JEAS
Journal of Economics and Administrative Sciences
E-ISSN: 2148-1792 P- ISSN: 1302-2024
Volume 3, Supplement Issue 3
www.jeasweb.org

Investigation of electromagnetic fields in layers and measurement of optical parameters of a gold thin film using a phase step method

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ABSTRACT

Nowadays, the study and production of thin films have become very important in dam engineering sciences. The use of layers (films) has recently been considered as intermetallic coatings on the surface of various alloys. Studying films is much easier than alloy bodies because of the use of film. This study investigated the electromagnetic fields in the layers and measured the optical parameters of a gold thin film using a phase step method.
Keywords: Polarization, Magnetic Fields, Fresnel Coefficients, Optical Properties, Thin Films

Introduction

Studying the surface of objects and films is extremely important in different fields of physics and materials technology. The optical properties of thin films are very important both in terms of application and research. Thin films are used to cover optical devices, such as microscopes, telescopes, mirrors, and advanced cameras, as anti-reflective layers.

The most important properties in the study of thin layers (films) are the optical properties, i.e., refractive index (n), extinction coefficient (k), and layer thickness (h). The molecular structure is precisely determined by measuring these parameters, and electromagnetic fields must be examined to measure optical parameters. Therefore, this project first calculates and explains the equations of electromagnetic fields and the phenomenon of polarization and vertical and parallel polarizations, followed by an empirical description of the measurement of optical parameters.

Polarization of electromagnetic waves

The electric field equation of a monochromatic electromagnetic wave is as follows:

$$\vec{E} = \vec{E}_o e^{-1\left(\omega \tau - \vec{k}.\vec{r} + \varphi\right)} \qquad (1)$$

where the vector is the diffusion vector with size , is the phase difference (shift), and is the value of the phase variable.

The equation is a different quantity, which can be written as follows:

$$\vec{E} = E_o e^{-1(a+\varphi)} \qquad (2)$$

Therefore, each component of the electric field in the orthogonal coordinate system, equal to the real value, is as follows:

$$R[E_o e^{-1(a+\varphi)}] = E_o Co(a+\varphi) \qquad (3)$$

If is along the wave propagation, we have:

$$\vec{E}.\vec{S} = 0 \qquad (4)$$

The Z-axis is selected along the wave propagation. In this case, component Z is the Zero electric field, and the two components are non-zero, according to Equation (4). Then, we have:

$$\begin{cases} E_x = a_1 \cos(a+\varphi_1) \\ E_y = a_2 \cos(a+\varphi_2) \\ E_z = 0 \end{cases} \qquad (5)$$

Equation (5) can also be written as follows:

$$\begin{aligned} &(E_x / a_1)^2 + (E_y / a_2)^2 - 2(E_x E_y / a_1 a_2) \\ &\cos(\varphi_2 - \varphi_1) = \sin^2(\varphi_2 - \varphi_1) \end{aligned} \qquad (6)$$

By selecting $(\varphi_2 - \varphi_1) = \Delta$ as the phase difference of the components x and y, the electric field of Equation (6) is written as follows:

$$\begin{aligned} &(E_x / a_1)^2 + (E_y / a_2)^2 \\ &-2(E_x E_y / a_1 a_2)\cos\Delta = \sin^2\Delta \end{aligned} \qquad (7)$$

This is the equation of an ellipse, i.e., the end of the electric field vector $(\vec{E})$ travels in an ellipse at any moment. Such a wave is called elliptical polarization.

If $\Delta = 0$, Equation (7) is written as follows:

$$(E_x / a_1)^2 + (E_y / a_2)^2 - 2(E_x E_y / a_1 a_2) = 0$$

or

$$E_y = \pm \frac{a_1}{a_2} E_x \qquad (8)$$

Which is the equation of a line, called linear polarization. If $\Delta = \frac{\pi}{2}$, Equation (7) is written as follows:

$$(E_x / a_1)^2 + (E_y / a_2)^2 = 1$$

Which is the equation of an ellipse, the diameters of which correspond to the x and y axes. Also, $a_1 = a_2$ means the equation of a circle called circular polarization. If one of the components of the polarized electric field is parallel to the radiation surface, it is denoted by $E_{\parallel}$, and the other component, perpendicular to the radiation surface, is denoted by $E_{\perp}$.

The points of contact of the elliptic curve (i.e., polarization) with the sides of the rectangle with the sides parallel to the x-axis $(\pm a_1, \pm a_2 \cos\Delta)$ with the sides parallel to the y-axis $(\pm a_1 \cos\Delta, \pm a_2)$.

