and electric field strength of designed filter by using four materials of Ta_2O_2, Nb_2O_5 and ZnS as the materials with high refractive indexandSiO_2as a material with low refractive index are compared with each other. Finally, it is realized that the bandwidth of the reflection and the optical density of the structures (ZrO_2-SiO_2) ^ 9ZrO_2, (Nb_2O_5-SiO_2) ^ 9Nb_2O_5, (Ta_2O5-SiO_2) ^ 9Ta_2O5and(TiO_2-SiO_2) ^ 9TiO_2 increase respectively and the electric field strength reduces.

KEYWORDS: Rugate filter, Optical density, Reflection, Electric field, Refractive index

INTRODUCTION

The word rugate comes from the elementary shape of these filters, which is corrugated or wavy [1]. More precisely, a rugate filter is an interference coating consisting of one or multiple layers within which refractive index versus thickness profile is derived from sine or cosine functions, being of continuously varying value. This structure allows fabrication of reflective mirrors (notch filters) without the harmonic bands which are sometimes annoying in multilayer quarter wavelength filters [2], the rugate filter, as a special kind of graded refractive- index film, has continuously periodical modulation in the refractive index profile along the stack axis. Compared with a traditional filter, such a filter exhibits many advantages, such as a higher laser induced damage threshold [3] smaller sensitivity to angle variation of incident light [4] suppression of higher frequency harmonics,[5,6] smaller residual stress [6] and higher temperature stability [7]. However, preparation of the rugate filter is relatively difficult because of the requirement for accuracy in realizing the continuous refractive index profile. The filter can be fabricated by mixing two or more materials with high and low refractive indices [8–10] or by varying the content of the reactive gas with a single source [11, 12]. The electrochemical etching of silicon [13] and the glancing angle deposition [14, 15] are also used to make porous rugate filters.

Thoery

Arugate filter consists of a sinusoidal refractive index deposited on a substrate [16, 17] and takes its name from the Latin word "rugate", meaning to be wrinkled or creased [16]. This profile is periodic and continuous throughout the structure of the coating. This refractive index profile is given by**:**

$$n = n_a + \frac{n_p}{2}\sin\left(\frac{2\pi x}{n_a P} + \varphi_0\right) \qquad (1)$$

n_a is the average refractive index used, n_p is the peak-to-peak refractive index difference, $n_a P$ is the period of the sine wave in optical thickness, φ_0 is the phase at the substrate [rad], N is the number of sine wave cycles, and x *is* the spatial variable. The center of the reflection band λ_0 is given by [17]:

$$\lambda_0 = 2 n_a P \qquad (2)$$

And the bandwidth of the filter $\Delta\lambda$ is related to the other variables by [16]:

$$\frac{\Delta\lambda}{\lambda_0} = \frac{n_p}{2 n_a} \quad (3)$$

---

[*] **Corresponding Author:** Fatemeh Setareh, Department of Physics, Faculty of Science, University of Guilan, Rasht, Iran (Fatemeh.Setareh66@gmail.com)

Finally, given the condition that n_p is small in comparison with n_o the maximum reflectance at the center of the reflection band is given by [16]:

$$R_{\max} = \tanh^2\left(\frac{\pi n_p N}{4 n_a \cos\theta}\right) \quad \text{for s-wave} \quad (4)$$

$$R_{\max} = \tanh^2\left(\frac{\pi n_p N \cos 2\theta}{4 n_a \cos\theta}\right) \quad \text{for p-wave} \qquad (5)$$

θ -the propagation direction in the rugate filter related to the angle of incidence 90 on the filter and the refractive index of the medium of incidence n_0 by Snell's law or:

$$\frac{\sin\theta_0}{\sin\theta} = \frac{n_a}{n_0} \qquad (6)$$

In order to suppress the side lobes, we add the matching Eq. (9) and the apodizing function Eq. (8) to the refractive index profile Eq. (7), as shown in Fig. 1. The quantic matching layers at the substrate and the ambient medium sides are both 1 µm thick, and the refractive index varies from 1.52 to 1.92 [18].

