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CHARACTERIZATION OF INTERFACE DEEP LEVELS IN AS VAPOR GROWN EPI-GaAs

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In this work vapor phase epitaxial GaAs structures are investigated by the method of transient acoustoelectric spectroscopy. At the interface between a substrate and epilayer we identified four types of defects (EL3, EL5, EL6, EL17). We have measured the cross section for electron capturing, relaxation times of trapped charge and energetic levels in forbidden zone for said defects.

Keywords: A. semiconductors, B. epitaxy, D. electronic states (localized), D. recombination and trapping, E. ultrasonics.

1. INTRODUCTION

Semiconductor electrical properties are largely determined by their defects. Especially it is impotent for epitaxial structures, for which, on the one hand, the interfaces play a prevailing role and on the other the defects quantity is especially great on the boundaries. Numerous experimental methods are in use to study defects in semiconductors. The classical techniques, such as DLTS, photoconductivity, luminescence and C–V measurements, are reliable for the investigating defects in a volume and immediately at a surface [1]. The modern new methods, such as SPM, STM, allow to investigate a surface and its defects carefully. Especially, the properties of GaAs structures surface are under intensive study [2–5]. The deep levels at the internal boundary (interface) of the epitaxial structures layer-substrate can be characterized using transient acousto-electric spectroscopy [4, 5] only. In this work, for the first time, the epitaxial structures based on vapor grown GaAs are characterized.

2. METHOD OF TRANSIENT ACOUSTOELECTRIC SPECTROSCOPY

Transient acoustoelectric spectroscopy bases itself on the measurements of the direct transverse acoustoelectric voltage (TAV). Such voltage will arise due to non-linear acoustoelectric interaction if the surface acoustic waves propagate in a substrate of a system piezoelectric-semiconductor. This voltage is "transverse" to the plane of the ultrasonic wave propagation. One mechanism of such voltage origin is connected with the free charge carrier redistribution by the piezoelectric fields, penetrated into the semiconductor. Simultaneously, the existence of these fields results an alteration of the concentration of the carriers, trapped by the surface levels. The electric fields penetration depth is determined by effective Debye length, which in turn depends on a surface zones bending [6]. The characteristics of TAV connected with the second mechanism, are immediately determined by the properties of these levels. This fact allows to characterize said defects by an analysis of the TAV.

If ultrasound action is turn off, the free charge carrier TAV disappears practically instantly (about microseconds). If there are n types of traps at the interface, the falling part of "trapped" TAV signal can be interpolated by a sum of n exponential functions [4, 5]:

$$\mathrm{TAV}(t) = \sum_{i=1}^{n} \mathrm{TAV}_{oi} \exp(-t/\tau_i), \tag{1}$$

where TAV_{oi} is the voltage component due to trapping center of i-type. The transient time constants τ_i can be about milliseconds and more. Said time τ_i is known to depend on the position of center energy level (E_{ti}) in the forbidden zone and the center's trapping cross section, S_i:

$$\tau_i = \frac{1}{S_i V_T N_c} \exp\left(\frac{E_c - E_{ti}}{kT}\right) \tag{2}$$

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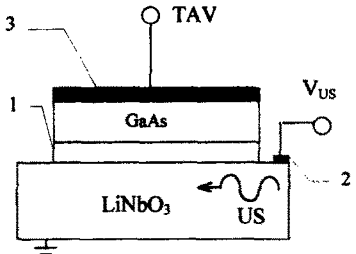

Fig. 1. Acoustoelectric system for measurements of TAV signal. 1 – epitaxial layer; 2 – electrode for ultrasound (US) excitation; 3 – registering electrode.

where V_T represents the carrier thermal velocity, N_c is the effective density of states at the bottom of the conduction band, E_c – energy position of the conductivity band bottom.

The TAV kinetic at a layered system piezoelectric-semiconductor is measured experimentally. The scheme of the TAV measurement is shown on the Fig. 1. The relaxation times τ_i were determined by interpolating the experimental data according to the equation (1) by means of a special program which minimized the errors.

If one knows τ only, he can not determine S and E_t. Some additional researches are necessary. For example, it is possible to study the temperature dependence of relaxation time τ. So the voltage amplitudes of the normalized TAV signal falling segment vs temperature are shown on Fig. 2.

The temperature dependencies of N_c and V_T for the nondegenerate semiconductor are well known: $N_c \sim T^{3/2}$, $V_T \sim T^{1/2}$. It is shown [7], that for attracting Coulomb centers at the room temperature $S \sim T^2$. Thus:

$$N_c(T)V_T(T)S_i(T) \approx \mathrm{const}(T) \tag{3}$$

Even if this ratio is not observed precisely, the first multiplier in equation (2) has a much weaker temperature dependence rather the second and it can be neglected for the enough deep levels ($E_c - E_t \gg kT$) and the small temperature changes. Therefore, the determination of τ_i for two different temperatures T_1 and T_2 permit to calculate E_t by formula (3):

$$E_c - E_{ti} = \frac{kT_2 \ln(\tau_i(T_1)/\tau_i(T_2))}{(T_2/T_1) - 1}. \tag{4}$$

One can enhance a precision of E_t determination by using a plot of $\ln \tau$ on T^{-1}, if the experiments are done in some temperature range. Further, calculation by formula (4) gives E_t:

$$\ln[\tau(T)] = (E_t/kT) + \mathrm{const}. \tag{5}$$

Knowing the characteristic relaxation times of the excess charge τ_i and the energy levels of the interface centers E_{ti}, we can calculate the effective capture cross section S_i for these levels by using equation (2).

