ELECTRICAL AND OPTICAL PERFORMANCE OF INAS / ALSB / GASB SUPERLATTICE PHOTODETECTOR

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Abstract

We report on electrical and optical performance of InAs/AlSb/GaSb type-II superlattice photodetectors. The detector structure is designed to operate in the MWIR domain with a cut-off wavelength of 4.3 µm at 125 K. The photodiode exhibits a dark current density of 1 x 10^{-10} A/cm^2 with a corresponding differential resistance area product (R_oA) of 6 x 10^6 Ωcm^2 at 77K and zero bias. We analysed dinamic resistance are product (R_dA) vs inverse temperature curves in each operating temperature range. The results show that the SL photodiode reveals diffusion limited behaviour at high temperatures and becomes generation-recombination (GR) limited below 125 K. Such results are discussed with extracted minority carrier lifetimes from J-V curve fitting..

Keywords: Superlattice, dark current, detectivity, GaSb/InAs Infrared detectors

1. INTRODUCTION

Minority carrier lifetimes are highly important parameters for understanding of carrier transport and improve the detector performance. Temperature dependent of dark current measurement is one of the efficient way to determine the minority carrier lifetimes. Identification of dominant current mechanism in each operating temperature may enable to extract the minority carrier lifetimes from the dark current measurements. Here we present electrical and optical performance of InAs/AlSb/GaSb based type-II SL N-structure photodiodes operating in the mid wavelength infrared range (MWIR). Depending on the configuration of the constituent alloys of InAs, AlSb and GaSb in the superlattice period, superlattice band structure may be adjusted in order to improve the overlap of carriers and HH-LH splitting energies to suppres the Auger recombination. The new photodetect or of N-structure is aimed to design for this purpose. N-structure is a pin photodiode with a unipolar electron barrier.

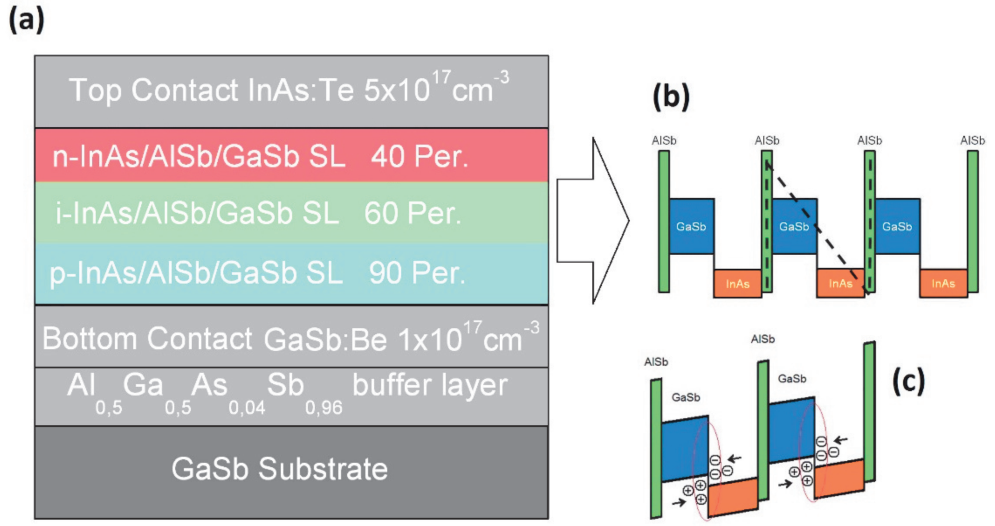

Fig. 1 (Color Online) (a) Schematic representation for the grown structure, (b) conduction and valance band profiles for the InAs/AlSb/GaSb T2SL “N” structure, (c) electron and hole confinement under reverse bias

The layer configurations and energy band alignment of the structure is shown in **Fig. 1 (a) and (b)** respectively. Thin AlSb layers are placed in between InAs and GaSb layers. Under reverse bias AlSb barrier pushes carriers towards GaSb/InAs interface to increase electron and hole wave function overlap enhancing type-II optical transition (**Fig. 1(c)**). Compairing to standard InAs/GaSb superlattice detectors, the overlap of carriers is increased by about 25% with N-structure design [1]. The specific detectivity was measured as 3×10^{12} Jones with cut-off wavelengths of 4.3 μm at 79 K reaching to 2×10^{9} Jones and 4.5 μm at 255 K [2].

