doi: 10.15407/ujpe62.11.0953

P.O. GENTSAR, O.I. VLASENKO, S.M. LEVYTSKYI

V.E. Lashkaryov Institute of Semiconductor Physics, Nat. Acad. of Sci. of Ukraine
(41, Nauky Ave., Kyiv 03028, Ukraine; e-mail: rastneg@isp.kiev.ua)

PACS 78.55.Hx, 78.40.Ha, 71.35.Cc

LASER-STIMULATED ENHANCEMENT OF THE REFLECTANCE OF SINGLE-CRYSTALLINE n-GaAs(100)

The results of optical researches concerning the reflection spectra of n-GaAs(100) single crystals with a specific resistance of 10 $\Omega\,$cm *(at room temperature) measured in a light wavelength interval of 0.2–1.7* μm *before and after the laser irradiation to an energy dose of 66–108 mJ/*cm^2 *are reported. The experiment revealed a growth in the reflectance of the examined crystals after their laser treatment. This integral effect is explained as a result of the difference between the optical characteristics (the complex refractive index) in the near-surface layer and in the bulk of the irradiated material.*

Keywords: n-GaAs(100), laser irradiation, reflection spectra, refractive index, near-surface layer.

Gallium arsenide (GaAs) is one of the main materials that are used as substrates for depositing various films, producing nano- and heterostructures, and fabricating light-emitting diodes, solar cells, and other modern electronic devices. The aim of this work is to study the influence of the laser radiation on the optical properties of n-GaAs(100) single crystals. The work continues other works of the authors dealing with the influence of the laser irradiation on the optical properties of semiconductors [1–3].

The laser treatment is used to change the optical and electrophysical properties of functional materials used in electronic engineering. In this work, we report the results of optical researches concerning the reflection spectra of n-GaAs(100) single crystals measured in a light wavelength interval of 0.2–1.7 μm before and after the laser irradiation to an energy dose of 66–108 mJ/cm^2.

As experimental specimens, we used semiconductor wafers of single-crystalline n-GaAs(100) with a specific resistance of 10 $\Omega\,$cm (at room temperature). The crystal surface was subjected to a mechanical-chemical treatment. Afterward, the specimens were treated with a laser. Namely, the crystal surface was uniformly irradiated at room temperature ($T = 300$ K) with nanosecond ($\tau = 7\div8$ ns) pulses of a Nd : YAG laser ($\lambda = 532$ nm) with the energy density E from 66 to 108 mJ/cm^2.

Figure demonstrates the reflection spectra of n-GaAs(100) depending on the laser irradiation energy.

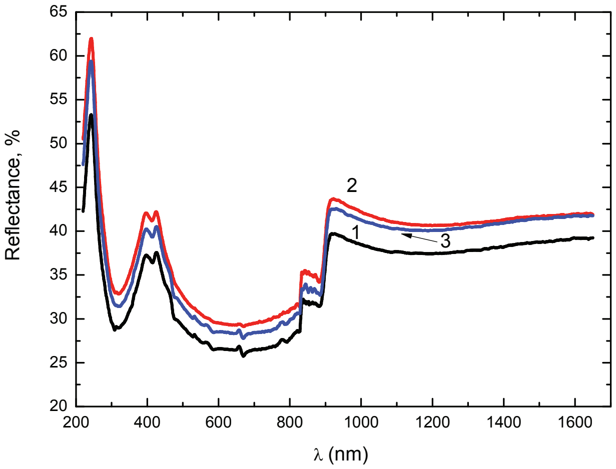
The quantitative parameter characterizing the reflection of electromagnetic waves is the energy reflectance R. At a normal incidence and a normal reflection of light with respect to the surface of a semiinfinite isotropic medium, the reflectance is determined by the formula [4]

$$R = \frac{(n-n_0)^2+\chi^2}{(n+n_0)^2+\chi^2}, \tag{1}$$

where n is the refractive index of the studied specimen, n_0 the refractive index of the medium, from which light (the electromagnetic wave) falls on the researched sample, and χ the extinction coefficient of the specimen.

The growth in the reflectivity of n-GaAs(100) single crystals under the laser irradiation in an energy interval of 66–108 mJ/cm^2 can be explained as follows. The laser treatment of the researched crystals induces structural changes in a thin near-surface layer, which makes its own contribution to the integral reflection effect. In other words, this is a result of the interference between the light (electro-

---



Reflection spectra of n-GaAs(100) single crystals: initial specimen (*1*) and specimens irradiated to 66 (*2*) and 108 mJ/cm^2 (*3*)

magnetic) waves reflected from the "air/thin near-surface layer" and "thin near-surface layer/crystal bulk" interfaces. The reflectance of crystals is determined by the refractive index n and the extinction coefficient χ. It is the difference between the optical characteristics of the near-surface layer and the material bulk (the complex refractive index in the near-surface layer, $\tilde{n}_s = n_s + i\chi_s$, differs from the complex refractive index in the material bulk, $\tilde{n}_v = n_v + i\chi_v$) that results in the integral effect depicted in Figure.

