Determination of Optical Constants of SnO_2 Thin Film for Display Application

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Abstract: -Thin absorbing films are becoming common in optical coating applications. Such films require proper techniques to insure unique results for both thickness and optical constants. This project describes the determination of optical constant and thickness of SnO_2 thin film. Various techniques are available for determining the properties of surfaces and thin films. A versatile method for determination of the optical constants is described that can be applied to a variety of coating materials. It is based on the use of an optical thin film synthesis program to adjust the constants of dispersion equations until a good fit is obtained between measured and calculated spectral transmittance and/or reflectance curves. The sensitivity of the determination can be increased by a suitable combination of measurement quantities. Because more than the minimum amount of data can be used, sensitivity to measurement errors and the chances of obtaining multiple solutions can both be reduced.The optical parameters, thickness and refractive index of a thin film can be calculated by analyzing the polarization changes, i.e. from the polarizer and analyzer angles.

Keywords: Thin Film, Ellipsometer, Optical Constants, Complex Refractive Index, Dielectric Function

INTRODUCTION

In current years there has been an intensifying need for an accurate data of the optical constants n and k of thin absorbing films over a wavelength range. Since the optical constants of the materials have generally been completely unknown or determined only in a narrow wavelength range, proposed designs for such films have had to be tested experimentally rather than by the much more rapid method of numerical simulation. The insufficient knowledge of optical constants has thus slowed progress in its application. The refractive index of a material is the most important property of any optical system that uses refraction. It is used to calculate the focusing power of lenses, and the dispersive power of prisms. Since refractive index is a fundamental physical property of a substance, it is often used to identify a particular substance, confirm its purity, or measure its concentration. Refractive index is used to measure solids (glasses and gemstones), liquids, and gases. Most commonly it is used to measure the concentration of a solute in an aqueoussolution. A refractometer is the instrument used to measure refractive index. For a solution of sugar, the refractive index can be used to determine the sugar content. In GPS, the index of refraction is utilized in ray-tracing to account for the radio propagation delay due to the Earth's electrically neutral atmosphere. It is also used in Satellite link design for the Computation of radiowave attenuation in the atmosphere.

OPTICAL PROPERTIES

Conductive materials, such as metals, show non-zero electrical conductivity coefficient, which has a major impact on their optical properties. Describing the behavior of electromagnetic wave in conductive materials needs to take into consideration additional conditions to those in dielectric media which solution of Maxwell equations must satisfy for this type of material. For this purpose, we consider the influence of magnetic field as:

$$\vec{\nabla} \times \vec{H} = \vec{D} + \vec{J}$$

Where ∇ is the Nabla operator, H is the magnetic field intensity, D is the electric displacement and J is the current density. There are also known the constitutive relationships:

$$\vec{D} = \varepsilon_0 \varepsilon_r \vec{E}$$

$$\vec{J} = \sigma \vec{E}$$

Where $\varepsilon 0$ is vacuum permittivity, εr is the relative permittivity (or dielectric constant) of the given material and E is the electric field intensity. If we assume that in a material there is a monochromatic wave propagating with wavelength equal to λ such as:

$$\vec{E} = \vec{E}(\omega) = \vec{E}_0 e^{-i\omega t}$$

Where $\omega = 2\pi c/\lambda$ is the angular frequency and c the speed of light in vacuum.

Generally:

$$\vec{\nabla} \times \vec{H} = \sigma\vec{E} - i\omega\varepsilon 0\, \varepsilon r\, \vec{E} = -i\omega\varepsilon 0 \left(\varepsilon r + \frac{i\sigma}{\omega\varepsilon 0}\right)\vec{E} = -i\omega\varepsilon 0 \tilde{\varepsilon} r \vec{E}$$

Where $\varepsilon\, r$ is a complex dielectric function ($\varepsilon\, r = \varepsilon 1 + i\varepsilon 2$).

Also it can be written in terms of a complex conductivity as:

$$\vec{\nabla} \times \vec{H} = \tilde{\sigma}\, E, \quad \tilde{\sigma} = \sigma_1 + i\sigma_2 \rightarrow \tilde{\sigma} = \sigma - i\omega\, \varepsilon_0\, \varepsilon_r$$

So we get,

$$\tilde{\varepsilon}_r = 1 + i\tilde{\sigma}/\omega\varepsilon_0$$

Now, it is possible to calculate real part of dielectric function:

$$\varepsilon_1 = 1 - \sigma_2/\omega\varepsilon_0$$

As well as the imaginary part:

$$\varepsilon_2 = \sigma_1/\omega\varepsilon_0$$

FRESNEL EQUATIONS

The Fresnel equations, deduced by Augustin-Jean Fresnel, describe the behavior of light when moving between media of differing refractive indices [4]. The reflection of light that the equations predict is known as Fresnel reflection. When light moves from a medium of a given refractive index N0 into a second medium with refractive index N1, both reflection and refraction of the light may occur.

