Semiconductor Physics, Quantum Electronics & Optoelectronics, 2020. V. 23, No 4. P. 400-407.

Optics

Determination of the parameters of coherent magneto-optical layers on a finite absorbing substrate from thermal radiation spectra

V.O. Morozhenko[1], V.P. Maslov[1], I.V. Bariakhtar[2], N.V. Kachur[1]

[1]*V. Lashkaryov Institute of Semiconductor Physics, NAS of Ukraine,*
41, prospect Nauky, 03680 Kyiv, Ukraine; e-mail: morozh@meta.ua
[2]*Department of Physics, Boston College, 140 Commonwealth Avenue, Chestnut Hill,*
Massachusetts 02467-3804, USA; e-mail: irina.bariakhtar@gmail.com

Abstract. A possibility of determining the parameters of a coherent magneto-optical layer on a finite incoherent absorbing substrate by analyzing the spectra of its thermal radiation (TR) has been investigated. On the example of a plane-parallel InAs semiconductor plate silver-coated on the back surface, it has been shown that a complex analysis of TR spectra, both without and with the presence of magnetic field, makes it possible to determine the thickness, optical, magneto-optical and electric parameters of the layer. Algorithms for the calculation and analysis of TR spectra are adduced, which simplify determination of layer parameters and increase the accuracy of results. Comparing the position of the extremes of the experimental zero-field spectrum with the theoretical calculations, the thickness of the sample and the plasma oscillation frequency in the used semiconductor have been determined. The analysis of the relative contrast of interference oscillations in the TR spectrum in the magnetic field using previously defined parameters enabled to ascertain the spectral dependence of the Faraday rotation angle and to determine the concentration, effective mass and type of current carriers. It has been assumed, that such analysis of luminescence spectra also allows determining the parameters of magneto-optical layers and structures.

Keywords: optical constants, electric parameters, magneto-optical layers, thermal radiation, Faraday effect.

https://doi.org/10.15407/spqeo23.04.400
PACS 44.40.+a, 42.25.Hz, 78.20.Ls, 79.60.Dp

Manuscript received 06.08.20; revised version received 15.09.20; accepted for publication 28.10.20; published online 19.11.20.

1. Introduction

Layered structures, including dielectric, semiconductor and magneto-optical materials, are widely used in devices of semiconductor technology, optoelectronics, photonics and integrated optics. The optical, physical and dimensional properties of the layers are very important, since they determine the characteristics of the device. In this regard, there is a need to control their parameters both in the process of formation and at the end of the technological manufacturing process. In addition, the study of the properties of layers and films enables to perform a targeted search for the necessary structural parameters required for practical applications.

Spectroscopic methods are traditionally used for studying both monolayer and multilayer structures. The analysis of transmission and reflection spectra is an accurate, fast and non-destructive method for determination of the refractive index (n), absorption coefficient (α) and thickness (d) of a plane-parallel sample, layer or film. In the case of multilayer structures, optical ones are the only practical methods for determining the parameters of layers. Determination of the thickness and optical characteristics of coherent layers on transparent substrates by using the transmission spectra is a well-known procedure. Swanepoel's method (envelope method) [1-4] is based on the usage of interference transmittance extrema and envelopes. Using the simplified transmission expressions and a fitting procedure for analysis, the method provides determination with sufficient accuracy of the values of d, n and α of the films, the average amplitude of the surface roughness and the energy band gap [2]. In [5-7], the methods for determining d and optical constants of both monolayers and films as a part of a multilayer structure by using the procedure of multi-parameter fitting the extremes of the interference fringes are described. In [8, 9], the methods for determining the optical constants of films on absorbing substrates by an iterative process of fitting the reflection spectrum by using the Fresnel laws and dispersion relations between the real and imaginary parts of the refractive index inherent to the film are presented. In [10], determination of optical constants of the films on absorbing substrates was carried out using the procedure for fitting the interference bands in the reflection spectra recorded at two different angles of incidence.

This work is a logical continuation of the research initiated in [11] on the search for new methods for determining the parameters of coherent magneto-optical layers. Spectra of intrinsic thermal radiation (TR) of layers in the absence of a magnetic field and in the field are the subject of the research. As it is known, the real-body TR contains information about the parameters of this body. Registration of semiconductor TR makes it possible to determine the value of the absorption coefficient and dispersion of the reflectivity [12], impurity concentration [13], lifetime of the non-equilibrium charge carriers [14], *etc*. In the paper, it has been proposed to use the features of the TR spectra interference pattern of the magneto-optical layer to determine its parameters. It has been shown that registration and analysis of TR spectra, both without the magnetic field and with the field, greatly expand the possibilities of studying the parameters of the layer. These complex studies of the semiconductor layer enable, in addition to the thickness and refractive index, also to determine the Faraday rotation angle and related parameters, namely: concentration, effective mass, and type of current carriers in the semiconductor.