The axes of the polarization ellipse are denoted by $o\zeta$ and $o\eta$. In this case, the components of the electric field along these axes will be as follows:

$$\begin{cases} E_{\zeta} = \pm a \cos + (\beta + \varphi_0) \\ E_{\eta} = \pm b \sin(\beta + \varphi_0) \end{cases} \quad (9)$$

If the dimensions of the diameters of the ellipse are shown by 2a and 2b (a>b), Equation (9) is as follows:

$$\begin{cases} E_{\zeta} = \pm a \cos + (\beta + \varphi_0) \\ E_{\eta} = \pm b \sin(\beta + \varphi_0) \end{cases} \quad (10)$$

$$a^2 = a_1^2 \cos^2 \gamma + a_2^2 \sin^2 \gamma + 2a_1 a_2 \cos\gamma \sin\gamma \cos\Delta \quad (11)$$

$$b^2 = a_1^2 \sin^2 \gamma + a_2^2 \cos^2 \gamma - 2a_1 a_2 \cos\gamma \sin\gamma \sin\Delta \quad (12)$$

Equations (11) and (12) add up as follows:

$$a^2 + b^2 = a_1^2 + a_2^2 \quad (13)$$

Following simplification, we will have:

$$\tan(2\gamma) = \frac{2a_1 a_2}{a_1^2 - a_2^2} = \cos\Delta \quad (14)$$

or

$$\tan(2\gamma) = \tan(2\psi)\cos\Delta \quad (15)$$

By measuring the values of ψ and Δ (by an ellipsometer), the value of γ and, consequently, the optical parameters can be calculated.

Now, the angle ε is defined as follows:

$$\tan\varepsilon = \frac{b}{a} \quad (16)$$

which is the ratio of two diameters of an ellipse.

From equations (13) and (14), we have:

$$\pm\frac{2ab}{a^2+b^2}=\sin(2\varphi)\sin\Delta \qquad (17)$$

Using Equation (16), we have:

$$\frac{2ab}{a^2+b^2}=\frac{2(a/b)}{1+b^2/a^2}=\frac{2\tan\varepsilon}{1+\tan^2\varepsilon}=$$
$$\sin(2\varepsilon)=\sin(2\varphi)\sin\Delta$$

or

$$\frac{2ab}{a^2+b^2}=\frac{2(a/b)}{1+b^2/a^2}=\frac{2\tan\varepsilon}{1+\tan^2\varepsilon}=$$
$$\sin(2\varepsilon)=\sin(2\varphi)\sin\Delta$$

Using the previous equations, we will easily have:

$$\tan\Delta=\frac{\tan(2\varepsilon)}{\sin(2\gamma)} \qquad (18)$$

By considering Equation (18) and the quantities $\Delta=\varphi_{\square}-\varphi\perp$ and $\tan\psi=\frac{|\gamma_{\square}|}{|\gamma_{\perp}|}$, the optical parameters of a reflecting surface can be obtained experimentally.

Investigation of electromagnetic equations at the separation level of media (N-phase (-layer) system)

In an N-phase system, there are (N-2) homogeneous, finite, and parallel plane-surface media between the beginning and end media. In this case, there are generally) $K=1,2,3,.......,N-1$ ($Z=Z_K$ layers. The corresponding matrix is Mk, whose spatial coordinates are Zk-1, and its final position is $Z\geq Z_{N-1}$.

The tangential fields at the initial boundary $z=z_1=0$ are related to the final boundary $Z=Z_{n-1}$ by the following equation:

$$\begin{bmatrix}u_1\\v_1\end{bmatrix}=M_2M_3....M_{N-1}\begin{bmatrix}u_{N-1}\\v_{N-1}\end{bmatrix}=M\begin{bmatrix}u_{N-1}\\v_{N-1}\end{bmatrix}$$

Here, M is a characteristic matrix of the coordinates of a plane and finite N-layer group. Moreover, u_k and v_k are the tangential components of the field domain at the boundary *K*. For the polarization of T_E at surface (1), we have $u_1=E_y^{\circ}$ and $v_1=H_x^{\circ}$, and for the polarization of $u_k=H_x^{\circ}$, we have $u_k=H_x^{\circ}$.

