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Determination of the optical constants of selenium films

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Abstract. The optical constants of evaporated Se films are calculated following Valeev's method and applied to Se in the visible region. The calculated values are in good agreement with published data.

Keywords. Optical constants; selenium films; transmission coefficient.

1. Introduction

Many investigators have dealt with the measurement of optical constants of Se thin films, namely the refractive index (n) and absorption coefficient (K) in the visible region (Pribytkova 1957; Köehler *et al* 1959; Prosser 1960; Subashiev *et al* 1965). In the present paper the optical constants of Se films are calculated by following Valeev's method. This method is based on measuring the transmission coefficient T_0 and T versus wavelength for coated and uncoated substrates.

2. Theory

According to Valeev, the formula for relating transmission coefficient of the uncoated substrate T_0 with refractive index n_3 of the substrate is

$$T_0 = T_{34}^2/(1-R_{34}^2) = 2n_3/(n_3^2+1), \tag{1}$$

T_{34}, R_{34} are the transmission and reflection coefficient of one surface of substrate

$$T_{34}=4n_3/(n_3+1)^2;\ R_{34}=\left(\frac{n_3-1}{n_3+1}\right)^2.$$

Equation (1) is derived from

$$T_0 = T_{34}/(1+R^2{}_{34}-2R_{34}\cos a),$$

$$a = 4\pi n_3 h_3/\lambda.$$

h_3 is the thickness of the substrate. After some approximation $h_3 \gg \lambda$ gives equation (1).

The formula of the transmission coefficient for the same substrate coated with weakly absorbing thin film of refractive index n_2 and absorption coefficient K_2 is

$$T = T_{34}/[(1/T_{31}) - R_{34}(R_{31}/T_{31})]$$

where T_{31}, R_{31} are the transmission and reflection coefficients of Se layer for light incident from the substrate

$$\frac{1}{T_{31}} = \frac{1}{16 n_2^2 n_3}[(n_3+n_2)^2(n_2+1)^2 \exp(\gamma_2) + (n_3-n_2)^2(n_2-1)^2 \exp(-\gamma_2) + 2(n_3^2-n_2^2)(n_2^2-1)\cos\alpha_2 + 4K_2(n_3+1)(n_2^2-n_3)\sin\alpha_2] \quad (3)$$

$$\frac{R_{31}}{T_{31}} = \left[\frac{1}{16 n_2^2 n_3}(n_3-n_2)^2(n_2+1)^2 \exp(\gamma_2) + (n_3+n_2)^2(n_2-1)^2 \exp(-\gamma_2) + 2(n_3-n_2^2)(n_2^2-1)\cos\alpha_2 - 4K_2(n_3-1)(n_2^2+n_3)\sin\alpha_2.\right]$$

The extreme values of T coincide with the extreme values of

$$\frac{1}{T_{31}} - \frac{R_{31}}{T_{31}} R_{34},$$

$$T_{ext} = \frac{16 n_2^2 n_3}{(n_2+1)^3(n_2+n_3^2)\exp(\gamma_2) - (n_2+1)^3(n_3^2-n_2)\exp{-\gamma_2} + (-)^m . 2(n_2^2-1)(n_3-n_2^2)} \quad (4)$$

$$\gamma_2 = m\pi K_2/n_2.$$

In the case of complete absence of absorption, $K_2=0$ or $\gamma_2=0$, and we get

$$T_{ext} = T_0 = (2 n_3/n_3^2+1) \text{ for } m \text{ even,} \quad (5)$$

$$T_{ext} = \frac{4 n_2^2 n_3}{(n_2^2+1)(n_3^2+n_2^2)} \text{ for } m \text{ odd.} \quad (6)$$

This means that for even values of m the extreme values of transmission in the absence of absorption coincide with the transmission of the substrate alone, and that for odd values of m they differ.

3. Experimental procedure

The determination of the optical constants n_2 and K_2 of Se film, requires the determination of the refractive index of the substrate n_3 and measurement of the transmission coefficient (T_0) of the uncoated substrate and the transmission coefficient (T) of the same substrate coated with an evaporated Se film and their variation with wavelength.

The optical system used is shown in figure 1 which measures the square absolute values of transmissivity. To determine T_0 a substrate is used in the form of an optical flat of $\pm 0{\cdot}0001$ mm flatness. The spectral transmissivity T_0 of the uncoated substrate is represented in figure 2a. To obtain the spectral variation of transmissivity T of Se film the same substrate is coated with Se film prepared by thermal evaporation from Ta boat in an oil diffusion pumping system at a pressure of $< 10^{-5}$ mm Hg. The rate of evaporation was 25 Å/sec. The thickness of Se is 6890 Å as determined by multiple beam Fizeau fringes at reflection (Tolansky 1948).