2. Theoretical consideration and basic relations

Let us consider a system consisting of a coherent layer located on a finite incoherent substrate, as it is shown schematically in Fig. 1. Let the layer be characterized by a thickness d_L, refractive index n_L and absorption coefficient α_L. The substrate is characterized by a refractive index n_S and absorption coefficient α_S. The external magnetic field (**B**) is directed along the normal to the surfaces of the system.

According to the Kirchhoff law, the intensity of thermal radiation emitted by the heated system is determined as

$$P = P_{b.b.}(1 - R - T), \tag{1}$$

where T and R are, respectively, the transmittance and reflectance of the system, $P_{b.b.}$ is the intensity of black body TR under the same conditions. In this paper, we focus only on the thermal radiation that is going out through the mirror R_1 normally to its surface. To determine T and R, let us consider the external light incident onto the system from the side of the layer normally to it, as it is shown in Fig. 1. Using the matrix method [15, 16], the following analytical expressions for T and R were obtained:

$$T = \frac{T_L \eta_s (1 - R_3)}{1 - \eta_s^2 R_L R_3}, \quad R = R_L + \frac{T_L^2 \eta_s^2 R_3}{1 - \eta_s^2 R_L R_3}, \tag{2}$$

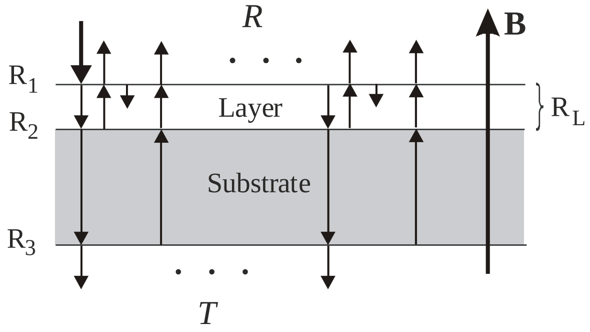


Fig. 1. Schematic representation of light propagation in a system consisting of a coherent layer located on a finite incoherent substrate.

where

$$T_L = \frac{(1 - R_1)(1 - R_2)\eta_L}{1 - 2\eta_L \sqrt{R_1 R_2} \cos 2\delta + R_1 R_2 \eta_L^2}, \tag{3}$$

$$R_L = \frac{R_1 - 2\eta_L \sqrt{R_1 R_2} \cos 2\delta + R_2 \eta_L^2}{1 - 2\eta_L \sqrt{R_1 R_2} \cos 2\delta + R_1 R_2 \eta_L^2}. \tag{4}$$

Here, T_L and R_L are the transmittance and reflectance of the coherent layer, respectively, $\eta_s = \exp(-\alpha_s d_s)$, $\eta_L = \exp(-\alpha_L d_L)$.

In a longitudinal light magnetic field, the transmittance and reflectance of the magneto-optical layer split into two components, which depend on the Faraday rotation angle [11]:

$$T_L^{\pm} = \frac{(1 - R_1)(1 - R_2)\eta_L}{1 - 2\eta_L \sqrt{R_1 R_2} \cos 2(\delta \pm \varphi) + R_1 R_2 \eta_L^2}, \tag{5}$$

$$R_L^{\pm} = \frac{R_1 - 2\eta_L \sqrt{R_1 R_2} \cos 2(\delta \pm \varphi) + R_2 \eta_L^2}{1 - 2\eta_L \sqrt{R_1 R_2} \cos 2(\delta \pm \varphi) + R_1 R_2 \eta_L^2}, \tag{6}$$

where $\delta = 2\pi n_L d_L / \lambda$, φ is the single-trip Faraday rotation angle. Thus, the thermal radiation of the system in a magnetic field also splits into two components, the interference extrema of which are shifted relatively to each other by 4φ:

$$P^{\pm} = P_{b.b.}(1 - R^{\pm} - T^{\pm})/2, \tag{7}$$

where

$$R^{\pm} = R_L^{\pm} + \frac{(T_L^{\pm})^2 \eta_s^2 R_3}{1 - \eta_s^2 R_L^{\pm} R_3}, \quad T^{\pm} = \frac{T_L^{\pm} \eta_s (1 - R_3)}{1 - \eta_s^2 R_L^{\pm} R_3}. \tag{8}$$

The total TR spectrum is a sum of these components.

$$P = P^{+} + P^{-}. \tag{9}$$

As seen, TR of the coherent layer is an oscillating function, and it contains information about optical parameters of the layer, and in a magnetic field – about the Faraday rotation and related parameters, for example, in the case of semiconductors, about the concentration of free current carriers and their effective mass.

