

Dark currents in GaInAsSb based heterojunction photodiodes with a low diameter area at low temperatures

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Current flow mechanisms have been studied for Liquid Phase Epitaxy (LPE) grown n -GaSb / n -GaInAsSb / p -GaAlAsSb heterostructures with a low sensitivity area. An experimental investigation of current-voltage characteristics has been done in the temperature range from 77–210K, and have been determined the mechanism of the flow of dark current. 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 charge the key role at low temperatures under both forward and reverse biases.

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1. Introduction

GaInAsSb / GaSb / GaAlAsSb hetero-structures 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 communications 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. Variation of the composition of $\text{Ga}_{1-x}\text{In}_x\text{As}_{1-y}\text{Sb}_y$ can alter the degree of overlap of the energy bands at the heterojunction with GaSb so that both staggered-lineup and broken-gap hetero-junctions can be obtained [6]. GaSb-based materials are widely used narrow band gap semiconductors for infrared detection in 0.9-2.55 μm spectral range[7].

At the same time Thermophotovoltaic (TPV) devices based on III-V semiconductor alloys with bandgap energies corresponding to the mid-infrared wavelength range 2.2 to 2.5 μm (0.5 to 0.56 eV) are being developed. To date, the highest performing TPV devices in this wavelength range have been achieved for devices based on GaInAsSb and AlGaAsSb alloys lattice matched to GaSb substrates. We presented results of investigations of current-voltage characteristics of photodiode structures on the base of Ga In As Sb with a low diameter area. The results obtained will be useful both for improving the material synthesis technology and for developing optoelectronic devices.

2. Experimental

The structures were fabricated by liquid phase epitaxy method on n -type GaSb (III)B substrata, doped with Te to a carrier concentration of $(5-7)\times 10^{17} \text{ cm}^{-3}$. The structures were actually double heterostructures, in which a narrow-gap n -GaInAsSb active layer ($E_g = 0.54 \text{ eV}$ at $T = 300 \text{ K}$) was sandwiched between a GaSb substrate and a wide-gap p -GaAlAsSb layer (the ‘window’, $E_g = 1.1\text{eV}$ at $T = 300 \text{ K}$), doped with Ge to a carrier concentration of $(1-3)\times 10^{19} \text{ cm}^{-3}$. 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 70-75 μm in diameter were fabricated from these structures by photolithography. Thermal evaporated AuGe/Ni/Au and Cr/Au/Ni/Au ohmic contacts with annealing at 300°C for 30s in H_2 atmosphere were applied to the p -GaAlAsSb top of each MESA and to the back of n -GaSb substrate, respectively. The current-voltage (I - V) measurements were performed by the use of KEITHLEY 6517A Electrometer 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. The results of measurements were fed via an IEEE-488 interface into a computer for storage and processing.

3. Results and discussion

Have been studied the capacitance-voltage characteristics and the forward and reverse of the voltage-current characteristics in the temperature range of 77 - 210K. Fig. 1 shows the capacitance-voltage (C-V) characteristics taken at a room temperature and frequency $f = 1$ MHz.

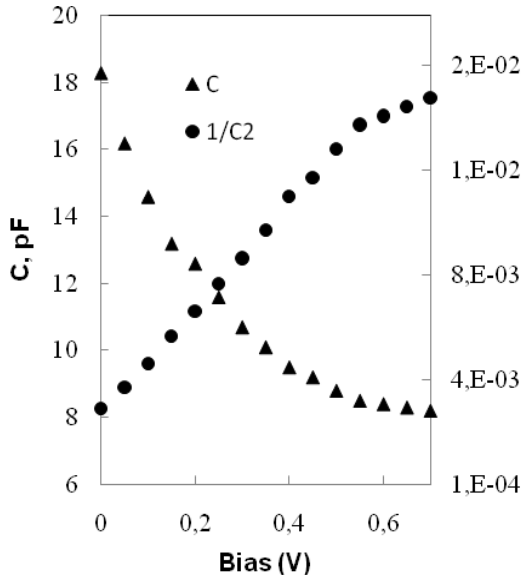


Fig. 1. Capacitance-voltage characteristics of the investigated of GaSb-GaInAsSb-GaAlAsSb heterojunctions at room temperature.

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 lay mostly in the narrow-gap active region. The contact potential difference V_D found the linear dependence of C^{-2} on V (0.27 eV) coincides with the band offsets at the GaSb-GaInAsSb interface, in agreement with the data of [9,10]. Using the approximation of an asymmetric $p-n$ junction of area S , we determined the donor concentration in the GaInAsSb narrow-gap layer:

$$C = S \sqrt{\frac{q\epsilon_s N}{2(V_D - V)}} \quad (1)$$

where ϵ_s is the dielectric constant. The values obtained lie in the range $(3-4) \times 10^{17} \text{ cm}^{-3}$.