In this study, we report current density-voltage (J-V) characteristics of InAs/AlSb/GaSb based type-II SL N-structure photodiodes. Dominant current mechanisms are analysed from temperature dependence of R_dA as a function of temperature (77-271 K). We then report the estimated minority carrier lifetimes used by Shockley Formula to at different temperatures.

2. DEVICE STRUCTURE

The superlattice photodiode was grown by commercially (IQE Inc. USA) with molecular beam epitaxy. First a 100 nm GaSb buffer layer is deposited on unintentionally p-type doped (100) GaSb substrate followed by a 20 nm lattice matched $Al_{0,4}Ga_{0,6}As_{0,04}Sb_{0,96}$ buffer layer. 1000 nm thick p-type GaSb:Be ($p=1 \times 10^{17}$ cm^{-3}) bottom contact is grown on the buffer layer. The p-i-n detector structure consists of 9/2/8.5 MLs) of InAs/AlSb/GaSb SL layers as 90 periods of p-region with GaSb:Be ($p=1.5 \times 10^{17}$ cm^{-3}), 60 period of i-intrinsic region and 40 periods of n-region with InAs:Te ($n=5 \times 10^{17}$ cm^{-3}). The device is terminated by 20 nm InAs: Te n-contact ($n=5\times10^{17}$ cm^{-3}). Standard lithography was used to define square mesas with different dimensions. The fabrication details is given by elsewhere [3]. Single pixel photodetectors were fabricated by 400x400 and 500x500 μm^2 square mesas. Ti and Au metalization were performed as ohmic contacts. Sample was bonded to a chip carrier for I-V characterizations.

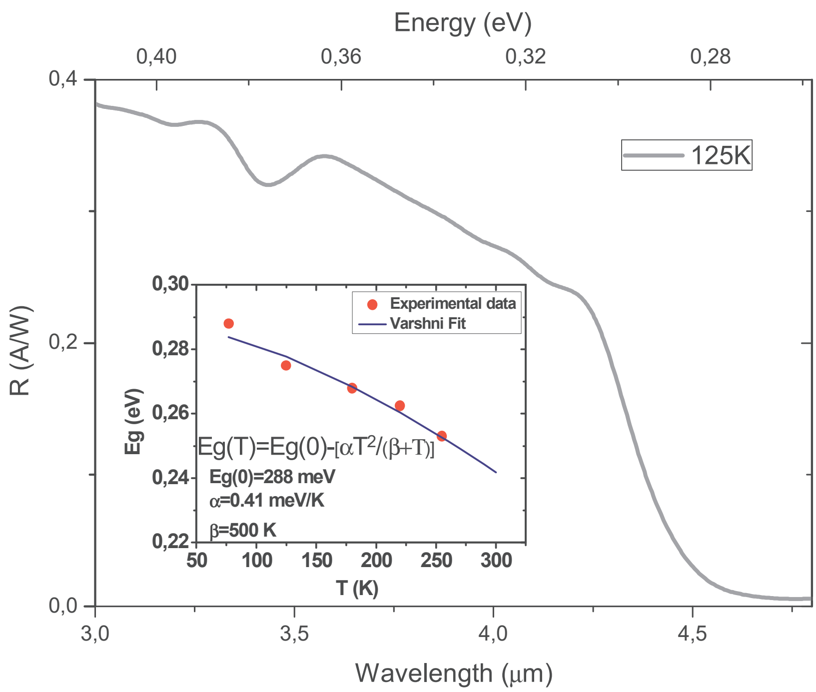

Fig. 2 (Color online) Responsivity spectrum of N-Structure at 125 K. Inset shows Varshni fit for band gap energy extracted from optical response spectra for different temperatures