The matrix properties for the *j*th layer for the polarization of T_E are given by the following equation:

$$M_j = \begin{bmatrix} Cos\beta_j & \frac{-i}{p_j} Sin\beta_j \\ -ip_j Sin\beta_j & Cos\beta_j \end{bmatrix} T_E \text{ polarization}$$

$$M_j = \begin{bmatrix} Cos\beta_j & \frac{-i}{q_j} Sin\beta_j \\ -iq_j Sin\beta_j & Cos\beta_j \end{bmatrix} T_M \text{ polarization}$$

The shape of the N-phase system

Reflection and transmission coefficients in an N-layer system

Consider a plane wave propagating in a multilayer medium, where all the layers continue from Z = 1 to Z = N homogeneously and adjacent to each other and in one direction. Moreover, $\varepsilon_1, \mu_1, \varepsilon_N, \mu_N$ are the magnetic permittivity and permeability of the first medium and the *n*th medium, respectively. Also, is the angle between the incident wave and the transmission with the z-axis. To calculate the intensity of the reflected and transmitted fields for TE waves, we can write:

$$V_0 = P_1(Ey_1^{0t} - Ey_1^{0r}) \qquad U_0 = Ey_1^{0t} + Ey_1^{0r}$$

$$V(z) = P_N(Ey_N^{0t}) \qquad U(z) = Ey_N^{0t}$$

$$P_1 = (\frac{\varepsilon_1}{\mu_1})^{1/2} Cos\theta_1, P_N = (\frac{\varepsilon_N}{\mu_N})^{1/2} Cos\theta_N$$

$$Q_0 = MQ$$

Here, the matrix M can be written as follows:

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix}$$

$$Q(z) = \begin{bmatrix} U(z) \\ V(z) \end{bmatrix} \qquad U_0 = \begin{bmatrix} U_0 \\ V_0 \end{bmatrix}$$

Using the above equations, we can write:

$$\begin{bmatrix} U_0 \\ V_0 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \times \begin{bmatrix} U(z) \\ V(z) \end{bmatrix}$$

$$\begin{bmatrix} U_0 \\ V_0 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \times \begin{bmatrix} Ey_N^{0+} \\ P_N^{0+} \end{bmatrix}$$

$$U_0 = Ey_N^{0t}(m_{11} + P_N m_{12}) = Ey_1^{0r} + Ey_1^{0t}$$

$$V_0 = Ey_N^{0+}(m_{21} + P_N m_{22}) = P_1(Ey_1^{0r} - Ey_1^{0r}$$

$$t_E = \frac{Ey_N^{0t}}{Ey_1^{0t}} = \frac{2P_1}{(m_{11} + P_N m_{12})P_1 + (m_{21} + P_N m_{22})}$$

$$r\perp=\frac{Ey_1^{0t}}{Ey_1^{0t}}=1-\frac{(m_{21}+P_N m_{22})}{P_1}\times\frac{2P_1}{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})}$$

$$r\perp=\frac{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})-2(m_{21}+P_N m_{22})}{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})}$$

$$r\perp=\frac{(m_{11}+P_N m_{12})P_1-(m_{21}+P_N m_{22})}{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})}$$

According to these equations, the above equations can be obtained for TM waves by modifying P_1, P_N to q_1, q_N.

Studying electromagnetic fields in a multiphase system

To study the electromagnetic fields, the coordinate axes are considered so that x is perpendicular to the radiation surface, y is parallel to the radiation surface along the layer separation surface, z is on the layer separation surface, and the wave propagates along the z-axis.

The equations of the electromagnetic fields for such a system are as follows:

$$\frac{\partial}{\partial y}[\frac{-c}{i\omega\mu}\frac{\partial E_x}{\partial y}]-\frac{\partial}{\partial z}[\frac{-c}{i\omega\mu}\frac{\partial E_x}{\partial z}]+\frac{i\omega\varepsilon}{c}E_x=0$$

$$\frac{-c}{i\omega\mu}\frac{\partial^2 E_x}{\partial yz}-\frac{c^2}{i\omega\mu}\frac{\partial^2 E_x}{\partial z^2}+n^2k^2E_x+\frac{\partial E_x}{\partial z}[\frac{c}{i\omega}\frac{\partial}{\partial z}(\frac{1}{\mu})]=0$$

$$\frac{\partial^2 E_x}{\partial y^2}+\frac{\partial^2 E_x}{\partial z^2}+n^2k^2E_x=\frac{d}{dz}[\log\mu]\frac{\partial E_x}{\partial z}$$

$$n=\sqrt{\varepsilon\mu} \qquad k=\frac{\omega}{c}=\frac{2\pi}{\lambda}$$

The differential equation is simply a function of z, y. Therefore, the answer can be as follows:

$$E_x(y,z)=Y(y)Z(z)$$

By substituting the experimental solution in the differential equation, we have:

$$\frac{1}{Y}\frac{d^2Y}{dy^2}+\frac{1}{u}\frac{d^2u}{dz^2}-n^2k^2+\frac{d}{dz}[\log\mu]\frac{1}{u}\frac{du}{dz}=0 \qquad \text{(A)}$$

