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Dark currents in GaSb/GaInAsSb heterojunction photodiodes at high temperatures

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Current flow mechanisms have been studied for Liquid Phase Epitaxy (LPE) grown GaSb/GaInAsSb/GaAlAsSb heterostructures lattice-matched to GaSb substrates. The epitaxial layers have shown a good surface morphology and straight interface lines. The dark current mechanisms were investigated at several temperatures. The qualitative comparison of experimental results with theory shows that, the high temperature region the diffusion mechanism of the current flow dominates in both, forward and reverse biases. The tunneling current becomes substantial at peak junction electric fields as low as 10^4 V/cm due to the small direct energy gaps and small effective masses of the structure tested.

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1. Introduction

GaInAsSb / GaSb / GaAlAsSb heterostructures have attracted a lot of scientific interest in the last few years mainly because of their importance for promising optoelectronic devices working in the wavelength region 1.5-4.8 μm. Both efficient light-emitting devices [1-3] and high-speed detectors [4-5] have been prepared and may be used for gas pollution monitoring, as well as for optical communica-tions in the new generation of fibers. The unusual band energy diagram in type II heterojunctions results in electron and holes being localized in self-consistent quantum wells on either side of the interface [6,7]. Variation of the composition of $Ga_{1-x}In_xAs_{1-y}Sb_y$ can alter the degree of overlap of the energy bands at the heterojunction with GaSb so that both staggered-lineup and broken-gap heterojunctions can be obtained [6].

The quaternary semiconductor GaInAsSb is an interesting candidate for thermophotovoltaic applications. Thermophotovoltaic sistems convert the thermal infrared radiation fron emitter into electricity. Operating temperatures are in the 1000-1500 °C range, which implies an optimum thermophotovoltaic cell with a band gap between 0.4 and 0.7 eV.

Of primary interest for applications in thermophotovoltaic and transmission systems, however, where the detector must be highly sensitive over a wide frequency band, which mainly defined by the dark currents in them. Moreover, with heat radiation detector temperature may be raised and the current flow mechanism also will change. Therefore, it is very important to know a current flow mechanism at high temperatures.

In our previous work, we have reported the dark current mechanisms in isotype $N^+ - n^0 - N^+$ heterojunctions [8]. Dark currents in the uncooled InAs/InAsSbP photodiodes were reported in [9] and electrical properties of n-Si/Cu Schottky diodes were discussed in [10]. Photoelectrical characterisctics of GaSb/GaInAsGb/GaAlAsSb heterojunctions are shown in this volume [11].

We presented results of investigations of high temperature current-voltage characteristics of photodiode structures on the base of $Ga_{1-x}\ In_x\ As_y\ Sb_{1-y}$ with $x \le 0.24$ which are known as the type II staggered-lineup heterojunctions. The results obtained will be useful both for improving the material synthesis technology and for developing optoelectronic devices [12].

2. Experimental

2.1. Device fabrication and measurements

The structures were fabricated by liquid phase epitaxy method on p-type GaSb (III)B substrata, doped with Te to a carrier concentration of $(5\text{-}7)\times10^{17}$ cm^{-3}. The structures were actually double heterostructures, in which a narrow-gap p-GaInAsSb active layer (E_g = 0.54 eV at 300 K) was sandwiched between a GaSb substrate and a wide-gap n-GaAlAsSb layer (the 'window', E_g = 1.1eV at 300 K) , doped with Ge to a carrier con-centration of $(1\text{-}3)\times10^{19}$ cm^{-3}. At the temperature of the epitaxial growth of the solid solution layer, it was isoperiodical with the GaSb substrate. Mesa samples with a working area 300-500 μm in diameter were fabricated from these structures by photolithography.

The current-voltage (*I-V*) measurements were performed by the use of Keithley 2400 voltage source and capacitance-voltage measurements were performed by the use of KEITHLEY 590/1M *C-V* Analyzer using a temperature-controlled Janis CCS-150 cryostat, which enables us to make measurements in the temperature range of 10 - 360 K. All measure-ments were controlled by a computer via an IEEE-488 standard interface so that the data collecting, processing and plotting could be accomplished automatically.

