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Acoustic Wave Corrected Current–Voltage Characteristics of GaAs-Based Structures with Schottky Contacts

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Abstract—The effect of ultrasonic treatment (UST) on the current–voltage (*I–U*) characteristics of Au–TiB_x–n-n^+-GaAs diode structures has been studied. Upon acoustic loading with an intensity below 2 W/cm^2, the character of the UST-induced changes in the reverse branches of *I–U* curves depends on the predominating mechanism of current transfer. UST at a power density above 2.5 W/cm^2 increases the reverse current by one or two orders of magnitude. It is shown that UST favors a significant increase in the homogeneity of the characteristics of devices manufactured using integral heat sink technology.

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In recent years, much attention has been devoted to the effect of ultrasound on the defect structure and electrical properties of semiconductors and related device structures [1–4]. It was established that acoustic oscillations can induce the reconstruction of various defect complexes, stimulate the diffusion of impurities, and cause the transformation of a defect structure of interfaces. However, the elucidation of the mechanisms of the acoustic wave–defect interaction in low-dislocation crystals requires further investigation. An interesting and convenient object for these investigations is offered by structures with Schottky contacts [5]. Indeed, factors influencing the properties of such structures are well known (see, e.g., [6–8]). In addition, these structures are characterized by internal stress fields favoring the manifestation of effects stimulated by the acoustic action [3, 4]. Finally, such investigations can open prospects for the ultrasonic control over the characteristics of devices based on surface barrier structures.

This Letter presents the results of investigations of the effect of ultrasonic treatment (UST) in various intensity and frequency regimes on the current–voltage (*I–U*) characteristics of Au–TiB_x–n-n^+-GaAs diode structures.

The base n-n^+-GaAs structures were grown by means of gas-phase epitaxy and comprised a 3-μm-thick n-GaAs layer on a 350-μm-thick n^+-GaAs substrate. The dopant (Te) concentration in the film and substrate was 6×10^{15} and 6×10^{18} cm^{-3}, respectively. The ohmic contacts were formed using an AuGe eutectic, and the TiB_x and Au layers were deposited by magnetron sputtering. The Schottky contact had a diameter of 40 μm. The diodes were manufactured using integral heat sink technology. Each sample contained 20–25 diodes, the *I–U* curves of which were studied before and after ultrasonic loading. The forward and reverse branches of the *I–U* curves were measured at room temperature in the dark, for the current I varied in the range from 3×10^{-10} to 10^{-3} A. The acoustic loading was effected by introducing a longitudinal acoustic wave into the samples from the substrate side using a lithium niobate piezoelectric transducer [2]. The UST was performed in various regimes characterized by the frequency f_{UST} = 4–30 MHz and the intensity (power density) W_{UST}, which could be increased up to 3 W/cm^2; the treatment duration at each W_{UST} was 5 h.

For the forward-bias measurements, the experimental *I–U* curves were approximated using the following formula [6]:

$$I_F = SA^{**}T^2\exp(-\varphi_b/kT)\exp(qU_F/nkT), \qquad (1)$$

where S is the ohmic contact area, A^{**} is a modified Richardson constant, φ_b is the effective Schottky barrier height, n is the nonideality factor, and U_F is the applied bias voltage. Using this relation, it is possible to determine the φ_b and n values for the samples studied.

The initial (prior to UST) φ_b values for the entire set of diodes ranged within 0.730–0.750 eV, and the initial values of n were 1.06–1.08. The n and φ_b values were determined to within ±0.01 and ±0.004 eV, respectively. The obtained values of n being very close to unity might be indicative of an insignificant contribution of the generation–recombination processes to the current transfer. The UST-induced changes in the φ_b and n values were relatively small. For W_{UST} = 1–2 W/cm^2, the barrier height φ_b increased approxi-

