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Photoelectrical characteristic of isotype N^+-GaSb / n^o-GaInAsSb / N^+- GaAlAsSb type II heterojunctıons

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Photoelectrical characteristics and energy diagrams have been studied for LPE grown isotype heterostructures lattice-matched to GaSb substrates. The photocurrent sign dependence on photon energy as a function of forward bias in isotype N^+-GaSb/n^0-GaInAsSb/N^+-GaAlAsSb heterojunctions due to hole confinement at the type II interface is observed and discussed. This effect is due to modulation of the barrier transparency at the interface limiting the tunnel transitions of the conduction electrons and to the localization of photoholes in the potential well at the type II interface. The sign reversal of the photocurrent on photon energy as a function of applied voltage takes place only on the forward bias.

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Keyword: Photoelectrical characteristics, İsotype heterostructures, Photocurrent sign

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]. 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]. In our previous work, we have reported the mechanism of photocurrent amplification in isotype $N^+ - n^0 - N^+$ heterojunctions [8].

Dark currents in the InAs/INAsSbP photodiodes and in GaSb/GaInAsSb Schottky diodes were discussed in [11]

In the present paper we shall deal only with staggered type II heterojunction based on quaternary $Ga_{1-x}In_xAs_ySb_{1-y}$ (x=0.22) and $Ga_{1-x}Al_xAs_ySb_{1-y}$ (x=0.34) solid solutions lattice-matched to GaSb substrate. The dark *I-V* characteristics of isotype *N*-GaSb/*n*-GaInAsSb/ *N*-GaAlAsSb structures with double heterojunctions were investigated and analyzed in the temperature range 90-300 K and the photocurrent sign dependence on photon energy as a function of forward bias in isotype N^+-GaSb/n^0-GaInAsSb/N^+-GaAlAsSb hetero-junctions due to hole confinement at the type II interface is observed and discussed.

2. Experimental

Structures were fabricated by LPE on *n*-type GaSb substrates, doped with tellurium to a carrier concentration of (5-7) × 10^{17} cm^{-3}. Structures were actually double heterostruc-tures in which a narrow-gap n^o-GaInAsSb layer with a thickness 2-3 μm (E_g = 0.53 eV) is sandwiched between N^+-GaSb layer and a wide-gap N^+-GaAlAsSb (E_g = 1.2 eV) layer with a carrier concentration 3×10^{17} cm^{-3}.

Mesa samples with a working area 250-300 μm in diameter were fabricated from these structures by photolithography. An abrupt junction was found by capacitance-voltage (*C-V*) measurements, with a narrow-gap n^o-GaInAsSb electron concentration 5×10^{15} cm^{-3}. Fabricated devices were mounted into a glass Dewar with a cold shield for detailed electrical measurements at variable tempera-tures, where the sample *I-V* characteristics were measured using a KEITHLEY 485 pA meter and junction *C-V* characteristics were measured using a KEITHLEY 590/1M *C-V* Analyzer. The photosensitivity spectra were measured with SPM-2 monochromator equipped with a LiF prism and with the use of a globar light source. All measurements were computer controlled.

3. Results and discussion

The *C-V* characteristic taken at a room temperature and frequency 1 MHz is shown in Fig. 1, which satisfactorily described by the dependence $C^{-2} \sim V$, typical of an abrupt junction.

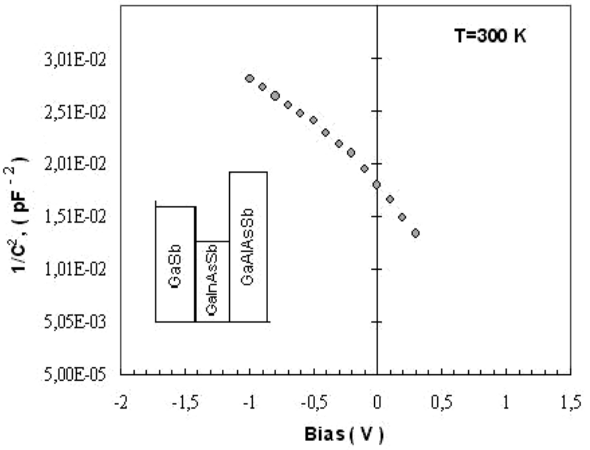

Fig. 1. Typical C-V characteristic of the isotype N^+-GaSb / n^o-GaInAsSb / N^+-GaAlAsSb hetero-structure at room temperature.