3. RESULTS AND DISCUSSION

In this work we anaysed optical and electrical performance of InAs/AlSb/GaSb based type-II SL N-structure photodiodes. For minority carrier calculations we define the band gap energy of the SL structure from responsivity spectra. Responsivity spectra are measured in the temperature range 79-255 K with cut-off wavelengths of 4.2-4.9 µm [3]. **Fig. 2** shows responsivity spectrum of the photodiode at 125 K. The device gives 0.375 A/W peak response with a 50% cut-off wavelength (λ_c) at 4.3 µm. Inset in the figure shows the obtained band gap energies from responsivity spectra fitted with Varshni's parameters. For electrical performances, current density-voltage (J-V) characteristics of InAs/AlSb/GaSb based type-II SL N-structure photodiodes are measured at different temperatures [1,2].

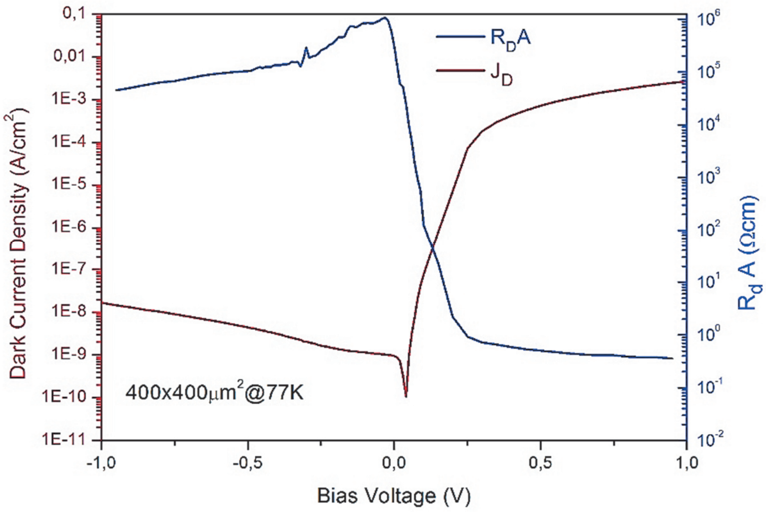

Fig. 3 (Color Online) Dark current density and R_dA characteristic as a function of applied bias at 77K

Fig. 3 shows dark current density and R_dA product performance as a function of applied bias masured at 77 K. Dark current density and dynamic resistance at zero bias are measured as 1.1×10^{-10} A/cm^2 and 1.05×10^6 Ωcm^2, respectively. Results show that the detector structure promises for excellent thermal imaging capability operating at 77 K.

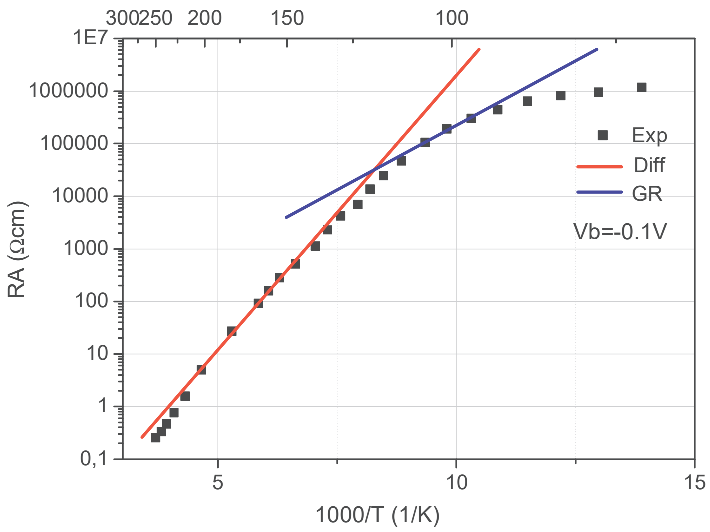

Fig. 4 R_dA vs inverse temperature (1000/T) for N-structure with fitted diffusion and GR components

