Theoretical simulation of the barrier T2SLs InAs/InAsSb/B-AlSb longwave detector operating under thermoelectrical cooling

P. Martyniuk¹, K. Michaleczewski¹, T.-Y. Tsai², C. H. Wu³, Y. R. Wu²

1 Institute of Applied Physics, Military University of Technology, 2 Urbanowicza Str., 00-908 Warsaw, Poland
2 Graduate Institute of Photonics and Optoelectronics, National Taiwan University, Roosevelt Str., 10617 Taipei, Taiwan

Abstract—The paper reports on the barrier longwave infrared nBnn⁺ detector based on InAs/InAsSb (xSb = 0.38) type-II superlattice operating under thermoelectrical cooling (T > 190 K). AlSb was proved to minimize barrier in valence band in analyzed superlattice operating under thermoelectrical cooling (> 230 K). A few papers have been published on HOT T2SLs detectors yet. Müller et al. showed T2SLs InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb detectors operating in cryogenic temperatures were reported by Teng et al. exhibiting D* = 7.3×10¹⁰ cmHz⁴/2/W for 8 µm 50 % cut-off (InAs/GaSb), Kim et al. D* = 10¹⁰ cmHz⁴/2/W for 13.2 µm cut-off (InAs/InAsSb) and Haddadi et al. with D* ~ 2×10¹¹ cmHz⁴/2/W for 9 µm (InAs/InAsSb) [8–10]. In this paper, we demonstrate theoretical modeling of LWIR nBn barrier photodetector with T2SLs InAs/InAsSb (xSb = 0.38) active layer where AlSb barrier (B) was incorporated to provide nearly zero valence band offset (VBO) allowing unimpeded transport of the minority carriers (holes in terms of nBnn⁺ structure).

I. INTRODUCTION

Infrared (IR) detectors operating in longwave range (LWIR) have many applications to include gas sensing being relevant for health condition monitoring and could be used in industry for the gas leak detection [1]. Sb based type-II superlattices (T2SLs) have been proposed as an alternative to the well known HgCdTe and T2SLs InAs/GaSb with lower fabrication cost and better performance with low dark current due to suppressed Auger generation-recombination (GR) rate and tunneling current [2]. The limiting factor of the widely studied T2SLs InAs/GaSb is the short minority carrier lifetime. That could be circumvented by “Ga-free” T2SLs InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7]. The barrier nBn T2SLs InAs/InAsSb and InAs/GaSb immersed single pixel detector for LWIR with detectivity (D*) = 3×10⁹ cmHz⁴/2/W for 9 µm 50 % cut-off [7].

II. SIMULATION PROCEDURE AND RESULTS

The nominal simulated LWIR T2SLs InAs/InAsSb/B-AlSb barrier structure is presented in Fig. 1. T2SLs InAs/InAsSb active layer (3 µm) and both contact layers (0.15 and 0.4 µm) were assumed to have 2.8 nm (InAs₉₆Sb₃₈) and 10.4 nm (InAs). The T2SLs InAs/InAsSb contact layers - 0.15 µm n-type, 10⁶ cm⁻³ and 0.4 µm n-type 5×10¹⁷ cm⁻³ and absorber - 3 µm, 10⁶ cm⁻³ were assumed.

Table 2. Bowing parameters for InAs/InAsSb.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbols</th>
<th>GaAs</th>
<th>InAs</th>
<th>InSb</th>
<th>GaSb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lattice constant</td>
<td>a(T=300K)</td>
<td>5.65325</td>
<td>6.0583</td>
<td>6.4794</td>
<td>6.0959</td>
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<tr>
<td>Bandgap</td>
<td>E_g(T=0K)</td>
<td>0.34</td>
<td>0.276</td>
<td>0.32</td>
<td>0.417</td>
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<tr>
<td>Luttinger parameters</td>
<td>g_B</td>
<td>2.35</td>
<td>8.5</td>
<td>15.5</td>
<td>4.7</td>
</tr>
<tr>
<td>Deformation potentials</td>
<td>ω_B</td>
<td>1</td>
<td>7.17</td>
<td>5.08</td>
<td>1.06</td>
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<tr>
<td>Elastic constant</td>
<td>C_{11}(GPa)</td>
<td>560</td>
<td>395.9</td>
<td>311.1</td>
<td>432.2</td>
</tr>
<tr>
<td>Spin-orbit energy</td>
<td>Δₛ(eV)</td>
<td>0.341</td>
<td>0.39</td>
<td>0.82</td>
<td>0.76</td>
</tr>
<tr>
<td>Kane potential</td>
<td>Δ₂(eV)</td>
<td>21.81</td>
<td>21.5</td>
<td>24.08</td>
<td>24.76</td>
</tr>
<tr>
<td>Valence band offset</td>
<td>VBO(eV)</td>
<td>0.8</td>
<td>0.59</td>
<td>0.038</td>
<td>0.038</td>
</tr>
</tbody>
</table>

The 80 nm, n-type 10⁶ cm⁻³ AlSb barrier was introduced to the detector’s structure.
Calculated energy band diagram for nBnn+ is presented in Fig. 3 for 230 K and 200 mV bias. Barrier in conduction band was estimated at the level of 1.5 eV.

Dark current characteristic versus reciprocal temperature for nBnn+ barrier structure for two selected voltages 50 mV and 200 mV is presented in Fig. 4 while photocurrent was shown in Fig. 5.

We demonstrated theoretical modeling of LWIR nBnn+ photodetectors with T2SLs InAs/InAsSb active layer where AlSb barrier was implemented. It was shown that material introduces nearly zero VBO in analyzed barrier structure. The highest $D^*$ of the simulated structure was assessed at the level of ~ $10^{9}$ cmHz$^{-1/2}$/W at 230 K assuming immersion lens contribution.

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REFERENCES