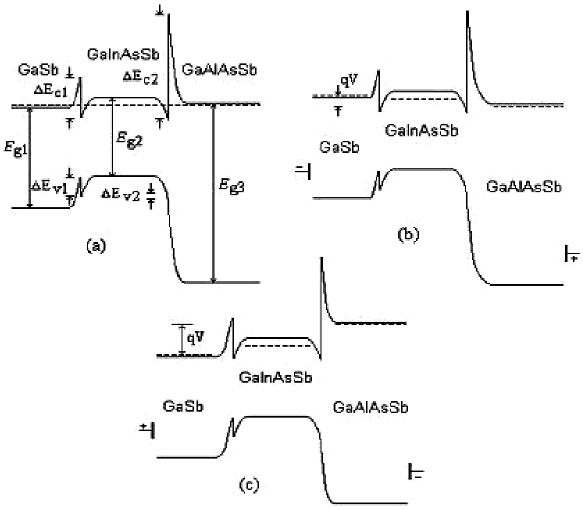

Fig. 2. Energy band diagram of N^+-GaSb / n^o-GaInAsSb / N^+- GaAlAsSb heterostructure in equilibrium (a); under forward (b) and reverse (c) biases.

The band offsets of the GaSb/GaInAsSb heterointerface were found to be ΔE_{C1}= 0.3 eV and ΔE_{V1} = 0.1 eV [12]. The standard calculation the measurements give the ΔE_{C2} value of 0.73 eV and the valance band offset value of 0.05 eV for GaInAsSb/GaAlAsSb heterointerface, which are in reasonable agreement with the published data [13]. The energy band diagram of the structure in equilibrim (a), forward (b) and reverse (c) applied biases are presented in Fig. 2.

Current transport across a N^+-n hetero-junction is similar to that of a metal-semiconductor junction : Diffusion, thermionic emission as well as tunneling of carriers across the barrier can occur. The dominant current transport mechanism at high temperature region is the thermionic emission of carriers over the barrier, and the current as a function of applied bias V is given by the relation [14]

$$J = J_0\left[\exp\left(\frac{qV_a}{kT}\right) - 1\right] \tag{1}$$

where

$$J_0 = R^* T^2 \exp\left(-\frac{qV_i}{kT}\right) \tag{2}$$

Here R^* is the effective Richardson constant, V_a is applied voltage, V_i is built-in voltage and other symbols have their usual meanings. Whereas expression (1) is similar to that of metal-semiconductor barrier, it differs in that the temperature dependence is somewhat modified and the reverse bias current increases with voltage.

The experimental *I-V* characteristics in the forward and reverse bias region for several temperatures are shown in Fig. 3. The forward current as a function of applied bias, can be written in the following empirical form:

$$J = J_0\left[\exp\left(\frac{qV_a}{\beta kT}\right)\right] \tag{3}$$

where β increases as the temperature is lowered from 3.36 (300 K) to 6.78 (160 K). This indicates that the predominantly tunneling nature of the current at the whole investigated temperature range.

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

$$J = J_0\left[\exp\left(\alpha\frac{qV_a}{kT}\right)\right]\left[\exp\left(\frac{qV_a}{\beta kT}\right) - 1\right] \tag{4}$$

where α is a parameter, which is equal to 0.076 (300 K) and 0.032 (160 K).

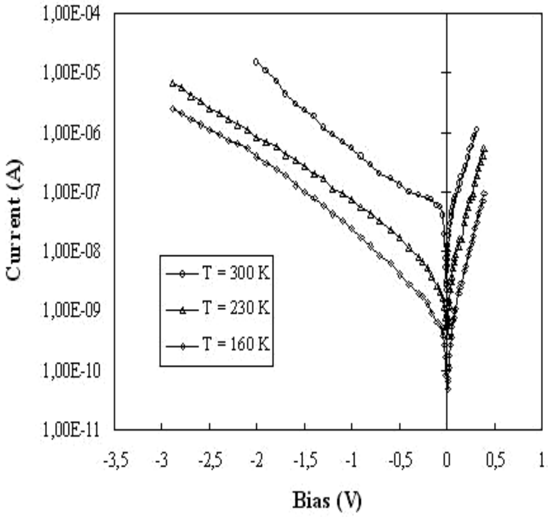

Fig. 3. Typical I-V characteristics of the isotype N^+-GaSb/n^o-GaInAsSb/N^+-GaAlAsSb hetero-structure at several temperatures.

