The Optical Constants of Highly Absorbing Films Using the Spectral Reflectance Measured By Double Beam Spectrophotometer

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Abstract

The optical constants of the metal thin films of Rhodium have been determined, the phase angles was determined using the measured spectral reflectance R(λ) by Kramers-Kronig relations. Then, the real part of the refractive index is calculated by the approach of Heavens when the film is highly absorbing, in that range the real refractive was found to be in order of the extinction coefficient k.

The interference reflectance spectra at normal incidence for different thicknesses of amorphous metal films deposited by thermal evaporation have been obtained in the spectral range 400–800 nm. We propose a method for determination of the refractive index and extinction coefficients of highly absorbing films. This method is based on measurements of reflectance of the film at normal incidence alone, simulations of the theoretical accuracy and the effect of the error of the spectral reflectance measurements in the determination of the optical constants of the film are analyzed.

Keywords: optical constants , refractive index , thin film ,reflectance and absorption coefficient .

1. Introduction

The determination of the optical properties of thin films is a topic of fundamental and technological importance (Jyh-Jian Chen, et al ,1999). Most of the optical applications of metal coating are based on the knowledge of the optical constants. For the metal coating (Rh) film which was used, this metal is inert , so changes due to oxidations should be minimal. The optical constants are important parameters for predicting the performance of an optical system. The optical constants are sensitive to the microstructure, which is effected by the deposition conditions.

A good knowledge of film parameters is necessary for the design and manufacture of new optical coatings and devices such as multilayers coatings and regulate filters[Manifacier.J.C, et al 1976]. An optical constant is sometimes called a complex refractive index and is described by the expression of (n-ik), where n and k are the refractive index and the extinction coefficient respectively of the film. Measurements of the optical constants of highly absorbing thin films on transparent or slightly absorbing substrates have been extensively investigated. Especially the method based on only a single measurements of the transmission spectrum at normal incidence is widely used to determine the refractive index and extinction coefficient of a film(Swanepoel. R, 1984). Also, there are the method of interference of the spectral transmittance and reflectance (Özcan Bazkir,2007).

2.Theoretical considerations

In the highly absorbing films, according to the notation of Heaven, the reflectance can approach to the following formula :

$$R_f = \frac{(n-1)^2 - k^2}{(n+1)^2 + k^2} \qquad (1)$$

In the above approach the sample is considered to be in air so $n_0=1$, the refractive index of vacuum and practically the incident rays are quasi-parallel.

In the fundamental absorption region (i.e., $\alpha_f \geq 10^5\ cm^{-1}$ or $\alpha_f d_f \geq 1$), transmission measurements become impractical and the optical constants have to be determined from reflectivity measurements alone. This is possible, in principle, when the amplitude r and phase angle θ of the complex reflectivity are both determined as a function of hω as follows:

$$\hat{r}(\omega) = r(\omega)e^{i\theta} \qquad (2)$$

It is achieved in ellipsometry where the polarization state of a light beam impinging at non-normal incidence onto the specimen surface is a analyzed (J.D .Joannopoulos & G.Lucovsky, 1984). Since ellipsometry is very surface sensitive, it has so far been applied to study the growth and the oxidation of plasma deposited amorphous films. An ε_2 spectrum of HF etched a-SiH is given in (J.D .Joannopoulos & G.Lucovsky ,1984). It is possible to derive both r(ω) and θ(ω) from measurements of $|r_2|^2$ at normal incidence alone using the Kramers-Kronig dispersion relationship between r and θ (Özcan Bazkir,2007), as follows:

$$\theta(\omega_0) = -\frac{\omega_0}{\pi}\int_0^{\infty}\frac{\ln r(\omega)}{\omega^2-\omega_0^2}\,d\omega \qquad (3)$$

On the other hand the phase angle $\theta = 2\pi/\lambda(\ n - ik\ ).d$ (4)

d is the film thickness.

