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SIMULATION OF THE DEPTH OF THE MELTED LAYER ON THE SURFACE OF A SEMICONDUCTOR USING JAVA CROSS-PLATFORM APPLICATION

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Анотація. В роботі описано метод одержання p-n переходів за рахунок лазерної перекристалізації поверхні напівпровідникових зразків CdTe, а також розроблений на мові Java програмний додаток, який дозволяє моделювати теплові процеси на межі розділу епітаксийний шарпідкладка при лазерному опроміненні поверхні напівпровідника. Він дозволяє робити прогнози стосовно товщини проплавленого шару, що буде впливати на параметри приладів, виготовлених на базі одержаних бар'єрних шарів. Проведено теоретичне моделювання процесів, які відбуваються при поглинанні лазерного випромінювання приповерхневим шаром напівпровідника.
Ключові слова: p-n-перехід, лазерний промінь, товщина розплавленого шару, програма Java, лазерне випромінювання.
Annotation. The paper describes a method for obtaining p-n transitions due to the laser recrystallization of the surface of CdTe semiconductor samples, as well as a software application developed in Java that allows the simulation of thermal processes at the boundary of the epitaxial layer-substrate with laser irradiation of the semiconductor surface. It allows to make predictions regarding the thickness of the melted layer, which will affect the parameters of the devices made on the basis of the obtained barrier layers. The theoretical modeling of the processes taking place at absorption of laser radiation by the surface layer of a semiconductor is carried out.
Key Words: p-n junction, laser beam, the thickness of a melted layer, Java application, laser radiation.

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INTRODUCTION

Modern environmental control systems cannot exist without the use of devices that measure the parameters of radiation, light and other emissions. Such devices include photoconverters that work as radiation detectors. The development of new and improvement of existing photodetectors requires the introduction of modern or modified methods of their production. One of these methods is the use of laser surface treatment of CdTe and CdMnTe semiconductor crystal samples, which are used to manufacture radiation photodetectors, including radiation-resistant ones. Laser melting of the surface allows for a controlled influence on the structure of the semiconductor both in general and in local areas [1]. The paper describes a software application that can be used to simulate thermal processes at the epitaxial layer-substrate interface during laser irradiation of the semiconductor surface. It allows you to determine the dependence of the thickness of the fused layer on the energy of laser radiation.

SETTING TARGETS

Laser irradiation at a certain energy density leads to a change in the real structure of the semiconductor and can influence its characteristics [2]. For example, irradiation of the surface of a semiconductor with a certain energy density can lead to the melting of a thin near-surface layer of this semiconductor with its subsequent recrystallization. At the same time, the stoichiometric composition of the semiconductor may change due to the loss of a volatile component that evaporates during laser irradiation of the surface. In the case of CdTe, this component is Cd. If the irradiated CdTe substrate had n-type conductivity, then the melted layer due to Cd evaporation changes the conductivity to p-type [3]. This technique is used to obtain surface-barrier structures.

1. SELECTION OF A THEORETICAL MODEL

The theoretical model that was used in this work is based on the fact that the main result of laser irradiation in semiconductors is the heating of the material due to the absorption of radiation in the surface layer, and cooling - when the heat is removed deep into the material. Heat radiation from the surface according to the Stefan-Boltzmann law was not taken into account, since, according to various estimates [4], the influence of this effect is insignificant. The absorbed radiation is almost instantly transformed into heat energy, which is dissipated according to the theory of heat conduction.

When the surface of the material reaches the melting temperature, phase transformation processes of the substance occur: melting, intense evaporation from the liquid phase, as well as the process of absorption of laser radiation energy by vapors of this material. We will assume that the cross-section of the laser beam is much larger than the thickness of the heated sample, thus, the boundary effects can be neglected.

