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Acoustoelectric transient spectroscopy of microwave treated GaAs-based structures

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Abstract. The effects of microwave (2.45 GHz) treatment influence on the cross section for electron capture and the energy of the deep levels in the forbidden gap of GaAs monocrystals and n-n^+ epitaxial structures have been investigated using acoustoelectric transient spectroscopy.

Keywords: microwave treatment, deep level, gallium arsenide.

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1. Introduction

The external factors influence on semiconductors and semiconductor-based structures is widely studied, both to understand degradation processes into semiconductor devices and to find new technological decisions of the such devices fabrication. The influence of some factors, such as radiation, is studied completely enough [1,2]. In recent years, a number of papers are devoted to the new influence methods, such as ultrasonic treatment [3,4] or microwave (MW) electromagnetic irradiation [5–7]. For example, it is shown that MW treatment leads to relaxation of the internal mechanical strain of the Schottky-barrier GaAs structures [5], redistribution of the impurities [5,6], gettering of the point defects [7]. However, information about microwave influence on the structure defect parameters is practically unknown.

In this paper, we present results of investigation MW irradiation influence on the parameters of deep levels located into the under-surface region of n-GaAs monocrystals and GaAs n-n^+ epitaxial structures.

2. Samples and experimental technique

The following three types of samples were investigated in this work:

1) The monocrystal GaAs wafer. The (100) wafer, 300 μm thick, was doped with Sn. The electron concentration was $(1.5\div2.5)\times10^{18}$ cm^{-3} (for the sample labeled as GA1) or $(3\div5)\times10^{16}$ cm^{-3} (sample GA2). The (111) wafer, 300 μm thick, doped with Te, $n = (1\div2)\times10^{18}$ cm^{-3}, labeled GA3;

2) The GaAs epitaxial n-n^+ structures. The Te-doped GaAs epitaxial layer (free carrier concentration was 3.9×10^{15} cm^{-3} for the sample GAE1, 3.5×10^{15} cm^{-3} for GAE2 and 5×10^{15} cm^{-3} for GAE3) grown on monocrystal Te-doped GaAs substrate ($n = 2\times10^{18}$ cm^{-3}). The thicknesses of the layer and the substrate were 6 and 300 μm, respectively.

3) The GaAs:Te epitaxial n-n^+ structures with a buffer layer. The layer, 1 μm thick, $n = 8\times10^{16}$ cm^{-3}, and the layer, 2 μm thick, $n = 7\times10^{15}$ cm^{-3}, grown consistently on (100) GaAs substrate ($n = 2\times10^{18}$ cm^{-3}). The GAB1 and GAB2 samples are made from different wafers.

All investigated epitaxial structures were fabricated using the industrial vapor phase epitaxy method and possessed standard technical characteristics.

Samples were irradiated in free space at the room temperature using magnetron radiation. The microwave frequency was 2.45 GHz, the specific power density was 1.5 W/cm^2. The total treatment time was 20 to 60 seconds for different samples; the influence continuous duration was 5–10 s to avoid sample heating.

The parameters of deep centers (the electron capture cross section σ_n and the energy depth of the electron trap level counted from the edge of conductivity band $(E_C - E_t)$) have been determined before and after the microwave treatment. The method of acoustoelectric tran-

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sient spectroscopy is used [8,9]: the GaAs samples are placed by the epitaxial layer on the piezoelectric plate ($LiNbO_3$ – see Fig.1); during propagation of acoustic waves in the plate, the direct transverse acoustoelectric voltage (TAV) arose in semiconductor samples. After an ultrasonic impulse ending, TAV decreased to zero. This decrease can be interpolated by the exponential function; the characteristic relaxation time τ is known to be determined by parameters of the deep level, located in the near-surface region [8,10]:

$$\tau = (\sigma_n \upsilon_T N_c)^{-1} \exp((E_C - E_t)/kT) \qquad (1)$$

where υ_T represents the free electron thermal velocity; N_c is the effective density of states at the bottom of the conductivity band. The experimental measuring of TAV kinetic at different temperatures allowed to define dependence $\tau(T)$. The angle of the declination of a plot $\ln(\tau)$ on $(kT)^{-1}$ allowed to determine $(E_C - E_t)$ and then to calculate σ_n by using the equation (1).