Fig. 4(b) shows the R_dA vs inverse temperature (1000/T). Data are taken at reverse bias of 100 mV. The photodetector shows diffusion limited behaviour (Arrhenius type) with associated activation energy (E_a) of 270 meV at high temperatures (271-125 K) while, at low temperatures (below 125 K), the photodetector shows generation-recombination (GR) limited behaviour (E_a~E_g/2). The J-V curves are fitted by using Shockley Formula [3, 4] in order to identify the dominant dark current mechanism in each operating temperature range. **Fig. 5** shows the measured dark current fitted by calculated diffusion and GR components of dark current at 150K. Minority carrier lifetimes are extracted from current density-voltage measurement (J-V) curve quantatively at different temperatures as given by elsewhere [3]. The estimated minority carrier lifetimes are shown in **Table 1**. At 87 K temperature, minority carrier lifetime is limited by GR mechanism with an estimated recombination lifetime of 15 ns, and diffusion lifetime 1 ns respectively. At 190 K, the minority carrier lifetime is limited by diffusion mechanism with an increased diffusion and GR lifetimes of 110 ns and 60 ns respectively.

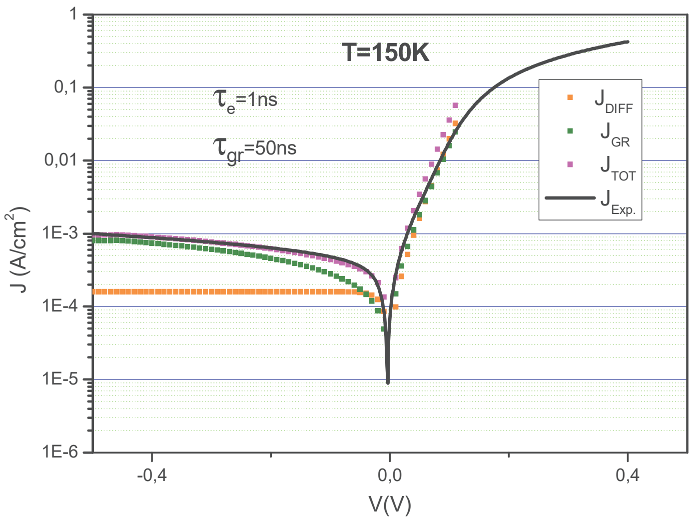

Fig. 5 (Color online) Experimental $J_{Exp.}$ (solid line) and modeled J_{DIFF} (yellow dot), J_{GR} (green dot) and J_{TOT} (pink dot) total modelled dark current densities versus voltage of N-structure SL photodiode at T = 150 K

Table 1 Minority carrier lifetimes at various temperatures

T (K)	Diffusion Lifetime (ns)	GR Lifetime (ns)
87	1	15
150	1	50
190	110	60

4. CONCLUSION

Temperature dependence of R_dA characteristics is analysed in InAs/AlSb/GaSb based T2SL N-structure. Deduced from J-V curve-fitting, minority carrier lifetimes have been calculated in the temperature range 87-190 K. Diffusion lifetime is estimated as 1ns in temperature range 87-150 K and gradually increased to 110ns at 190 K, while GR lifetimes are increased from 15 to 60ns with temperature range 87- 190K. At 77K and under -0.1V bias voltage, the dark current density is measured as 2×10^{-9} A/cm^2 and corresponding dynamic resistance area product (RA) is determined as 4×10^5 Ωcm^2. Temperature range 190-125 K, the dark current density reveals diffusion-limited behavior (Arrhenius type). In lower temperature range (125-87 K), the dominant mechanism starts to become generation recombination (GR).

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