N^+-GaSb / n^o-GaInAsSb / P^+- GaSb type II heterojunction photodiodes with low radiation damage

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The electrical characteristics of a double type II heterojunction in the GaSb/GaInAsSb/GaSb system with staggered band alignment were studied. The dark current mechanisms in the heterostructures were investigated at several temperatures. The experimental results shows that, the low temperature region the tunneling mechanism of the current flow dominates in both, forward and reverse biases. Have been investigated the radiation effect of ^{60}Co (γ)-ray source with 6 MeV photon energy and 1.5x10^{11} gamma/cm^2 fluency on the electrical and optical characteristics.

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1. Introduction

GaInAsSb /GaSb 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 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 [6, 7].

Thermophotovoltaic (TPV) devices are being explored for a variety of terrestrial and space applications [8-9]. The systems approach has been to use silicon devices matched to selective emitters or design low-band gap compound semiconductor cells matched to blackbody emitters. The first 0.55-eV TPV cells based on GaInAsSb alloy lattice matched to GaSb substrates were reported at the Third NREL Conference on Thermophotovoltaic Generation of Electricity in 1997. Smaller bandgap TPV devices have subsequently been reported with concurrent improvements in TPV device performance. Recently excellent progress has been made in GaSb related thermophotovoltaic cells [10].

Of primary interest for applications in TPV devices however, where the detector must be highly sensitive over a wide frequency band, which mainly defined by the dark currents in them. Also, the TPV devices semiconductor devices used in outer space are required to operate in strongly ionizing radiation and in high-temperature atmospheres. In this work we have investigated the dark currents and radiation effect of ^{60}Co (γ)-ray source with 6 MeV photon energy and 1.5×10^{11} gamma/cm^2 fluency on the current-voltage $((I-V)$, capacitance-voltage $(C-V)$ and spectral characteristics in GaSb / GaInAsSb /GaSb type II heterojunction photodiodes.

2. Experimental

In present study, to grow the GaSb, GaInAsSb, GaAlAsSb materials standard liquid phase epitaxy (LPE) system with the horizontal quartz reactor was used. After loading the source materials, a graphite boat was annealed in H_2 flow at 720 ^{o}C for 4 h in the case of the GaSb-related semiconductors. Then the system was cooled to room temperature, and the substrate was placed in the boat. The temperature was raised to 640 ^{0}C and held for 15 min. The system was then cooled down to the growth temperature.

High-quality $Ga_{0.78}In_{0.22}As_{0.18}Sb_{0.82}$ solid solutions with composition near the miscibility gap boundary were grown at T=600^{0}C on Te-doped GaSb(100) substrates. The crystalline quality of the grown layers, the surface morphology and heterostructure interface abruptness have been studied with photoluminescence (PL) spectroscopy, scanning electron microscopy (SEM) and X-ray diffraction methods. X–ray diffraction studies revealed a high quality of the grown layers which were isoperiodic with GaSb. The chemical composition of the solid solutions at the surface and its variation across the thickness (nolmal to the heterointerface plane) was determined on a JXA-5 “Camebax” x-ray microanalyzer. According to X-ray diffractometry data, the lattice mismatch between the GaInAsSb epitaxial layer with 2-3 μm thickness and GaSb(100) substrate was positive ($\Delta a/a$ = (2-5)×10^{-4} at T =300K). The width of the $Ga_{0.78}In_{0.22}As_{0.18}Sb_{0.82}$ band gap determined from PL data and transmission spectra was 0.58 eV at T = 80K (0.53 eV at T = 300K). A wide-gap $Ga_{0.66}Al_{0.34}As_{0.025}Sb_{0.975}$ layers with 2 μm thickness was grown at T = 599°C.

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 500 μm in diameter were fabricated from these structures by photolithography. An abrupt junction was found by $C-V$ measurements, with a narrow-gap n^o- GaInAsSb electron concentration 9.97×10^{15} cm^{-3} at room temperature. Fabricated devices were mounted into a glass Dewar with a cold shield for detailed electrical measurements at variable temperatures, where the sample $I-V$ characteristics were measured using a KEITHLEY 6517A Electrometer and junction $C-V$ characteristics were measured using a TEGAM 3550 LCR Meter. All measurements were controlled by a computer via an IEEE – 488 standard interface so that the data collecting, processing and plotting could be accomplished automatically. The photoresponsivity was measured using Cornerstone 260 monochromator with triple grating, which is designed to diffract VIS and NIR rays with wavelengths from 450 to 2300 nm. The signals from sample and reference photodiodes are both connected to separate lock-in amplifiers (SRS830) which measure the incident photocurrent produced on each respective photodiodes.