Then the thermal conductivity equation will have the form:

$$\frac{\partial T}{\partial t} = \frac{\alpha}{\rho C_p} I(z,t) + \frac{1}{\rho C_p} \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z} \right) , \qquad (1)$$

where *I (z, t)* - is the energy density of laser radiation at depth *z* at time *t*; *T* - temperature; *ρ* - is the density of the sample material; C_p - specific heat capacity; *k* – thermal conductivity coefficient; *α* is the radiation absorption coefficient of the sample. In a homogeneous medium, the energy density can be written as:

$$I(z,t) = I_0(t)(1-R)\exp(-\alpha z) , \qquad (2)$$

where $I_0(t)$ - is the time dependence of laser radiation energy; *R* - is the reflectivity of the target.

Finding the coordinates of the front between the liquid and solid phase at an arbitrary moment in time was carried out using the expression:

$$\rho L v_{\phi} = k_s \left(\frac{\partial T}{\partial z} \right)_s - k_l \left(\frac{\partial T}{\partial z} \right)_l , \qquad (3)$$

where *L* - is the specific heat of fusion of the material; v_ϕ - is the speed of movement of the phase transition front; k_s , k_l - are thermal conductivity coefficients for the solid and liquid phases, respectively.

The maximum value of the z coordinate of the phase transition front during the process of heating the surface layer of the semiconductor sample due to laser radiation, and its subsequent cooling due to the removal of heat deep into the material, is the penetration depth.

When creating photodiode structures, the depth of the p-n junction is proportional to the penetration depth, which depends on the energy of the incident radiation. In turn, the depth of the barrier affects the spectral distribution and the amount of photosensitivity of the detector structures. Therefore, it is necessary to determine in advance the dependence between the energy of laser irradiation and the depth of the p-n junction, which in turn makes it possible to technologically set this depth.

1. COMPLEX DATA SECURITY IN CASE OF AN INDEPENDENT SYSTEM AND INFORMATION SECURITY AND PROTECTION OF INFORMATION

The latter protection of information can only secure a complex data, which allows one-hour use of hardware, software and cryptographic benefits (necessary additional security).

A similar approach transmits analysis and optimization of the entire system, and not just a few parts, which allows you to ensure a balance of characteristics, although it is not uncommon to increase some parameters to improve others.

The standard for the security system is ISO / IEC 17799 [7, 12], which conveys an integrated approach to the completion of the tasks set. Compliance with this standard allows you to vary the level of security of confidentiality, integrity, reliability and availability of data.

Organizations come in, who get used to a complex approach, as an independent tool and unite all methods, like victorious, into a single wholesome mechanism. Such a child will ensure the safety of data at all stages of their processing. When properly organized, the system does not create serious incompatibilities in the process of work.

A comprehensive analysis includes a detailed analysis of the implementation of the system, the assessment of security threats, the prevention of damages, which are victorious in the event of a system, and those capabilities, the analysis of the response of internal and external threats, and the assessment of the possibility of making changes to the system.

2. TAKING INTO ACCOUNT THE PROCESSES OF EVAPORATION OF THE SUBSTANCE

Since the samples were irradiated in a vacuum, it is obvious that the process of melting the surface of the material was accompanied by intense evaporation of the substance. Therefore, the calculation of the penetration depth, in such a case, needs to take into account the effects that accompany the process of gas phase formation.

First, the evaporation of a substance occurs with the absorption of a certain amount of heat, which is determined by the specific heat of evaporation. Secondly, this process is irreversible, that is, the amount of substance that evaporated from the surface of the sample does not condense back. Thirdly, the vapors of the material absorb the energy of the laser radiation and thus affect the density of the energy falling on the surface of the sample. Finally, by creating gas-dynamic pressure on the molten surface of the samples, the evaporation products increase the boiling point of the molten material [5, 8].

It is possible to estimate the value of the critical energy of laser radiation, at which appreciable evaporation of the surface layers of the material is achieved, according to the formula [4, 9]

$$I_k = t_i \frac{\sqrt{\pi}}{2} \left(\frac{T_k k}{\sqrt{D t_i}} \right), \tag{4}$$

where t_i - is the pulse duration; T_k - is the boiling point of the substance; $D=k/\rho C_p$ - is the coefficient of thermal conductivity.

To describe the process of intensive evaporation, the expression is use

$$I_k = G \rho \sqrt{D t_i} , \tag{5}$$

where G - is the specific heat of vaporization.

