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Influence of Laser Radiation on Optical Properties of Semiconductor Materials

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In this paper, the transmission and reflection spectra of n-Si(100) single crystals are measured; n-GaAs(100); solid solutions of $Ge_{1-x}Si_x$ (x = 0.85) in the range (0.2 - 1.7)·10^{-6} m before and after laser irradiation at the wavelength λ = 532 nm. It is established that the main mechanism of influence of pulsed laser irradiation on the optical properties of thin surface layers of the investigated crystals is structural gettering, that is, the absorption due to the presence of sections of semiconductors that have a defective structure and have the ability to actively absorb defects and points.

Key words: transmission, reflection, absorption, laser irradiation, n-Si(100), n-GaAs(100), $Ge_{1-x}Si_x$.

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Introduction

Due to the intensive development of semiconductor material science, including nanophysics and nanoelectronics, study of electronic phenomena, that manifest themselves in the optical spectra of the surface layers and the volume of functional electronic materials is relevant. As you know, there are many ways of surface treatment of functional materials of electronic engineering - ion bombardment, laser irradiation or film deposition. This leads to changes, in particular, of the electrical and optical properties of the material, which is important for the production of electronic devices of today. Recently, laser irradiation has been used very successfully for surface treatment (surface layers). Semiconductors Si, GaAs, solid solutions Ge1-hSih are basic materials micro and nanoelectronics, namely on the basis produced a number of transducers and detectors of various types of radiation.

To date, the main problem in the technology of manufacturing semiconductor sensor structures is the processing of the crystal surface and the formation of electrical contacts, as well as the creation of metal-semiconductor contacts with specified properties. Surface treatment plays a major role in the manufacture of detectors, since the surface properties of crystals affect many aspects of the structure's efficiency and operation, such as the maximum of applied voltage, often limited by surface conductivity. Irradiation of crystals with nanosecond laser pulses can change the structure and morphology of the surface. In order to control the state of the surface, optical spectra (transmittance and reflection) were measured before and after laser irradiation. Spectroscopy is one of the effective methods that are very sensitive to changes in the surface condition, system defects and energy band structure of semiconductors.

In this paper, the transmission and reflection spectra of n-Si(100) single crystals with specific resistivity ρ = 5 Ω·cm are measured to elucidate the mechanisms of the influence of pulsed laser irradiation on thin surface layers of semiconductors; n-GaAs with a resistivity ρ = 10 Ω·cm; solid solutions $Ge_{1-x}Si_x$(x = 0.85) in the range (0.2 - 1.7)·10^{-6} m before and after laser irradiation in the energy range 66 - 108 mJ/cm^2 for n-Si(100) and n-GaAs, in the energy range 46.6 - 163.5 mJ/cm^2 for solid solutions $Ge_{1-x}Si_x$ (x = 0.85).

Studying the mechanisms of laser irradiation is important for the further progress of laser technology. There are mechanisms of thermal and non-thermal nature (shock, photochemical and plasma mechanisms of laser processing). The thermal mechanism of laser treatment is in most cases the main mechanism of action of laser radiation. The mechanisms of non-thermal nature of the action of pulsed laser radiation on semiconductor materials include the following: ionization mechanism; mechanism of non-radiative recombination; mechanism of radiative recombination; shock wave mechanism (structural gettering).

Methods of laser gettering will allow to avoid additional defects of the crystal and to create the necessary configuration of the deformation field (local sections) [1-3].

I. Experimental results and their discussion

The test specimens were subjected to mechanical treatment (cutting, grinding, polishing) followed by chemical treatment. In the next step, the samples were laser-treated, namely, the crystal surface was uniformly irradiated at room temperature (T = 300 K), with pulses of neodymium laser radiation (λ = 532 nm) of nanosecond duration (τ = 7-8 ns) with different energy densities.