The diodes were exposed to an energetic ^{60}Co Gamma irradiation with photon energy of 6 MeV in Siemens MD2 Linear Accelerator. Before and after irradiation, the $I-V$, $C-V$ and photoresponsivity of the photodiodes were measured at room temperature.

3. Results and discussion

The current-voltage characteristics were investigated at temperatures over the range from 80 K to 370 K. According to the results of analysis the forward branches of the current-voltage characteristics, the dependence of forward current on voltage may be described by this empirical expression:

$$I = I_0 \exp\left(eV/\beta kT\right) \quad (1)$$

where β is the ideality factor. The measurements is shown in Fig. 1, which the ideality factor β is increased with decreasing temperature, from β=1.04 at high temperatures to β=3.97 at the T=77K.

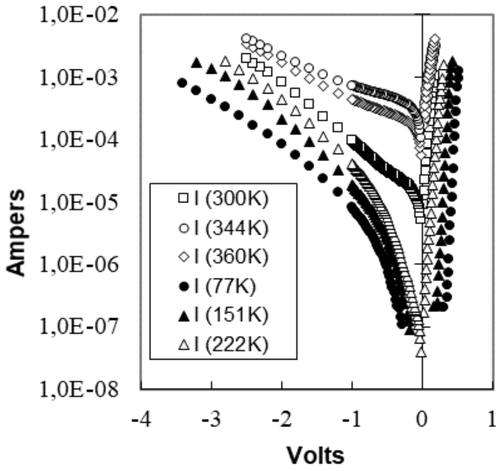

Fig. 1. Current-voltage characteristics of GaSb-GaInAsSb-GaSb heterojunctions at several temperatures

At temperatures over the range from 370 K to 300 K and at temperatures from 230 K to 180 K the direct current was determined by a to different mechanisms of the flow of the current, by diffusion and recombination mechanisms, respectively. At the low temperatures (T ≤ 160 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.

Analysis of the reverse current–voltage characteristics at several temperatures shown that, at temperatures over the range from 280 K to 360 K and in the range of voltage from 0.5V to 3V, the reverse current was defined by generation of carriers in the depletion region and finely obeyed an expression:

$$I = \frac{en_i WA}{\tau_{eff.}} \quad (2)$$

where n_i is the intrinsic carriers concentration.

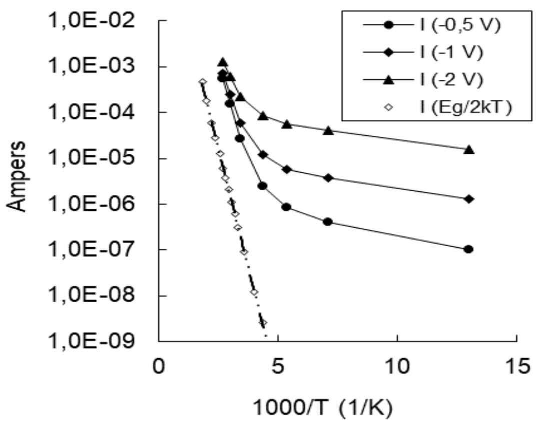

Fig. 2. The reverse current as a function of reciprocal temperature at different reverse applied bias

Fig. 2 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 280 K to 360 K was E_a = 0.27 ± 0.02eV, 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 [11]. Fig. 2 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 [12].

