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Computer simulation of reflectance due to dielectric mirror

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ABSTRACT

The present work is calculating the reflectance due to stacked multilayer dielectric material. The calculation is based on the analysis of the characteristic matrix of an arrangement of n layers, each containing parameters that dealing with reflection (reflective index, optical thickness, wavelength of incident wave, angle of incident wave). The implication of this calculation on a dielectric mirror is pointed out. For certain arrangement of dielectric layers with a particular thickness, maximum reflectance can be obtained. In this work, FORTRAN program has been written to obtain the product of matrices. Calculation of reflectance and transmittance which are particularly needed in this context have been obtained.

1. Introduction

A dielectric mirror is consisting of multilayer dielectric materials of alternating refractive indices (Kapsap, 2001; Charles, 2012). Multilayer thin-film materials are widely used to enhance and reduce the reflectance of surfaces as well as to filter radiation flux. When a light wave is incident on a surface of glass or dielectric material, part of it will reflect and part of it will transmit, however, absorption of light can occur for those layers that contain a complex refractive index. With the index in the form n-ik, the extinction coefficient k represents the effect of absorption.

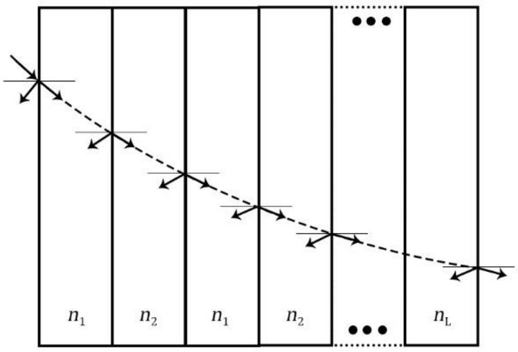

Fig. 1. Stacked multilayer dielectric materials

Referring to Fig. 1, the reflected waves from the interfaces interfere constructively and give rise to a substantial reflected light. Reflected waves should be in phase for the reflectivity to be a maximum. Reflectivity (R) of the layer combination depends on the value of phase shift δ, which in turn is determined by the thickness, angle of inclination, refractive index and wavelength (Macleod, 1986). The electromagnetic boundary conduction is applied at each interface so that the amplitude of the waves in any layer is being readily written in terms of the adjacent layers. Thus, for n-layers, the amplitude of the wave emerging from one side to other can be expressed in terms of the incident wave. In this situation, each layer could be represented by a 2×2 matrix, known as the characteristics matrix of the thin film (Macleod, 1986), which contains the layer thickness and refractive index.

2. Theory

Based on Maxwell's formulation of the electromagnetic theory of light and applying the boundary condition of electric and magnetic fields on the interface between the two media, one can find (Macleod, 1986; Darkwi *et al.*, 2000; Shingi et al., 1998).

$$\begin{bmatrix} B \\ C \end{bmatrix} = M_1 M_2 \ldots M_j \begin{bmatrix} 1 \\ N_{L+1} \end{bmatrix} \tag{1}$$

Where M_j is the characteristic matrix of the assembly given by

$$M_j = \begin{bmatrix} \cos\delta_j & i\sin\delta_j/N_j \\ iN_j\sin\delta_j & \cos\delta_j \end{bmatrix} \; (j = 1, \ldots, L) \tag{2}$$

The phase difference δ_j is given by

$$\delta_j = \frac{2\pi}{\lambda} N_j d_j cos\phi_j \tag{3}$$

For normal incident, $cos\phi_j = 1$. The B and C are the function of the electric and magnetic fields, respectively. N_j and N_{L+1} are the admittance of j[th] layer and substrate respectively. The λ is the wavelength of light and d_j is the thickness of j[th] layer. The admittance of multilayer simply,

$$Y = \frac{C}{B} \tag{4}$$

The characteristics matrix of the dielectric film takes a simple form if the optical thickness is an integer number of quarter or half wave (Charles, 2012). For half-wave optical thickness$[Nd = m(\lambda_0/2)]$, the phase sift in eq. (3) for normal incident become δ=m π, where m is an integer number. Thus, the characteristic matrix becomes

$$M = \pm\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{5}$$

This unit matrix has no effect on the reflectance. For quarter-wave optical thickness$[Nd = m(\lambda_0/4)]$, the phase shift for normal incidence is δ=mπ/2. Thus, for an even number, the characteristic matrix is as in eq. (5), while for an odd integer number, the matrix will be

$$M = \pm\begin{bmatrix} 0 & {}^{i}/_{\eta} \\ i\eta & 0 \end{bmatrix} \tag{6}$$

From eq. (1)