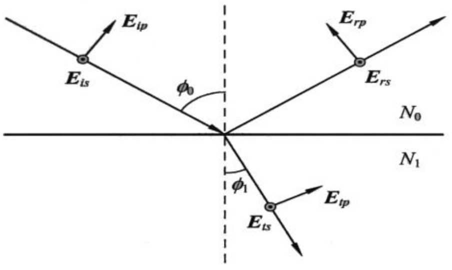


Fig. 1 The reflection and transmission of the light between two phases [3].

The electric field of the light can be divided into two components, Ep (parallel) and Es (perpendicular). The refractive angle φ1 is given by Snell's law written below:

$$N_0 \sin\Phi_0 = N_1 \sin\Phi_1$$

By using the continuity conditions for the tangential components of the electric field and magnetic field at the interface, and the fact that the frequency is the same in media 0 and 1, the Fresnel equations can be derived [3,14]. Fresnel equations give the reflection coefficients of the s-component and p-component of the electric field according to:

$$r_s = E_{rs}/E_{is} = (N_0 \cos\Phi_0 - N_1 \cos\Phi_1)/(N_0 \cos\Phi_0 + N_1 \cos\Phi_1)$$

$$r_p = E_{rp}/E_{ip} = (N_1 \cos\Phi_0 - N_0 \cos\Phi_1)/(N_1 \cos\Phi_0 + N_0 \cos\Phi_1)$$

Complex Index of Refraction

Fresnel's equations are used to describe the reflection of light by a plane interface between two media with different refractive indices. The assumptions made are that, the incident light is described by a monochromatic plane wave and that the media are homogeneous and isotropic, such that the optical properties of the material can be described as scalar functions. The media can then be described by the complex refractive index.

$$\tilde{n} = n + ik$$

Where n is the index of refraction and k is the extinction coefficient. The complex refractive is related to ε through:

$$\varepsilon_1 = n^2 - k^2$$

$$\varepsilon_2 = 2nk$$

n is a ratio of the light velocity c and v – the phase velocity of radiation of a specific frequency in a specific material while k is called the extinction coefficient.

Complex Dielectric Function

The interaction between the electromagnetic wave and matter consists with three parts [14]. One of them is the reaction with free electrons. It can be described as below:

$$\tilde{\varepsilon} = 1 - ne\, e^2 / m\varepsilon_0(\omega^2 + i\omega\gamma) = \varepsilon_\infty - \omega_p^2 / \omega^2 + i\omega\gamma$$

Where m is a mass of electron, ne is a free electron concentration and ωp is a plasma oscillation:

$$\omega_p = \sqrt{(ne\, e^2/m\varepsilon_0)}$$

The electromagnetic waves interact not only with the free electrons, but also with crystal structure and valence electrons, what is the reason of the interband transitions. All of above give us the whole complex dielectric function:

$$\tilde{\varepsilon}(\omega) = 1 + \chi_{fe} + \chi_{ve} + \chi_{cs}$$

Where χ_{fe} is interaction with free electrons,

χ_{ve} is interaction with valence electrons

and χ_{cs} is interaction with crystal structure.

In other way:

n m

$$\tilde{\varepsilon}(\omega) = \varepsilon_\infty - \omega^2{}_p/(\omega^2 + i\omega\gamma) + \sum f_j/(\omega_j^2 - \omega^2 - i\omega\Gamma_j) + \sum A_k\omega^2{}_{TK}/(\omega^2{}_{TK} - \omega^2 - i\omega\Gamma_k)$$

$j=1$

$k=1$

Where:

$\varepsilon_\infty - \omega_p{}^2 / (\omega^2 + i\omega\gamma)$ is Drude's part describing the interaction with free electrons

n

$\sum f_j/(\omega_j{}^2 - \omega^2 - i\omega\Gamma_j)$ is describing interband transitions