Our measurements were carried out in the temperature range 290 to 350 K except for GAB1 and GAB2; for these samples TAV appeared after sample heating up to 310 K only.

3. Experimental results and discussion

Fig. 2 represents the typical τ temperature dependencies for the two samples before and after MW irradiation. It is visible, that both the plot slopes (related to $(E_C - E_t)$) and the characteristic relaxation time value changed after the microwave treatment. The other samples dependencies are similar; all results are presented in the Table.

The obtained results have some features. At first, the irradiation influence on the carrier trapping cross section is considerably stronger than the influence on the energy level position. It is confirmed by σ_n can change value by an order as well as, for example, by $(E_C - E_t)$ did not change practically, while σ_n increased by a factor of 4 approximately at GAB1 after 20 s MW influence.

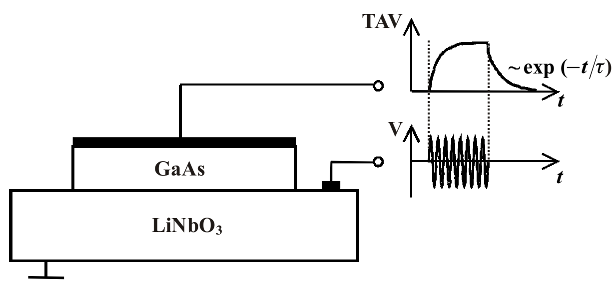

Fig. 1. System for TAV signal measurements. Shown in the insert is the time dependence of the pulse high-frequency (2.6 MHz) voltage V for existing of with ultrasound in the piezoelectric plate and the resulting TAV signal.

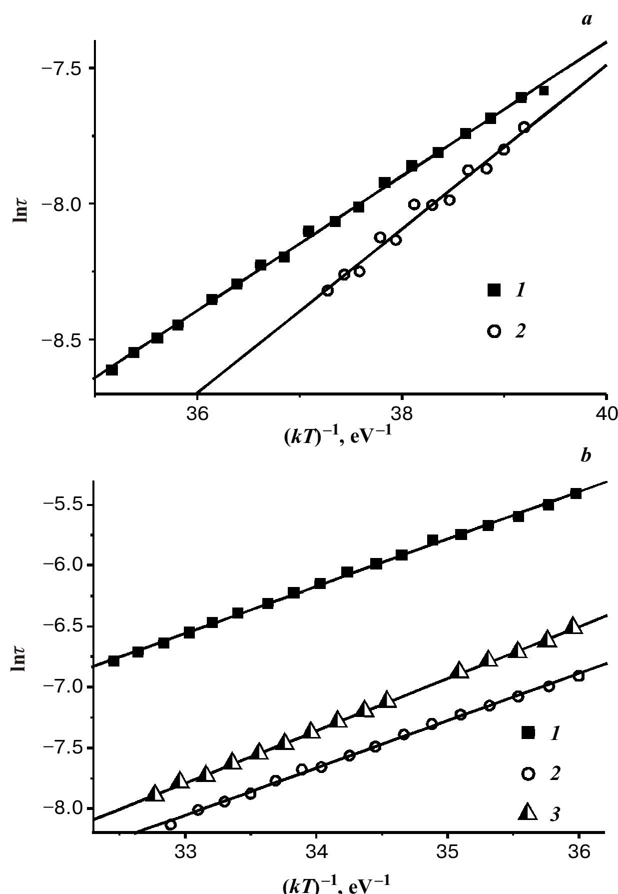

Fig. 2. Temperature dependence of the characteristic TAV relaxation time for the samples GAE2 (*a*) and GAB1 (*b*). The curve 1 corresponds to the unirradiated samples, curves 2–3 – to the irradiated samples. The microwave treatment time is 20 s (curve 2, *b*), 40 s (curve 3, *b*), 60 s (curve 2, *a*).

Secondly, the irradiation dose for a substantial center parameters changing for the epitaxial structures is higher than for monocrystalline samples: it is possible to compare results for the samples of the GA-set and GAB-set after 20 s irradiation. After the repeated 20 s irradiation of the GA sample, the TAV signal diminished considerably and exceed the measuring range. It correlates with data obtained in [7]; this work reports of the decrease in the concentration of the centers with energy level at the forbidden band top half due to microwave annealing. Thirdly, the changes character at the monocrystalline wafers and at the epitaxial structures is different: $(E_C - E_t)$ and σ_n decrease in monocrystals and increase at structures with a buffer layer as well as without it. Finally, the MW stimulated changes degree depend on the free carrier concentration. It is possible to compare results for the GA1 and GA2; these samples differ by the free carrier concentration value only.