If the light wave falls normally on the "thin near-surface semiconductor layer/semiconductor bulk" interface, the reflectance of the system equals [5, 6]

$$\rho = \frac{\rho_{12} + \rho_{23}\exp\left(2i\delta\right)}{1 + \rho_{12}\rho_{23}\exp\left(2i\delta\right)}, \qquad (2)$$

where

$$\rho_{12} = r_{12}\exp\left(i\varphi_{12}\right) = \frac{(n_0 - N_1)}{(n_0 + N_1)},$$

$$\rho_{23} = r_{23}\exp\left(i\varphi_{23}\right) = \frac{(N_1 - N_2)}{(N_1 + N_2)}$$

are the Fresnel reflectances for the external (between the external environment and the thin near-surface layer) and internal (between the thin near-surface layer and the semiconductor bulk) interfaces; n_0 is the refractive index of the external environment; $N_1 = n_1 + ix_1$ and $N_2 = n_2 + ix_2$ are the complex refractive indices in the thin near-surface layer and the semiconductor bulk, respectively; φ_{12} and φ_{23} are the phase shifts of the light wave beams reflected from the surface of the thin near-surface layer and from the interface between the thin near-surface layer and the semiconductor bulk, respectively; the quantity $\delta = \left(\frac{2\pi}{\lambda}\right) N_1 d$; d is the thickness of the thin near-surface layer; and λ the wavelength.

Neglecting the quantities of the third and fourth orders of smallness, the reflectance R of the system composed of a thin near-surface layer of the semiconductor and the semiconductor bulk can be written in the form

$$R = (r_{12}^2 + r_{23}^2\exp(-2x_1 d^*) + 2r_{12}r_{23}\exp(-x_1 d^*) \times$$
$$\times \cos\varphi_-)/(1 + r_{12}^2 r_{23}^2\exp(-2x_1 d^*) +$$
$$+ 2r_{12}r_{23}\exp(-x_1 d^*)\cos\varphi_+), \qquad (3)$$

where

$$\varphi_\pm = \varphi_{12} \pm (\varphi_{23} + n_1 d^*),$$

$$d^* = \frac{4\pi}{\lambda}\, d.$$

As one can see from Figure, the intensity of high-energy peaks in single-crystalline n-GaAs(100) increases after the laser irradiation. These are the peaks at E_1 ($\Lambda_{3V} - \Lambda_{1C}$), $E_1 + \Delta_1$ ($\Lambda_{3V} - \Lambda_{1C}$), and E_2 ($\Sigma_V - \Sigma_C$) [5, 7]

The accumulated body of the results concerning the capabilities of a laser treatment of thin near-surface layers in metals, semiconductors, and insulators testifies to advantages of its application and the necessity of further researches aimed at revealing and studying the regularities and specific features in the action of the laser irradiation with various parameters on the functional materials used in electronic engineering. The study of the mechanisms of laser irradiation is also important for the further progress in the development of a laser equipment. There are the thermal and non-thermal mechanisms of laser radiation action. The latter include the impact, photochemical, and plasma mechanisms of laser treatment. In most cases, the thermal mechanism of laser treatment prevails at the laser irradiation.

Plenty of calculations were made to determine the temperature profile in the area of the laser beam action and its evolution in time. The calculations were performed for various semiconductor materials characterized by various physical parameters, and for various laser operation modes. The difficulties arising at theoretical calculations – namely, the variation of thermal constants of researched materials in time, the account for non-thermal mechanisms of nonequilibrium charge carrier recombination, and others – testify that it is expedient to continue further the researches dealing with the laser action on thin near-surface layers in the materials.

The following mechanisms are classed to non-thermal ones:

1) the ionization mechanism: ionization and variation in the charge state of defects in the semiconductor substrate under the action of laser pulses gives rise to the annealing of radiation-induced defects and their complexes;

2) the mechanism of radiationless recombination: the influence of Auger processes, including the surface Auger recombination;

3) the mechanism of radiative recombination: the reorganization of sections in the semiconductor structure that were not directly subjected to laser irradiation, but are located in the region of the recombination radiation propagation;

4) the shock-wave mechanism: it becomes active in the structure under the action of powerful light pulses; in this case, the sign-alternating fields of mechanical stresses generate vacancies with a high mobility, which promotes the diffusion of impurity (interstitial) atoms toward deformations (the motion of interstitial and impurity atoms is called gettering); the methods of laser gettering make it possible to avoid additional defects in the crystal and create a required configuration of the deformation field (local sections).