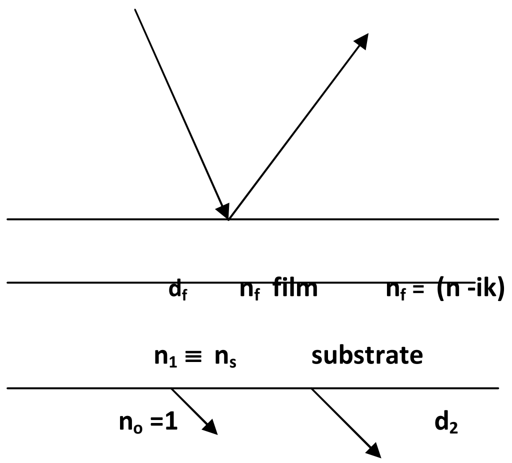

Figure (1) demonstrates the optical constants used in the calculation of thin highly absorbing film

The Kramers-Kronig relationship links the value of θ at a particular frequency ω_0 to an integral over reflectivities extending over all energies hω. The latter is, however, only known over a limited region in ω and methods have therefore been developed to extrapolate r(ω) to very low or very high frequencies in a physically reasonable way.

The sum rules relations are considerable help in this procedure. The most useful of these in the present work is that which relates ε_∞, the long wavelength dielectric constant to an integral over $\varepsilon_2(\omega)$.

The advantage of the methods that use the envelope of transmittance or reflectance measurements is that the dispersion of the complex refractive index of the index of a thin film is obtained easily. The disadvantage. However, is that the thin film must be thick (J.M.Gonzalez-leal et al, 2004). Here there is no new method for n and k determination of the film . But an improvement to obtain the accurate values of the optical constants by comparing two methods, one of them is the interference method and the other is a method depends on the spectral reflectance of the film involved the correction of the multi-reflections inside the substrate.

The theoretical idea of this work is the determination of the optical constants n_f and k_f for the highly absorbing films using the measured reflectance R_f at normal incidence using KK relations.

3.Results and discussions

The reflectance of the samples has been measured by double beam spectrophotometer with high accuracy ± 1% as shown in figure (2). To obtain the accurate values of the optical constants by comparing two methods, one of them is the interference method which depends on the maxima and minima of the transmittance and reflectance (Yanfi Zheng & Kazuo kikuchi,1997), the other is a method depends on the spectral reflectance of the film involved the correction of the multi-reflections inside the substrate. Figures (2) shows the experimental spectral reflectance of Rh film, by applying equation (3),we calculated the values of the phase angle using the measured reflectance data, the value of θ has been found to be 1.8435 . Then by substitution in equation (2) and computing the Fresnel coefficients, the real refractive index n and k have been determined, it is noted that the values of n and k are nearly equal as the thickness of the film decreases and the wavelength λ increases.

In this work the values of θ have been calculated from the integral (3) over the range from 1.55 - 4.14 eV. By solving equations (1) and (4), the real refractive index n can be determined , then the extinction coefficient k can be estimated by equation (1). Where d is the film thickness and λ is the incidence wavelength.

ω_0 in the calculations has been taken to be around $0.75*10^{15}$ Hz , and the interval $d\omega$ was 1 Hz. As the extrapolation of the reflectance increases , this means more accuracy.

The integral (3) has been estimated numerically using a computerizing program, the uncertainty of estimation within ± 2%.

Table (1) illustrates the values of the calculated refractive index n_{kk} and the extinction coefficient k_{kk} of the absorbing film comparing them with that determined by interference method of $R(\lambda)$ and $T(\lambda)$. It is clear that the error between the two values is acceptable with respect to this type of measurements around ± 5%. The advantage of this method its accuracy because the optical constants directly determine from the measured spectral reflectance $R(\lambda)$ of the film especially the metal films at normal incidence.

5. Conclusions

-From the previous analysis it was conclude that the optical constants of film depend on the method of calculation. The accuracy of the suggested method depends on the extrapolation of the curve of the spectral reflectance of the sample.

-It is preferable to use the spectral reflectance measured by the spectrophotometer at normal incidence as the film is highly absorbing and the thickness is thin.