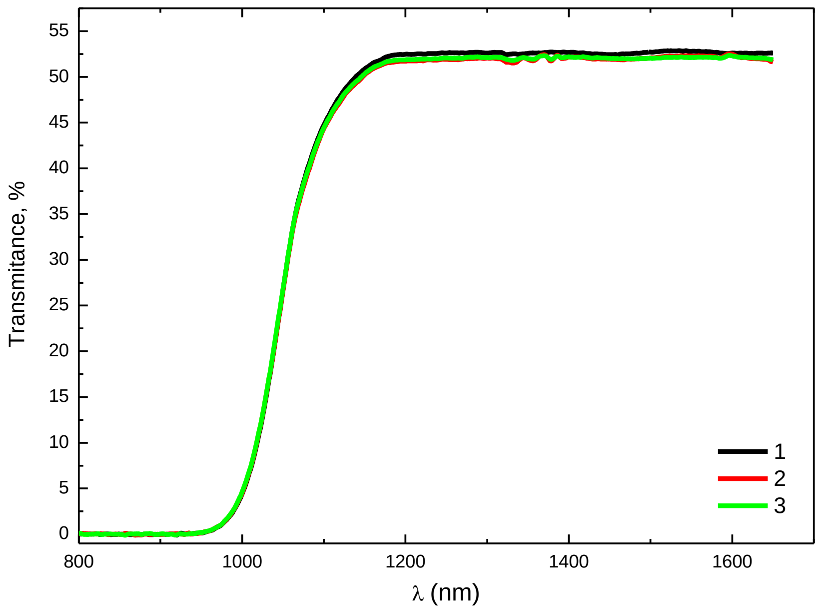

Fig. 1. Transmission spectra of single crystals n-Si(100): original sample is curve 1 and the samples are irradiated with energy of 66 mJ/cm^2; 108 mJ/cm^2 - curves 2, 3 respectively.

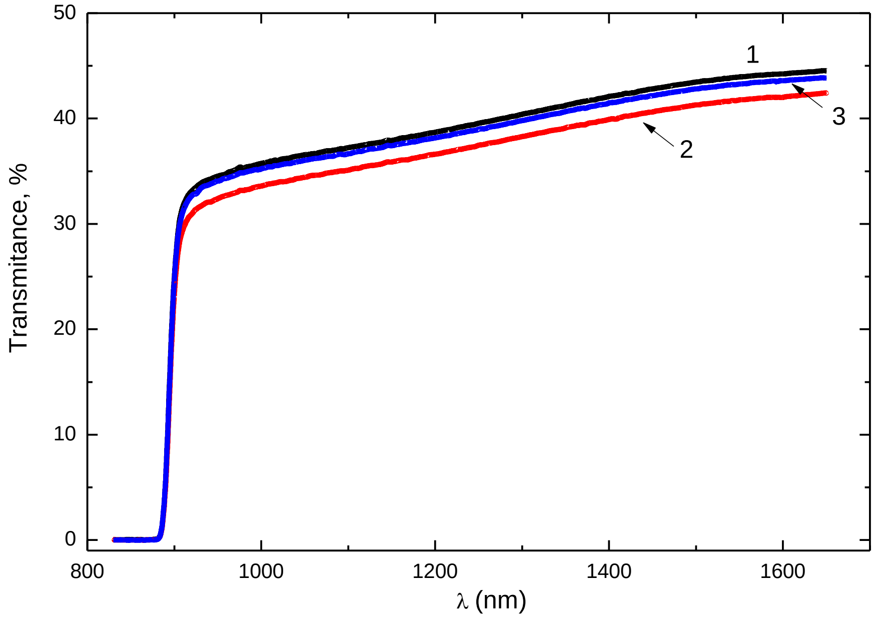

Fig. 2. Transmission spectra of single crystals n-GaAs(100): original sample is curve 1 and the samples are irradiated with energy of 66 mJ/cm^2; 108 mJ/cm^2 - curves 2, 3 respectively.

