Influence of the thickness on optical properties of cadmium sulfide thin films

A.I. Kashuba1, R.Yu. Petrus2, B. Andriyevsky2 and M. Piasecki3
1Lviv Polytechnic National University, Department of General Physics, 12 Bandera Str., Lviv 79046, Ukraine, E-mail: andrii.i.kashuba@lpnu.ua
2E-mail: roman.s.petrus@pmu.edu
3Koszalin University of Technology, Faculty of Electronics and Computer Sciences, 2 Sniadeckich Str., Koszalin 75-453, Poland, E-mail: bandriyevsky@gmail.com

1Jan Długosz University Częstochowa, Faculty of Science and Technology, 13/15 Armii Krajowej Al., Częstochowa 42-201, Poland, E-mail: piaseckiwm@gmail.com

EXPERIMENTAL DETAILS

CdS sulfide thin films with different thickness were deposited on quartz substrates by the method of high-frequency magnetron sputtering using a VUP-5M vacuum station (Selmi, Ukraine). Commercial target of 99.99 % purity was used for deposition. The target–substrate distance was equal to 60 mm. The start and end of the sputtering process were controlled by means of a movable shutter. The phase analysis and crystal structure refinement was examined with X-ray diffraction data (XRD) obtained on DRON 2.0M diffractometer at room temperature with the Cu radiation (λ=1.5406 Å) of Fe. The spectral dependence of optical transmittance and reflection of the obtained samples were measured using the visible and near infrared regions (300-1500 nm) at room temperature using spectrometer Shimadzu UV-3600.

RESULTS AND DISCUSSION

Crystal structure of CdS thin films has been determined from XRD. Cadmium sulfide thin film crystalizes in hexagonal structure (structure type - ZnO, space group P6_3mc (No. 186)). No additional peaks (by X-ray analysis) belonging to other phases can be detected, which indicates the formation of a pure single phase of CdS.

Fig. 1 shows the transmission spectrum of the CdS thin films–substrate combinations. The transmission coefficient strongly depends on the film structure, which is determined by the preparation methods, film thickness and deposition conditions. The transmission spectra of the thin films exhibit periodic peaks and minima associated with interference effects, indicating the high structural perfection of thin films. A very rough surface will destroy the interference due to multiple reflections.

To determine the thickness of the films under investigation, we can use the following equation:

\[ d = \frac{M \cdot n_1 \cdot \lambda}{2 \cdot (n(\lambda_1) - n(\lambda_2))} \]

where, \( n_1 \) and \( n_2 \) are the wavelengths corresponding to the neighboring extreme points in the transmission spectrum and M=1 for two neighboring extrema of one type (max–max, min–min) and M=0.5 for two neighboring extrema of opposite types (max–min, min–max). The thickness of the CdS thin films is listed in Table 1.

To estimate the absorption band edge energy of the films the first derivative of the optical transmittance can be used. Position of the characteristic highest first peak of \( \partial T/\partial \lambda \) corresponds to the optical band gap energy. The optical bandgap \( E_g \) has been determined also from the spectrums of the absorption coefficient \( \alpha(\lambda) \) for the polytopic structure \( \alpha(\lambda) \) can be obtained by means of parabolic extrapolation of experimentally determined points that coincide with the location of interference maxima and minima (see Fig. 1).

Refractive index of CdS thin films can be calculated using the following equation:

\[ n = \sqrt{N + (N^2 - n^2)^{1/2}} \]

where \( n_1 \) is the refractive index of the substrate, \( T_{\text{m}} \) is the transmittance of the substrate in the transparent zone. For the quartz substrate \( n_1=1.513 \). The calculated refractive index \( n \) of the thin film studied decreases with increasing wavelength \( \lambda \). Here, the dispersion \( n(\lambda) \) is normal and may be well approximated by the single oscillator model (proposed by Wemple and Di Domenico). Result of analysis are listed in Table 2.

Absorption coefficient \( \alpha(\lambda) \) for CdS thin films can be calculated using the following equation:

\[ \alpha(\lambda) = \frac{1}{d} \ln \left[ \frac{[n-1][n-n_1]}{[n+1][n+n_1]} \left( \frac{T_{\text{m}}}{T_{\text{max}}} \right)^{1/2} + 1 \right] \]

It is known that the real and imaginary parts, \( e_1 \) and \( e_2 \) (see Fig. 2), of the complex dielectric permittivity \( e = e_1 + i e_2 \), are related to the refractive index \( n \) and extinction coefficient \( k \) by the Eqs. (4),

\[ e_1 = n^2 - k^2 \]

\[ e_2 = 2n \cdot k \]

For the values of \( n \) much greater than \( k \), the value of \( e_1 \) is approximately equal to \( n^2 \) and the dependence of \( e_2(\lambda) \) can be fitted using the relation valid for the free electrons light absorption,

\[ e_2 = \frac{n_0^2}{m_e} \]

where \( m^* \) is the effective mass of the carrier, \( N_e \) is the carrier density, \( e \) is the electronic charge, and \( e_2(\lambda) \) is the high-frequency dielectric constant. To obtain the high frequency dielectric constant \( e_2(\lambda) \), we plot a graph \( m^* \) as a function of \( k^2 \) and extrapolated the linear part of the curve to \( k^2 = 0 \) (see Table 3).