It is seen from Fig. 3, that at room temperature a lightly saturation of the reverse current was observed for small biases (V< 800 mV), indicating that in this case a thermionic emission current mechanism prevails. This current is due to thermal activation of electrons from GaInAsSb into GaSb over the barrier at the heterointerface. Since, the barrier height seen from the GaInAsSb remains unchanged, a primary cause the reverse current to increase with bias is a partly tunneling of electrons from the GaInAsSb into GaSb. Indeed, a large reverse bias can cause the barrier in the GaInAsSb / GaSb heterointerface to become thin enough for significant tunneling of electrons from GaInAsSb. At low temperatures, the tunneling mechanism of the current dominates, since passing over the barrier becomes improbable. This is confirmed by the weak temperature dependence of the reverse current at low temperature region.

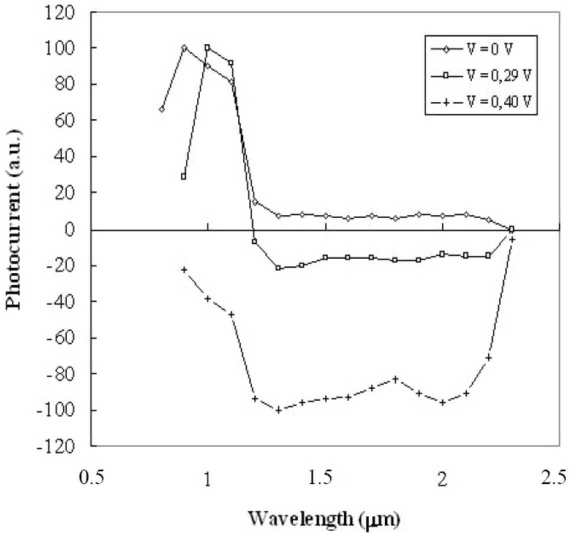

Fig. 4. Spectral response of the N^+-GaSb/n^o-GaInAsSb/N^+-GaAlAsSb isotype hetero - structure as a function of the forward bias at room temperature.

As stated above, spatial separation of electrons and holes at the type II heterointerface leads to new quantum effects that manifest themselves in phenomenon of photocurrent amplification on N-n heteroboundary [6]. A photoelectric phenomenon - the dependence of the photocurrent sign on photon energy as a function of forward bias in N^+-GaSb/n^o-GaInAsSb/N^+-GaAlAsSb structures have been studied in this work. This effect is due to modulation of the barrier transparency at the interface limiting the tunnel transitions of the conduction electrons and to the localization of photoholes in the potential well at the type II interface. In this type of N-n junction a photo-voltage will be produced, which may depend in sign on the photon energy. It is important to note that in our case the sign reversal of the photocurrent should not be attributed to the surface states at the interface as in [15] because the structures studied were well lattice-matched and observes were no double saturation branches on the forward or reverse *I-V* characteristics as opposed to results of [15]. The barrier depth and width vary with the composition of solid solution and the layer doping level. If we excite the structure with light whose wavelength falls in the intrinsic absorption band of the narrow-gap semi-conductor, non-equilibrium holes are generated and eventually tunnel through the barrier in the valence band. The barrier transmission for electrons in the conduction band is extremely sensitive to the presence of non-equilibrium holes at the interface. The accumulation of these holes results in narrowing of the barrier, which augments the tunneling of conduction electrons.

The spectral response of the isotype GaSb–GaInAsSb heterostructure as a function of forward biases at room temperature is presented in Fig. 4. At zero or small forward bias, the photocurrent is positive, which corresponds to photoelectrons crossing the barrier towards GaSb and to photoholes drifting and diffusing in the opposite direction.

The forward bias of several millivolts applied to the structure lowers the energy barriers at the heterojunction, and the energy bands become partly unbent (see Fig. 2b). It becomes possible for non-equilibrium electrons photogenerated in GaSb to pass to GaInAsSb layer and move further toward the positive contact. At larger forward bias, electrons photogenerated in the GaInAsSb layer are no more able to cross the barrier and holes accumulate at the interface. The resulting narrowing of the barrier could enhance the dark current due to electrons coming from GaSb, which thus appears as a negative photocurrent.

4. Conclusions

In this letter we have considered the electrical and photoelectric properties of a single type II heterojunction in the GaSb/GaInAsSb system with the staggered band alignment. It is shown that a type II staggered heterojunction can behave as Schottky diode and the dark *I-V* characteristics of this heterostructure are rectifying over the whole temperature range of 90-300 K. The qualitative comparison of experimental results with theory shows that various components of current flowing (diffusion, thermal emission tunnelling) through the heterojunction make contribution to dark current flow, dominating at different temperatures. The sign reversal of the photocurrent on photon energy on forward bias has been studied. This effect is due to modulation of the barrier transparency at the interface limiting the tunnel transitions of the conduction electrons and to the localization of photoholes in the potential well at the type II interface. The sign reversal of the photocurrent on photon energy as a function of applied voltage takes place only on the forward bias.

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