2. 2. Experimental results and discussion

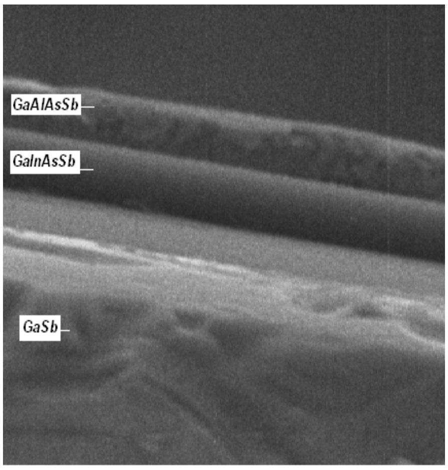

Fig. 1. Cross sectional SEM micrograph for GaSb-GaInAsSb-GaAlAsSb heterstructure

The epitaxial layers have shown a good surface morphology and straight interface lines for invastigated structures (see figure 1). Have been studied the capacitance-voltage characteristics and the forward and reverse of the voltage-current characteristics. Fig. 2 shows the capacitance-voltage (*C-V*) characteristics. It is seen that, the p-n junctions obtained were an asymmetric abrupt, with $1/C^2 \sim f(V)$, and they had a wide space-charge (depletion) region, which lays mostly in the narrow-gap active region.

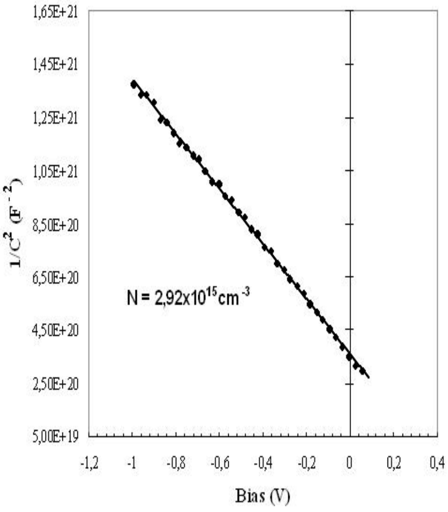

Fig. 2. Capacitance-voltage characteristics of the investigated of GaSb-GaInAsSb-GaAlAsSb heterojunctons at room temperature.

The junction current as a function of applied bias, can be written in the following empirical form:

$$I = I_0\left[\exp\left(\frac{qV_a}{\beta kT}\right) - 1\right] \tag{1}$$

where β is the ideality factor.

The comparison of theoretically calculated and experimental *I-V* characteristics in the forward bias region for several high tempera-tures are shown in Fig. 3. It is seen that the β-factor determined from the slope of the (I_F-V_F) characteristics at high temperatures ($T \geq 300$K) for small forward bias region, is equal to $\beta = 1.1 \pm 0.03$ and indicates the pre-dominantly diffusion nature of the current at investigated temperature range. The discrepancy from the theory for large forward bias voltages can be explained as due to the effect of series resistance.

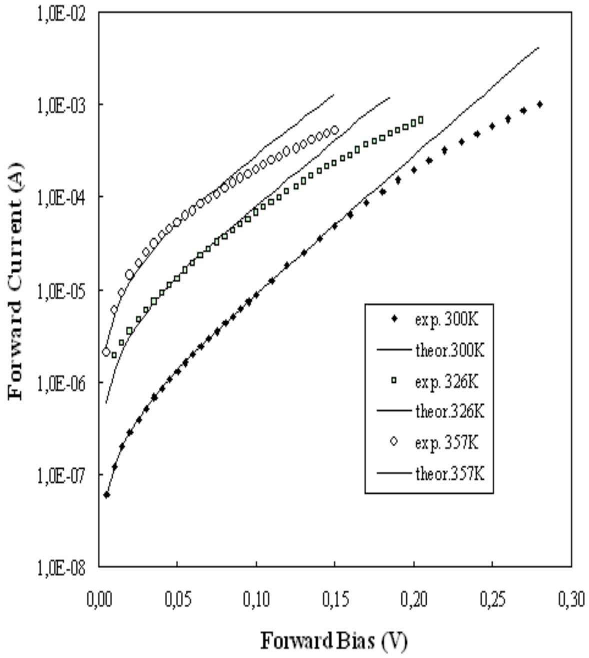

Fig. 3. Comparison of theoretically calculated (continuous line) and experimental (discrete points) I-V characteristics in the forward bias region atseveral temperatures.