Figure 2b represents the variation of transmissivity T with wavelength for such Se film.

4. Results

The refractive index n_3 of the uncoated substrate is determined from its corresponding spectral transmission relation (see figure 2a and equation (1)).

Taking into account $K_2 \ll 1$ the transmission curve is defined by alternate maxima and minima. The approximation for n_2 is obtained by applying expression (6) with an odd value of m. To determine the values of n_2 and K_2 for even values of m

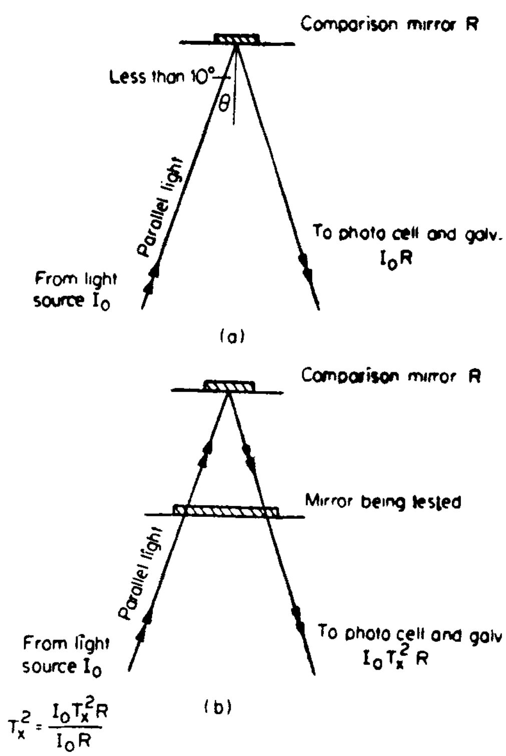

Figure 1. Optical system for transmissivity measurement

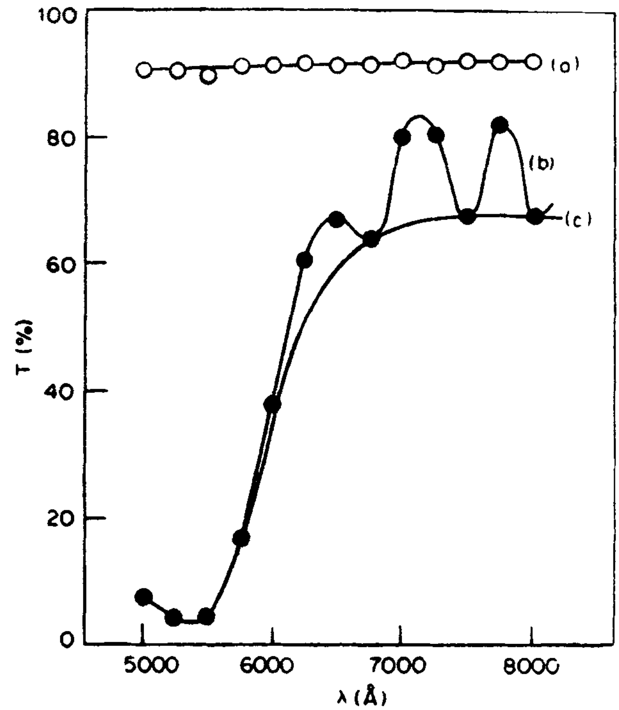

Figure 2. Transmission curves of: a. Substrate. b. Same substrate coated with a Se layer.

and since the odd values of m occur at other wavelengths, it is necessary to use an interpolated curve that smoothly joins all the extreme values of T corresponding to odd values of m (figure 2c). The extreme values of the transmission coefficient corresponding to different wavelengths are given in table 1 and from such values, the refractive indices n_2 were obtained (figure 3) by using the envelope of the family of curves T. The nomogram given in figure 3 was constructed from the following equation:

$$T_{ext} = 4\, n_2^2\, n_3/(n_3^2+1)\,(n_3^2+n_2^2).$$

Table 1. Experimental result of the optical constants of Se-layer of thickness 6890 Å