Figs. 3 and 4 respectively show the typical $I-V$ and $C-V$ characteristics, before and after irradiation with photon energy of 6 MeV. From Fig. 3 it is noted that both the forward and reverse currents changes very small. This is evidence about not the appearance of the lattice defects in the investigated structures with such radiation doses. Also, the capacitance and photoresponse (see Fig. 5) of the photodiodes changes very slightly after irradiation

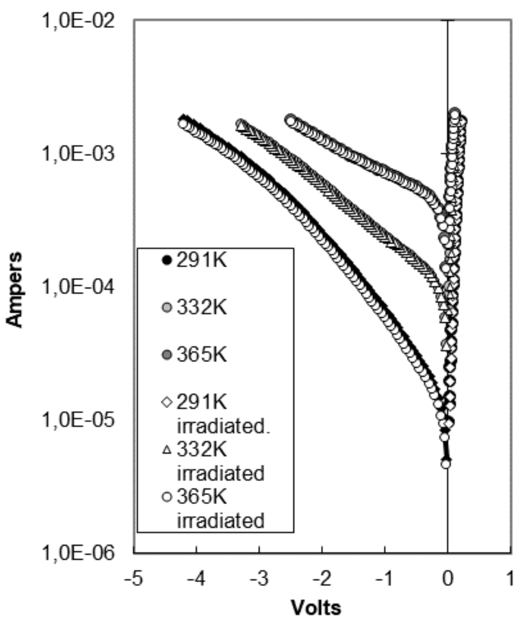

Fig. 3. Comparison of theurrent-voltage characteristics at high temperatures before and after ^{60}Co Gamma irradiation with photon energy of 6 MeV

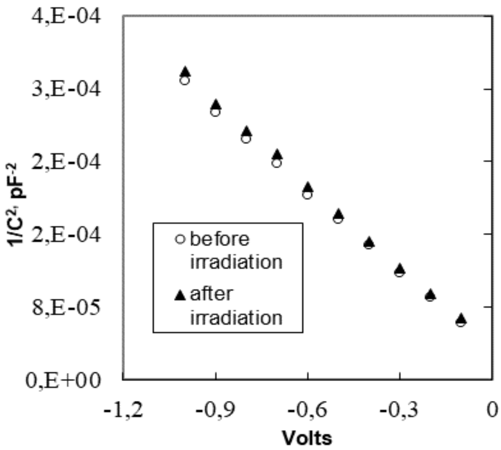

Fig. 4. Capacitance-voltage characteristics of the investigated of GaSb-GaInAsSb-GaSb heterojunctions temperatures before and after 60Co Gamma irradiation

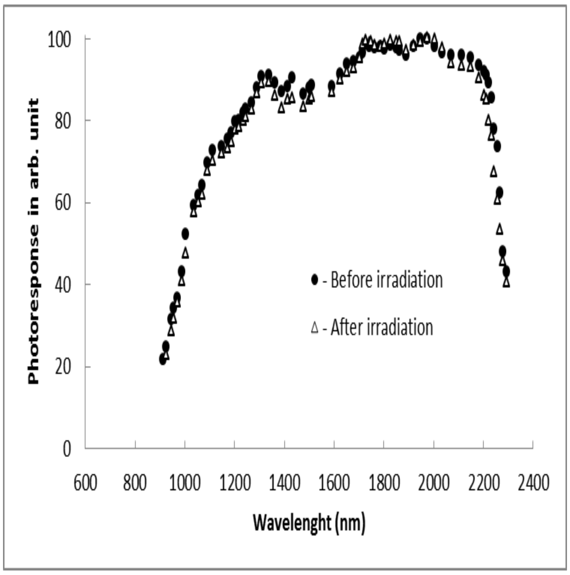

Fig. 5. Spectral distribution of photosensitivity for the GaSb- GaInAsSb-GaAlAsSb heterojunctions after ^{60}Co Gamma irradiation with photon energy of 6 MeV

4. Conclusions

We presented the results of dark current analysis of N - GaSb / n – GaInAsSb / P – GaSb type II staggered-lineup heterojunctions studying in several temperatures. This work demonstrated diffusion current dominates at the high temperature in small forward bias region while generation – recombination current dominates in the intermediate temperature region. At the low temperature region the tunneling mechanism of the current flow dominates in both, forward and reverse biases. Investigations of radiation effect of ^{60}Co (γ)-ray source with 6 MeV photon energy and 1.5×10^{11} gamma/cm^2 fluency on the $I-V$, $C-V$ and photoresponse characteristics shows that, after irradiation with such radiation doses these are changes very slightly. Therefore, this photodiodes have a low radiation damage and suitable for application in the medium of " γ " radiation with 6 MeV photon energy and below. Studies of these heterojunctions provided the physical basis for the fabrication of the photodetectors operating in the wavelength range 1.2 – 2.4 μm, important for TPV application.

Acknowledgments

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