Assume that $\frac{1}{Y}\frac{d^2Y}{dy^2}=-k^2$;
or

$$\frac{1}{u}\frac{d^2y}{dy^2}=-k^2y\Rightarrow y=ae^{iky}$$

Therefore, it turns into Equation (A)

$$\frac{d^2u}{dz^2} - \frac{d(\log\mu)}{dz}\frac{du}{dz} + n^2k^2 = k^2u$$

Therefore, (A')

$$E_x = U(z)e^{i(ky-\omega y)}$$

Then, we have:

$$\begin{cases} H_y = V_{(z)}e^{i(k\alpha y-\omega t)} \\ H_z = U_{(z)}e^{i(k\alpha y-\omega t)} \end{cases}$$

or

$$\begin{cases} \frac{\partial}{\partial y}[W_{(z)}e^{i(ky-\omega t)}] - \frac{\partial}{\partial z}[V_{(z)}e^{i(k\alpha y-\omega t)}] + \\ \frac{i\omega t}{c}[U_{(z)}e^{i(k\alpha y-\omega t)}] = 0 \\ ikW_{(z)} - V'_{(z)} + ik\varepsilon U_{(z)} = 0 \\ V'_{(z)} = ik[\alpha W_{(z)} + \varepsilon U_{(z)}], V'_{(z)} = \frac{dV_{(z)}}{dz} \end{cases}$$

we have:

$$\frac{\partial}{\partial y}[U_{(z)}e^{i(ky-\omega t)}] - \frac{i\omega\mu}{c}V_{(z)}e^{i(k\alpha y-\omega t)} = 0$$

$$U'_{(z)} = ik\mu V_{(z)}$$

$$\alpha U_{(z)} + \mu W_{(z)} = 0$$

$$V'_{(z)} = ik\left(\varepsilon - \frac{\alpha^2}{\mu}\right)U$$

$$U'_{(z)} = ik\mu V_{(z)} \quad \text{(B)}$$

Then, we have:

$$\frac{d^2u}{dz^2} - \frac{d}{dz}[\log\mu]\frac{du}{dz} + k^2(n^2-\alpha^2)u = 0$$

$$v' = ik\left(\varepsilon - \frac{\alpha^2}{\mu}\right)u$$

$$\frac{d^2u}{dz^2} = ik\left(\varepsilon - \frac{\alpha^2}{\mu}\right)\frac{du}{dz} + iRu\frac{d\left(\varepsilon - \frac{\alpha^2}{\mu}\right)}{dz}$$

$$\frac{d^2v_{(z)}}{dz^2} = ik\left(\varepsilon - \frac{\alpha^2}{\mu}\right)ikv_{(z)} + iku_{(z)}\frac{d\left(\varepsilon - \frac{\alpha^2}{\mu}\right)}{dz}$$

$$\frac{d^2v_{(z)}}{dz^2} = -k^2\left(\varepsilon - \frac{\alpha^2}{\mu}\right)\mu V_{(z)} + \frac{iku_{(z)}}{ik\left(\varepsilon - \frac{\alpha^2}{\mu}\right)}\frac{d\left(\varepsilon - \frac{\alpha^2}{\mu}\right)}{dz}$$

$$\frac{d^2v_{(z)}}{dz^2} = -k^2(\varepsilon - \alpha^2)V_{(z)} + \frac{d}{dz}[\log\left(\varepsilon - \frac{\alpha^2}{\mu}\right)]$$

$$\frac{d^2v_{(z)}}{dz^2} - \frac{d}{dz}[\log\varepsilon - (\frac{\alpha^2}{\mu})]\frac{dv_{(z)}}{dz} + k^2(n^2 - \alpha^2)V_{(z)} = 0$$

With similar calculations for the wave zM, where $H_y = H_z = 0$, we will have:

$$\begin{cases} H_x = u_{(z)}e^{i(k\alpha y - \omega t)} \\ E_y = -v_{(z)}e^{i(k\alpha y - \omega t)} \\ E_z = -w_{(z)}e^{i(k\alpha y - \omega t)} \\ u'_{(z)} = ikv_{(z)} \\ v' = ik\left(\mu - \frac{\alpha^2}{\varepsilon}\right)u \end{cases}$$

