КРАТКИЕ СООБЩЕНИЯ

OPTICAL CONSTANTS OF ZINC SELENIDE IN VISIBLE AND INFRARED SPECTRAL RANGES

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Transmittance spectrum of ZnSe in the infrared and visible wavelength range at normal incidence was investigated by an IRTracer-100 spectrometer and a TU-19 Double-Beam Visible spectrophotometer, and the optical constants of ZnSe were obtained based on modelling transmittances of two ZnSe slabs. The results show that the transmittance values of the ZnSe slabs are higher than 0.7 in the wavelength range of 2.5–15 μm; however they decrease dramatically when the wavelength is larger than 15 μm. The refractive index of ZnSe varies within 2.6–2.8 in the wavelength range of 0.55–0.85 μm and 2.2–2.4 in the wavelength range of 2.5–20 μm. The extinction coefficient of ZnSe varies within 10^{-8}–10^{-6} in the wavelength range of 0.55–0.85 μm and 10^{-5}–10^{-4} in the wavelength range of 2.5–20 μm.
Keywords: *zinc selenide, optical constants, transmittance spectra.*

ОПТИЧЕСКИЕ КОНСТАНТЫ СЕЛЕНИДА ЦИНКА В ВИДИМОМ И ИНФРАКРАСНОМ ДИПАЗОНАХ СПЕКТРА

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Спектр пропускания ZnSe в ИК и видимом диапазонах при нормальном падении исследован с помощью спектрометра IR-Tracer-100 и двухлучевого спектрометра видимого диапазона TU-19. Оптические константы ZnSe получены на основе моделирования коэффициентов пропускания двух пластинок ZnSe. Получено, что пропускание пластинки ZnSe выше 0.7 в диапазоне 2.5–15 мкм, однако оно резко падает, когда длина волны >15 мкм. Показатель преломления ZnSe ~2.6–2.8 в диапазоне 0.55–0.85 мкм и ~2.2–2.4 в диапазоне 2.5–20 мкм. Коэффициент экстинкции ZnSe ~10^{-8}–10^{-6} в диапазоне 0.55–0.85 мкм и ~10^{-5}–10^{-4} в диапазоне 2.5–20 мкм.
Ключевые слова: *селенид цинка, оптические константы, спектр пропускания.*

Introduction. Zinc selenide (ZnSe) is an important and promising compound semiconductor material, with very wide applications in the optical and electronic devices [1–5], such as blue-green laser diodes (LDs), white light emitting diodes (LEDs), optically controlled switches, tunable mid-IR laser sources for remote sensing applications, photovoltaic and photoelectrochemical devices. Some solar cells and narrow bandgap semiconductor devices also use zinc selenide as one of the base layers [6, 7]. The optical properties of ZnSe are key parameters for measuring optical constants of liquid sample in experimental measurement [8–10].

The applications of ZnSe have been researched more than 50 years [11–17]. Adachi et al. [11] studied the optical response of ZnSe in the 1.5–5.3 eV photon-energy range at room temperature by spectroscopic ellipsometry. Aven et al. [12] studied the electrical and optical properties of ZnSe and obtained the first set of peaks, 2.7 and 3.15 eV, which are believed to be due to exciton and interband transitions with a spin-orbit valence band splitting of 0.45 eV. The second set of peaks, 4.75 and 5.1 eV, is tentatively assigned to transitions with a spin-orbit splitting of 0.35 eV. Kimi et al. [13] measured the spectral data of a ZnSe film grown on GaAs(100) at room temperature by spectroscopic ellipsometry in the photon energy range between 1.5 and 6 eV in steps of 5 meV. Merz et al. [14] investigated five substitutional donors in ZnSe: Al, Ga, In, Cl, and F by measuring the I2 lines and the two-electron transitions associated with each other, and determined the donor binding energies. Sankar et al. [15] revealed the possibility of phosphorus. Recently, Li et al. [16, 17] measured the transmittance spectrum of ZnSe glass in the infrared wavelength 0.83–21 μm at normal incidence by a Bruker V70 FTIR spectrometer, and investigated the optical constants of ZnSe glass. However, the optical properties of ZnSe published in the early times were limited in the wavelength region.