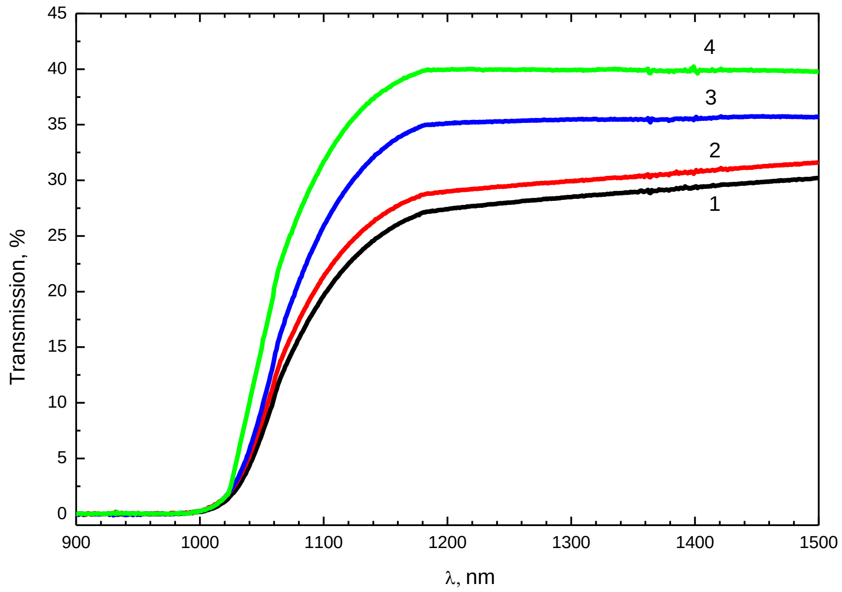

Fig. 3. Transmission spectra of solid solutions $Ge_{1-x}Si_x$(x = 0.85): original sample is curve 1 and the samples are irradiated with energy of 46.66 mJ/cm^2; 102.3 mJ/cm^2, 163.5 mJ/cm^2 - curves 2-4 respectively.

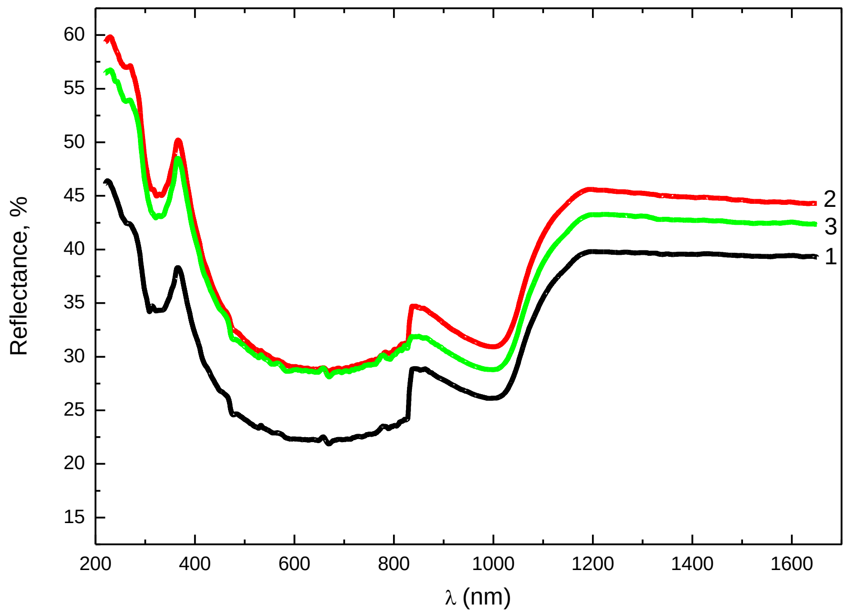

Fig. 4. Reflection spectra of single crystals n-Si(100): original sample is curve 1 and the samples are irradiated with energy of 66 mJ/cm^2; 108 mJ/cm^2 - curves 2, 3 respectively.

In Fig. 1-3 shows the optical transmission spectra of $T = f(\lambda)$ single crystals of n-Si(100) with a specific resistance of 5 Ω·cm, of single crystals n-GaAs(100) with a specific resistance of 10 Ω·cm (original sample is curve 1 and the samples are irradiated with energy of 66 mJ/cm^2; 108 mJ/cm^2 - curves 2, 3 respectively) and solid solutions $Ge_{1-x}Si_x$(x=0.85) (original sample is curve 1 and the samples are irradiated with energy of 46.66 mJ/cm^2; 102.3 mJ/cm^2, 163.5 mJ/cm^2 - curves 2-4 respectively). As can be seen from the figures for single crystals of n-Si(100) and n-GaAs(100), the transmittance does not decrease significantly after laser treatment. At the same time, the transmittance of the solid solution $Ge_{1-x}Si_x$(x = 0.85) increases with increasing laser energy density (Fig. 3).