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

$$I = I_0 \left[\exp\left(\frac{qV_a}{\beta kT}\right) - 1 \right] \quad (3)$$

where β is the ideality factor.

The comparison of theoretically calculated and experimental $I-V$ characteristics in the forward bias region for several temperatures are shown in Fig. 2.

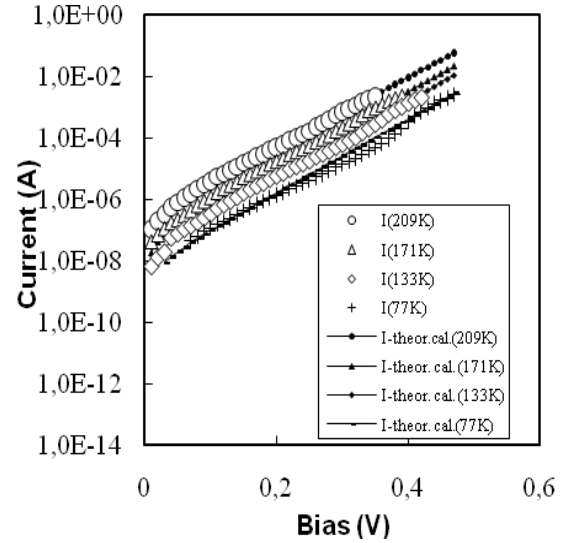


Fig. 2. Comparison of theoretically calculated (continuous line) and experimental (discrete points) $I-V$ characteristics in the forward bias region at several temperatures.

The measurements is shown that the ideality factor β is increased with decreasing temperature, from $\beta = 2.1$ at temperatures over the range $T = 210 - 160$ K to $\beta = 5.4$ at the $T = 77$ K.

At temperatures over the range from 210 K to 160 K the forward current was determined by recombination mechanisms. At the low temperatures ($T \leq 140$ K) the contribution of tunneling component was carry in essential to the mechanism of the flow of the current. This was proved by the weak dependence of the forward current on temperature at this temperature region.

The flow of holes from the p - region reaches the negative contact unimpeded, but electrons encounter a high barrier at the heterointerface and find themselves in a deep potential well. Some electrons and holes with high energy pass over the barriers at the heterointerface. However, the carrier recom-bination at the heterointerface, with subsequent tunneling of carriers through it, makes a substantial contribution to the total current. At low temperatures, the tunneling processes become dominant, since passing over barriers becomes improbable.

Fig. 3 shows the reverse $I-V$ characteristics at several temperatures.

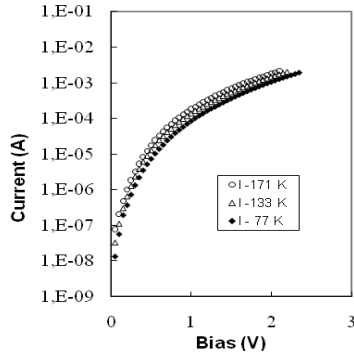


Fig. 3. Reverse current-voltage characteristics of GaSb-GaInAsSb-GaAlAsSb heterojunctions at several temperatures.

Estimations show that at investigated low temperatures the tunneling mechanism of the current dominates. This is also confirmed by the weak temperature dependence of the current under reverse biases $V > 50$ mV. Apart from the tunneling through the reverse-biased p - n junction, one more mechanism may contribute to the total current. The reverse bias applied to the p - n junction lowers the energy barriers at the heterojunction, and the energy bands become partly unbent. It becomes possible for electrons to pass from the conduction band of p -GaAlAsSb to the conduction band of n -GaInAsSb, from where they are drawn by the strong field of the p - n junction, pass into the n -GaSb layer, and move further toward the positive contact.

Fig. 4 shows the reverse current versus $10^3/T$ as a function of reverse bias. The activation energy, determining by this dependence at 0.4 V and the temperatures over the range from 210 K to 170 K was $E_a = 0.026 \pm 0.002$ eV. Estimations show that at low temperature region the current determined by tunneling over whole reverse bias range. This is confirmed by the weak temperature dependence of the current as shown in Fig. 4.

