INTERFEROMETRIC DETERMINATION OF THE OPTICAL CONSTANTS OF THIN METALLIC FILMS OF ANTIMONY AND SILVER

N. Barakat
Faculty of Science, Ain Shams University Cairo, Egypt

S. Mokhtar, M.S. Shaalan, M. Sobee, and F. Abdel Aziz
National Institute of Standards, Cairo, Egypt.

and W. Osman
Faculty of Science, Cairo University Cairo, Egypt.

Abstract:

Measurement of the change of phase in transmission through vacuum evaporated films of Antimony and Silver were carried out. Both real and imaginary parts of the complex refractive index were thus evaluated. The method has been applied to deduce the optical oonstants of thin films of Silver and Antimony. Previous data on Bismuth and Manganese is utilized to deduce their extinction coefficients.

Introduction and Previous Work:

A thin absorbing film deposited on a non-absorbing substrate may be characterised by its thickness d, the optical constants n and k where $\hat{n} = n + i\,k$ is the complex refractive index at the wavelength λ of the incident radiation. K is the extinction coefficient related to the absorption coefficient by the relation $\alpha = \frac{4\pi}{\lambda} kd$, (1), n the real part of the complex refractive index is usually termed the refractive index of the film.

Classically the optical constants n and k are determined from measurements on the reflected intensities, where the light in fact deals only with the surface layers of the film. The inner most layers formed at the early stages of nucleation with their peculiar structural properties do not contribute critically to the measured surface reflectivity. Reviews of such methods may be referred to in (2),(3),(4).

However, the phase changes accompaning reflection and transmission at air/film interface are not only sensitive quantities to changes in n and k, (2), but also readily and accurately measured by interferometric techniques, (5), (6). Studies on the behaviour of the phase quantities as function of d and reveal their dependence on film thickness and structure, (7), (8). Recent publications, Barakay et al. (9), (10) on the determination of n and k for Mn & Bi and for Au and Te from measurements

of the change of phase in transmission as function of d showed two distinct ranges of behaviour, a non linear variation showing maxima and minima for film thicknesses below a critical value d_c and c clear straight line portion for $d \geq d_c$ where the film behaves as bulk like. The present paper further uses γ vs. d straight line variation for $d \geq d_c$ to determine n and k for Silver and Antimony films. Also the constant k is determined for manganese and bismuth films.

The principle of the method:

The phase change in transmission γ of monochromatic radiation λ incident on a homogeneous and isotropic thick film of thickness d and complex refractive index $\hat{n}_1 = n_1 + i\,k_1$ situated between two dielectric medii is given approximately by

$$\gamma = \psi_{01} + \psi_{12} + \frac{2\pi}{\lambda} n_1 \quad d \tag{1}$$

This formula assumes that the effect of multiple reflections within the film boundaries ceased, due to the combined effect of absorption and thickness. The criterion is that $\mathrm{Exp}(2k\eta) \gg 100$ where $\eta = \frac{2\pi}{\lambda} d$, this would correspond approximately to single air/film reflection.

In eqn. (1), ψ_{01}, and ψ_{12} are the phase changes at reflection at the first and second film surfaces and given by

$$\psi_{01} = \tan^{-1} \frac{-k_1}{n_0 + n_1}$$

$$\psi_{12} = \tan^{-1} \frac{n_2 k_1}{n_1^2 + k_1^2 + n_2 n_1}$$

n_2 is the refractive index of the glass substrate and is taken to be 1.50. The experimental curves giving relative to air are represented by