In [4-6] it was observed that the spectra of optical reflection (Figs. 4, 5) of single crystals of n-Si(100) and n-GaAs(100) showed that laser-stimulated increase of the reflectivity of these semiconductors materials (the integral effect is explained by the differences in the optical characteristics of the surface layer and the volume material, that is, the complex refractive index of the surface layer $\tilde{n}_s = n_s + i\chi_s$ is different from the complex refractive index of the volume material $\tilde{n}_v = n_v + i\chi_v$).

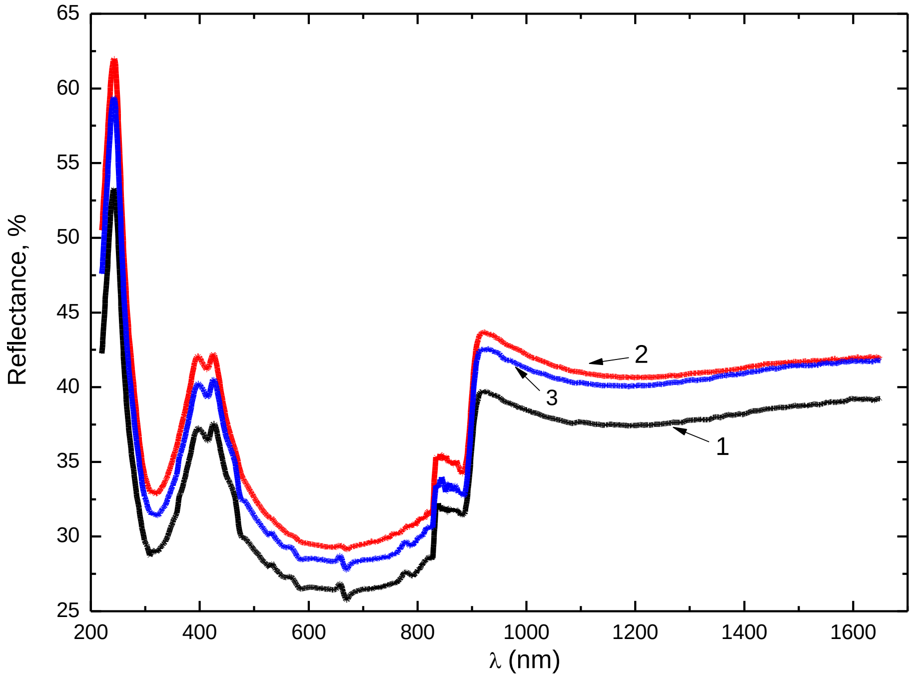

Fig. 5. Reflection spectra of single crystals n-GaAs(100): original sample is curve 1 and the samples are irradiated with energy of 66 mJ/cm^2; 108 mJ/cm^2 - curves 2, 3 respectively.

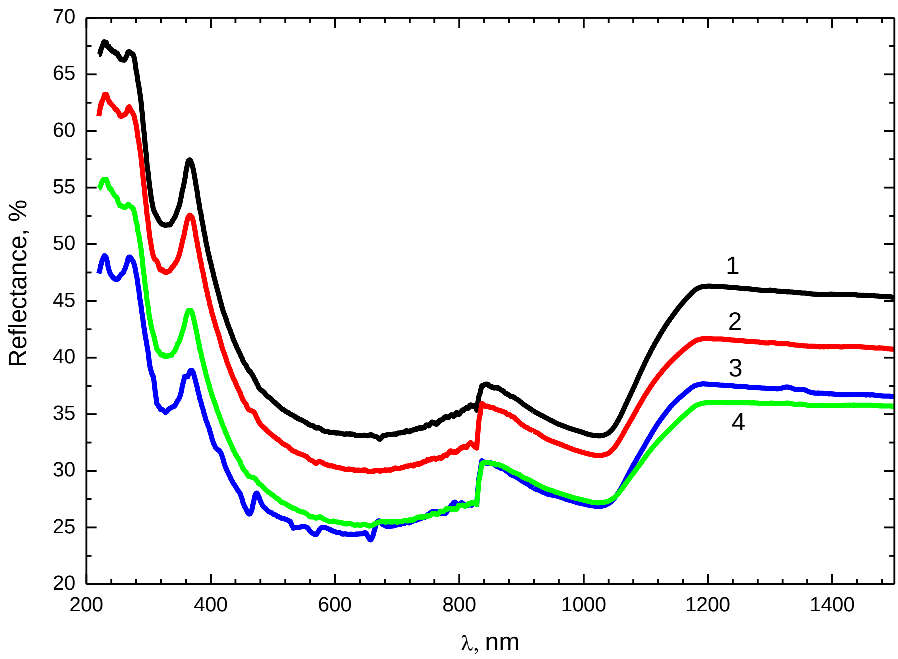

Fig. 6. Reflection spectra of solid solutions $Ge_{1-x}Si_x$(x = 0.85): original sample is curve 1 and the samples are irradiated with energy of 46.66 mJ/cm^2; 102.3 mJ/cm^2, 163.5 mJ/cm^2 - curves 2-4 respectively.