$j=1$

m

$\sum A_k\omega^2{}_{TK}/(\omega^2{}_{TK} - \omega^2 - i\omega\Gamma_k)$

$k=1$

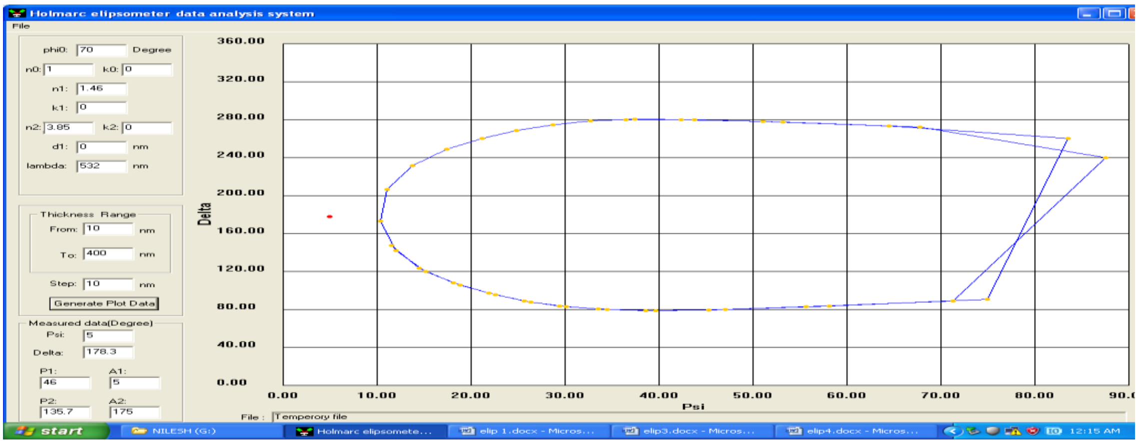
RESULT AND DISCUSSION

In this project for finding optical constant and thickness of SnO_2 thin film, this film is coated on glass substrate. I have used Ellipsometry experimental method and MATLAB curve fitting tool box method to find optical constant value and thickness of these thin films. Result obtained from ellipsometer experimental method and MATLAB curve fitting tool box method has discussed below.

Result From Ellipsometery Experimental Method

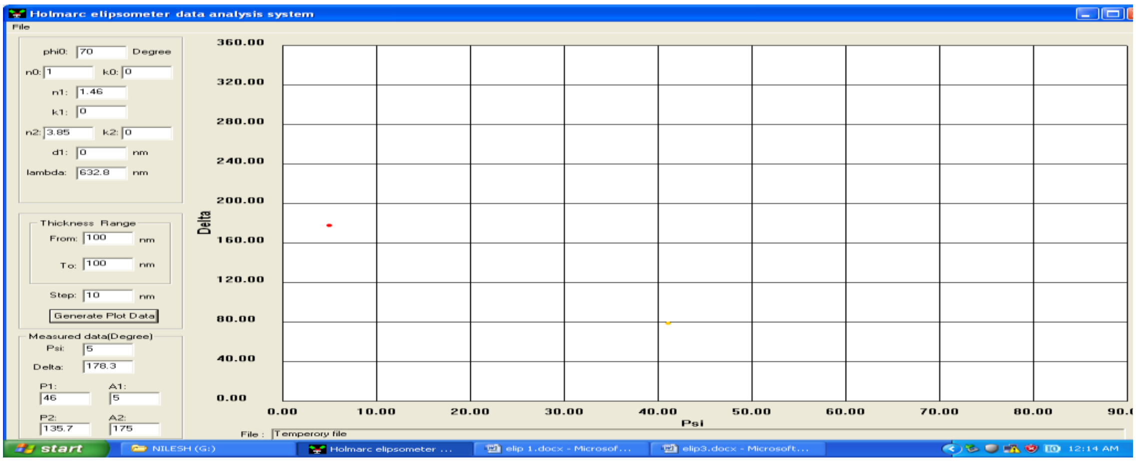
Ellipsometry is an indirect method, i.e. the calculated Δ and ψ cannot be directly converted in to optical constants of the sample. Software plots the ψ - Δ graph and the optical constant will be obtained from the graph. is describing the interaction with crystal structure n this report the complex dielectric function was modelled by Drude-Lorentz oscillator model and Drude-TOLO oscillator model.

Delta and psi graph obtain from ellipsometeric software:



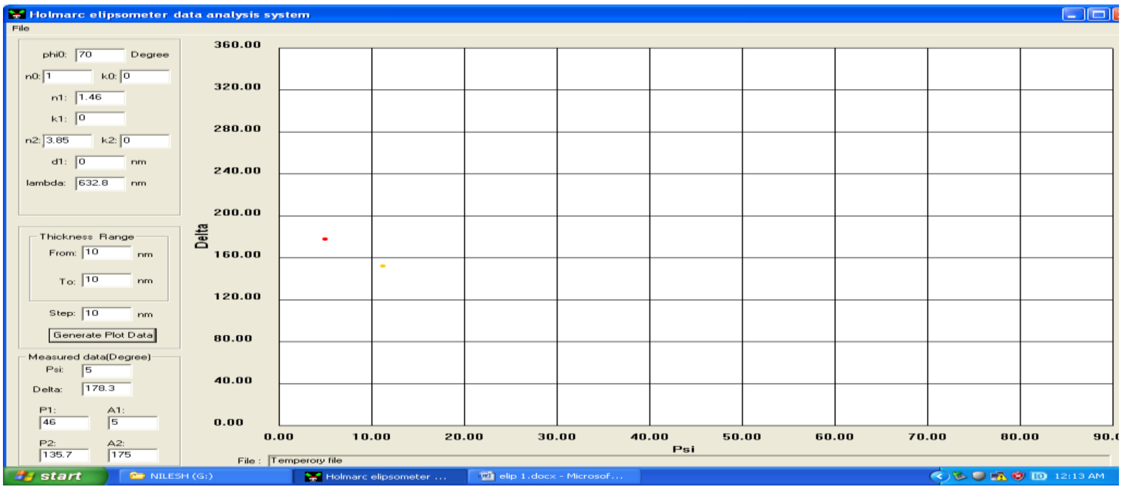
phi0: 70 Degree
n0: 1 k0: 0
n1: 1.46
k1: 0
n2: 3.85 k2: 0
d1: 0 nm
lambda: 532 nm
Thickness Range
From: 10 nm
To: 400 nm
Step: 10 nm
Measured data(Degree)
Psi: 5
Delta: 178.3
P1: 46 A1: 5
P2: 135.7 A2: 175
File : Temperory file