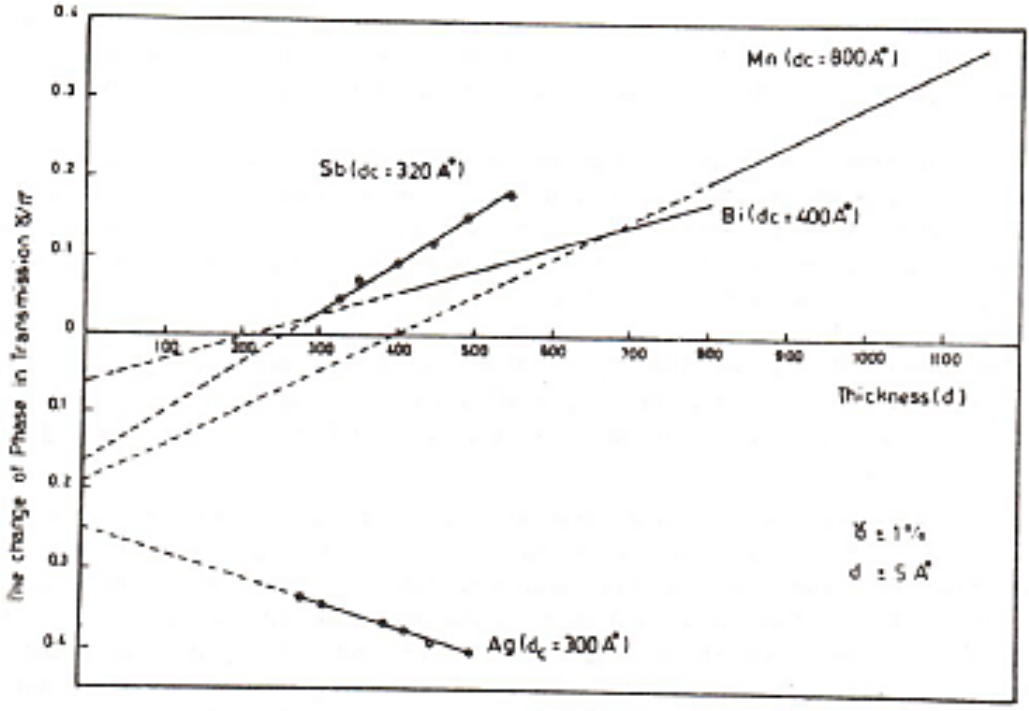
$$\gamma = \psi_{01} + \psi_{12} + \frac{2\pi}{\lambda} (n_1 - 1)\, d \tag{2}$$

clearly γ in the last expression (2) represents a straight line relation between d and with ψ_{01} and ψ_{12} constants. The slope is $\frac{2\pi}{\lambda}(n_1 - 1)$ d where γ is taken as fraction of .

The intercept of the straight line on the axis at d = 0 would be

$$\gamma_0 = \psi_{01} + \psi_{12}$$

$$\text{with, } \tan\gamma_0 = \frac{\tan\psi_{01} + \tan\psi_{12}}{1 - \tan\psi_{01} \tan\psi_{12}} \tag{3}$$


Mn (dc = 800 A°)
Sb (dc = 320 A°)
Bi (dc = 400 A°)
Ag (dc = 300 A°)
Thickness (d)
δ ± 1%
d ± 5 A°
The change of Phase in Transmission δ/n

Fig(1)

Substituting the values of $\tan \Psi_{01}$ and $\tan \Psi_{12}$ in (3) leads to

$$k_1^3 + k_1^2 (n_1 + 2.5) \tan \gamma_0 + K_1 (n_1^2 - 1.5) + (n_1^3 + 2.5 n_1^2 + 1.5 n_1) \tan \gamma_0 = 0 \qquad (4)$$

The optical constant n_1 is obtained from the slope of the straight line and then substitution in (4) for n_1 and $(\gamma_0)_{Exp.}$ would produce k_1 as the only real root of eqn. (4).

Experimental procedure and results

Antimony, silver, bismuth and manganese films were vacuum evaporated on glass substrates at rate of some 20 A°/S at 10^{-5} Torr or better. Film thickness was determined by Tolansky's multiple beam interference technique at reflections(11).

The change of phase in transmission relative to air was determined experimentally for each individual film using the Rayleigh-Lowe refractometer following the technique used by Ishiguro (12) and Barakat et al. (13). In the procedure two beams are allowed to intersect forming interference fringes after one beam has passed through the layer under study and the other beam through an air layer of the same thickness. The lower system forms the reference system for the two beams passing through air, the upper system results from one beam passing through a layer of thickness (d) A°. The fringe shift gives the change of phase in transmission as a fraction of order separation. The overall uncertainty in determining γ is of the order of 1.5%.

Fig. (1) shows the straight line variation of γ vs. d for Ag, antimony Bi and Mn, each straight line starts at (d_c) where d_c is the thickness separating the nonstraight line properties from the bulk like behaviour. Table (1) gives the optical constants n_1 and k_1 for the four metals and their critical thicknesses (d_c) at which the bulk like γ vs. d behaviour starts. The results demonstrate the general availability of the interferometric technique first used to obtain the optical constants by Barakat et al. in (9), (10) provided that the film thickness is above the limiting value separating thin film and bulk like behaviour.

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Table (1): Optical constants of Bulk Metals at 5875A°

Metal	n	k
Antimony	3.2	4.48
Bismuth	1.76	1.36
Manganese	2.41	3.79
Silver λ 5460 A°	0.51	3.32