The relationship between *w* and *u* is as follows:

$$u + \varepsilon w = 0$$

V and *u* estimate the two linear differential equations.

$$\frac{d^2u}{dz^2} - \frac{d}{dz}[\log\varepsilon]\frac{du}{dz} + k(n^2 - 1)u = 0 \qquad (I)$$

$$\frac{d^2v}{dz^2} - \frac{d}{dz}[\log\left(\mu - \frac{\alpha^2}{\varepsilon}\right)]\frac{dv}{dz} + k(n^2 - 10)v = 0 \qquad (II)$$

In these equations, *u* and *v* are complex and a function of *z*. The domain of E_x with a fixed surface is as follows:

$$|u(z)| = Cte.$$

A fixed-phase surface has the following equation:

$$\phi_{(z)} + k\alpha y = Cte.$$

$\phi_{(z)}$ is located in the medium *u*. A surface cannot have two directions at the same time; thus, E_x and similarly H_y and H_z are inhomogeneous waves. For a $(dxdy)$ shift in the direction of this simultaneous surface, we have:

$$\phi_{(z)}dz + kdy = 0$$

$$tg\theta = \frac{-dz}{dy} = \frac{k}{\phi_{(z)}}$$

In a particular case for a homogeneous wave, we have:

$$nSin\theta = 1 \qquad \phi_{(z)} = kznCos\theta$$

Since the functions $u_{(z)}, v_{(z)}$ held in the differential equations (I) and (II) for an N-layered medium.

$u_{(z)}, v_{(z)}$ may be linear from two special solutions u_1, v_1 and u_2, v_2. Special solutions cannot be arbitrary. According to Equation (X), we have:

$$u_2' = ik\mu v_2 \qquad u_1' = ik\mu v$$

$$v_2' = ik\left(\varepsilon - \frac{\alpha^2}{\mu}\right)u_2 \qquad v_1' = ik\left(\varepsilon - \frac{\alpha^2}{\mu}\right)u$$

These equations show that:

$$u_1v_2' - v_1'u_2 = 0 \qquad v_1u_2' - u_1'v_2 = 0$$

The above equation can be written as follows:

$$\frac{d}{dz}(u_1v_2 - u_2v_1) = 0$$

The determinants of this equation are as follows:

$$D = \begin{vmatrix} u_1 & v_1 \\ u_2 & v_2 \end{vmatrix}$$

The special solutions of the above equation are assumed as follows:

$$u_2 = F_{(z)} \qquad u_1 = f_{(z)}$$

$$v_2 = G_{(z)} \qquad v_1 = g_{(z)}$$

We also have:

$$F_{(0)} = g_{(0)} = 1 \qquad f_{(0)} = G_{(0)} = 0$$

$$V_{(0)} = V_0 \qquad U_{(0)} = U_0$$

$$Q_0 = \begin{bmatrix} u_0 \\ V_0 \end{bmatrix} \qquad Q = \begin{bmatrix} u_{(z)} \\ V_{(z)} \end{bmatrix}$$

$$N = \begin{bmatrix} F_{(z)} & f_{(z)} \\ G_{(z)} & g_{(z)} \end{bmatrix}$$

Since D and the determinants of the square matrix N are constant, the constant value is obtained at z = 0 as follows:

$$|N| = Fg - fG = 1$$

Fresnel coefficients $r_{\parallel}, t_{\parallel}, r_{\perp}, t_{\perp}$ are calculated for parallel and vertical polarizations as follows:

$$V_0 = P_1(Ey_1{}^{0t} - Ey_1{}^{0r}) \qquad U_0 = Ey_1{}^{0t} + Ey_1{}^{0r}$$

$$V_{(z)} = P_N(Ey_N{}^{0t}) \qquad U_{(z)} = Ey_N{}^{0t}$$

$$P_N = \left(\frac{\varepsilon_N}{\mu_N}\right)^{1/2} Cos\theta_N \qquad P_1 = \left(\frac{\varepsilon_1}{\mu_1}\right)^{1/2} Cos\theta_1$$

$$Q_0 = MQ$$

Where the matrix M is as follows:

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix}$$

$$Q_{(z)} = \begin{bmatrix} U_{(z)} \\ V_{(z)} \end{bmatrix} \qquad U_0 = \begin{bmatrix} U_0 \\ V_0 \end{bmatrix}$$