$$n(x) = n_a + \frac{1}{2} n_p f(x) \sin\left(\frac{4\pi x}{\lambda_0}\right) \qquad (7)$$

$$f(x) = 10x^3 - 15x^4 + 6x^5 \qquad (8)$$

$$n(x) = n_s + (n_a - n_s)(10x^3 - 15x^4 + 6x^5) \qquad (9)$$

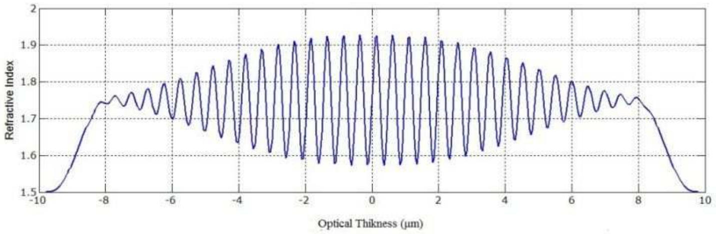

Figure1. Refractive index distribution of the rugate filter with quintic apodization and quintic matching on each side.

In order to design this filter we use λ_0=532 nm, n_a=1.75, n_p=0.35, and n_s=1.5.

Designing method of Rugate filter by using different materials

Optical interference filters are usually made by deposition of separated layers of materials with different indices of refraction. A simple rugate filter can be made by deposition of layers by high and low refractive index with a thickness of a quarter of wavelengths that have been deposited periodically.

Here the formula has been used for dielectric multi-layer stacked structures of the rugate filter is $(HL)^m H$, where m is an integer and the number of courses. We considered the 19-layer structure of (HL) ^ 9H and we used four materials such as Ta_2O_2, Nb_2O_5, ZnS,TiO_2 as high refractive index n_H and SiO_2 as low refractive index layer n_L in visible region.

In this simulation, the incident wavelength is considered 532 nm and white is selected as lighting. Air with n = 1.0 is considered as landing environment and glass with n = 1.52 as the substrate and the exit environment and detector is assumed ideal and broadband.

In this section, ZrO_2 with a refractive index of n = 2.22, Nb_2O_5 with the refractive index of n = 2.33, Ta_2O_2 with the refractive index of n = 2.42, TiO_2 with the refractive index of n = 2.28 are materials as high refractive index and SiO_2 with n = 1.46 as the low refractive index are considered for 19-layer of (HL) ^ 9H in the visible structure of n_L. Here the reflective charts, optical density, electric field strength of every material of each structure are calculated and checked.

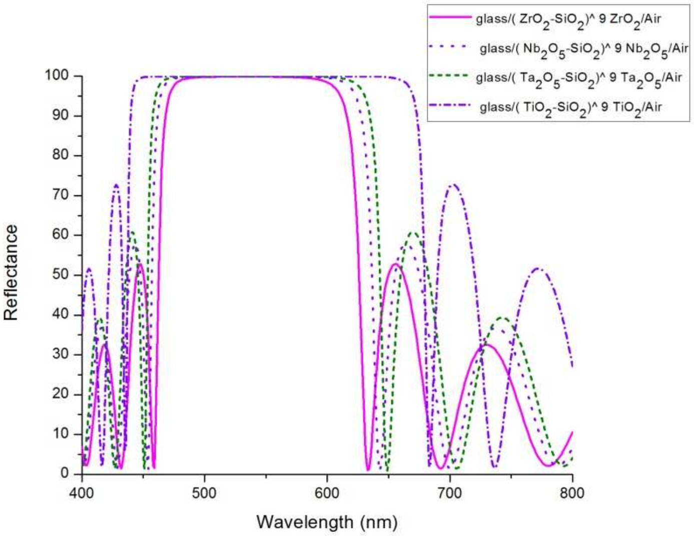

Figure 2.Reflection of Rugate filter for each structure (HL) ^9Hinthe visible region range.