In this case, the rate of evaporation exceeds the rate of heat propagation, that is, the substance mostly evaporates from the surface of the sample while the thickness of the molten layer becomes minimal [10, 11].

3. RESULTS AND DISCUSSION

The selected theoretical model, which describes the process of the movement of the crystallization front during laser irradiation, taking into account the effects of evaporation of matter, became the basis of the software application, which allows to model the thickness of the melted semiconductor layer as a result of laser irradiation, based on known input data. This is important because the duration of the technological processes that are associated with the manufacture of p-n junctions by the method of laser recrystallization can now be significantly reduced. In order to plot graphs of the dependence of the penetration depth on the energy density of laser irradiation, it is necessary to set the input parameters (Figure 1).

Figure 2 shows a family of curves that interpret the dependence of the thickness of the melted layer of the CdTe substrate on the energy density of laser radiation at different boiling temperatures (which depend on the pressure of the surrounding medium) of the melt. It can be seen from the figure that at relatively small values of the energy density of laser radiation, the depth of the penetration increases faster with increasing energy than at higher values. This is due to the fact that when the surface of the samples is irradiated with a beam of low energy, the part of it that is spent on the evaporation of the substance does not exceed the energy that goes to heating and melting the surface layer.

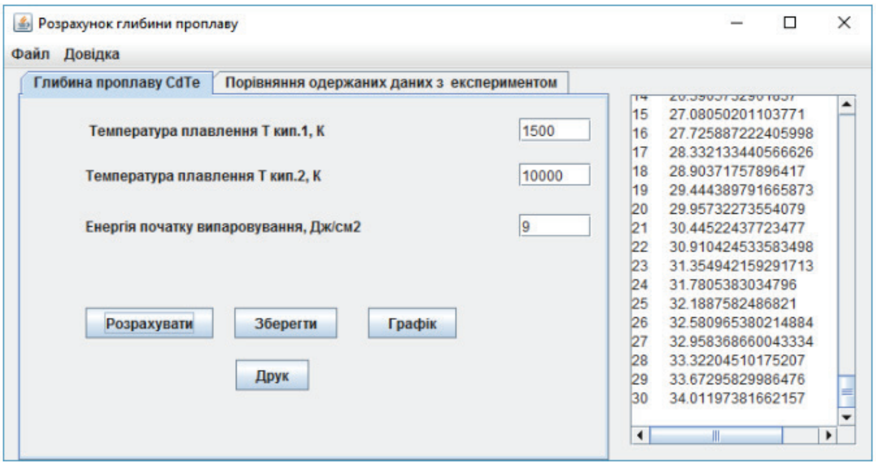

Figure 1 – Entering input parameters

As the energy of the laser beam increases, the evaporation process becomes noticeable, which limits the increase in the thickness of the melted layer. With an increase in the boiling temperature, which can be associated, for example, with an increase in the pressure in the chamber in which the samples are processed, the value of the radiation energy density increases, at which evaporation becomes noticeable.

In addition, higher boiling temperatures of the substance correspond to greater penetration depths of the surface layer at the same values of the energy density of laser radiation.

The reliability of the selected theoretical model and the obtained curves was checked by comparing the calculated and experimental data regarding the depth of the p-n junction (Figure 3), which were obtained as a result of the irradiation of CdTe samples with a single-pulse ruby laser GOR-100M with a wavelength of λ=0.693 µm.