It should be noted that although the GaAs levels subjacent a conductivity band bottom on 0.25, 0.31, 0.33,

Table. Parameters of deep levels in GaAs structures before and after the microwave treatment.

Sample	Total time of microwave treatment, s	$(E_C - E_t)$, eV	σ_n^*, cm^2
GA1	0	0.31	3×10^{-17}
	20	0.30	2×10^{-17}
GA2	0	0.33	4×10^{-17}
	20	0.28	6×10^{-18}
GA3	0	0.49	5×10^{-14}
	20	0.4	2×10^{-15}
GAE1	0	0.24	2×10^{-18}
	60	0.29	1×10^{-17}
GAE2	0	0.25	2×10^{-18}
	60	0.30	2×10^{-17}
GAE3	0	0.43	8×10^{-17}
	60	0.46	7×10^{-16}
GAB1	0	0.39	1×10^{-17}
	20	0.39	4×10^{-17}
	40	0.43	1×10^{-16}
GAB2	0	0.40	1×10^{-16}
	20	0.41	1×10^{-16}
	40	0.45	4×10^{-16}

* T=300 K for samples GA1–GA3, GAE1–GAE3, and T=340 K for GAB1 and GAB2

0.43 eV and having a small trapping cross section ($10^{-16}\div10^{-18}$ cm^2) are known in literature (for example, see [11]), but the levels exact atomic configuration is not investigated; they are assumed to relate to the point defects containing an impurity atom. The level $(E_C - E_t) = (0.40\div0.42)$ eV and $\sigma_n = (10^{-15}\div10^{-16})$ cm^2 is usually assigned to the configuration $V_{Ga} - V_{As}$ (EL5 center) [12, 13] .

On our opinion, the changes of the deep level parameters are related to the structural-impurity alteration of a semiconductor near-surface region, caused by microwave treatment. Such alteration is earlier found out in [5-7]. Namely, according to [5,7], defects are gettered in a material surface layer after this MW irradiation. The charged defects concentration increase must result in the electric field strength increase in this region. Simultaneously, the capture cross section of the levels $E_C - 0.33$ eV, $E_C - 0.31$ eV and $\sigma_n = (10^{-17}\div10^{-18})$ cm^2 is known [11] to decrease when the electric field increase. The cross section decrease is observed for the samples GA1-3. If the free carrier concentration is higher, than the charged defect screening is more effective and, consequently, the change of GA1 ($n = 10^{18}$ cm^{-3}) is less significant than that of GA2 ($n = 10^{16}$ cm^{-3}). In addition, the samples with high resistance have the larger "skin-depth" of the microwave penetration [14]. The microwave induced increase of the surface curvature radius and the internal mechanical strain relaxation of n-n^+-GaAs structure near-surface layers were observed in [5]. It takes place due to the separate dislocation origin and their diffusion along sliding planes toward structure depth. Thus, the changing of value of the both electric and mechanical field intensity take place in the near-surface region, and it, on our opinion, results in the deep level alteration and parameter changing. And, if the changes take place due to the linear and point defects spatial moving, then the microwave influence must depend on crystal orientation (see GA1 and GA3, for example).

It is considered in [8,9] that the trap TAV appearance in the epitaxial structures relates to centers at the internal epilayer-substrate boundary (internal surface). The monocrystal TAV is caused by the defects at the external surface. On our point of view, it is this spatial location difference that is the reason of the MW induced changes character difference (point defects move from sample depth toward external surface, dislocation to opposite side) as well as dose the dependence difference for the epitaxial and monocrystalline wafers.

4. Conclusions

The microwave irradiation influence on the electron capture cross section and the energy level of centers in the forbidden gap of n-GaAs monocrystal and n-GaAs-based epitaxial structures has been investigated for the first time. It was found that the deep level parameters are modified, and the character of changes is different for monocrystals and epitaxial structures. The observed changes is likely to be due to gettering the defects in the material surface layer and internal stress relaxation induced by the microwave treatment applied.

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