Ferroelectric based multilayered antireflection coating system

F. KARAOMERLIOGLU, A. M. MAMEDOV[a]
Cukurova University, Faculty of Art & Science, Department of Physics, 01330, Balcali, Adana, Turkey
[a]*Gökdemir Apt., 125/5A Street, Guzelyali, 01170, Seyhan, Adana, Turkey*

The antireflection coating is the critically important technology to obtain high performance of optoelectronic devices. In this paper, a multilayered antireflection coating system on the ferroelectric based was developed. We have designed a broad-band antireflection coating on ferroelectric based substrate using a modified minimizing search technique. The design approach consisting of tuning and minimizing operations is effective in refining the antireflective performance and simplifying the design structure of desired solution. It is shown that the maximum wide angular visible spectral reflectance of minimizing search antireflection coating design for a some ferroelectric materials multilayer system is reduced to less than 0.35% with 10-12 layered. In this type of antireflection coating we can regulate the optical properties of the system by external electrical or thermal field and design broadband ultralow reflection coating system for optoelectronic devices.

(Received February 7, 2007; accepted July 9, 2007)

Keywords: Ferroelectric thin film, Multilayer structure, Antireflection coating

1. Introduction

Antireflection (AR) coatings are among the most investigated class of optical coatings. They have been the primary subject of numerous papers [1,2]. It is well known that the excellent AR coatings based on an inhomogeneous layer can be obtained over an extremely wide spectral region if the refractive index of coating is reduced slowly and smoothly from the substrate to the ambient medium [3]. Therefore in this work we used ferroelectric thin films for creation AR coating. To our knowledge, this is the first study on this important problem. In this communication some direct formulas, valid for any incidence, and wavelength, are applied to illustrate the general problem of AR coatings and to analyse in some detail, the properties of ferroelectric/dielectric bi-or multilayers combination.

2. Theory

The characteristic matrix for the jth sublayer with index n_j and thickness d at normal incidence is given by

$$M_j = \begin{bmatrix} \cos\phi_j & \frac{i}{n_j}\sin\phi_j \\ in_j\sin\phi_j & \cos\phi_j \end{bmatrix} \tag{1}$$

where $\phi_j = \left(2\pi/\lambda\right) n_j d$ is the optical phase thickness of the jth sublayer and λ is the wavelength of the light beam.

The matrix relation defining the N-layer AR coating problem as below

$$\begin{bmatrix} B \\ C \end{bmatrix} = M_N M_{N-1} \ldots M_2 M_1 \begin{bmatrix} 1 \\ n_{sub} \end{bmatrix} \tag{2}$$

where n_{sub} is the substrate index, B and C are total electric and magnetic field amplitudes of the light propagating in the medium.

The optical admittance Y defined by,

$$Y = \frac{C}{B} \quad . \tag{3}$$

The reflectivity is given by

$$R = \left|\frac{Y_0 - Y}{Y_0 + Y}\right|^2 = \left|\frac{n_0 - n_e}{n_0 + n_e}\right|^2 \tag{4}$$

where Y_0 is the admittance of free space i.e. some constant in siemens, $n_0 = 1$ is the refractive index of free space, and $n_e = Y/Y_o$ is the effective index of the N-layer assembly.

The order of high and low indices of film layers is a crucial parameter for designing highly AR coating. The correct index order is: air/low index n_L/high index n_H/………/substrate for AR coatings.

On the other hand we know that in ferroelectric materials temperature and polarization dependences of refractive index shows nonlinear characters [4]:

$$n(p) = n(0) + \frac{1}{2!}\frac{\partial^2 n}{\partial p^2}\Delta p^2 + \ldots \tag{5}$$

where $n(p)$ is the refractive index depend on spontaneous polarization on ferroelectric phase, $n(0)$ is refractive index on nonpolar phase, Δp is the polarization difference on ferroelectric phase. (the same expansion we can write for $n(T)$ too)

Therefore in all following design we will use this equation.

3. Design

The home-design algorithm and programmes of digital broad-band AR coatings are shown by following steps:

Step 1. For design choose a set of high, middle and low indices, n_H, n_M and n_L [5].

Step 2. Firstly select a total geometrical thickness d and then divide d into dozens of very thin sublayers of the same physical thickness D=d/N, where N is the total number of sublayers. We have considered many total physical thicknesses for digital searches and find that the optimal total thicknesses for different starting designs are different, but most of them have a thickness close to 400nm. Thus, we select an initial thickness near the value of 400nm.

