 

# Angular dependences of ellipsometric parameters of thin Cr and Ti films under surface polariton excitation

*Ya.A.Shybiko, I.A.Shaykevich, L.Yu.Melnichenko*

T.Shevchenko Kyiv National University,
6 Acad. Glushkov Ave., 03127 Kyiv, Ukraine

The 80 Å and 100 Å thick Cr films and 45 Å thick Ti ones were obtained by the vacuum evaporation on glass substrates. The ellipsometric parameter $\Psi$ (azimuth of the restored linear polarization $\Psi$) was measured at $\lambda = 546.1$ nm both at the air side and the glass one under various angles of incidence. In the second case, the surface polaritons were excited using the Kretchman method by means of a transparent semi-cylinder. Parameters measured at the air side were used to calculate optical constants $n$ and $k$. Ellipsometric parameters under surface polariton excitation were calculated. The obtained theoretical results conform to the experimental data. The last fact testifies that the Airy formulas can be used to calculate both ellipsometric parameters and reflection and transmission coefficients under surface polariton excitation.

Угловые зависимости эллипсометрических параметров, а именно азимута восстановленной линейной поляризации $\Psi$, измерялись для тонкой пленки Ti толщиной 45 Å и Cr толщиной 80 Å и 100 Å (пленки были получены методом вакуумного напыления на стеклянные подложки) как со стороны воздуха, так и со стороны стекла (то есть, при возбуждении поверхностных поляритонов по методу Кречмана при помощи прозрачного полуцилиндра на длине волны $\lambda = 546{,}1$ нм). По данным, полученным со стороны воздуха, вычислялись оптические постоянные пленок $n$ и $k$ и рассчитывались эллипсометрические параметры при возбуждении поверхностных поляритонов. Полученные теоретические результаты согласовываются с экспериментальными данными. Последнее свидетельствует о том, что формулы Эйри можно использовать для расчетов как эллипсометрических параметров, так и коэффициентов отражения и пропускания при возбуждении поверхностных поляритонов.

Angular dependences of ellipsometric parameters (phase shift $\Delta$ and azimuth of the restored linear polarization $\Psi$) under surface polaritons excitation by Kretchman method [1] can be calculated using Airy formulas [2] but it has not been ever used in any known monograph aimed at surface polaritons [1, 3]. In order to check experimentally the possibility of Airy formulas usage under surface polaritons excitation by Kretchman method, thin films of Cr and Ti were investigated.

The films were deposited onto glass substrates by the vacuum evaporation under $10^{-4}$ Pa pressure using an electron gun. The film thickness $d$ was determined by quartz thickness measuring device and was 45 Å for Ti film and 80 and 100 Å for Cr films. Then parallel-sided plates with thin films thereon were pasted by an oil with $n = 1.46$ onto a glass semi-cylinder (to eliminate the interference effects in the gap between the glass plate and semi-cylinder) and were placed on the table of spectroellipsometer for measurements by Kretchman method. The ellipsometric parameters $\Psi$ and $\Delta$ were measured using the Beatty method [4]. Two measurements were carried out: at the air side and at the semi-cylinder side (surface polariton excitation by Kretchman method). The wavelength $\lambda$ was 5461 Å. The measurements were done at different angles of incidence φ. Using data obtained for the air side, the refractive index $n$ and absorption coefficient $k$ were determined. In [5], the formula for phase shift was derived for the case of metal films, when the film thickness $d < \lambda$.

$$\mathrm{tg}\Delta = \qquad (1)$$
$$= \frac{n_0 n_1^2 \sin\varphi \mathrm{tg}\varphi (n_0^2 + n_1^2 - n^2 + k^2)\cdot \frac{4\pi d}{\lambda}}{(n_1^2 - n_0^2)(n_1^2 - n_0^2 \mathrm{tg}\varphi) + 2nkn_0 n_1^2 \sin\varphi \mathrm{tg}\varphi \cdot \frac{4\pi d}{\lambda}},$$

where $n_0$ is the refractive index of medium above the film (air); $n_1$ that of the substrate; φ, the angle of incidence; λ, the light wavelength; $k$, the film absorption coefficient; $d$, the film thickness.

