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DEEP LEVELS IN Ga_2Se_3/GaP (111) HETEROSTRUCTURES

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Deep levels in GaP near Ga_2Se_3/GaP (111) heterostructures interface were investigated by deep level transient spectroscopy, capacitance-voltage characteristics and photoluminescence methods. For the first time a decrease in concentration of charge localization levels due to GaP surface selenium vapor processing has been found. The values of the activation energy and capture cross sections of deep levels in Ga_2Se_3/GaP heterostructures have been determined.
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1. Introduction

Gallium phosphide (GaP) is widely used for the manufacture of optoelectronics and photonics devices. Its use in light-emitting structures and photo detectors imposes a number of requirements on the quality of the heterojunction, such as a low concentration of defects and non-radiative recombination rate near the surface region; the ability to control the potential barrier height; the stability of the material properties and the surface protection against environmental influences. The structural and phase transformations on GaP (111) surface after heat treatment in selenium vapor were studied in [1], where the formation of a Ga_2Se_3 (111) ($\sqrt{3}\times\sqrt{3}$) - R30° surface phase with ordered stoichiometric gallium vacancies was found. The aim of this work is to study the deep levels (DL) parameters in Ga_2Se_3/GaP (111) heterostructures by deep level transient spectroscopy (DLTS) and photoluminescence (PL) methods. The appearance of the Schottky barrier height dependence on the metal work function was found by the capacitance-voltage (C-V) method. This indicates a surface-state density reduction and the Fermi level unpinning on the GaP(111) surface after heat treatment in selenium vapor. However, the reduction of DL concentration was only qualitatively shown by DLTS.

2. Experimental

We used an n-type n-GaP (111) substrates with (400 ± 50) μm thickness and a carrier concentration of $2\cdot10^{18}$ cm^{-3}. GaP (111) substrates were prepared by chemical-dynamic polishing in a $K_3[Fe(CN)_6]$ and KOH aqueous solution. Me/GaP and Me/Ga_2Se_3/GaP, heterostructures obtained by thermal vacuum deposition of aluminum (Al) and gold (Au) contacts on the surface of GaP before and after the treatment in selenium vapor (GaP substrate temperature – (675 ± 1) K, the partial pressure of selenium vapor – 1.5 Pa, time of processing – 600 s). Samples have been studied by DLTS and C-V methods. Also, PL spectra of Ga_2Se_3/GaP heterostructures and original GaP substrates surface were measured at 300 K.

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3. Results and discussion

The results of the C-V studies with test signal frequencies of 10^4, 10^5 and 10^6 Hz are shown in the Table 1. The absence of the potential barrier height Φ_B dependence from the metal electron work function in the diode Me/GaP structures is determined by the Fermi level pinning at the surface and corresponds to the values known from the literature: 1.07 eV for the Al and 1.3 eV for the Au contacts [2]. Reducing of the test signal frequency on the C-V examinations leads to a change of volt-farad parameters values obtained from the reverse-bias C^{-2}-V curves: increases Φ_B and decreases donor concentration which determines the concentration of free charge carriers on the semiconductor depletion and quasi-neutral regions boundary (N_d). Probably, this effect is associated with the DL action in the spatial charge region of the barrier structure. In the diode Me/Ga_2Se_3/GaP structures, formed after processing in selenium vapor, Φ_B value strongly depends on the metal electronic work function (Φ_{Al} =4.2 eV, Φ_{Au} = 5.2 eV) in comparison with the initial Me/GaP structure. The difference in the work function values $\Phi_{Au} - \Phi_{Al}$ = 1 eV is comparable with Φ_B difference of barrier height in Ga_2Se_3/GaP - based structures with Al and Au contacts. It shows a charge localization levels density reduction and the Fermi level unpinning on the GaP surface as a result of processing in selenium vapor.

Table 1. Schottky barrier heights (Φ_B) and donor concentrations (N_d) obtained from the reverse-bias C^{-2}-V curves at different test frequencies for heterostructures Me/GaP and Me/Ga_2Se_3/GaP

Heterostructure type	Frequency, Hz	10^6		10^5		10^4	
	Metal of contact (Me)	Φ_B, eV	N_d, 10^{18} sm^{-3}	Φ_B, eV	N_d, 10^{18} sm^{-3}	Φ_B, eV	N_d, 10^{18} sm^{-3}
Me/GaP	Al	1,03	1,7	1,39	0,3	1,55	0,6
	Au	1,39	1,2	1,77	0,3	1,42	0,2
Me/Ga_2Se_3/GaP	Al	0,56	0,9	0,75	0,5	0,85	0,6
	Au	1,56	0,9	1,98	0,3	2,1	0,4