Plot (1)



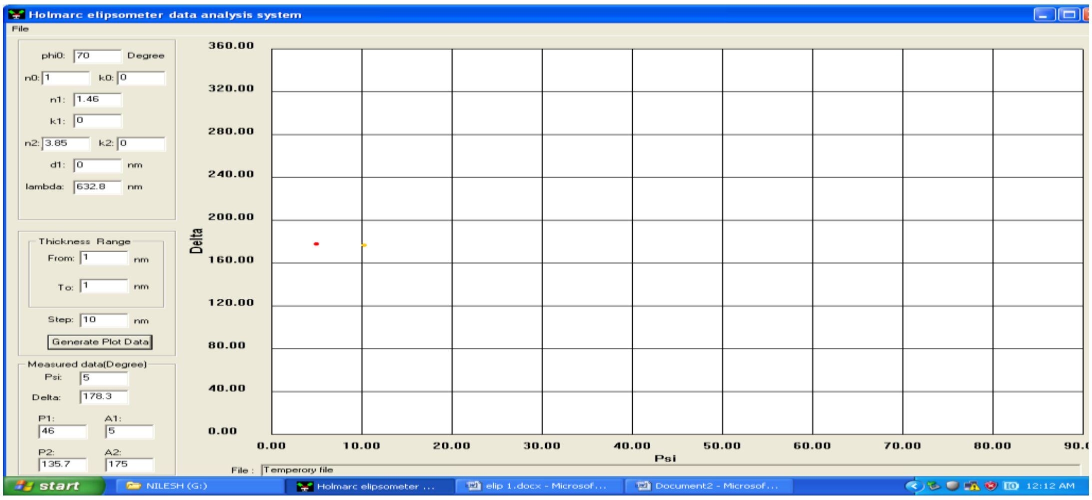
phi0: 70 Degree
n0: 1 k0: 0
n1: 1.46
k1: 0
n2: 3.85 k2: 0
d1: 0 nm
lambda: 632.8 nm
Thickness Range
From: 100 nm
To: 100 nm
Step: 10 nm
Measured data(Degree)
Psi: 5
Delta: 178.3
P1: 46 A1: 5
P2: 135.7 A2: 175
File : Temperory file

Plot (2)



phi0: 70 Degree
n0: 1 k0: 0
n1: 1.46
k1: 0
n2: 3.85 k2: 0
d1: 0 nm
lambda: 632.8 nm
Thickness Range
From: 10 nm
To: 10 nm
Step: 10 nm
Generate Plot Data
Measured data(Degree)
Psi: 5
Delta: 178.3
P1: 46 A1: 5
P2: 135.7 A2: 175
File : Temperory file

Plot (3)



phi0: 70 Degree
n0: 1 k0: 0
n1: 1.46
k1: 0
n2: 3.85 k2: 0
d1: 0 nm
lambda: 632.8 nm
Thickness Range
From: 1 nm
To: 1 nm
Step: 10 nm
Generate Plot Data
Measured data(Degree)
Psi: 5
Delta: 178.3
P1: 46 A1: 5
P2: 135.7 A2: 175
File : Temperory file

Plot (4)

Figure shows the delta (Δ) and psi (ψ) curves. ψ - Δ curves are typically used to visualize the Ellipsometer parameters for different layer thickness and refractive index. The value of refractive index (n) is 1.517 and thickness of Sno2 thin film is 250 nm obtained from ellipsometer experimental method.

CONCLUSION

In this project optical constant and thickness of SnO_2 thin film has been measured through ellipsometric experimental method. Ellipsometry is an indirect method, i.e. the calculated delta (Δ) and psi (ψ) cannot be directly converted in to optical constants of the sample. Software plots the ψ - Δ graph and the optical constant will be obtained from the graph. The value of delta is 179.3 and psi is 5. The value of refractive index is 1.627 and thickness of thin film 254 nm is obtained from ellipsometric software.

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