Optical density characterizes the attenuation of performance of a filter and it is always expressed as the negative of transmission logarithm:

$OD = -\log_{10}(T)$ (10)

In Fig. 3, the optical density of this 19 layers filter according to the wavelength is plotted and in Fig. 4,the diagram of distribution of Electric field intensity for per layer in the central wave length of 532 nm has been plotted [19]. As it is seen, the bandwidth of the reflection and the optical density of the structures (ZrO_2-SiO_2) ^ 9ZrO_2, (Nb_2O_5-SiO_2) ^ Nb_2O_5, (Ta_2O_5-SiO_2) ^ Ta_2O_5 and (TiO_2-SiO_2) ^ TiO_2 increase and the electric field strength reduces.

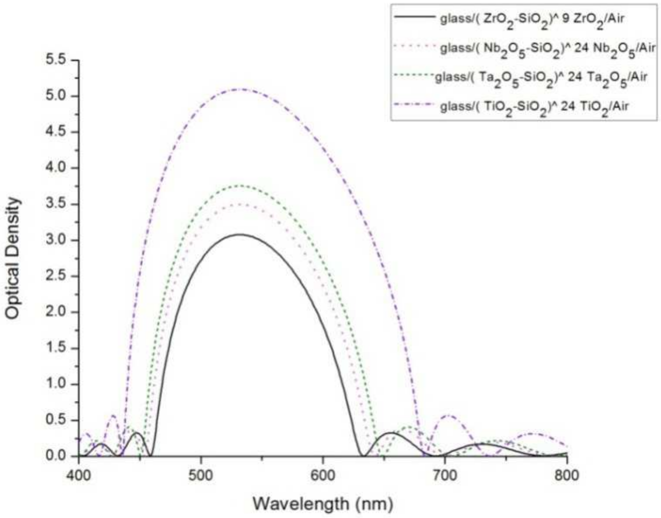

Figure 3.Optical Density of Rugate filter for each structure of (HL) ^ 9Hinthe visible region.

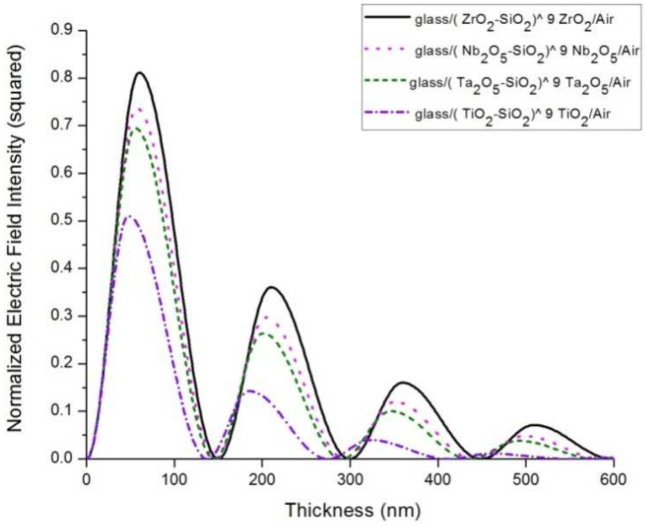

Figure 4.Distribution of electric field intensity of rugat filter in layers for each structure of (HL) ^ 9H in the visible region.

Conclusion

A rugate Filter is an example of multilayer Filters that the absorption of heat caused by radiation in each point is proportional to the electric field strength at the same point. For the structures of (ZrO_2 SiO_2) ^ 9ZrO_2, (Nb_2O_5-SiO_2) ^ Nb_2O_5, (Ta_2O_5-SiO_2) ^ 9Ta_2O_5 and (Ti_2O_5-SiO_2) ^ 9Ti_2O_5 the reflective bandwidth and optical density increase via refractive index difference in ZrO_2, Nb_2O_5, Ta_2O_2 TiO_2 and SiO_2, but the maximum and minimum of electric field strength reduces by increasing the refractive index difference of material; and the intensity of the electric field is also reduced to zero in the lower layers. Filters by High optical density are useful for expanding the dynamic area of detector systems and reducing the output current of laser. The electric field strength in the mentioned rugate filter reduces which it causes to reduce the laser damage threshold in materials and available components. It fundamentally affects on costing, designing, and operation of large laser systems.

