Calculation of optical waves propagation through gyrotropic anisotropic media: chalcogenide glass plates and thin films

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As is well known in the glass as in fluids have short-range order. In addition, numerous studies show that the glasses are typically somewhat middle order. Chalcogenide glasses in this respect demonstrate much higher rate than the canonical silicate glasses. Some elements, such as As, in combination with S or Se, the structure provide such polymers. It is also known assumption of the existence in glasses As - S (Se) even paracrystalline structure. This requires a large extent clarified electrodynamic model in optical studies of such media. At the microscopic level, it concerns the theory of the local field. In the macroscopic respect - this clarification of constitutive equations, which are used in the solution of Maxwell's equations. Necessary averaging microscopic theory when considering the spatial nonlocality of the medium response to the electromagnetic disturbance is extremely difficult. However, it is known that these difficulties cost, if we consider the spatial dispersion immediately phenomenologically. In this case, we write the dependence of the electric displacement vector of the electric vector $\mathbf{D} = \mathbf{D}(\mathbf{E})$ in some different from conventional ($\mathbf{D} = \varepsilon\mathbf{E}$, where ε – dielectric tensor) form. If we consider only the spatial dispersion of the first order, you can use the representation $\mathbf{D} = \varepsilon\mathbf{E} + \gamma \mathrm{rot}\mathbf{E}$, where γ is the second rank tensor. If γ is scalar, then the last relation describes gyrotropic medium. It is for this constitutive equation in the present report shows the method for solving Maxwell's equations and application to thin films and plates.

According to the Berreman's 4×4-matrix formulation, the Maxwell’s equations, along with the constitutive equations for a particular optical media shall be converted into a scalar system of four first order differential equations in four unknowns, which are the field components E_x, E_y, H_x, H_y in the Cartesian coordinates system:

$$\begin{cases} E_x' = \dfrac{\gamma k_x^2}{\varepsilon_{zz}} E_y - \dfrac{ik_z^2}{k_0 \varepsilon_{zz}} H_y, \\ E_y' = ik_0 H_x, \\ H_x' = \dfrac{ik_y^2}{k_0} E_y + k_0^2 \gamma H_y, \\ H_y' = -ik_0 \varepsilon_{xx} E_x - k_0^2 \gamma H_x, \end{cases} \qquad (1)$$

where $k_y^2 = k_0^2 \varepsilon_{yy} - k_x^2$, $k_z^2 = k_0^2 \varepsilon_{zz} - k_x^2$, $k_x = k_0 \sin\phi_0$, $k_0 = \omega / c = 2\pi/\lambda$, ϕ_0 – an angle of incidence, and λ is the wavelength in vacuum. Here, the dependence of the fields **E**, **H** and **D** from the time t at a frequency ω is built according to the harmonic rule ~ exp($i\omega t$), where c is the speed of light in vacuum. Hereafter, the prime (') denotes differentiation with respect to z.

In [1] was the first to show that the system (1) is reduced to the solution of the following fourth order equation

$$\left(E_y''\right)'' - \mathcal{A}E_y'' + \mathcal{B}E_y = 0,$$

where $\mathcal{A} = \frac{\varepsilon_{xx}}{\varepsilon_{zz}}k_z^2 + k_y^2 + k_0^4\gamma^2$, $\mathcal{B} = \frac{\varepsilon_{xx}}{\varepsilon_{zz}}\left(k_y^2 k_z^2 - k_0^4 k_x^2 \gamma^2\right)$.

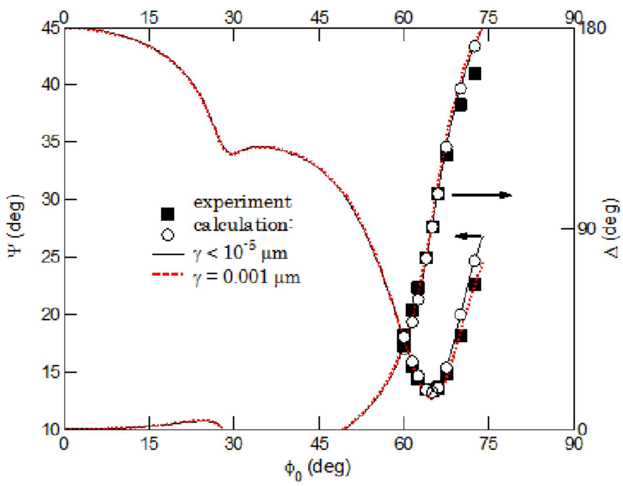

Fig. 1. Ellipsometric angles Ψ and Δ as a function of the incidence angle ϕ_0 of As_2S_3 thin film, refractive index n_f = 2.453, d = 2.103 μm at different γ.

The remaining components of the field easily calculated from the system.

We see that there are four waves – apply two forward and two – in the opposite direction. The challenge for a plate or thin film is solved by using the usual boundary conditions. This leads to solving a system of linear algebraic equations of order eight. As an example, we show the effect of the degree of gyrotropy on ellipsometric spectra of thin films (Fig. 1). As you can see, to the extent gyrotropy $\gamma \sim 10^{-5}$ (corresponds to a rotation of the polarization plane of quartz 188 deg/cm) does influence unnoticed. When $\gamma \sim 10^{-3}$ observed contrast and improved agreement between the experimental and theoretical values for angles of incidence greater than the critical angle.

The calculation results of several common examples are listed in [1]. Detailed mathematical calculations will soon be published in expanded form.

1. Kozak M.I. , General approach in polarimetry-ellipsometric calculation, Proc. of the X Int. Conf. “Electronics and applied physics”, October, 22-25, 2014, Kyiv, pp. 197–198.