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{bmatrix} 0 & i/\eta \\ i\eta & 0 \end{bmatrix} \begin{bmatrix} 1 \\ \eta_{sub} \end{bmatrix} \tag{7}$$

Then,

$$Y = \frac{C}{B} = \frac{\eta^2}{\eta_{sub}} \tag{8}$$

For an odd number of quarter-wave layers of index η on substrate η_{sub} acts as a single surface of index η^2/η_{sub} (Joseph, *et al.*, 2000). In this case, the amplitude of reflection coefficient ρ is:

$$\rho = \frac{\eta_0 - \frac{\eta^2}{\eta_{sub}}}{\eta_0 + \frac{\eta^2}{\eta_{sub}}} \tag{9}$$

Or

$$\rho = \frac{\eta_0 - Y}{\eta_0 + Y} \tag{10}$$

Total reflectance $R(\lambda)$ due to multilayer is

$$R(\lambda) = \rho\rho^* = \frac{(\eta_0 - Y)(\eta_0 - Y)^*}{(\eta_0 + Y)(\eta_0 + Y)^*}$$

$$R(\lambda) = \frac{(\eta_0 B - C)(\eta_0 B - C)^*}{(\eta_0 B + C)(\eta_0 B + C)^*} \tag{11}$$

The transmittance

$$T(\lambda) = \frac{4\eta_0 Re(N_{L+1})}{(\eta_0 + Y)(\eta_0 + Y)^*}$$

$$T(\lambda) = \frac{4\eta_0 Re(N_{L+1})}{(\eta_0 B + C)(\eta_0 B + C)^*} \tag{12}$$

and the absorbance

$$A(\lambda) = 1 - R(\lambda) - T(\lambda) \tag{13}$$

3. Results and discussion

Fig. 2 shows the reflectance and transmittance of light passing from air to multilayer dielectric thin films with a glass substrate. No absorption shows up, because of the layers with real refractive index. The stack of alternating layers of high and low refractive index (HLHLH . . .) make a better mirror for application. The optical thickness of each layer is $(\lambda_0/4)$ with the reference wavelength λ_0, is 0.5 μm.

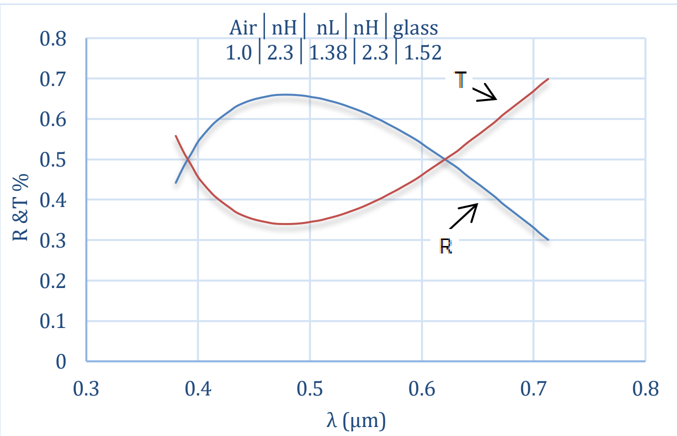

Fig. 2. Reflectance and Transmittance for 3 layers assembly of thin film with glass substrate

The reflectance increases steadily with the increase in the number of layers as shown in Fig. 3 and Fig. 4, while the transmittance becomes low.