The structural gettering is the absorption associated with the presence of n-GaAs(100) sections that have a defect structure. Those sections can actively absorb point-like defects and capture impurities. In gallium arsenide, the role of a getter is played by Ga_2O_3, As_2O_5, and other layers.

It should be noted that the light wave penetration depth into the specimen equals α^{-1}. For typical semiconductors, $\alpha \approx 10^4 \div 10^6$ cm^{-1} above the absorption edge. At so large absorption coefficient values, light propagates only in a very thin (about 1 μm or less) layer near the specimen surface. The method of light reflection has been used for a long time. It is traditionally applied, while measuring the optical constants and studying the optical properties of functional materials used in electronic engineering.

To summarize, our optical researches of reflection spectra carried out for n-GaAs(100) single crystals with a specific resistance of 10 Ω cm (at room temperature) and subjected to the laser irradiation with an energy expose dose of 66–108 mJ/cm^2 in a spectral interval of 0.2–1.7 μm showed the following:

i) laser irradiation stimulates structural modifications in a near-surface layer of single-crystalline n-GaAs(100);

ii) the experimental results testify to a higher reflectance of the crystals concerned after their laser treatment;

iii) the integral effect of reflectance enhancement in the examined specimens is explained by the difference between the optical characteristics in the near-surface layer and the bulk of the material: the complex refractive indices in the near-surface layer, $\tilde{n}_s = n_s + i\chi_s$, and in the material bulk, $\tilde{n}_v = n_v + i\chi_v$, become different.

1. P.O. Gentsar, O.I. Vlasenko, S.M. Levytskyi, I.B. Yanchuk, S.P. Lavoryk. Influence of laser radiation on optical properties of thin $Ge_{1-x}Si_x$ near-surface layers. *Fiz. Khim. Tverd. Tila* **15**, 303 (2014) (in Ukrainian).
2. P.O. Gentsar, O.I. Vlasenko, S.M. Levytskyi, V.A. Gnatyuk. Laser-stimulated enhancement of semiconductor reflectance. *Fiz. Khim. Tverd. Tila* **15**, 856 (2014) (in Ukrainian).
3. P.O. Gentsar, S.M. Levytskyi. Laser-stimulated processes in semiconductors. *Khim. Fiz. Tekhnol. Poverkhni* **7**, 186 (2016) (in Ukrainian).
4. P.Y. Yu, M. Cardona. *Fundamentals of Semiconductors: Physics and Materials Properties* (Springer, 2010).
5. V.A. Tyagai, O.V. Snitko. *Electroreflection of Light in Semiconductors* (Naukova Dumka, 1980) (in Russian).
6. A.M. Yevstigneev, O.V. Snitko, L.V. Artamonov, P.A. Hentsar, A.N. Krasiko. Surface contribution to electroreflection effect and its separation using polarization anisotropy. *Ukr. Fiz. Zh.* **31**, 756 (1986) (in Russian).
7. V.I. Gavrilenko, A.M. Grekhov, D.V. Korbutyak, V.G. Litovchenko, *Optical Properties of Semiconductors: A Handbook* (Naukova Dumka, 1987) (in Russian).

Received 27.08.17.
Translated from Ukrainian by O.I. Voitenko

П.О. Генцарь, О.І. Власенко, С.М. Левицький

ЛАЗЕРНО-СТИМУЛЬОВАНЕ ЗБІЛЬШЕННЯ ВІДБИВАЮЧОЇ ЗДАТНОСТІ МОНОКРИСТАЛІЧНОГО n-GaAs(100)

Резюме

У даній роботі представлені результати оптичних досліджень спектрів відбиття монокристалів n-GaAs(100) з питомим опором 10 Ом·см (при кімнатній температурі) в діапазоні 0,2–1,7 мкм до та після лазерного опромінення в інтервалі енергій 66–108 мДж/см^2. Експериментально показано збільшення відбиваючої здатності досліджуваних кристалів при даній лазерній обробці. Даний інтегральний ефект пояснено відмінностями оптичних характеристик приповерхневого шару та об'єму матеріалу (комплексний показник заломлення приповерхневого шару $\tilde{n}_s = n_s + i\chi_s$ відрізняється від комплексного показника заломлення об'єму матеріалу $\tilde{n}_v = n_v + i\chi_v$).