Using the above equations, we can write:

$$\begin{bmatrix} U_0 \\ V_0 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \times \begin{bmatrix} U_{(z)} \\ V_{(z)} \end{bmatrix}$$

$$\begin{bmatrix} U_0 \\ V_0 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \times \begin{bmatrix} Ey_N{}^{0t} \\ Pl_N{}^{0t} \end{bmatrix}$$

$$U_0 = Ey_N{}^{0t}(m_{11} + P_N m_{12}) = Ey_1{}^{0t} + Ey_1{}^{0t}$$

$$V_0 = Ey_N{}^{0t}(m_{21} + P_N m_{22}) = p_1(Ey_1{}^{0r} - Ey_1{}^{0t})$$

$$\frac{Ey_N{}^{0t}(m_{11} + P_N m_{12})}{Ey_1{}^{0t}} = 1 + \frac{Ey_1{}^{0r}}{Ey_1{}^{0t}}$$

$$\frac{Ey_N{}^{0t}(m_{21} + P_N m_{22})}{Ey_1{}^{0t} P_1} = 1 - \frac{Ey_1{}^{0r}}{Ey_1{}^{0t}}$$

or

$$\frac{Ey_N{}^{0t}(m_{11}+P_N m_{12})}{Ey_1{}^{0t}}+\frac{Ey_1{}^{0r}}{Ey_1{}^{0t}}\frac{(m_{21}+P_N m_{22})}{P_1}=2$$

$$\frac{Ey_N{}^{0t}(m_{11}+P_N m_{12})}{Ey_1{}^{0t}}+\frac{(m_{21}+P_N m_{22})}{P_1}=2$$

$$t_E=\frac{Ey_N{}^{0t}}{Ey_1{}^{0t}}=\frac{2P_1}{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})}\quad r_\perp=\frac{Ey_1{}^{0r}}{Ey_1{}^{0t}}=1-\frac{(m_{21}+P_N m_{22})}{P_1}\times\frac{2P_1}{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})}$$

$$r_\perp=\frac{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})-2(m_{21}+P_N m_{22})}{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})}$$

$$r_\perp=\frac{(m_{11}+P_N m_{12})P_1-(m_{21}+P_N m_{22})}{(m_{11}+P_N m_{12})P_1+(m_{21}+P_N m_{22})}$$

According to these equations, the above equations can be obtained for TM waves by modifying P_1, P_N to q_1, q_N.

Description of the proposed method and results

For each light-absorbing medium, the complex refractive index is expressed using the equation $\hat{n}=n+ik$, where *n* is the real part of the complex refractive index, and *k* is the extinction coefficient.

When light enters from the first medium to the second medium, the two media of the Fresnel coefficients for the transmission and reflection beams with vertical polarization at the separation surface are as follows:

$$r_{\perp 12}=\frac{\hat{n}_1 Cos\theta_1-\hat{n}_2 Cos\theta_2}{\hat{n}_1 Cos\theta_1+\hat{n}_2 Cos\theta_2}\quad t_{\perp 12}=\frac{2\hat{n}_1 Cos\theta_1}{\hat{n}_1 Cos\theta_1+\hat{n}_2 Cos\theta_2} \qquad (19)$$

where $\hat{n}_2, \hat{n}_1$ are the refractive indices of the first and second media, θ_1 and θ_2 are the angles of incidence and refraction, respectively. The index $\perp$ represents vertical polarization. If a system consists of three media with two completely parallel separation surfaces (Figure 1), the transmission coefficient of a beam with vertical polarization is as follows:

$$t_\perp=\frac{t_{\perp 12}t_{\perp 23}e^{-i\beta}}{1+r_{\perp 12}r_{\perp 23}e^{-2i\beta}} \qquad (20)$$

where $\beta=2\pi\frac{h}{\lambda}\hat{n}_2 Cos\theta_2$ and *h* are the thickness of the second medium (i.e., film). The thickness of the third medium is very large compared to the second medium. The transmission *T* is:

$T_\perp$ = (incidence energy in the first medium) / (refractive energy in the third medium)

The transmittance absorption is:

$$A=-\log_{10}T_\perp \qquad (21)$$

The substrate is glass; thus, in this case, the first medium is air, the second medium is the gold film, and the third medium is glass. Part of the film is wiped off a glass blade with a mercury-soaked cotton swab. The refractive index of glass (i.e., substrate) was measured using an optical method and a microscope, $n_3=1.504$ and $k_3=0$ (i.e., it is transparent). This value of n corresponds to the result of the measurement by the symbol meter.