In [5, 7], it was shown that in the region of the fundamental optical transition E_0 of a solid solution of $Ge_{1-x}Si_x$(x=0.85) the reflectivity decreases and the transmittance increases with the increase of laser irradiation, ie it is shown that structural changes occur during irradiation of the surface (surface layer) of a solid solution of $Ge_{1-x}Si_x$(x=0.85), while the refractive index of the surface layer becomes smaller than the refractive index of the solid solution (Figs. 3, 6).

Since the reflection coefficient $R = f(\lambda)$ is related to the transmittance $T = f(\lambda)$ and the absorption coefficient $D = f(\lambda)$ by the ratio $R+T+D=1$ (thus the scattering of the light wave in the sample is not taken into account), the absorption spectra $D=1-(R+T)$ of the light (electromagnetic) wavelength λ are also constructed in this paper.

The constructed optical absorption spectra $D = [1-(T+R)] = f(\lambda)$ of these materials are completely

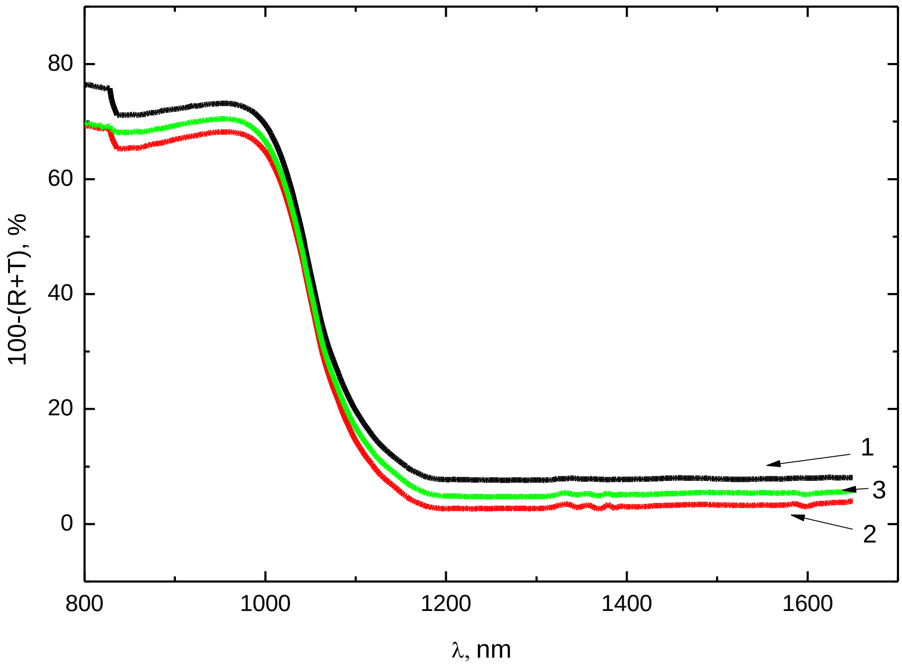

Fig. 7. Absorption spectra of single crystals n-Si(100): original sample is curve 1 and the samples are irradiated with energy of 66 mJ/cm^2; 108 mJ/cm^2 - curves 2, 3 respectively.