The present measurement techniques of the optical constants of solid materials are outlined as the inversion methods based on reflectance and transmittance spectra [18–21], the single reflectance method [22] and the single transmittance method [23, 24], the spectroscopic ellipsometry [25, 26], and the double-thickness transmittance method [16, 17]. The inverse calculation process of the single reflectance method and the single transmittance method need to be combined with the Kramers-Kronig (K-K) dispersion equation [22–24]. The mechanism of the double-thickness transmittance method is simple, and the K-K equation is not introduced in inverse calculation [16, 17].

A method to determine the optical constants of ZnSe was presented in [16]. Measurements of transmittance spectra of ZnSe in the infrared and visible wavelength regions were carried out by an IRTracer-100 spectrometer and a TU-19 Double-Beam Visible spectrophotometer. The optical constants of ZnSe were drawn from the experimental data.

Experimental method. Spectrophotometric measurements at normal incidence were made by an IR-Tracer-100 spectrometer and a TU-19 Double-Beam visible spectrophotometer in the infrared and visible wavelength regios. For each measurement, the transmittance is a function of the transmitted and incident intensity of light as follows:

$$T = I/I_0 \tag{1}$$

where I_0 and I are the incident and transmitted intensities of light, respectively. The incident intensity was measured with the ZnSe removed from the beam's path. The transmitted intensity was measured with ZnSe placed in the optical path. Measurements were made with a resolution of 4 cm^{-1}.

The transmittance of ZnSe at normal incidence is given as [16]

$$R_s = \rho + \frac{(1-\rho)^2 \rho \exp(-8\pi kL/\lambda)}{1-\rho^2 \exp(-8\pi kL/\lambda)}, \quad T_s = \rho + \frac{(1-\rho)^2 \rho \exp(-4\pi kL/\lambda)}{1-\rho^2 \exp(-8\pi kL/\lambda)}, \quad A_s = 1 - T - R, \tag{2}$$

where T_s is the transmittance of ZnSe at normal incidence, ρ is the interface reflectance for surface between air and slab, k is the extinction coefficient of the ZnSe material, L is the thickness of the ZnSe slab, and λ is the wavelength.

The interface reflectance ρ are calculated based on Fresnel's relations:

$$\rho = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}, \tag{3}$$

where n is the refractive index of the ZnSe material.

If the extinction coefficient and refractive index of the ZnSe material in the wavelength λ are known, the measured transmittances T_1 and T_2 of the two single ZnSe slabs at normal incidence with the slab thicknesses L_1 and L_2 are given by [16]

$$T_1 = \rho + \frac{(1-\rho)^2 \rho \exp(-4\pi kL_1/\lambda)}{1-\rho^2 \exp(-8\pi kL_1/\lambda)}, \quad T_2 = \rho + \frac{(1-\rho)^2 \rho \exp(-4\pi kL_2/\lambda)}{1-\rho^2 \exp(-8\pi kL_2/\lambda)}. \tag{4}$$

A double-thickness transmittance method was introduced in [16]. The relationship equations obtained from Eqs.(4) are presented as follows [16]:

$$\rho = \frac{1 - \sqrt{T_1^2 + T_1\left[\exp(4\pi k L_1/\lambda) - \exp(-4\pi k L_1/\lambda)\right]}}{1 + T_1 \exp(-4\pi k L_1/\lambda)}, \tag{5}$$

$$k = \frac{\lambda}{4\pi L_2} \ln\left[(1 + \sqrt{1 + 4c^2\rho^2})/(2c)\right], \quad c = T_2/(1-\rho)^2. \tag{6}$$

From Eq. (3), the refractive index of ZnSe material n can be calculated by

$$n = \frac{(1+\rho) + \sqrt{(1+\rho)^2 - (1-\rho)^2(1+k^2)}}{1-\rho}. \tag{7}$$

To solve the above expressions, a calculation procedure based on an iteration technique was adopted as the following steps: 1) take the assumed k values; 2) calculate the ρ values by Eq. (5), and determine the new k values by Eq. (6); 3) analyze the calculation errors between the assumed k values and the new k values. If the errors are rational, the k values calculation is finished, otherwise the assumed k values will be substituted by the new k values; then return to 2); 4) calculate n values by Eq. (7) on the basis of k values.