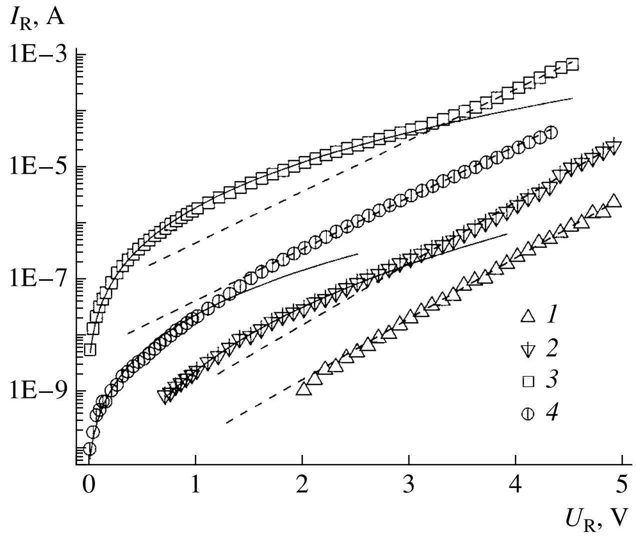

Fig. 1. The typical reverse branches of *I–U* curves for diodes of the (*1*, *2*) first (low-current) and (*3*, *4*) second (high-current) groups measured (*1*, *3*) before and (*2*, *4*) after UST ($W_{UST} \approx 1.8$ W/cm^2, $f_{UST} = 4.1$ MHz). Points present the experimental data; solid and dashed curves show the approximations using formulas (3) and (2), respectively.

mately by ~0.010 eV, while n decreased by no more than 0.02. For UST intensities above 2.5 W/cm^2, the character of changes was different: φ_b decreased by 0.015–0.030 eV, while n increased by 0.02–0.03.

It should be noted that UST produced a much more pronounced effect on the reverse branches of *I–U* curves. In the case of $W_{UST} < 2$ W/cm^2, the character of the UST-induced changes dramatically depended on the initial (prior to UST) values of the reverse current (I_R). In the group of diodes with small initial currents ($I_R < 10^{-7}$ A at a reverse bias voltage of $U_R = 2$ V), the UST leads to an increase in I_R by one or two orders of magnitude (see Fig. 1, curves *1* and *2*). In the other group of diodes, which are characterized by greater initial currents ($I_R > 2 \times 10^{-7}$ A), the UST induced a decrease in I_R by a factor of 10–500 (Fig. 1, curves *3* and *4*). We believe that this substantial difference in the UST-induced changes in *I–U* curves is related to a difference in the predominating mechanism of current transfer through the Schottky barrier for the diodes with different initial states.

Let us first consider diodes of the first group before UST, in which case the semilogarithmic plot of I_R versus U_R is almost linear (Fig. 1, curve *1*). This behavior is characteristic of a tunneling mechanism of current transfer [6]. Calculations performed within the framework of the Padovani–Stratton theory show that the field and/or thermionic emission in the structures under study can be significant only at $T < 10$ K. Therefore, the mechanism of tunneling in this case must be different. For example, Evstropov et al. [8, 9] suggested that the excess current through the potential barrier can be determined by electrons transferred via a chain of deep centers related, in particular, to defects such as dislocations [8]. In this case, the *I–V* curves are described by the following relation [8, 9]:

$$I_R = I_0 \exp(qU_R/\xi), \qquad (2)$$

where the coefficient I_0 is determined to a considerable extent by the concentration of defects creating deep centers, while ξ depends on the type of such defects.

For diodes of the second group before UST, the plot of $\ln I_R$ versus U_R at small reverse bias voltages ($U_R < 2.5$ V) is substantially nonlinear (Fig. 1, curve *3*), and it is not until $U_R > 3$–3.5 V that a behavior typical of the tunneling mechanism is established. For small bias voltages, the experimental curves are well approximated by the relation

$$I_R = I_0' \exp(aU_R^{1/4}), \qquad (3)$$

where I_0' and a are constant quantities. This dependence (whereby $\ln I_R \sim U_R^{1/4}$) is characteristic of a thermionic mechanism of current transfer [6], whereby rather large absolute values of I_R can be related both to the energy states localized at the semiconductor boundaries and to the lateral inhomogeneity of the metal–semiconductor contact [7, 10].

