Optik 127 (2016) 6673–6681

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Synthesis of controlled semi-reflecting multilayer broad band mirrors

S.S. Farag

A member of the Optics group of the Physics Department, Faculty of Science, Ain Shams University, Abbasia, Cairo, Egypt

ARTICLE INFO

Article history:
Received 29 February 2016
Accepted 19 April 2016

Keywords:
Thin films
Broad-band mirrors design
Light propagation
Interferometry

ABSTRACT

Broad-band dielectric multilayer mirrors formed by staggering achromatic periods are developed here to reach multilayer systems of controlled reflectance as well as band width. The basic theory and the complete synthesis procedure are presented for the design of multilayer mirrors with controlled reflectance. Six designs with different reflectance levels, ranging from 44% up to 90%, average reflectance over the whole visible region, are presented. These broad mirrors are useful in many research experiments of interferometry and spectroscopy.

1. Introduction

Periodic structures of high- and low-index multilayer thin films, besides their great impact on the industry of optics, are always assumed a vital topic for many authors [1–8] involved in the development of modern optics. As a branch of high reflectance coatings, semi, or partial reflecting coatings are achieved by either metallic or all-dielectric layers. In the present work, multilayer all-dielectric reflectors are concerned, apart from metallic ones. Mirrored interferometers are one of the most popular applications of partial reflectors, by which beam splitting is achieved. Many authors approached the subject in previous works [9–11]. In the present work a different approach, considering the group propagation of waves is presented, for the design of broad band multilayer partial (semi) reflectors at normal incidence of light waves.

This approach is based on a previous study of a double layer interferometer DLI [12,13]. What concerns us presently, about that study, is the comparison between the path lengths of the two different dispersive media comprising the DLI. The optical thicknesses of those media filling the interferometer gaps, are of integral proportionality within the range of spectrum studied, and they exactly match each other at a certain wavelength λ_o, where the waves are travelling with their group velocities. Thus, achromatization takes place at λ_o.

The idea of matching two dispersive media in an interferometer, is reformulated here to apply to periods of thin films. Each period is formed of two dispersive high- and low-index materials. These periods are treated as double layer interferometers which are, in our case, considered as the basic unit for multilayer systems built up of periods of alternative high- and low-index materials. Also, design techniques for broad band mirrors are developed here to fit our approach.

2. Method

As well known, the classical stack of quarter-wave thickness dielectric layers of alternate high- and low-index is the basic way to obtain all dielectric high reflectance mirrors. The high- and low-index layers form periods of equal phase thicknesses,

E-mail address: samy_zhran@yahoo.com

http://dx.doi.org/10.1016/j.ijleo.2016.04.104

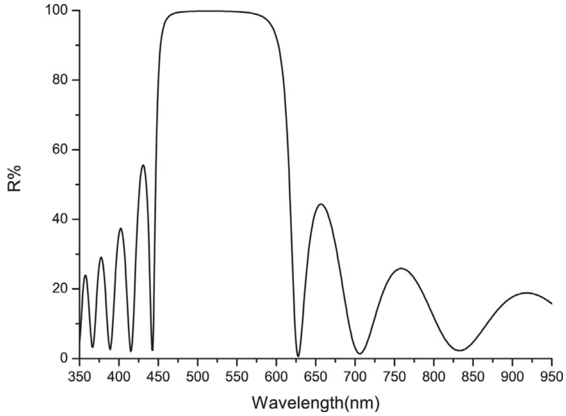

Fig. 1. The typical performance of a classical stack of 15 alternating high- (Ti_2O_3) and low-index (SiO_2) layers each of thickness $\lambda_o/4$ where λ_o = 550 nm.

which are repeated to reach the required reflectance level. Fig. 1 shows the characteristic curve for the reflectance of a typical classical stack of multilayer. The high- and low-index layers are matched according to the equation,

$$n_H h_H = n_L h_L \tag{1}$$

where n and h are the refractive index and the geometrical thickness, respectively, the suffices H and L symbolize the high- and low-index, respectively. A serious defect in such systems is that the high reflectance is obtained over a limited range of wavelengths. This defect was a real challenge for many pioneers [14–16] who made a number of attempts to extend the range of reflectance by altering the design of the basic classical stack. Most of these attempts have involved the staggering of the successive layers throughout the stack to form a regular progression, so that at any wavelength in a wide range of spectrum, enough layers in the stack have optical thicknesses near a quarter-wave to give high reflectance. As an example of how this staggering method was achieved, Heavens and Liddel [17] computed the thicknesses of successive layers so as to be in either arithmetic or geometric progression.

The method presented here is also a staggering method which differs from before in that it is actually a staggering of periods [18–20] of high- and low-index layers, rather than of successive layers, building up the stack. Also, the essentials of the achromatization condition, states that at λ_o

$$n_H h_H G_H = n_L h_L G_L \tag{2}$$

That is the optical thicknesses are modulated with the group propagation factors G, where

$$G_H = 1 - \left(\frac{\lambda}{n_H}\right)\left(\frac{dn_H}{d\lambda}\right)\lambda_o \tag{3}$$

and

$$G_L = 1 - \left(\frac{\lambda}{n_L}\right)\left(\frac{dn_L}{d\lambda}\right)\lambda_o \tag{4}$$

Therefore, the two layers forming a unit period are not just matched by their optical thicknesses, by the way of (1), but also by their dispersion functions by the way of (2), within the range $d\lambda$.

Thus, the matching Eq. (2) can take the form

$$(nHh_H - n_L h_L)\lambda_o = \lambda_o \left[h_H \left(\frac{dn_H}{d\lambda}\right)\right] - h_L \left(\frac{dn_L}{d\lambda}\right)\lambda_o \tag{5}$$

which may be restated as

$$\frac{(n_H h_H - n_L h_L)\lambda_o}{\lambda_o[h_H(dn_H/d\lambda) - h_L(dn_L/d\lambda)]\lambda_o} = 1 \tag{6}$$

at the specified reference wavelength λ_o. At other wavelengths, for the same matched period, Eq. (6) differs from unity. Therefore, (6) is used here as the staggering tool, by which we can change the reference wavelength λ_o for each period, in the progression pattern, forming the complete design.

Now we can summarize our method as follows:

First, the starting wavelength λ_o is chosen, and the first basic period is calculated by the way of (2), at the starting wavelength.