Result and discussions. The experimental transmittance spectra of ZnSe in the infrared and visible wavelength regions at room temperature, whose layer thicknesses are respectively 2 and 3 mm, are shown in Fig. 1. It is clear that the shapes of transmittance spectra of 2 and 3 mm ZnSe slabs are similar, but they are different for the infrared and visible regions for the same thickness. All ZnSe slabs have a wide transparent region, in which the transmittance of ZnSe slabs exceeds 60%; however, the transmittance of ZnSe declines rapidly in infrared wavelength region at wavelengths larger than 15 um.

The optical constants of ZnSe were established by the method of the present work. The results of this work and published data [27] on extinction coefficient and refractive index are shown in Fig. 2. The refractive index of ZnSe varies within 2.6–2.8 in the wavelength range of 0.55–0.85 μm and 2.2–2.4 in the wavelength range of 2.5–20 μm. The extinction coefficient of ZnSe varies within 10^{-8}–10^{-6} in the wavelength range of 0.55–0.85 μm and 10^{-5}–10^{-4} in the wavelength range of 2.5–20 μm.

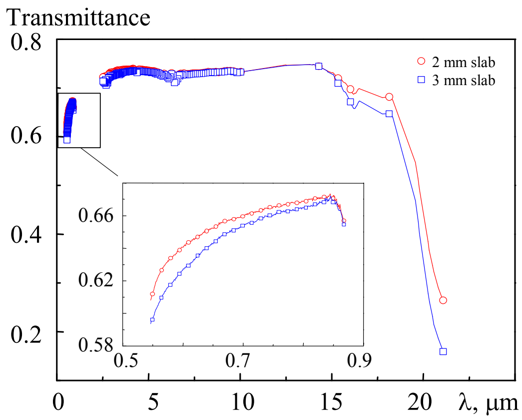

Fig. 1. Transmittances of ZnSe (IR and UV spectrograms).

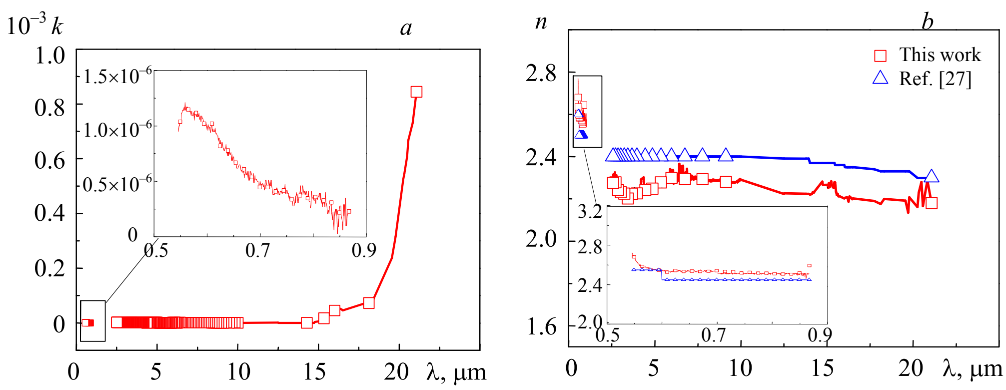

Fig. 2. Measured and published values of extinction coefficients (a) and refractive index (b) of ZnSe (IR and UV spectrograms).

Conclusion. The transmittance spectra of ZnSe in the infrared and visible wavelength regions were measured. The ZnSe has a wide transparent region, especially in the wavelength range of 2.5–15 μm, where the transmittance value is higher than 0.7, however, the transmittance of ZnSe is relatively low in the other regions; in particular the transmittance of ZnSe decreases dramatically when the wavelength is larger than 15 μm. The refractive index of ZnSe varies within 2.6–2.8 in the wavelength range of 0.55–0.85 μm and 2.2–2.4 in the wavelength range of 2.5–20 μm. The extinction coefficient of ZnSe varies within 10^{-8}–10^{-6} in the wavelength range of 0.55–0.85 μm and 10^{-5}–10^{-4} in the wavelength range of 2.5–20 μm.

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