Using well-known values $n_0 = 1$ and $n_1 = 1.52$ and the thickness $d$, form measured Δ values for two angles of incidence φ, it is possible to find $n$ and $k$ from formula (1). Table 1 presents the obtained $n$ and $k$ values for the films studied.

The thickness values of the investigated films were chosen in such a way that formula (1) gave high-accuracy results. In [6], the accuracy of different approximate formulas for reflection and transmission coefficients of thin films has been considered. Those approximate formulas are obtained by expanding the accurate Airy formulas in a series with respect to $d/\lambda$ and neglecting some terms of the series. Depending on how many terms are ignored, different formulas are obtained. Formula (1) is derived for ellipsometric parameter Δ in the same way. As is shown in [6], different approximate formulas gave satisfactory accuracy for different metals at film thickness varying from 0 to about 150 Å. Thickness of the studied films chosen by us fall within that range.

The obtained optical constants (see Table ) are substituted in the known Airy formulas [2], which are accurate for small thickness:

Table. Obtained optical constants $n$ and $k$ for thin Ti and Cr films

| Sample | $n$ | $k$ | $d$, Å |
|---|---|---|---|
| Ti | 1.213 | 1.209 | 45 |
| Cr 1 | 1.118 | 1.627 | 80 |
| Cr 2 | 1.724 | 1.740 | 100 |

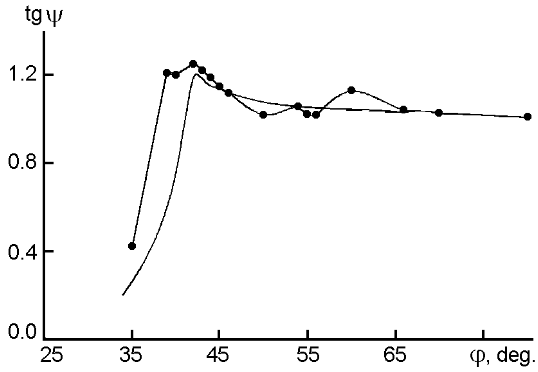


Fig. 1. The curves tgΨ from the angle of incidence φ for Ti film (d = 45 Å).

$$\tilde{R}_p = \frac{r_{12}^p + r_{23}^p \cdot e^{i\beta}}{1 + r_{12}^p r_{23}^p \cdot e^{i\beta}}, \qquad (2)$$
$$\tilde{R}_s = \frac{r_{12}^s + r_{23}^s \cdot e^{i\beta}}{1 + r_{12}^s r_{23}^s \cdot e^{i\beta}},$$

where $\tilde{R}_p$ and $\tilde{R}_s$ are complex amplitudes of the wave reflected from the film; $r_{1,2}{}^{p,s}$ and $r_{2,3}{}^{p,s}$, the Fresnel reflection coefficients at the interface of media 1–2 and 2–3 for p- та s- components, respectively; $\tilde{\beta} = (4\pi/\lambda)\tilde{n}_2\cos\tilde{\chi}_2 d$; $\tilde{n}_2 = n + ik$; $\tilde{\chi}_2$, the complex angle of refraction at transition from the media 1 to the media 2.

If we consider the refraction at the air-film interface, then the media 1 is air, 2 is the metal film, 3 is glass. If the refraction with surface polariton excitation by Kretchman method is considered, then media 1 is glass, 2 is the metal film and 3 is air. The ratio of the first (1) and second formulas (2) looks like:

$$\frac{\tilde{R}_p}{\tilde{R}_s} = \mathrm{tg}\Psi e^{i\Delta} = \qquad (3)$$
$$= \frac{(r_{12}^p + r_{23}^p \cdot e^{i\beta})(1 + r_{12}^s r_{23}^s \cdot e^{i\beta})}{(1 + r_{12}^p r_{23}^p \cdot e^{i\beta})(r_{12}^s + r_{23}^s \cdot e^{i\beta})}.$$

Using correlation (3), it is possible to obtain Ψ(φ) and Δ(φ) dependences under surface polariton excitation by Kretchman method.