3. Experimental

In our studies, a semiconductor plane-parallel InAs plate of 8×6 mm size was used. The plate was cut from a single crystal boule. Its broad sides were grinded and polished. A silver layer was deposited on one of the wide sides of the plate by vacuum evaporation.

The experimental setup for studying the TR spectra in a magnetic field is shown schematically in Fig. 2. The InAs/Ag system, fixed on the flat heater with the clean side out, was positioned between the poles of the electromagnet, so that the magnetic field was directed along the normal to its wide faces. The thermal radiation generated by the plate along the magnetic field was outgoing from the outside due to a germanium prism. An unwanted TR from the heater was shielded by the opaque silver layer on the back surface of the sample and an aperture that had a temperature close to the background (room) and low emissivity (high reflectance). The sample temperature was maintained at 375 K. The spectra were measured by an infrared Fourier spectrometer with the resolution close to 2 cm^{-1}.

4. Results and discussion

4.1. Determination of thickness and refractive index

In Fig. 3, the experimental TR spectrum of the system InAs/Ag in the absence of a magnetic field is shown. As can be seen, the spectrum of TR is oscillating with the pronounced interference maxima and minima.

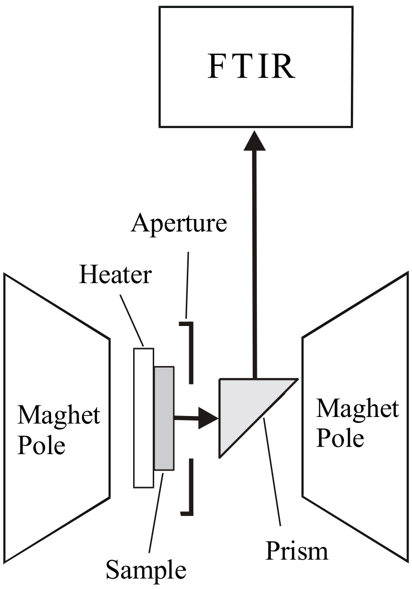


Fig. 2. Scheme of the experimental setup for studying the thermal radiation spectra in magnetic field.

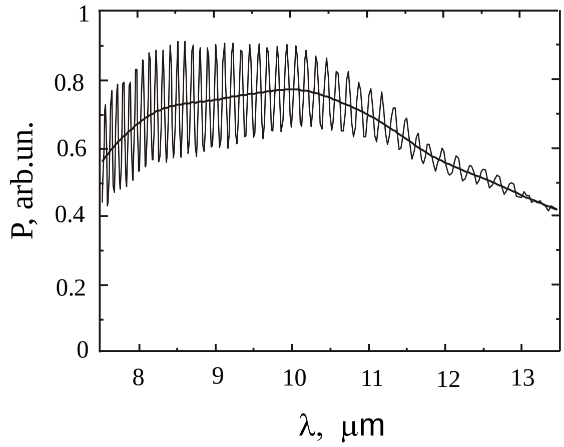


Fig. 3. Experimental spectrum of thermal radiation from the InAs/Ag system (oscillating curve) and a smoothed spectrum (smooth line).

The decrease in the amplitude of the oscillations with increasing the wavelength is primarily caused by the spectral dependence of the coefficient of absorption related with free carriers. The sample becomes less transparent, which reduces the contrast of the TR interference pattern. At the wavelengths $\lambda > 13.5$ μm, the InAs plate becomes opaque and the interference disappears.

In the second place, the decrease in the amplitude of oscillations is related with the dispersion of refractive index. In a highly doped semiconductor, such as InAs, the spectral dependence of the refractive index is described by the known expression

$$n(\lambda)^2 = \varepsilon_\infty \left(1 - \lambda^2 / \lambda_p^2\right), \quad (10)$$

where

$$\lambda_p^2 = \left(2\pi c / \omega_p\right)^2 = \pi c^2 \varepsilon_\infty m^* / e^2 N\,, \quad (11)$$

ω_p is the plasma oscillations frequency, ε_∞ – RF permittivity, N – concentration of free current carriers, e – electron charge, m^* – carrier effective mass, c – speed of light in vacuum. Since in our case R_1 is the reflection coefficient inherent to the free surface, its value decreases, reducing the amplitude of the interference oscillations of TR.

The distance between the interference extrema of the thermal radiation clearly depends on the thickness and refractive index of the InAs plate. It enables to use the resulting TR spectrum to determine these parameters. It should be noted that in our case the problem of finding the refractive index is reduced to ascertaining its dispersion law, namely, finding the value of λ_p.

