InAsSb/InTlSb Superlattice: A Proposed Heterostructure for Long Wavelength Infrared Detectors

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A novel superlattice (SL) heterostructure, comprising of InTlSb well and InAsSb barrier lattice matched to InSb, is proposed for long wavelength 8–12 μm detectors. Improvements in the InTlSb epilayers’ structural quality are expected, as it will be sandwiched between higher quality zinc-blende InAsSb epilayers. Preliminary energy band calculations of 30Å InAs_{0.59}Tl_{0.41}/100Å InAsSb SL show the band alignment favorable to type I with three heavy-hole subband confinement in the valence band and a partial electron subband confinement in the conduction band due to the small conduction band offset. Including the effect of strain indicates significant changes in the band offsets, with optical bandgap essentially unaltered. The optical band gap of this SL was computed to be 0.127 eV (9.7 μm) at 0K, indicating its potential for long wavelength applications.

Key words: InAsSb/InTlSb, long wavelength infrared (LWIR) detector, superlattice

INTRODUCTION

Currently, there is an increasing research interest to find an alternate material in lieu of current industrial standard HgCdTe in the long-wavelength 8–12 μm range, as poor compositional uniformity and thermal instability are some of the well-known problems associated with this material system.1 Hence, alternatives based on intersubband transition in III-V compounds multilayered structures2–4 involving GaAs/GaAlAs, GaAs/GaInP, InP/InGaAsP systems and interband transitions based on type II strained layer superlattice (SL)4–6 with InSb/InAsSb and InAs/InGaSb are being explored. These are in principle more attractive than those composed of II-VI materials, due to the better metallurgical properties, and more mature growth and device processing technologies. However, due to the inherent quantum mechanical limitations and restrictions, these detectors are predicted to remain inferior to those based on HgCdTe infrared detectors.

In recent years, thallium based III-V compounds4–5 have been proposed as potential candidates for long-wavelength infrared (LWIR) electro-optic receiver and emitter devices. The theoretical work7,8 on TIP, TlAs, and TlSb suggests that these binaries are lattice matched to InP, InAs, and InSb, respectively, and are the only compounds in III-V systems which are predicted to exhibit negative band gaps. Hence, the corresponding ternary alloys, which should cover a range of band gaps, should encompass the entire long wavelength infrared region. Of these possible ternary alloys, only the growth of InTlSb has been reported in literature.9–12 However, InTlSb system is predicted to exhibit a large miscibility gap separating the zinc-blende (ZB) compound InSb from the nearly pure TlSb crystal of closed packed structure, thus leaving only a small phase area of stable ZB alloy at low Tl composition. Hence, only dynamic growth techniques such as molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD) can be employed.

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for the growth of this alloy system. Preliminary work on the growth of these alloys by MOCVD is quite encouraging, and the theoretical calculations of the band structure strongly suggest a marked similarity between HgTe/CdTe and TlSb/InSb systems.

In this paper, we propose a novel InAs$_y$Sb$_{1-y}$/In$_{1-x}$Tl$_x$Sb SL as a potential candidate for long wavelength detector and emitter applications. Energy band calculations have been made with and without consideration of strain for the heterostructure compositions $y = 0.07$ and $x = 0.07$, corresponding to the SL band gap in the wavelength region of 10 $\mu$m. Due to the presence of high quality InAsSb layers in this lattice matched SL, it is expected that the structural quality of the system should be superior to that of bulk InTlSb as the latter is reported to be a difficult material to grow.

**DISCUSSION**

As the material parameters for TlSb is not well established, many of the physical parameters needed for the energy band computation of the heterostructures such as band offsets and effective masses were estimated from the comparison of InTlSb with HgCdTe system. Other ternary material parameters were determined on the basis of linear interpolation from the available binary materials. The linear interpolation method provides a good estimation of the material parameters such as effective mass of compounds in the absence of any empirical data. It is valid for lattice parameter variation with alloy composition (Vegard's Law) and is approximately valid by adding bowing terms in the case of energy band gap parameters variation with composition.

The composition of the InTlSb alloy was thus determined using the above method for an energy gap corresponding to a wavelength of 10 $\mu$m. A Tl content of 7% was calculated for a well (In$_{0.93}$Tl$_{0.07}$Sb) thickness of $t_w = 100$Å and the barrier (InAs$_{0.07}$Sb$_{0.93}$) thickness of $t_b = 30$Å, the mismatch between the free-standing SL and InSb is less than $2 \times 10^{-5}$. Thus, we could neglect the strain effect from the substrate on InAs$_{0.07}$Sb$_{0.93}$/In$_{0.93}$Tl$_{0.07}$Sb SL. The calculated electron and hole effective masses in the InTlSb layer were very close to those of InSb as the Tl content is small. The band offsets in this SL structure were estimated from the band offsets of the two individual alloys with respect to InSb independently and thereby calculating the band offsets between the two desired alloy systems assuming the transitivity and commutative properties to hold good. This is a fairly good assumption as it is well proven for this class of materials.

The composition thus obtained, suggests InAs$_{0.07}$Sb$_{0.93}$/In$_{0.93}$Tl$_{0.07}$Sb is a type-I SL with a valence band-offset ratio of 62% in a strain-free state, as shown in Fig. 1.

Subband energy calculations were made using modified Kronig-Penney formalism developed by Cho and Prucnal using Bastard's boundary condition. As shown in Fig. 2, these computations in InAsSb/InTlSb superlattice yielded three heavy hole confined subbands. These subbands were located at 4.9, 19.1, and 40.6 meV lower than In$_{0.93}$Tl$_{0.07}$Sb valence band maximum, with an increasing band width of 0.09, 4.1, and 11.2 meV, respectively. Note that we merely estimate the heavy hole states in this paper, since they play a more important role than the light hole ones, due to their larger density of states. Only partial electron confinement was obtained in the conduction band with the minimum energy of 7.7 meV above the InTlSb conduction band minimum. The resultant energy gap of the superlattice thus determined was 127 meV corresponding to 9.7 $\mu$m in wavelength at 0K.

In order to estimate the strain effects on the SL of 30Å InAs$_{0.07}$Sb$_{0.93}$/100Å In$_{0.93}$Tl$_{0.07}$Sb on InSb substrate, it was assumed that $C_{11} \approx 2C_{12}$ for InTlSb alloy, where $C_{11}$ and $C_{12}$ are the elastic constants and this relation-