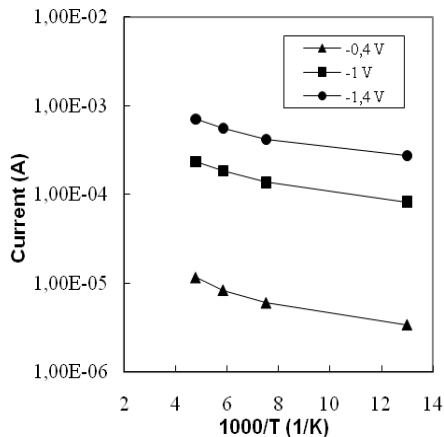


Fig. 4. The reverse current as a function of reciprocal temperature at different reverse applied bias.

To further test the tunneling 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. 5.

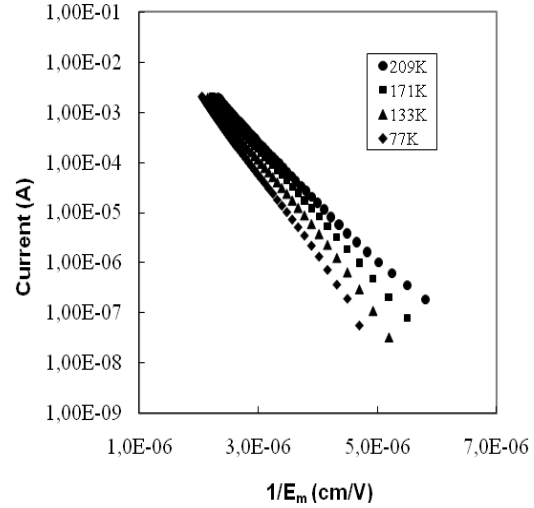


Fig. 5. Reverse biased dark current dependence on maximum electric field at several temperatures.

Note the tunneling 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 $E_m = [2qN_d(V_{bi} - V)/\epsilon_2]^{1/2}$. The data show considerable curvature at low electric fields, with the curvature more pronounced at higher temperatures. This behavior indicates that tunneling becomes the dominant source of leakage with increasing field and decreasing temperature.

4. Conclusions

We presented the results of dark current analysis of n -GaSb / n -GaInAsSb / p -GaAlAsSb type II staggered-lineup hetero-junctions with low sensitivity area, studied in low temperature regions. The experimental results shows that the recombination mechanism predominant contribution of to forward dark current at temperatures over the range from 210 K to 160 K. Estimations show that at investigated low temperatures the tunneling mechanism of the current dominates in both, forward and reverse biases. Studies of these heterojunctions provided the physical basis for the fabrication of the photodetectors operating in the wavelength range 1.6 – 2.2 μm , important for third-generation infrared fiber-optic communication systems and suitable for tasks involving ecology and protection of the environment.

References

- [1] A. N. Baranov, N. Bertu, Y. Cummin et al., Appl. Phys. Lett. **71**, 735 (1997).
- [2] Y. R. Meyer, C. A. Hoffman, F. Y. Bartoli, Appl. Phys. Lett. **67**, 757 (1995).
- [3] A. N. Baranov, D. E. Dzhurtanov, A. N. Imenkov, A. A. Rogachev, Yu. M. Shernyakov, Yu. P. Yakovlev, Sov. Phys. Semicond. **20**, 1385 (1986).
- [4] I. A. Andreev, M. A. Afrailov, A. N. Baranov, S. G. Konnikov, M. A. Mirsagatov, M. P. Mikhailova, O. V. Salata, V. E. Umansky, G. M. Filaretova, Yu. P. Yakovlev, Sov. Phys. Tech. Lett. **15**, 253 (1989).
- [5] M. A. Afrailov, A. N. Baranov, A. P. Dmitriev et al., Fiz. Tekh. Poluprovodn. (Leningrad) **24**, 1397 (1990) [Sov. Phys. Semicond. **24**, 876 (1990)].
- [6] M. P. Mikhailova, A. N. Titkov, Semicond. Sci. Technol. **9**, 1279 (1994).
- [7] T. L. Troy, S. N. Thennadil, J. Biomed. Optics **6**, 167 (2001).
- [8] A. M. Monakhov, V. V. Sherstnev, A. P. Astakhova, Yu. P. Yakovlev, G. Boissier, R. Teissier, A. N. Baranov, Appl. Phys. Lett. **94**, 051102 (2009).
- [9] M. A. Afrailov, M. P. Mikhailova, N. R. Rahimov, Tr. J. of Phys. **21**, 1229 (1997).
- [10] M. S. Bresler, O. B. Gusev, A. N. Titkov et al., Semiconductors **27**, 341 (1993).
- [11] H. Kroemer, Appl. Phys. Lett. **46**, 504, (1985).
- [12] S. Sze, Physics of Semiconductor Devices, Wiley, New York, 1981.

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