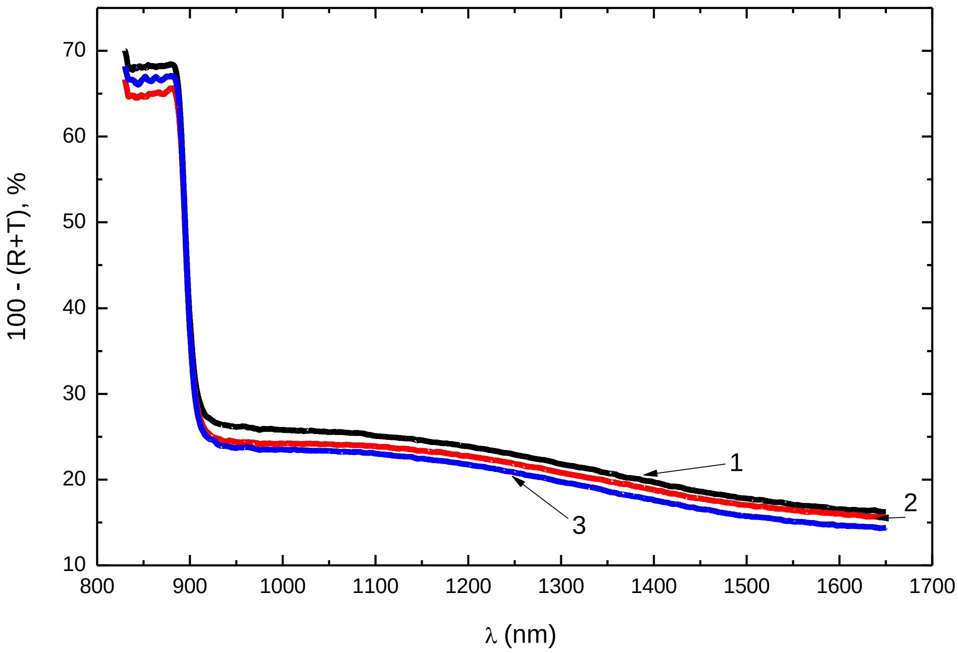

Fig. 8. Absorption spectra of single crystals n-GaAs(100): original sample is curve 1 and the samples are irradiated with energy of 66 mJ/cm^2; 108 mJ/cm^2 - curves 2, 3 respectively.

correlated with the optical transmission spectra $T = f(\lambda)$ and the reflection $R = f(\lambda)$. From the absorption spectra (Fig. 7-9) of the material shows that the lower energies, ie at the energies of light (electromagnetic) waves E which is much lower than the fundamental optical transition energy E_0, these materials absorption is minimal. At energies E, they are commensurate with the fundamental optical transition energy E_0, ie $E \leq E_0$, the absorption increases and reaches the maximum value.

Based on the Heisenberg uncertainty principle for energies E and time t ($\Delta E \cdot \Delta t \geq \hbar$), the relaxation effects in light absorption by a crystal are described by the expansion parameter $\Delta E = \hbar / \tau$ (the broadening of the electronic transition E_0 is related to the free charge