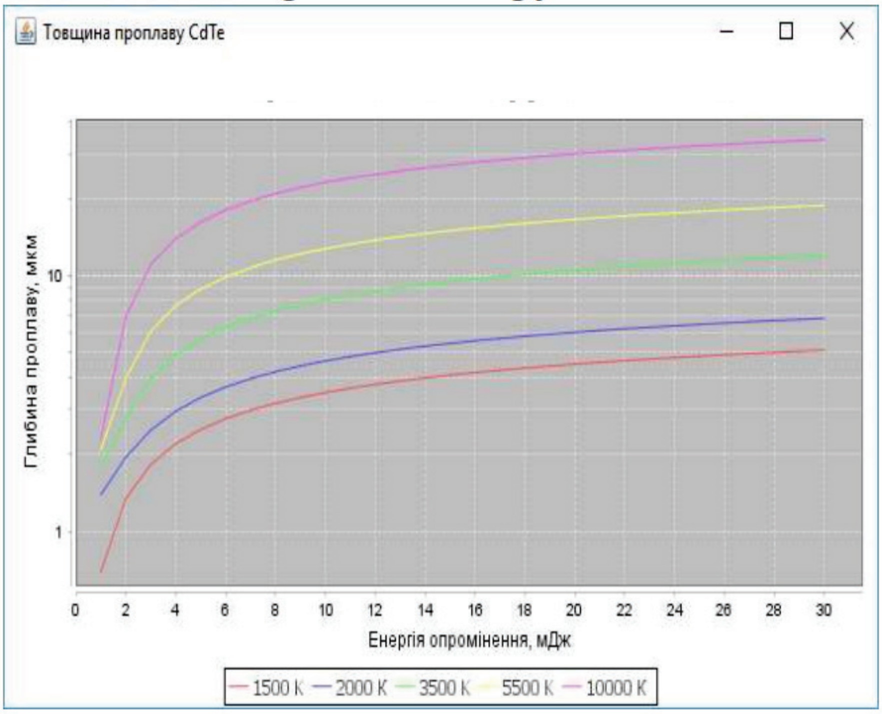

Figure 2 – Dependencies of the melt thickness on the energy density of laser irradiation at different temperatures

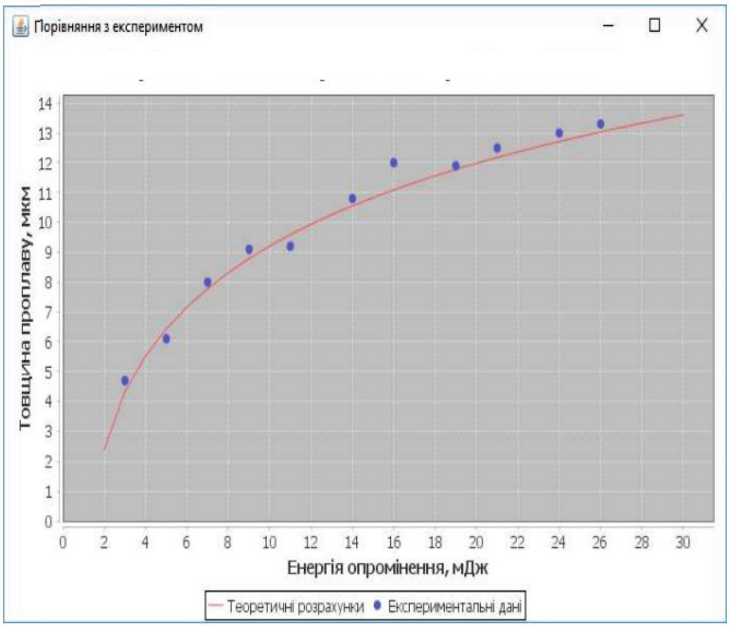

Figure 3 – Comparison of theoretical and experimental data

As can be seen from Figure 3, an acceptable correlation of the calculated and experimental data was obtained, which allows us to assert the correctness of the choice of the theoretical model and the assumptions made regarding the intensity of evaporation of the substance at high energies of laser irradiation.

CONCLUSION

Laser irradiation of the surface of $Cd_{1-x}Mn_xTe$ solid solution samples was also carried out for different values of x, and the described application was used to determine the depth of p-n deposition in such samples. It should be noted that the discrepancy between the calculated and experimental data in this case appears to a greater extent, which may be associated with a change in temperature processes during laser irradiation in a semiconductor with Mn admixture. The developed JAVA software application allows modeling the depth of penetration of the surface of the CdTe semiconductor sample depending on the input conditions: the boiling temperature of the melt, the energy density of the laser beam at which the vaporization of the substance begins, etc. The results of the work can be used for practical purposes and applied to the evaluation analysis of the depth of the p-n junction in CdTe samples when they are irradiated with pulses of a ruby laser with a wavelength of λ=0.693 µm in order to obtain surface barrier structures.

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