-Table (1) are very important in the calculation of the optical constants of the highly absorbing films.

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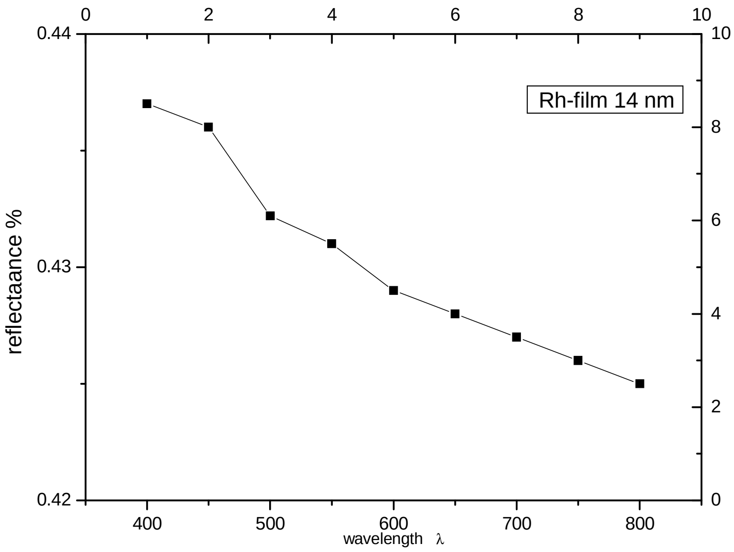

Figure (2a) illustrates the spectral reflectance of Rh film (14nm) meaured by the spectrophotometer

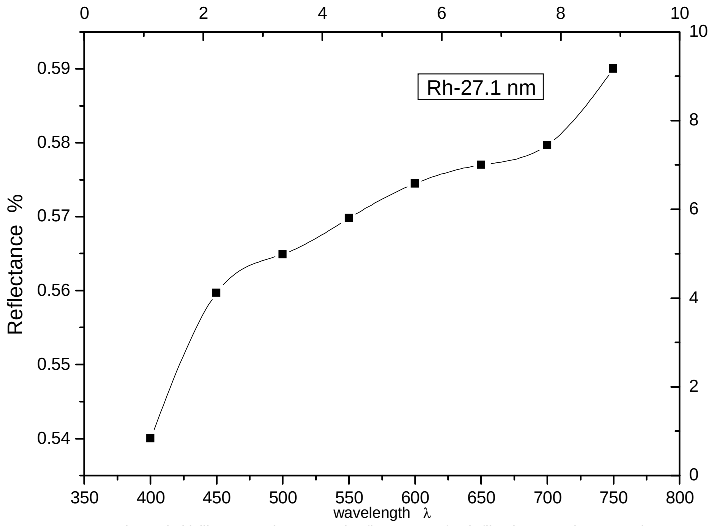

Figure (2b) illustrates the spectral reflectance of Rh film (27.1 nm) meaured by the spectrophotometer

Table. (1) : A comparison between the calculated and reported values of the refractive index n and the extinction coefficient K for the Rh films

Material	Wavelength λ nm	Thickness t	Measured reflectivity R	Refractive index n_{kk}	Extinction coefficient k_{kk}	n_f	K_f
Rh	450		0.4367	2.550	2.551	2.4	3.28
	500		0.4322	2.500	2.522	2.6	3.40
	550	14.2	0.4311	2.50	2.51	2.78	3.53
	600		0.4294	2.50	2.51	2.95	3.65
	650		0.4284	2.50	2.50	3.11	3.77
	700		0.4282	2.497	2.50	3.23	3.91
	450		0.5597	2.50	3.54	2.27	3.25
	500		0.5649	2.56	3.58	2.39	3.41
Rh	550	27.1	0.5698	2.60	3.62	2.51	3.58
	600		0.5745	2.62	3.69	2.62	3.74
	650		0.5770	2.65	3.70	2.75	3.88
	700		0.5797	2.70	3.76	2.78	4.03

*Reported n and k according to (Arndt D.P, Borgongo . J. P. et al,1984).