DLTS study of Au/GaP and Au/Ga_2Se_3/GaP heterostructures confirmed the results obtained from the C-V analysis. DLTS spectra comparison presented in Fig. 1 shows a significant decrease in the DL concentration near the GaP surface after its processing in selenium vapor. The initial Au/GaP structure is characterized by a continuous spectrum, having a large amplitude DLTS signal throughout the entire scanning temperature interval. This indicates a high surface deep levels concentration in the forbidden band of the semiconductor. The absence of clearly defined peaks in the DLTS spectrum is associated with the signal overlay from multiple DL with similar energies. Consequently, it is impossible to determine uniquely the parameters of levels in the initial Au/GaP structure. In the spectrum of Au/Ga_2Se_3/GaP structures there are three peaks, corresponding to the donor-type states, and one minimum corresponding to the acceptor-type trap. From the analysis of DLTS spectra, activation energies and capture cross sections of deep levels shown in Fig. 1 were identified. Electronic trap with an activation energy E_1 = 0.34 eV also was found in [3], based on the analysis of differential coefficients of the current-voltage characteristics and the thermo-stimulated capacity in light-emitting GaP based diodes. Its activation energy value varies depending on the method of investigation in the range of 0.30 to 0.35 eV. A deep level with an activation energy E_2 = 0.45 eV may be associated with a defect complex, including V_{Ga}-V_P divacancy [4,5]. A deep level with an activation energy E_3 = 0.27 eV was recorded in some studies [3,5,6]. However, we received the value of the capture cross section 4-5 orders of magnitude lower than those already stated by the above-mentioned authors. Whereas this maximum in the DLTS spectrum appears at a higher temperature than would follow from the literature data. Acceptor trap with an activation energy E_A = 0.74 eV is well known and determines the non-radiative recombination in GaP. The model of corresponding complex defect $V_PV_{Ga}Ga_PV_P$ is

discussed in detail in [6]. The concentration of acceptor levels near E_A = 0.74 eV is maximal in epitaxial layers grown at high temperature [7]. It is associated with a shift of the stoichiometric composition of the growing layer towards greater concentration of Ga atoms, which leads to the appearance of an excess of phosphorus vacancies V_P and antistructural Ga_P type defects [8].

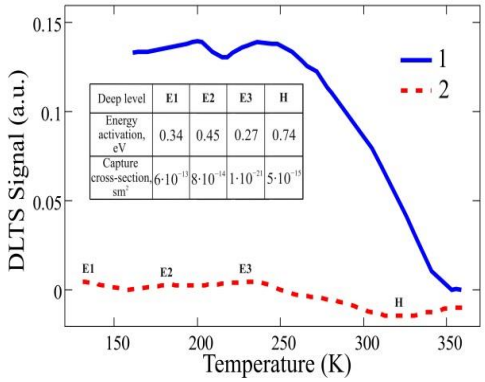

Fig. 1. DLTS spectrums for Au/GaP heterostructure (line 1) u Au/Ga_2Se_3/GaP heterostructure (line 2) were taken under the experimental conditions of a reverse bias of –1 V and a filling pulse of +3V with 5 ms duration. DL parameters insert on picture.

Comparison of PL spectra (Fig. 2) and DLTS spectra (Fig. 1) allows us to make an assumption about the correlation between electron trap activation energy values and positions of the maximums on the PL spectrum. The observed almost tenfold decrease in the photoluminescence intensity of these peaks in the PL spectrum also shows a decline in the concentration of the corresponding deep levels. In our opinion, more than twofold intensity of the main peak decrease, corresponding to interband transitions of electrons, is due to the presence of a narrow-band window on the surface of GaP as a thin layer of gallium selenide, whose forbidden band width is about 1.8 eV. Therefore, there may be a probability of absorption of photons emitted by the film whose energy is greater than the width of the forbidden zone of the Ga_2Se_3 film.

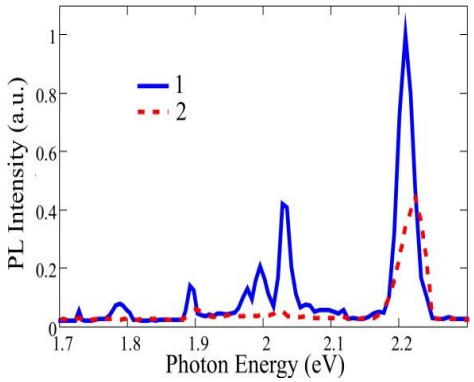

Fig. 2. PL spectrums for Au/GaP heterostructure (line 1) and Au/Ga_2Se_3/GaP heterostructure (line 2).

4. Conclusions

Thus, the data show a decrease in the concentration of defects and corresponding DL in the near-surface GaP region due to the treatment of its surface in the selenium vapor. The activation energies and the capture cross sections of these centers are determined.

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