One light source used is the 1mw gas (helium-neon) laser, the beam wavelength of which was measured using the Fresnel biprism and diffraction grating methods. The result of the first method is $\lambda = 639nm$, and the result of the second method is $641nm$. The value of the wavelength in the calculations is equal to the average of the two, i.e., $640nm$. Another light source was used, a 200-watt bulb embedded in a chamber. Red beams of 652 nm and green beams of 525 nm were generated using color filters. The wavelength of these beams was measured using the above methods.

The polarization of the radiation beam was adjusted using a polarizer in the desired direction, i.e., perpendicular to the incidence surface (to the surface at the point of incidence). Absorption was measured in all cases by a photometer connected to a sensitive lux meter. Part of the substrate was covered with film, and the other part is without film. The absorption difference between the two states was measured by shifting the film blade horizontally in a direction perpendicular to the incidence path (i.e., the film blade is positioned vertically on a circular graduated surface) from the film surface to the film-free surface (Figure 2).

Because T= (incidence beam intensity) / (transmission beam energy)

$E_0 = \frac{I_0}{d^2}$ **:** Illumination by the direct incidence of the incidence beam

$E_{t0} = \frac{I_{t0}}{d^2}$ **:** Illumination of the transmission beam without film

$E_t = \frac{I_t}{d^2}$ **:** Illumination of the transmission beam with film

(*I* is the intensity of the beam and *d* is the distance of the film blade from the photometer).

Then:

$\frac{E_{t0}}{E_0} = \frac{I_{t0}}{I_0} = T_0$ **:** Transmission of a beam passing through the glass

$\frac{E_t}{E_0} = \frac{I_t}{I_0} = T$ **:** Transmission of a beam passing through the film

We have always made sure that *d* is the same for all cases.

The values of *E* were determined directly from the photometer degrees for each case, and the values of *T*s were also calculated. Hence, according to Equation (21), we can write:

Transmission absorption when the beam passes through the film and substrate is as follows:

$$A_T = -\log_{10} T$$

Transmission absorption when the beam passes through the film-free substrate is as follows:

$$A_{T0} = -\log_{10} T_0$$

Then:

$$\Delta A = A_T - A_{T0} = \log\left(\frac{T_0}{T}\right) \qquad (22)$$

Considering Equations (19) - (22), it is observed that ΔA is a function of the angle of incidence (θ), k, n, and h/λ. The first medium is air; thus, $n_1 = 1$ and the third medium is glass, whose value is n. The output angle was also measured for each incidence state, and the θ_3 angle was also calculated using the law of refraction. *T* values were calculated for different angles of incidence and wavelengths and are shown in Table 1.

Using the values of *T*, the absorbance for certain angles of incidence (by rotating the film by the calibrated plate and measuring the degrees) was measured by vertical polarization for the gold thin film, and consequently, the desired quantities were calculated. The absorptions for gold films with different Qs are as follows:

$$\Delta A_1 = f_1(n_2, k_2, h/\lambda, \theta_1)$$
$$\Delta A_2 = f_2(n_2, k_2, h/\lambda, \theta_2)$$
$$\Delta A_3 = f_3(n_2, k_2, h/\lambda, \theta_3)$$

Since θ s and ΔA s are determined, the values of $n, k, h/\lambda$ were calculated, and their results are shown in Table 2.

According to the numbers listed in the table, it is clear that the average thickness of the gold film tested is h = 26.6 nm. By accurately measuring the mass of the film (i.e., the difference between the mass of the blade and the film and the mass of the blade removed from the film), the length and width of the gold bar, its thickness was calculated using the film degradation method, which is h = 22.1 nm. There is not much difference in the size of the film thickness resulting from two quantitative methods, which can be attributed to the non-uniform thickness of the film in all parts because in layering using the vacuum technique method, complete thickness homogeneity for a surface of more than 10 cm^2 is practically impossible.

Optical constants of several other gold films and indium(III) oxide film were also determined, which are not included in the article for brevity.