REFERENCES

[1] Macleod H A.,1986. Thin Film Optical Filters, Macmillan, p. 588.

[2] Minott G, Sprague R, Shnapi B,2004. Rugate notch filters find use in laser-based applications, Laser Focus World, 40(9): 107-111.

[3]Lappschies M., GortzB., *and* Ristau D., 2006. Application of optical broadband monitoring to quasi- rugate filters by ion-beam sputtering, Applied Optics45(7): 1502–1506.

[4] Southwell W. H., 1988.Spectral response calculations of rugate filters using coupled-wave theory,Journal of Optical Society of America A, 5(1): 1558-1564.

[5]Ishikura N, Fuji M. i, Nishida K., HayashiS., DienerJ., MizuhataM., *and* DekiS.,*2008*. Broadband rugate filters based on porous silicon, Optical Materials 31(1): 102-105.

[6]Tang C. J., Jaing C.C., LeeK.S., Lee C.C.,2008.Residual stress in Ta_2O_5-SiO_2 composite thin-film rugate filters prepared by radio frequency ion-beam sputtering, Applied Optics, 47(13): C167–C171.

[7] Polenzky C., Rickers C., Verg¨ohl M.,2009. Properties of cosputtered SiO_2–Ta_2O_5-mixtures, Thin Solid Films, 517(10):3126.

[8] Gunning W.J., Hall R.L., Woodberry F.J., Southwell W.H., and Gluck N. S.,1989. Codeposition of continuous composition rugate filters, Applied Optics28(14): 2945–2948.

[9] Lee C. C., Tang C. J., Wu J. Y., 2006. Rugate Filter Made with composite Thin Films by Ion-Beam Sputtering, Applied Optics45(7): 1333-1337.

[10] *Li* L., Xiong-Rui *S.,*2008. Enhanced optical nonlinear absorption of compositefilms, Chinese physicsB, 17(6): 2170–2174.

[11]Bartzsch H., Lange S., Frach P., Goedicke K., 2004.Graded refractive index layer systems for antireflective coatingsandrugate filters deposited by reactivepulse magnetron sputtering, SurfaceCoatingTechnol 180-181:616-620.

[12] H. Ukita, Y. Katagiri, S. Fujimori, 1990. Ion beam sputtered $(SiO_2)_x (Si_3N_4)_{1-x}$ antireflection coatings on laser facets produced using O_2–N_2 discharges, Applied Optics 29(34): 5074–5079.

[13] Ilyas S., *Böcking* T., Kilian K., Reece P.J., Gooding J., Gaus K., Gal M.,*2007.* Porous silicon based narrow line- width rugate filters, Optical Materials 29(6): 619-622.

[14] Hawkeye M M., Brett M J.,2006. Narrow bandpass optical filters fabricated with one-dimensionally periodic inhomogeneous thin films, Journal ofAppliedPhysics100(4): 044322.

[15] Kong W J., Shen Z C., Wang S H., Shao J D., Fan Z X.., Lu C J.,2010.Design and fabrication of broadband rugate,Chinese Physics B21(5):044210.

[16] Braun M M., Pilon L.,2006. Effective optical properties of non-absorbing nanoporous thin films, Thin Solid Films 496(2):505 – 514.

[17] Chang H. M., Liao C.,2011. A Parallel Derivation to the Maxwell-Garnett Formula for the Magnetic Permeability of Mixed Materials, World Journal of Condensed Matter Physics 1(2): 55-58.

[18] Jun-Chao Zh., Ming F., Yu-Chuan Sh., Yun-Xia J., Hong-Bo *H.,2011.* Rugate filters prepared by rapidly alternating deposition, *Chinese physicsB* 20(9): 094212-1-4.

[19] Mahdieh M H., Alavi-Nejad M.,2005. A New Method for for Electric Field Optimization in High Power Laser Multilayers, Iranian Journal of Science & Technology29(A3): 401.