



HAL
open science

Electrical properties of short period InAs/GaSb superlattice.

Philippe Christol, L. Konczewicz, Yvan Cuminal, Jean-Baptiste Rodriguez,
André Joullié

► **To cite this version:**

Philippe Christol, L. Konczewicz, Yvan Cuminal, Jean-Baptiste Rodriguez, André Joullié. Electrical properties of short period InAs/GaSb superlattice.. 2006. hal-00103689v1

HAL Id: hal-00103689

<https://hal.science/hal-00103689v1>

Preprint submitted on 5 Oct 2006 (v1), last revised 2 Apr 2018 (v3)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Electrical properties of short period InAs/GaSb superlattice.

P. Christol^{*1}, L. Konczewicz², Y. Cuminal¹, H. Aït-Kaci¹, J.B. Rodriguez¹, and A. Joullié¹

¹ Institut d'Electronique du Sud (IES-CEM2), UMR CNRS 5507, Case 067, Université Montpellier 2, 34 095 Montpellier cedex 05, France.

² Groupe d'Etude des Semiconducteurs (GES), UMR CNRS 5650, Case 074, Université Montpellier 2, 34 095 Montpellier cedex 05, France.

Received zzz, revised zzz, accepted zzz

Published online zzz

PACS 72.40.+w, 73.21.Cd, 73.40.Kp, 73.50.Dn

Electrical properties in the temperature range between 80K and 300K of type-II short period InAs/GaSb superlattice (SL) photodiode are reported. Resistivity and Hall measurements have been carried out on a 300 periods unintentionally doped SL grown on semi-insulating GaAs substrate while capacitance-voltage and electrical-voltage measurements have been performed on the same SL structure elaborated on n-type GaSb substrate. Whatever the electrical investigations, the behaviour of the InAs/GaSb SL versus temperature exhibited a reproducible change in type of conductivity. The SL is n-type at high temperatures range with $n(300\text{K}) = 6 \times 10^{16} \text{cm}^{-3}$ whereas it is p-type at low temperatures with $p(100\text{K}) = 2 \times 10^{16} \text{cm}^{-3}$.

© 2003 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

1 Introduction

InAs/GaSb superlattice (SL) system is an attractive quantum system for infrared (IR) detection devices thanks to several theoretical advantages induced by its unique type II broken gap band alignment [1, 2]. Indeed, in this misaligned configuration, the effective band gap can be easily tailored by adjusting the layer thicknesses in order to reduced Auger recombination rate in comparison with bulk materials [3, 4] and to cover a wide range of wavelengths including the 3-5 μm mid-wavelength infrared (MWIR) and the 8-12 μm long wavelength infrared (LWIR) atmospheric windows. This last feature can be exploited for the realization of expected multicolor detection module. InAs/GaSb SL p-i-n photodiodes with noticeable detection performances were firstly reported for the LWIR domain [5-7] and more recently in the MWIR spectral range [8-10] with, in particular, a thermal imaging demonstration by using a focal plane array camera with 256x256 detector elements [11]. Nevertheless, improvement of device technology [12, 13] as well as better knowledge on fundamental properties of this binary/binary SL photodiodes [14-16] are still necessary to reach the criteria of third generation IR detectors [17].

In this paper, we report on results of electrical properties of short period InAs/GaSb SL adapted for detection in the MWIR domain. The objective of this work is to examine the behaviour of the InAs/GaSb SL as a function of temperature, exhibiting a reproducible change in type of conductivity.

2 InAs/GaSb superlattice samples description

Two kinds of samples were fabricated by molecular beam epitaxy (MBE). InAs/GaSb unintentionally-doped (nid) SL structures were grown on semi-insulating (001) GaAs substrate to perform hall measurement and on n-type (001) GaSb for electrical-voltage and capacitance-voltage investigations. Whatever the substrate, the SL's period is composed by equal number $N=10$ of InAs and GaSb monolayers

* Corresponding author: e-mail: Philippe.Christol@univ-montp2.fr, Phone: +33 467 52 43 68, Fax: +33 467 54 48 42

© 2003 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

(MLs) including one InSb ML at the InAs-GaSb interface. The aim of the inserted InSb layer is to eliminate the "GaAs-like" interface and to compensate the tensile effect of the InAs layers in order to achieve SL structure lattice matched to the GaSb substrate. This "GaSb" strain compensated SL structure exhibits room temperature cut-off energy near 220 meV ($5.6 \mu\text{m}$) [18].

For the sample on GaAs substrate, a 500 nm GaAs buffer layer was grown before the nid SL while a 500 nm Te-doped GaSb buffer layer was inserted in the case of n-type GaSb substrate. The nid short period SL is composed of 300 periods, corresponding to a total active zone thickness of $1.92 \mu\text{m}$, and the cap layer was already made by the last GaSb layer of the nid SL.