Fig. 4 shows the reverse *I-V* characteristics at several temperatures. It is seen that, at temperatures over the range from 300 K to 360 K and in the range of voltage from 1V to 4V, the reverse current was defined by generation of carriers in the depletion region and finely obeyed an expression:

$$I = \frac{en_i WA}{\tau_{eff.}} \tag{2}$$

where n_i is the intrinsic carriers concentration.

The effective life time of carries was calculated as τ_{eff} = (6-9)×10^{-8} s from the dark current values obtained experimentally. Figure 5 shows the reverse current versus $10^3/T$ as a function of reverse bias. The activation energy, determining by this dependence at 1V and the temperatures over the range from 300 K to 360 K was E_a = 0.26 ± 0.02 eV, this value was very nearly to a half band gaps value of narrow-gap structure. This is evidence of the generation mechanism of the flow of dark current [9].

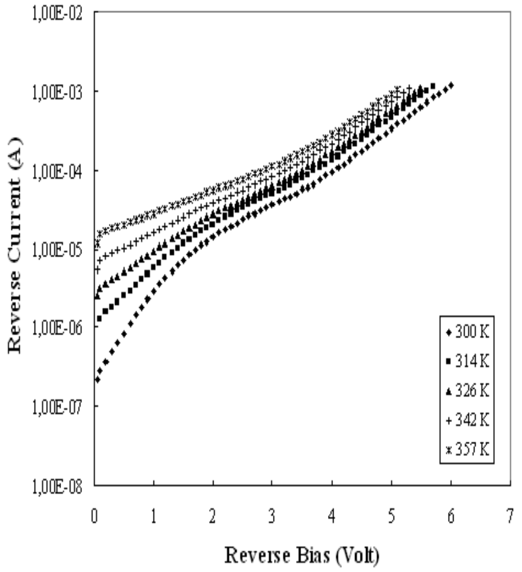

Fig. 4. Reverse current-voltage characteristics of GaSb-GaInAsSb-GaAlAsSb heterojunctions at several temperatures.

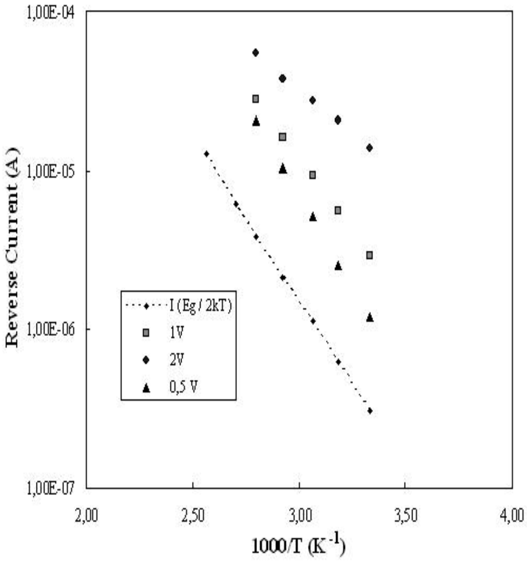

Fig. 5. The reverse current as a function of reciprocal temperature at different reverse applied bias.

Fig 5 also shows the calculated temperature dependence for the generation-recombination (GR) mechanism of the dark current. Obviously, the experimental data agree better with the dependence for the generation-recombination current. This kind of current has a temperature dependence of the form $I \sim T^{3/2}\exp(-E_g/2kT)$. The deviation of the experimental dependence from calculated dependence for the generation-recombination current is due to growth of the effect of the tunneling component of the dark current, which has a weaker temperature dependence and which is decisive in narrow-gap materials at high voltages and low temperatures. Estimations show that at high temperature region with reverse biases over 5 V, the tunneling mechanism of the current dominates. This is also confirmed by the weak temperature dependence of the current under reverse biases $V > 5$ V.

To further test the tunnelling model, the *I-V* characteristics of the investigated samples were used to obtain the dependence of current on $1/E_m$ at fixed E_g, as shown in Fig. 6.