In this paper, we used the method of fitting the position of the extremes by a theoretical function to the corresponding values of the experimental data.

Apparently, the spectral dependence of TR is quite complex. The oscillating part of the spectrum is modulated by the Planck function and the hardware function of the spectrometer. It increases the number of parameters that are needed to be applied and significantly complicates the fitting procedure. To simplify this procedure, the TR spectrum was divided by the midline (P_S) (curve *2* in Fig. 3). In [1-4], the midline was obtained manually. In [17], the interference fringes of transmission spectrum were removed using the integration method. We used smoothing the interference oscillations of the TR spectrum by using the Savitsky–Halley method. The normalized spectrum of TR (P/P_s) is shown in Fig. 4a.

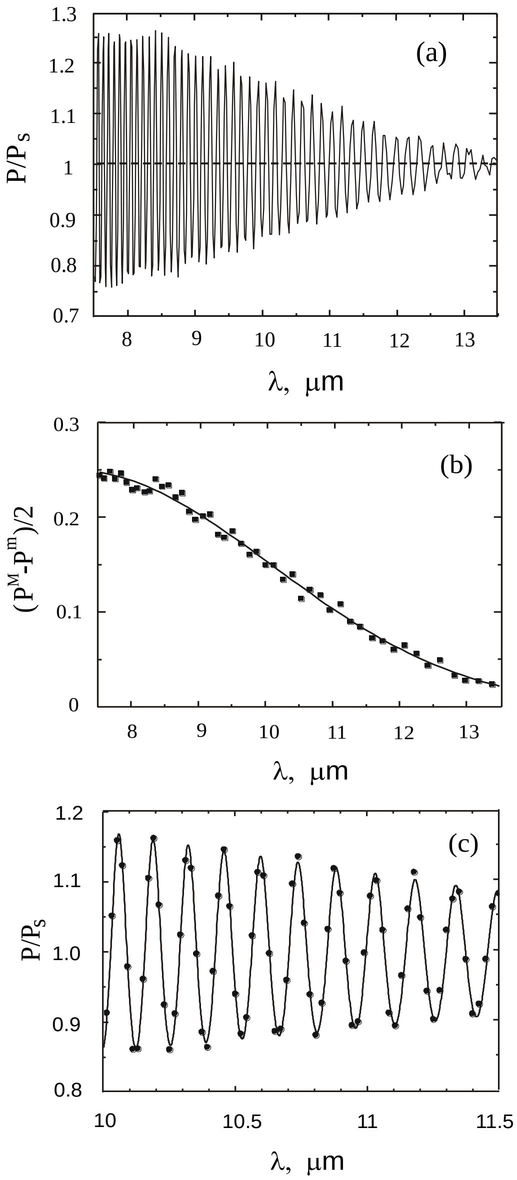


Fig. 4. (a) Normalized to the midline TR spectrum of the InAs/Ag system; (b) the spectral dependence of the amplitude of the TR oscillations (points) and its approximation (line); (c) the result of fitting the function $F(\lambda)$ (line) and the experimental normalized TR spectrum (dots).

The following formula with three fitting parameters, namely, a_1, a_2 and a_3 was used to describe the normalized spectrum:

$$F(\lambda) = \left[a_1 - f(\lambda) \cos\left(\frac{a_2}{\lambda} \sqrt{1 - \lambda^2 / a_3^2} \right) \right]^{-1} . \qquad (12)$$

It is similar to the expression that describes the radiation power of a coherent plate without regard to the substrate [18]. Since we are interested in finding the exact position of TR extremes, this feature is useful for this task. The function $f(\lambda)$ describes the change in the amplitude of oscillations with increasing the wavelength. To determine its appearance, the points of maxima (P^M) and minima (P^m) of oscillations were removed, and the spectral dependence of half their difference was approximated, as shown in Fig. 4b. Given that the TR spectrum was recorded at a fairly coarse resolution of 2 cm^{-1}, the points of the extracted extrema did not always coincide with the real extrema, as can be seen in Fig. 4c. In addition, noises were imposed on their amplitude. But due to the large number of points, we were able to find the optimal empirical formula for the dependence of the oscillation amplitude on the wavelength:

$$f(\lambda) = 0.25 \exp\left(-0.052 (\lambda - 7.0)^{2.05} \right) . \qquad (13)$$

The found values of *d* and λ_p (as well as all other determined parameters of the InAs plate) are shown in Table. To obtain $n(\lambda)$, we used the value of RF permittivity $\varepsilon_\infty = 12.37$ [19].