λ in Å	T in relative unit	n_2	γ_2	K_2
6250	0·58	3·10	0·300	0·029
6500	0·62	2·87	0·280	0·026
6750	0·64	2·73	0·260	0·022
7000	0·65	2·66	0·253	0.021
7250	0·66	2·63	0·246	0·020
7500	0·67	2·60	0·240	0·019
7750	0·67	2·58	0·235	0·019
8000	0·67	2·56	0·230	0·019

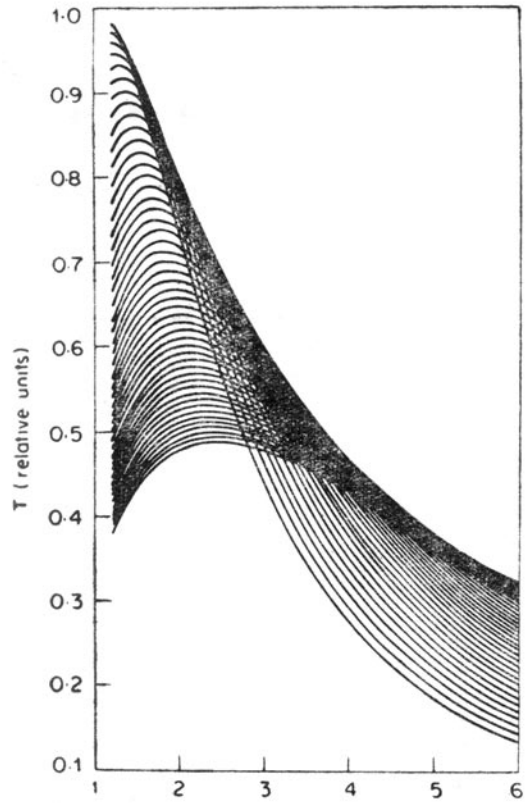

Figure 3. Nomogram for the determination of the refractive indices of non-absorbing substrates and layers.

The γ_2 values can be obtained from equation (4) which relates the values of T_{ext} at λ with n_2 and γ_2 at $n_3 = 1{\cdot}4$. Since n_2 and γ_2 are known, K_2 can be obtained from the formula $n_2\gamma_2/m\pi$ where m is the order of interference and it is found from the relation $\lambda_{m+1}/(\lambda_m - \lambda_{m+1})$ where λ_m and λ_{m+1} are the wavelengths of two adjacent extreme points having values of 7775 Å and 7100 Å and m is equal to 10. The net result is tabulated in table 1 which represents the variation of T_{ext}, n_2, γ_2 and K_2 with λ for evaporated semiconductor Se film of thickness 6890 Å. Figure 4 represents the variation of refractive index n_2 and absorption coefficient K_2 with λ for such Se film over the visible region.

5. Conclusion

Valeev's method previously applied to determine the optical constants of Cd Te films in the infrared region, has been successfully applied in this work to determine n and K for Se films in the visible region. The optical constants obtained are in good agreement with previously published data on selenium (Anon 1947: Koehler *et al* 1959).

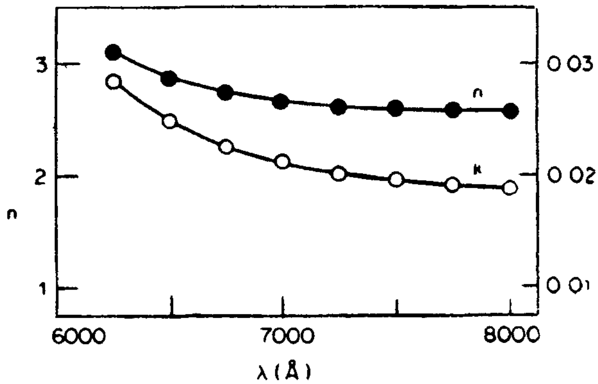

Figure 4. Optical constants n and K of Se-layer of thickness 6890 Å at different wavelengths.

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References

Anon 1947 Handbook of chemistry and physics Ed. chief Charles D. Hodgman (Ohio: Chemical Rubber Pub. Co.) 13th ed. p. 2231
Koehler W F, Odencrant Z F K and White W C 1959 *J. Opt. Soc. Am.* **49** 109
Pribytkova N N 1957 *Opt. J. Spectrosk.* **2** 625
Prosser V 1960 *Czech. J. Phys.* **10** 306
Subashiev V K, Dubrovskii G B and Kukhorskii A A 1964 *Sov. Phys. Solid State* **6** 830
Tolansky S 1948 Multiple beam interferometry (London: Oxford Univ. Press) p. 149
Valeev A S 1963 *Opt. Spectrosc.* **4** 269