The UST also influenced the character of the $I_R = f(U_R)$ curves. Indeed, diodes of the first group upon UST exhibited thermionic processes at small reverse bias voltages ($U_R < 2$ V), whereas diodes of the second group upon a low-intensity UST showed evidence of the tunneling process (manifested by the linear relation between $\ln I_R$ and U_R) at somewhat lower bias voltages (Fig. 1, curves *2* and *4*). The high-intensity UST ($W_{UST} > 2.5$ W/cm^2) led to a significant (by one or two orders of magnitude) growth in I_R and to an increase in the contribution of the thermionic mechanism.

The acoustic-wave-induced effects exhibited no significant dependence on the frequency of ultrasound. As the f_{UST} was increased, the character of changes remained the same, and only their quantitative characteristics slightly increased (to within 10%).

The observed phenomena can be explained as follows. First, the UST can produce smoothing of the local inhomogeneities of interfaces [3], which accounts for a significant decrease in I_R in diodes of the second group. Second, the UST can stimulate the redistribution of dopants [1] and various defects in depth of the semiconductor [4], which modifies the population of energy levels at the metal–semiconductor interface, influences the I_R of diodes of the first group, and changes the φ_b and n values in both groups. As the UST intensity exceeds a certain threshold, the acoustic wave induces the generation of defects in the bulk and subsurface regions of the semiconductor [1] and stimulates the

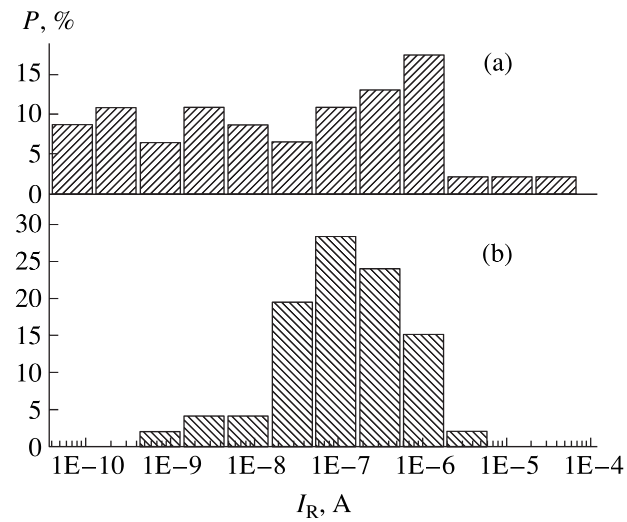

Fig. 2. Histograms showing distributions of the reverse current I_R (at U_R = 2 V) in Au–TiB_x–n-n^+-GaAs diodes (a) before and (b) after UST ($W_{UST} \approx 1.8$ W/cm^2, f_{UST} = 4.1 MHz); P is the percentage of diodes in which the I_R value falls within the corresponding interval.

reconstruction of a defect structure of the metal–semiconductor interface [3], which leads to a decrease in φ_b (due to the Schottky effect) and to an increase n. These changes are accompanied by the growth of thermionic current through the diode and by an increase in I_R.

Thus, we have studied for the first time the effect of UST with various intensities on the characteristics of Au–TiB_x–n-n^+-GaAs diodes with Schottky barriers. It is established that UST in the studied regimes more significantly influences the reverse branches than the forward branches of I–U curves. The character of the acoustic wave action depends on the predominating mechanism of current transfer: the UST causes an increase in I_R for a tunneling mechanism while decreasing I_R in the case of thermionic emission. An especially important effect of UST is a decrease in the scatter of characteristics and an increase in the homogeneity of parameters (Fig. 2) of the structures manufactured in the same technological cycle.

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