4.2. Determination of concentration and effective mass of free current carriers

Fig. 5 shows the experimental TR spectrum of the InAs/Ag in the magnetic field. As can be seen, with the presence of magnetic field, there is an amplitude modulation of oscillations of the TR intensity. The spectrum contains a region ($\lambda \approx 10\ldots10.5$ μm) in which interference is practically absent. This behaviour of the TR spectrum is caused by that in the magnetic field TR consists of two components, oscillations of which differ in phase by 4φ (see Eqs (7)–(9)). As a result, the beats are observed in the interference pattern of total TR.

Carrying out the laborious, but not complicated calculations, it can be obtained that the TR spectra, like the transmission spectra [11], can be converted into the spectral dependence of the Faraday rotation angle as follows:

$$\varphi = \frac{1}{2} \arccos \left[\frac{\left(\rho_B^M - \rho_B^m \right) \left(\rho_0^M + \rho_0^m \right)}{\left(\rho_B^M + \rho_B^m \right) \left(\rho_0^M - \rho_0^m \right)} \right] , \qquad (14)$$

where ρ are the functions that smoothly relate TR values with $2\delta = 2\pi j$ (ρ^M) and $2\delta = \pi(2j+1)$ (ρ^m) of the zero-field spectrum (ρ_0) and spectrum in the field (ρ_B).

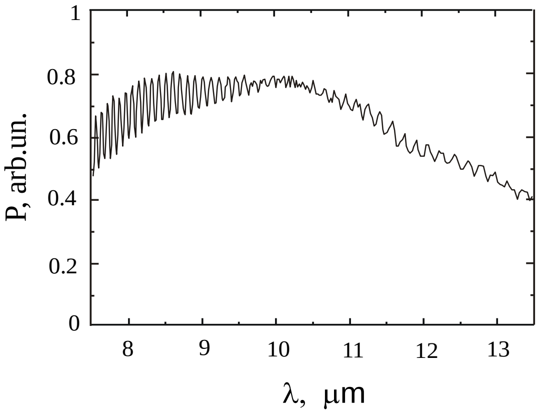


Fig. 5. Experimental spectrum of thermal radiation of the plane-parallel InAs/Ag system in the magnetic field. B = 1.1 T.

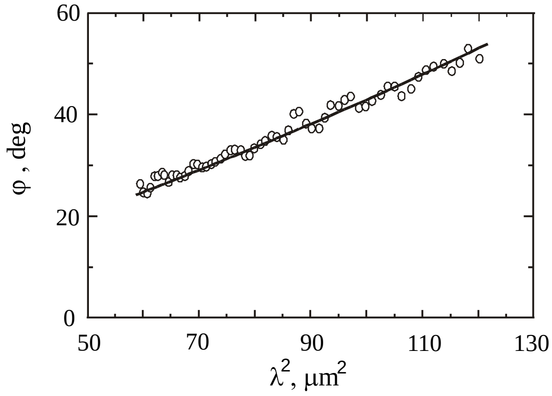


Fig. 6. Faraday rotation in the coherent plate InAs as a function of λ^2. B = 1.1 T; t =375 K. Dots show the results of processing of experimental spectra; line is the theoretical dependence $\varphi(\lambda^2)$ at the corresponding value of the magnetic flux density.

Taking into account the discreteness of the experimental TR spectra, a linear interpolation with nodes at points corresponding to the wavelengths of maxima ($\lambda_{0_k}^{\mathrm{M}}$) and minima ($\lambda_{0_k}^{\mathrm{m}}$) ($k = 1,2,3\ldots$) of the zero-field spectrum was applied to determine the functions $\rho^{\mathrm{M,m}}$, similar to whose done in [11]:

$$\rho_k^{\mathrm{m}}(\lambda) = P_k^{\mathrm{m}} + \frac{P_{k+1}^{\mathrm{m}} - P_k^{\mathrm{m}}}{\lambda_{0_{k+1}}^{\mathrm{m}} - \lambda_{0_k}^{\mathrm{m}}}\left(\lambda - \lambda_{0_k}^{\mathrm{m}}\right) \tag{15}$$

and

$$\rho_k^{\mathrm{M}}(\lambda) = P_k^{\mathrm{M}} + \frac{P_{k+1}^{\mathrm{M}} - P_k^{\mathrm{M}}}{\lambda_{0_{k+1}}^{\mathrm{M}} - \lambda_{0_k}^{\mathrm{M}}}\left(\lambda - \lambda_{0_k}^{\mathrm{M}}\right). \tag{16}$$

In Fig. 6, it is shown the spectral dependence of the Faraday rotation angle in the InAs plate obtained from the experimental spectra of TR without the magnetic field and at B = 1.1 T. The points φ were calculated for wavelengths $\lambda_{0_k}^{\mathrm{M}}$ and $\lambda_{0_k}^{\mathrm{m}}$. The small regular deviation of the points is caused by the low resolution of 2 cm^{-1}, and under this condition the spectral points do not always match the real extrema with a sufficient accuracy. Erratic spread of the points are caused by noise. As can be seen, the dependence $\varphi(\lambda^2)$ is close to linear, which is typical for Faraday rotation on free current carriers in the frequency range $\omega >> \omega_c$, where ω_c is the cyclotron frequency. The slight deviation of $\varphi(\lambda^2)$ from the linearity is due to the significant variance of the refractive index.