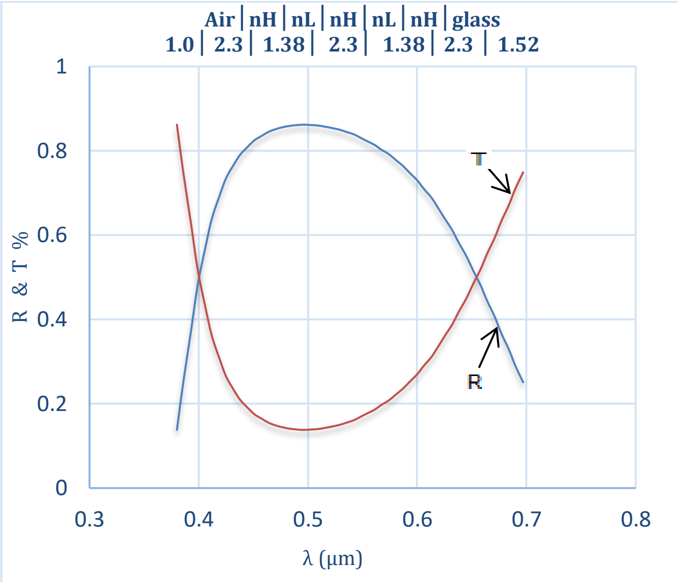

Fig. 3. Reflectance and Transmittance for 5 layers assembly of thin film with glass substrate

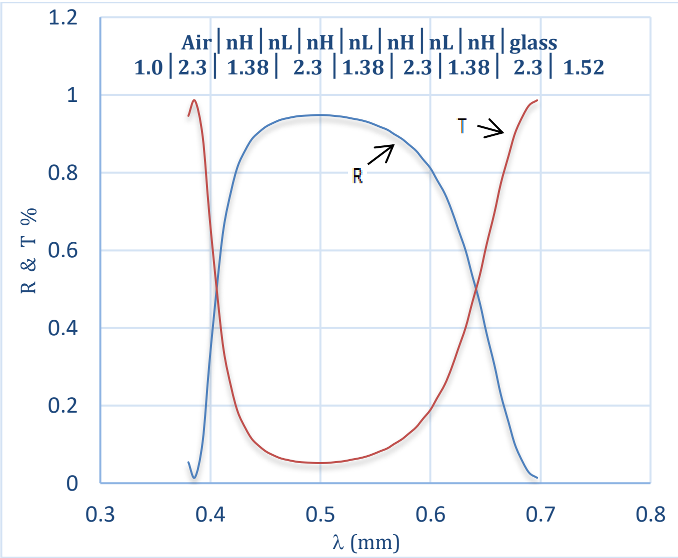

Fig. 4. Reflectance and Transmittance for 7 layers assembly of thin film with glass substrate

The high reflection zone can be seen to be limited in extent from 0.4 μm to 0.65 μm as shown in Fig. 5. The addition of extra layers does not affect the width of the zone of high reflectance but increases the reflectance within the zone.

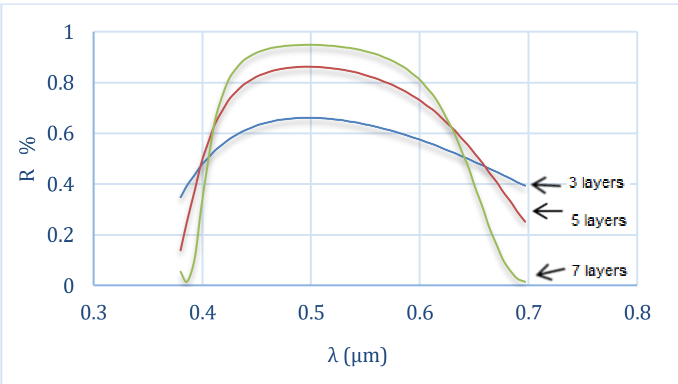

Fig. 5. Reflectance due to difference assembly of thin film at optical thickness of quarter wavelength 0.5 μm with glass substrate.

4. Conclusions

Multilayer stack of the dielectric thin film can be assembled to made dielectric mirror that can produce the desired reflectivity in a certain range of wavelength. By increasing the number of layers, the reflectivity becomes high, which makes a better mirror for applications such as the end mirrors of lasers. With the right choice of materials, the absorption of light can be low which makes the energy disputed in the device negligible.

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