Table 1: The values of the T transmission of a gold thin film for the angle of incidence and various wavelengths

T	The angle of incidence θ (°)	Wavelength λ (nm)
0.39	20	525
0.35	30	525
0.26	40	525
0.22	20	640
0.145	30	640
0.101	40	640
0.147	20	652
0.089	30	652
0.035	40	652

Table 2: Optical constants of the gold film with a thickness of 20.5 nm, calculated from various combinations of T

Optical Constants			T combinations with the angle of incidence			λ (nm)
k	n	h (nm)				
0.5911	0.8800	26.3	20	30	40	525
0.2422	0.7960	26.8	20	30	40	640
0.7512	0.7210	26.5	20	30	40	652

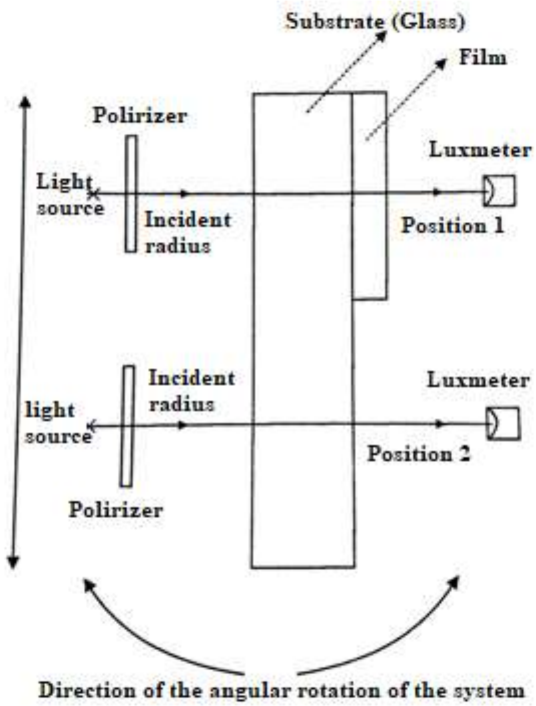

Figure 2: Schematic of the transmission measurement system

Position 1: The beam passing through the film; Position 2: The beam passing only through the substrate

Conclusion

This study investigated the optical constants and electrical properties of glass-laminated gold thin films using the transmission method. The degree of light absorption depends directly on the Fresnel coefficients and, consequently, on the optical constants $(h/\lambda, k, n)$. The transmission of T is proportional to the square of the transmission of t $[T \propto |t|^2]$ and the dependence of the transmission absorption on T such that $A = -\log T$. By measuring the absorption using a spectrophotometer with parallel and vertical polarizations, a different angle of incidences in the wavelength range of 500-650 nm was determined by using the equations related to the optical constants of the film. A comparison was made between the results of this study and those measured using ellipsometry, indicating similarities between them and confirming that transmission is undoubtedly an accurate and convenient method.

Also, the optical constants of a glass-laminated gold thin film were investigated using the method presented in this paper. The consistency between the results obtained and those obtained from the references [12, 13], as well as the approximately equal film thickness measured using the degradation and transmission methods, confirms that the proposed method is simple, easy, and accurate. The film thickness is determined using an experiment (with three different angles of incidences and one wavelength). Then, the values of n and k are easily determined with fewer equations in the longer wavelength range since h has been determined.

References

[1] B. A. Banks et al., NASA Tm (1999)
[2] P. L. William and J. A. David, sur. And Coat. Technol. 103 (1998) 178-184
[3] M. salehi, F. Karimizadeh, Suf. Coat. Tech 5(18) (2002). 168-372
[4] P. N Binduma havan, material science, and Engineering, A 315 (2001). 217-226
[5] N. M. Bashara, Surface science 47 (1985)
[6] W. J. Anderson, Determination the optical constant of thin films by internal reflection, Journal of the Optical Society of America, 1973, No. 63, pp.793
[7] W. N. Hansen and W. J. Anderson, thin Film Optical constants, Journal of the Optical Society of America, 1977, No. 73, pp.1120
[8] M. R. Behfrooz, Optical Constants of Monolayer Films. Iranian Journal of Science and Technology, 1987, Vol.1, No.1, pp.1-9.
[9] M. R Behfrooz and J. A. Wollam, optical properties of thin films of methalene-Blue and Crystal- Violet Organic Dyes using Variable Angle Spectroscopy Ellipsometry, Applied physics Communication, 1992, Vol. 11, No. 2 and 3, pp.117-126
[10] M. R. behfrooz. Optical parameters of water at IR, Iranian Annual physics Conference, Sanandaj, 1994.
[11] M. R. Behfrooz Measurement of optical and magneto-optical constants of TbFeCo thin films, Iranian Annual physics Conference, Mashhad, 1996.
[12] M. R. Behfrooz, Study of Ir thin films Deposited on sio2 Substrates, Journal of Science IRI, 2005, Vol. 16, No.2.
[13] J. M. Briceno- Valero, Optical properties of thin Gold films, physics, 1979, Rev. 101, 1281.