Comparison of the obtained experimental data with the theoretical dependence $\varphi(\lambda)$ allows determination of the effective mass of electrons in the semiconductor and their concentration. The Faraday effect on free current carriers is described by the expression:

$$\varphi = \frac{\pi}{\lambda} d\sqrt{\varepsilon_\infty}\left[\sqrt{1 - \frac{\lambda^2\lambda_c}{\lambda_p{}^2(\lambda_c + \lambda)}} - \sqrt{1 - \frac{\lambda^2\lambda_c}{\lambda_p{}^2(\lambda_c - \lambda)}}\right], \tag{17}$$

where

$$\lambda_c = 2\pi c/\omega_c = 2\pi m^* c^2/eB. \tag{18}$$

In Fig. 6, the line shows the result of fitting the theoretical spectral dependence $\varphi(\lambda)$ to the experimental points. Here, we have used the previously found values of d and λ_p. λ_c was used as a parameter of fit. Next, we obtained the value of the effective mass of current carriers m^* from the expression (18). Substituting the value of m^* to the expression (11) for the wavelength of plasma oscillations, the concentration of current carriers N in the sample was obtained. The found values of λ_c, m^* and N are shown in Table. Comparison of the obtained value of m^* with the known data [19] showed that its value agrees well with the value of the effective mass of electrons at these concentrations. From this, we can conclude that our sample has an electron type of conductivity (n-type).

Table. The determined parameters (m_e is the electron mass).

Determined parameters	d, μm	97
	λ_p, μm	20.3
	λ_c, μm	403 B = 1.1 T
	m^*/m_e	0.042
	N, cm^{-3}	$1.4\cdot10^{18}$
	Type of conductivity	n-type
Parameters obtained from other sources	d, μm	97 Microscope
	λ_p, μm	20.4 Reflection
	m^*/m_e	0.040–0.045 [19]

4.3. General results for the studies of parameters inherent to the InAs plate

The top lines of the table show all the parameters of the InAs plate that were determined by using TR spectra. In the lines at the bottom, parameters defined either from the literature or by the other methods are shown. The sources of information are indicated in the corresponding columns after parameter's values. It can be seen that the values of the respective parameters agree well with each other.

Thus, experimental studies of coherent InAs/Ag system have confirmed that the proposed method makes it possible to obtain reliable information about optical and electrical parameters in the sample material. The results can be applied for developing new methods of controlling the parameters of magneto-optical coherent plates, layers and layered structures in the technological process and to verify characteristics of the obtained products.

5. Conclusions

This paper presents results of studying the parameters of a magneto-optical semiconductor layer on an absorbing substrate by using the method of a complex analysis of the thermal radiation (TR) spectra both in the absence of a magnetic field and in the field. The results obtained in this paper have shown that the analysis of TR spectra enables to obtain reliable information about optical and electrical parameters of the magneto-optical layer on the absorbing substrate. The study of the system of coherent InAs semiconductor plate with a layer of silver on the back surface has shown that a comprehensive analysis of the TR spectra without a field and with the presence of magnetic field allows determining the following layer parameters: thickness, refractive index dispersion, concentration, effective mass, and type of current carriers.

At the first stage, the thickness and spectral dependence of the refractive index were determined by the procedure of fitting the theoretical function to the experimental zero-field TR spectrum. Attention was paid to the most accurate determination of the position of TR interference extrema. To simplify fitting and improving of its accuracy, the normalization of the TR spectrum to its midline was applied. This procedure eliminated deformation of the TR interference pattern by Planck distribution and hardware distortion of the spectrometer. To increase the accuracy of the fit, the extremes of the interference points were identified, and empirical formula that describes the change in the spectral oscillations' amplitude of TR was chosen.

At the second stage, the concentration, effective mass and type of current carriers in the semiconductor were determined. For this purpose, using the obtained points of extrema in the TR spectra without any magnetic field and in the field, the spectral dependence of the Faraday rotation angle was found by the proposed algorithm. Comparison of this dependence with the theoretical one by using the previously found thickness and dispersion of the refractive index enabled to determine the above-mentioned electrical parameters of the sample.