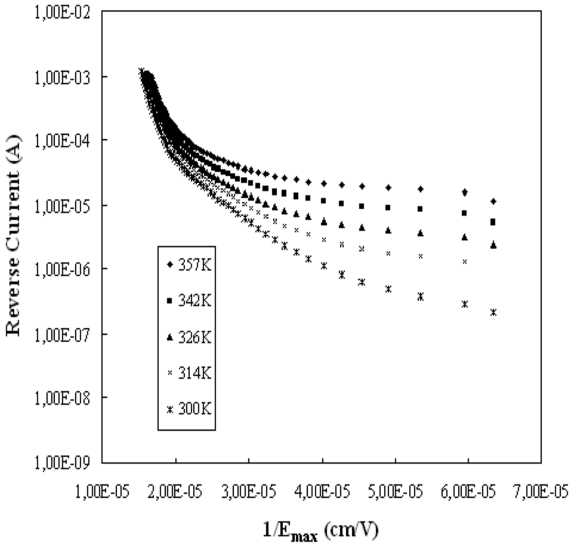

Fig. 6. Reverse biased dark current dependence on maximum electric field at several tempera-tures.

Note the tunnelling current for direct gap semiconductors is strongly dependent on the ratio $E_g^{3/2} / E_m$, therefore, this mechanism can account for the nearly exponential dependence of dark current on applied voltage. The maximum junction electric field can be found experimentally by

$$E_m = \left[2qN_d\left(V_{bi} - V\right)/\varepsilon_2\right]^{1/2} \qquad (3)$$

The data show considerable curvature at low electric fields, with the curvature more pronounced at higher temperatures. This behaviour indicates that tunnelling becomes the dominant source of leakage with increasing field and decreasing temperature.

3. Conclusion

We presented the results of dark current analysis of P-GaSb/p–GaInAsSb /N-GaAlAsSb type II staggered - lineup heterojunctions studying in several temperatures. This work demonstrated diffusion current dominates at the high temperature in small forward bias region. The experimental results shows that the generation-recombination mechanism is the pre-dominant contribution to reverse dark current at high temperatures. Estimations show that at high temperature region with reverse biases over 5 V, the tunneling mechanism of the current dominates. Studies of these hetero-junctions provided the physical basis for the fabrication of the photodetectors operating in the wavelength range 2.0 - 5.0 μm, important for third-generation infrared fiber-optic communication systems and suitable for tasks involving ecology and protection of the environment.

References

[1] L. M. Dolginov, L. M. Druzhinina, P. G. Eliseev, I. V. Kryukova, V. . Leskovich, IEEE J. Quantum Electron. **QE-13**, 609 (1977).
[2] H. Kano, S. Miazava, K. Sugiyama, Electron. Lett. **16**, 146 (1980).
[3] A. N. Baranov, D. E. Dzhurtanov, A. N. Imenkov, A. A. Rogachev, Yu. M. Shernyakov, Yu. P. Yakovkev, Sov. Phys. Semicond. **20**, 1385 (1986).
[4] G. Bougnot, F. De Lannoy, J. Electrochem. Soc. **135**, 783 (1988).
[5] A. N. Baranov, A. N. Imenkov, M. P. Mikhailova, A. A. Rogachev, Yu.P. Yakovlev, Proc. SPIE **1048**, 188 (1989).
[6] M. P. Mikhailova, A. N. Titkov, Semicond. Sci. Technol. **9**, 1279 (1994).
[7] M. A. Afrailov, Infrared Phys. and Technol. **45**, 169 (2004).
[8] M. Ahmetoglu (Afrailov), I. A. Andreev, E. V. Kunitsyna, M. P. Mikhailova, Yu. P. Yakovlev, Semiconductors, **41**(2), 150 (2007)
[9] M. Ahmetoglu (Afrailov), J. Optoelectron. Adv. Mater. **9**(11), 3567 (2007).
[10] M. Ahmetoglu (Afrailov), M. Ozer, O. Kadirov, S. R. Boydedayev, J. Optoelectron. Adv. Mater. **10**(10), 2511 (2008).
[11] M. Ahmetoglu (Afrailov), M. Alper, M. Safak, K. Erturk, B. Gurpinar, F. Kocak, K. Hciismaioglu, J. Optoelectron. Adv. Mater. **9**(4), 818 (2007)
[12] M. S. Tyagi, Introduction to Semiconductor Materials and Devices, Wiley, New York (1991).

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