The curves tgΨ(φ) for thin Ti film ($d$ = 45 Å) are shown in Fig. 1. The curve corresponds to experimental data and the 2 one, to theoretical calculations. As it is obvious from Fig. 1, experimental and theoretical data are in good qualitative accordance and the trend of tgΨ dependence on the angle of incidence φ is the same. Similar dependences for thin Cr films ($d$ = 80 Å and

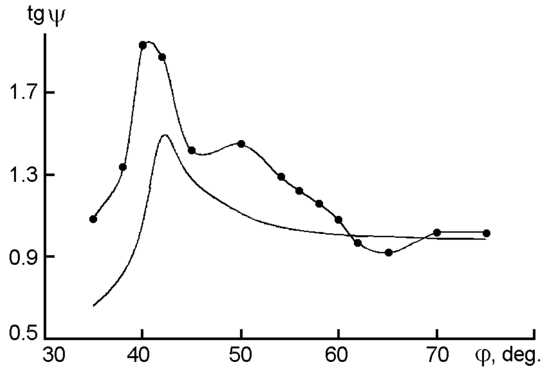


Fig. 2. The curves tgΨ from the angle of incidence φ for Cr film ($d$ = 80 Å).

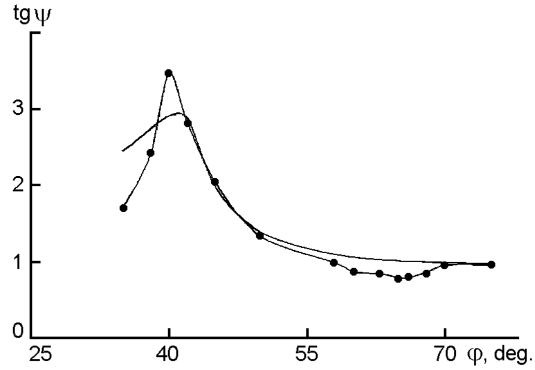


Fig. 3. The curves tgΨ from the angle of incidence φ for Cr film ($d$ = 100 Å).

$d$ = 100 Å) are presented in Figs. 2, 3. The trend of tgΨ(φ) curves is identical here, too. The quantitative coincidence of the curves 1 and 2 can be considered satisfactory.

Thus, it is possible to do a general conclusion that the Airy formulas can be used to calculate the amplitude and phase correlations in the reflected light wave under surface polaritons excitation by Kretchman method.

### *References*


1. Surface Polaritons, ed. by V.M.Agranovich and D.L.Mills, Nauka, Moscow (1985) [in Russian].
2. M.Born and E.Wolf, Principles of Optics. Pergamon Press, N.-Y. (1964).
3. N.L.Dmitruk, V.G.Litovchenko, V.L.Strizhevsky, Surface Polaritons in Semiconductors and Dielectrics, Naukova Dumka, Kyiv (1989) [in Russian].
4. A.V.Sokolov, Optical Properties of Metals, GIFML, Moscow (1961) [in Russian].
5. I.A.Shaikevich, *Vestn. Kiev. Univ.*, **18**, 24 (1977).
6. I.N.Shklyarevsky, O.I.Shklyarevsky, *Optika i Spektr.*, **27**, 654 (1969).


## Кутові залежності еліпсометричних параметрів тонких плівок Cr, Ti, Ag при збудженні поверхневих поляритонів

***Я.А.Шибіко, І.А.Шайкевич, Л.Ю.Мельниченко***

Плівка Ti товщиною 45 Å і плівки Cr товщиною 80 Å і 100 Å одержувалися методом вакуумного напилення на скляні підкладки і для них вимірювалися кутові залежності еліпсометричних параметрів, а саме азимуту відновленої лінійної поляризації як з боку повітря, так і з боку скла, тобто при збудженні поверхневих поляритонів за методом Кречмана за допомогою прозорого напівциліндра при довжині хвилі $\lambda$ = 546,1 нм. За даними, одержаними з боку повітря, обчислювалися оптичні сталі плівок $n$ і $k$, розраховувалися еліпсометричні параметри при збудженні поверхневих поляритонів. Одержані теоретичні результати узгоджуються з експериментальними даними. Останнє свідчить про те, що формули Ейрі можуть бути застосовані до розрахунків як еліпсометричних параметрів, так і коефіцієнтів відбивання і пропускання при збудженні поверхневих поляритонів.