The values of the ascertained parameters are in good agreement with the corresponding values found by the alternative methods or from the literature. The results obtained in this paper can be useful for developing the methods for controlling the parameters of semiconductor or magneto-optical layers in the manufacturing process of producing the high-quality films and structures with predetermined and reproducible characteristics. The disadvantages of the proposed method are as follows: 1) the analytical procedure involves the large number of extremes for statistical data processing. It complicates the study of layers with a thickness that is comparable to the wavelength; 2) complexity of the Faraday rotation analysis at small rotation angles, when the change in contrast of the interference pattern is comparable to the noise level. In addition, 3) since the intensity of TR in the visible and near-infrared ranges is low, application of this method for these ranges is difficult. It is important to note that, in the same way, it is possible to investigate the parameters of layers by using their own non-equilibrium radiation. Investigation of the spectral features of luminescence of the coherent magneto-optical layers in a magnetic field and without it can be useful for developing new methods for controlling and tuning the films and layered structure's parameters.

References

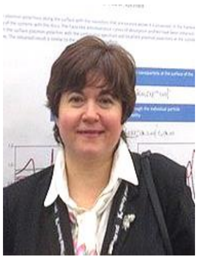
1. Essahlaoui A., Essaoudi H., Hallaoui A., Bouhadda M., Labzour A., Housni A. Calculation of the thickness and optical constants of lead titanate thin films grown on MgO from their transmission spectra. *J. Mater. Environ. Sci.* 2018. **9**, No 1. P. 228–234. https://doi.org/10.26872/jmes.2018.9.1.26.
2. Jin Y., Song B., Jia Zh., Zhang Y., Lin Ch., Wang X., Dai Sh. Improvement of Swanepoel method for deriving the thickness and the optical properties of chalcogenide thin films. *Opt. Exp*. 2017. **25**, No 1. P. 440–451. https://doi.org/10.1364/OE.25.000440.
3. Shaabana E.R., Yahiab S., El-Metwally E.G. Validity of Swanepoel's method for calculating the optical constants of thick films. *Acta Physica Polonica A.* 2012. **121**, No 3. P. 628–635. https://doi.org/10.12693/APhysPolA.121.628.
4. Caglar M., Caglar Y., Ilican S. The determination of the thickness and optical constants of the ZnO crystalline thin film by using envelope method. *J. Optoelectron. Adv. M.* 2006. **8**. P. 1410–1413.
5. Petrus R.Yu., Ilchuk H.A., Kashuba A.I., Semkiv I.V., Zmiiovska E.O., Lys R.M. Optical properties of materials for solar energy based on cadmium chalcogenides thin films. *Physics and Chemistry of Solid State.* 2019. **20**, No 4. P. 367–371. https://doi.org/10.15330/pcss.20.4.367-371.

6. Karpov A.G., Klemeshev V.A. Method for determining optical constants and the thickness of the thin film. *Vestnik Sankt-Peterburg. Universiteta. Prikladnaia Matematika*. 2017. **13**, No 1. P. 17–26. https://doi.org/10.21638/11701/spbu10.2017.102.
7. Mulato M., Chambouleyron I., Birgin E.G., Martnez J.M. Determination of thickness and optical constants of amorphous silicon films from transmittance data. *Appl. Phys. Lett*. 2000. **77**. P. 2133–2135. https://doi.org/10.1063/1.1314299.
8. Hamh S.Y., Han J.W., Kim T.H., Lee J.S. Determination of the optical constants of thin films based on normal-incidence reflectance measurements. *J. Korean Phys. Soc*. 2013. **63**, No 2. P. 241–245. https://doi.org/10.3938/jkps.63.241.
9. Mudavakkata V.H., Atuchinb V.V., Kruchininc V.N., Kayanid A., Ramana C.V. Structure, morphology and optical properties of nanocrystalline yttrium oxide (Y_2O_3) thin films. *Opt. Mater*. 2012. **34**, No 5. P. 893–900. https://doi.org/10.1016/j.optmat.2011.11.027.
10. Jitian S. The determination of thickness and optical constants for PbSe film from IR reflectance spectra. *Int. J. Eng*. 2011. **9**. P. 153–156.
11. Morozhenko V., Maslov V.P., Kachur N. Determination of Faraday angle under conditions of multiple-beam interference by using transmission and reflection spectra in non-polarized light. *J. Quant. Spectrosc. Radiat. Transf.* 2019. **236**. P. 106597. https://doi.org/10.1016/j.jqsrt.2019.106597.
12. Moss T.S., Burrel G.J., Ellis B. *Semiconductor Opto-Electronics*. London, Butterworths, 1973.
13. Malyutenko V.K., Chernyakovsky V.I., Piotrowski T. Characterization of oxygen impurity concentration in silicon based on thermal emission measurements. *Infrared Phys. Technol*. 1996. **37**. P. 499–504. https://doi.org/10.1016/1350-4495(95)00077-1.
14. Zinovchuk A.V., Tkachenko A.K. Measurement of surface recombination velocity and bulk lifetime in Si wafers by transient behavior of excess thermal emission. *Semiconductors*. 2011. **45**. P. 61–65. https://doi.org/10.1134/S1063782611010246.
15. Harbecke B. Coherent and incoherent reflection and transmission of multilayer structures. *Appl. Phys. B*. 1986. **39**. P. 165–170. https://doi.org/10.1007/BF00697414.
16. Katsidis C.C., Siapkas D.I. General transfer-matrix method for optical multilayer systems with coherent, partially coherent, and incoherent interference. *Appl. Opt*. 2002. **41**, No 19. P. 3978–3987. https://doi.org/10.1364/AO.41.003978.
17. King S.W., Milosevic M. A method to extract absorption coefficient of thin films from transmission spectra of the films on thick substrates. *J. Appl. Phys*. 2012. **111**. P. 073109–073109-9. https://doi.org/10.1063/1.3700178.
18. Kollyukh O.G., Morozhenko V. Angular and spectral peculiarities of coherent thermal radiation of the magneto-optical Fabry–Perot resonator in magnetic field. *J. Opt. A: Pure Appl. Opt*. 2009. **11**. P. 085503.
19. Madelung O. *Semiconductors: Data Handbook*. Berlin, Springer-Verlag, 2004.