Step 3. Assign to each sublayer an initial refractive index which can be n_H, n_L or n_M, then one can start with (a) all high-index layers, (b) all middle-index layers, (c) all low-index layers, or (d) alternating high-, middle- and low-index layers.

Step 4. Using the characteristic matrix theory discussed above [5], evaluate the calculated optical performance of the N-sublayer system over the visible region.

Step 5. Take the some of the square difference between the calculated reflectivity by using eq. (4) and (5).

Step 6. Iterate the index of each layer one at a time from high to low index or from low to high index and reevaluate the merit function. Continue the change if the optical performance is improved, otherwise restore the previous state of refractive index.

Step 7. After one pass of digital search of all sublayers and the performance has been improved, return to step (6) for another search pass, otherwise end the search.

4. Results and discussion

In order to demonstrate this technique, we use this algorithm to design some broad-band AR coatings for $LiNbO_3$. By using the equations (4) and (5) the substrate index was 2.28 and the indices of layers where n_L=2.05(ZrO_2) n_M=2.64(CdTe) or n_M=2.39(ZnSe) and n_H=2.97(Ag_2AsS_3) or n_H=3.42(Si). The merit function based on desired zero targets over the visible region was used. The layer was divided into 12 sublayers. The sublayers were initially set at 1) all n_H, 2) all n_M, 3) all n_L, 4) alternating n_H, n_M, and n_L, 5) alternating n_L, n_M, and n_H, 6) alternating n_M, n_H, and n_L, 7) alternating n_M, n_L, and n_H, 8) alternating n_L, n_H, and n_M, 9) alternating n_L, n_M, and n_H.

After about 20 passes of search, performances did not improve further. In Fig. 1, where the substrate is at z=0, the results indicate that the best performance of the average reflectivity was 0.35% over the entire visible region. For this figure, the dispersion of the substrate refractive index and coating materials were neglected, and the substrate index n_S=2.28 and the low, middle and high indices n_L=2.05, n_M=2.39 and n_H=2.97 used for the design and the performance was much better than that of the digital design using only n_L and n_H (alternating 5).

The advantages of this search technique are that only a few passes are necessary to obtain the solution without applying the thin-film theory. The performances using very thin n_L-, n_M- and n_H- layers are well. It is also shown that the optical performance can be improved as the polarization of substrate increases and as the thickness of sublayer decreases.

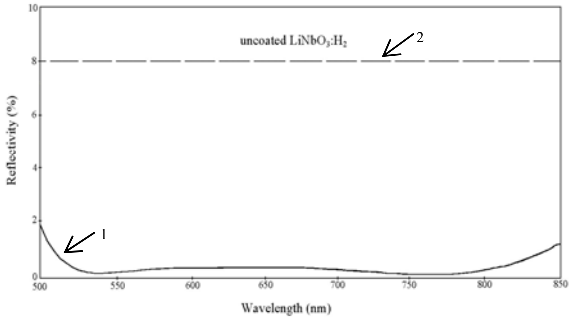

Fig. 1. Multilayer tuning iteration AR coating design starting with the thickness of 410nm and with initial setting of layer indices at n_L–n_M–n_H–n_L–n_M–n_H–*… [(1) visible AR performance of the design, (2) reflectance of uncoated substrate].*

5. Conclusion

We have designed a broad-band AR coating using very high-, middle- and low-index layers on ferroelectric based substrate. The optical performance is well and the average reflectivity across the entire visible region is about 0.35%.

References

[1] J. A. Dobrowolski, A. V. Tikhonravov, M. K. Trubetskov, T. Sillivan Brian, P. G. Verly, Appl. Opt. **35**(4), 644 (1996).
[2] H. A. Macleod, Thin Film Optical Filters, MacMillan, N.Y. 2nd ed. Chapter 2 p.49 (1986).
[3] C. Vassallo, IEE Proceedings, Optical Amplifiers for Communication. August **137**(41), Pt. J, (990).
[4] V. M. Fridkin, Ferroelectrics Semiconductors, New York and London, Consultant Bureau (1980).
[5] Y. Y. Liou, Jpn. J. Appl. Phys. **41**(9), 5568 (2002); S. Lorch, Annual Report, Optoelectronics Department, University of Ulm (2003); Duyar Ö, Durusoy HZ, Turk J. Phys. **28**, 139 (2004).

---

*Corresponding author: filizk@cu.edu.tr