3. RESULTS AND DISCUSSION

The structure of n-GaAs epi-layer on n-GaAs were used in the experiments. They were fabricated by an industrial vapor phase epitaxy method in the system Ga-$AsCl_3$-H_2. The substrate, 0.35 mm thick, was doped by Te with $N_{Te} \approx (1\text{–}2) \times 10^{18}$ cm^{-3}. The free carrier concentration of the epi-layers, doped by Te too, 6–9 microns thick for different samples, was $(0.6\text{–}1.2) \times 10^{15}$ cm^{-3}.

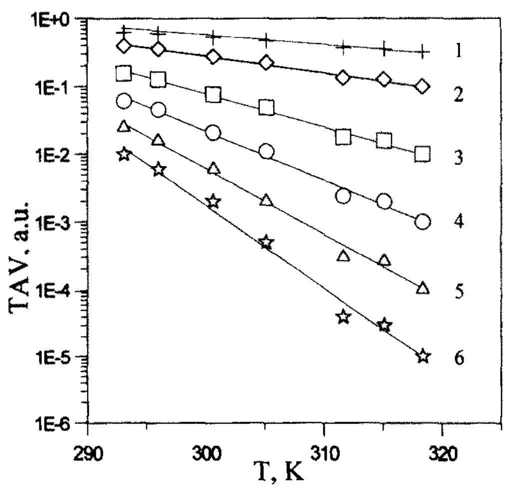

Fig. 2. Voltage amplitudes of the normalized TAV signal falling segment vs temperature at various times Δt after ultrasound switched of. For curve 1 – $\Delta t = 0.5$ ms; 2 – $\Delta t = 1$ ms; 3 – $\Delta t = 2$ ms; 4 – $\Delta t = 3$ ms; 5 – $\Delta t = 4$ ms; 6– $\Delta t = 5$ ms.

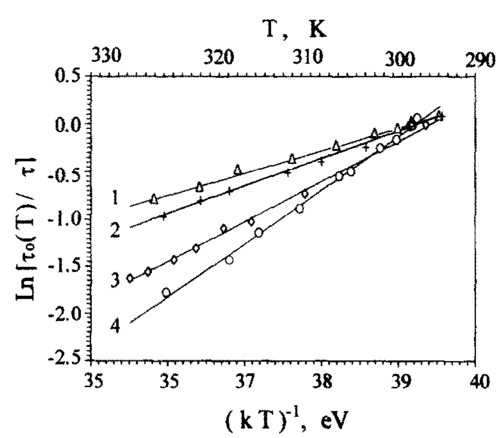

Fig. 3. Dependency of τ on T^{-1}. At room temperature the relaxation time τ is equal to 2.2 ms for the plot 1, 1.0 ms plot 2, 22 ms plot 3 and 1.7 ms plot 4. The slopes of plots 1 2, 3 and 4 give four levels E_1, E_2, E_3, E_4, respectively.

Table 1. Parameters of deep levels. ($T = 295$ K)

Level	τ, ms	S, cm^2	$E_c - E_t$, eV	Type
E_1	2.2 ± 0.2	$(0.7 \pm 0.1) \times 10^{-18}$	0.23 ± 0.02	EL17
E_2	1.0 ± 0.1	$(1.6 \pm 0.2) \times 10^{-17}$	0.29 ± 0.02	EL6
E_3	22 ± 2	$(1.4 \pm 0.2) \times 10^{-16}$	0.42 ± 0.02	EL5
E_4	1.7 ± 0.2	$(4 \pm 0.5) \times 10^{-13}$	0.56 ± 0.02	EL3

Our measurements were carried out in a temperature range 294 to 330 K. Four deep levels, which were designated as levels $E_{1,2,3,4}$, were detected at the samples under study. Figure 3 represents experimental results on temperature dependence of four different time τ_i. The determinated characteristic parameters of said centers are presented in Table 1. All calculation were done with the help of experimental data of the Figs 2 and 3 and formulas (1, 2, 5).

The identification of deep levels $E_1 - E_4$ can be carried out on a base of a literary data. The characteristics coincidence of E_4 level and the literacy data [8] allows to say that E_4 is electron center EL3. The configuration As_iV_{Ga} is assigned with this level. Really, the excess of the interstitial arsenic (As_i) and the gallium vacancies (V_{Ga}) should be observed in the GaAs, doped by tellurium. Certainly, the tellurium interstitial (Te_i) can be significant at this case too. It is possible to conclude that level E_1 is EL17 center [7, 8] and E_3 – EL5 center [9]. Level E_2 can be identified as electron center EL6 [11]. All these levels deals with the vacancies of gallium (V_{Ga}) and arsenic (V_{As}) [9–11].

The different GaAs centers are known to be observed in the samples, fabricated by different technique [8]. Epitaxial structures grown by MOCVD engineering have been investigated with the help of transient acousto-electric spectroscopy early [5]. There were found the levels with following parameters: (1) $E_t = 0.54$ eV, $S = 2.5 \times 10^{-13}$ cm^2, $\tau = 2$ ms and (2) $E_t = 0.42$ eV, $S \sim 10^{-15}$ cm^2, $\tau = 22$ ms. They coincide with found in this work levels E_4 and E_3, accordingly.

So, we can summarize new results:

(1) We have discovered that the electronic levels EL3, EL5, EL6 and EL17 are located at the interface GaAs epi-layer structure.

(2) We measured firstly the characteristic relaxation times of trapped charge by said levels EL3, EL5, EL6, EL17 in epitaxial GaAs : Te, grown by chlorine vapor method (see column of τ in Table 1). ($E_c - E_t$) and S for these levels have been determined with the help of transient TAV technique.

(3) The levels EL5 and EL3 can be present in the epitaxial structures grown by chlorine vapor method as well as by MOCVD technique.

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