Authors and CV

Vasyl Morozhenko, PhD in Physics and Mathematics, Senior Researcher at the Department of physics and technological basics of sensor materials science, V. Lashkaryov Institute of Semiconductor Physics. Author of more than 50 publications. The area of his scientific interests includes infrared spectroscopy, optical properties of semiconductors, photonics and magnetophotonics.

Volodymyr Maslov, Doctor of Materials Science, Head of the Department of physics and technological basics of sensor materials at the V. Lashkaryov Institute of Semiconductor Physics. Professor at the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" since 2010. Honored inventor of Ukraine. Author of more than 156 publications and more than 400 patents of Ukraine and USSR author's certificates. His research interests include several topics of optical engineering and physical behavior of functional materials as well as phenomena of surface plasmon resonance with application of it in medicine and ecology.



Irina Bariakhtar, PhD in Physics and Mathematics, Visiting Scholar at the Physics Department, Boston College, USA. Her research interests include theoretical and computational physics, optics, nanomaterials. Current projects are "Photovoltaic properties of nanocrystalline silicon thin films", "Prospective of sustainable energy". Author and co-author of 35 publications and monographs. Member of the American, European and Ukrainian Physical Societies.

Nataliya Kachur got her degree MS in Physics and Techniques at the National Aviation University of Ukraine, Mechanical faculty in 2006. The area of her scientific interests includes physics of surfaces, development and design sensors for applying in control of quality of transparent materials.

Визначення параметрів когерентних магнітооптичних шарів на кінцевій поглинаючій підкладці за спектрами теплового випромінювання

В.О. Мороженко, В.П. Маслов, І.В. Бар'яхтар, Н.В. Качур

Анотація. Досліджено можливість визначення параметрів когерентного магнітооптичного шару на некогерентній поглинаючій підкладці скінченної товщини шляхом аналізу спектрів його теплового випромінювання (ТР). На прикладі плоскопаралельної напівпровідникової пластини InAs, покритої сріблом на тильній поверхні, показано, що комплексний аналіз спектрів ТР як без магнітного поля, так і за його наявності дозволяє визначити товщину, оптичну, магнітооптичні та електричні параметри шару. Наведено алгоритми розрахунку та аналізу спектрів ТР, які спрощують визначення параметрів шару та підвищують точність результатів. Порівнюючи положення країв експериментального спектра нульового поля з теоретичними розрахунками, було визначено товщину зразка та частоту коливань плазми у використовуваному напівпровіднику. Аналіз відносної контрастності інтерференційних коливань у спектрі ТР у магнітному полі за допомогою раніше визначених параметрів дозволив встановити спектральну залежність кута повороту Фарадея та визначити концентрацію, ефективну масу та тип носіїв струму. Передбачається, що такий аналіз спектрів люмінесценції дозволяє також визначати параметри магнітооптичних шарів та структур.

Ключові слова: оптичні сталі, електричні параметри, магнітооптичні шари, теплове випромінювання, ефект Фарадея.