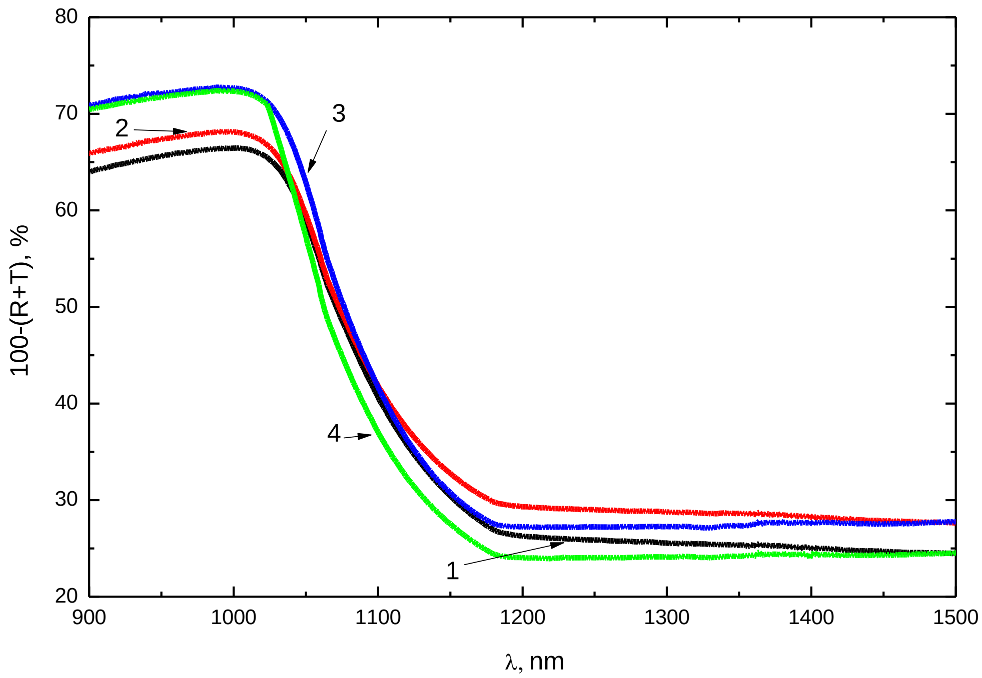

Fig. 9. Absorption spectra of solid solutions $Ge_{1-x}Si_x$(x = 0.85): original sample is curve 1 and the samples are irradiated with energy of 46.66 mJ/cm^2; 102.3 mJ/cm^2, 163.5 mJ/cm^2 - curves 2-4 respectively.

carrier life due their interaction with lattice vibrations, impurities, defects including surface character), where τ is the time of energy relaxation of the photo-generated steam.

According to the experimental data on the optical transmission and reflection spectra (Figs. 1 - 6) for single crystals n-Si(100) with a resistivity of 5 5 Ω·cm; single crystals of n-GaAs(100) with a resistivity of 10 Ω·cm; solid solutions $Ge_{1-x}Si_x$(x=0,85) the energy expansion of the optical spectra of these materials is 0.152 eV; 0.074 eV; 0.189 eV, respectively. Energy relaxation time of photogenerated pairs τ for single crystals n-Si(100); n-GaAs(100) and solid solutions $Ge_{1-x}Si_x$(x=0,85) is equal to $4.330 \cdot 10^{-15}$ s; $8.895 \cdot 10^{-15}$ s and $3.483 \cdot 10^{-15}$ s respectively.

The energy broadening of optical spectra (transmission, reflection) for single crystals of n-GaAs(100) is 0.074 eV. This numerical value is much smaller than for single crystals n-Si(100) equal to 0.152 eV and for solid solutions $Ge_{1-x}Si_x$(x = 0,85) equal to 0.189 eV. This is due to the fact that the GaAs semiconductor is a direct-gap semiconductor, and the semiconductor materials Si, $Ge_{1-x}Si_x$(x = 0.85) ($Ge_{1-x}Si_x$(x = 0.85) - acquire a silicon structure, as evidenced by optical the reflection spectra (Fig. 6) of this material) are non direct-gap. In non direct-gap semiconductors, both photons and quasiparticles of phonons are involved in the electronic optical transition E_0. It should be noted that in addition to solid solutions, additional mechanisms of scattering of light (electromagnetic) waves occur.

According to the literature data [8-10], the oxide coatings of the surfaces of the investigated materials are amorphous films, the thickness of which ranges from 0.5 to 0.7 nm. It should be noted that at the interface of the semiconductor-oxide there is a transition layer of oxide.

Conclusions

Experimental studies have shown that the main mechanism of influence of pulsed laser irradiation on the optical properties of thin surface layers of the investigated crystals is structural gettering, that is, the absorption due to the presence of sections of semiconductors that have a defective structure and have the ability to actively absorb defects. In silicon, the role of the heter is played by the surface layers of SiO_x, SiO_2, Si_3N_4, $SiO_{2-x}P$, SiC and others, in Germany - GeO_2 or GeO, in gallium arsenide - Ga_2O_3, As_2O_5 and others.

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Вплив лазерного опромінення на оптичні властивості напівпровідникових матеріалів

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В даній роботі поміряно спектри пропускання та відбивання монокристалів n-Si(100); n-GaAs(100); твердих розчинів $Ge_{1-x}Si_x$ ($x = 0,85$) в діапазоні $(0,2 - 1,7)\cdot 10^{-6}$ м до та після лазерного опромінення на довжині світлової хвилі $\lambda = 532$ нм. Встановлено, що основним механізмом впливу імпульсного лазерного опромінення на оптичні властивості тонких приповерхневих шарів досліджених кристалів є структурне гетерування, тобто поглинання, обумовлене наявністю ділянок напівпровідників що мають дефектну структуру і володіють здатністю активно поглинати точкові дефекти і зв'язувати домішки.

Ключові слова: пропускання, відбивання, поглинання, лазерне опромінення, n-Si(100), n-GaAs(100), $Ge_{1-x}Si_x$.