Further details of the epitaxial growth and GaSb(10MLs)/InAs(10MLs)/InSb(1ML) SL structural characterizations have been previously published [18]. Figures 1a and 1b report high-resolution X-ray diffraction spectra of 300 periods SL structure grown on GaAs and GaSb substrates, respectively.

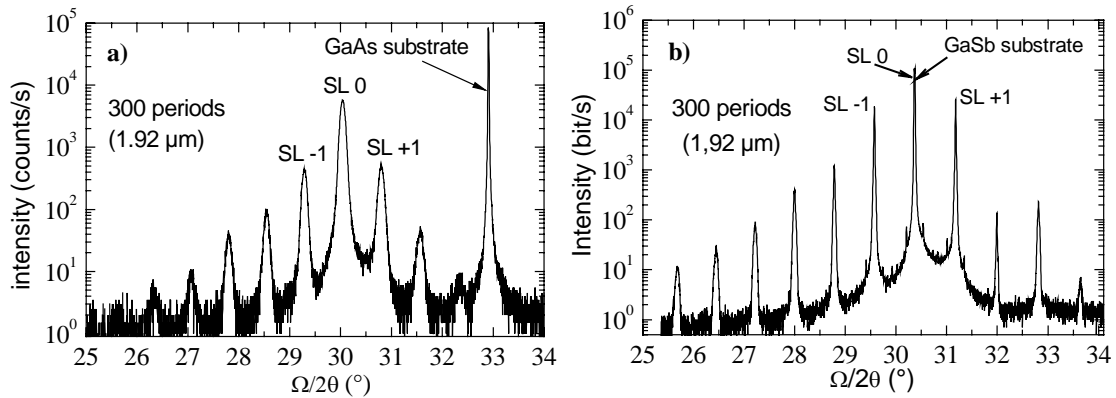


Fig. 1. High-resolution X-ray diffraction pattern of the GaSb(10MLs)/InAs(10MLs)/InSb(1ML) SL structures grown on GaAs substrate (a) ; on GaSb substrate (b).

In the case of the SL structure grown on GaSb substrate (Fig. 1b), X-ray diffraction rocking curve reveals many intense satellite peaks attesting a good crystalline quality of the layers and the zeroth-order SL peak position indicates that the SL is practically lattice matched (-0.03%) to the GaSb substrate. Comparison with curve simulation leads to a measured period of 63.56 \AA very close to the intended period of 64 \AA . Because of the discrepancy between the average lattice constant of the SL and the lattice constant of the GaAs substrate (-7.2%), the X-ray diffraction peaks observed in Fig. 1a are less intense but numerous. Up to the fifth satellite peaks can be noted with linewidth comparable to those recently reported for InAs/GaSb SL grown on GaAs by metalorganic chemical vapor deposition [19].

3 InAs/GaSb superlattice electrical properties

Resistivity and Hall measurements have been performed on the nid SL grown on semi-insulating GaAs substrate to determine the number and type of conduction channels in the SL. Measurements have been done as a function of temperature (77-300K) for magnetic fields in the [0-1] Tesla range. Temperature dependence of apparent carrier concentration and Hall mobility is presented in Fig. 2. A reproducible change in type of conductivity of the nid SL was noted at around 190K. The SL is n-type at high temperatures range with $n(300\text{K}) = 6 \times 10^{16} \text{ cm}^{-3}$ and a mobility of $1800 \text{ cm}^2/\text{V.s}$ while it is p-type at low temperatures with $p(100\text{K}) = 1.5 \times 10^{16} \text{ cm}^{-3}$ with a poor mobility value of $100 \text{ cm}^2/\text{V.s}$. This change in conductivity was already observed and reported but at lower temperatures 140K [3]. A simple two carriers analysis (electrons rather confined in InAs layer and holes in GaSb) cannot explain this versatile phenomena. To obtain the agreement with the experiments, it is necessary to consider a multi-carrier analysis approach including a third type of carriers with a density of 10^{13} cm^{-3} and a mobility of $10^5 \text{ cm}^2/\text{V.s}$ [3]. Undoubtedly, the presence of these carriers can be attributed to the influence of the inserted InSb layer at the InAs-GaSb interface.

Figure 3 displays resistivity results versus $1/kT$. The data show the temperature dependence of the resistivity with two well-defined slopes below and above 190K. From these two regimes, we can extract two thermal activation processes characterized by the activation energies $E_a=29\text{meV}$ and $E_d=136\text{meV}$ at low and high temperatures, respectively. These two values strongly suggest the influence of deep levels or traps in such SL structure. At low temperature, the SL is p-type because acceptor traps dominate the carrier generation and recombination mechanisms through the traps. At higher temperature, deep donor traps can then be activated leading to an n-type SL structure, especially at room temperature.

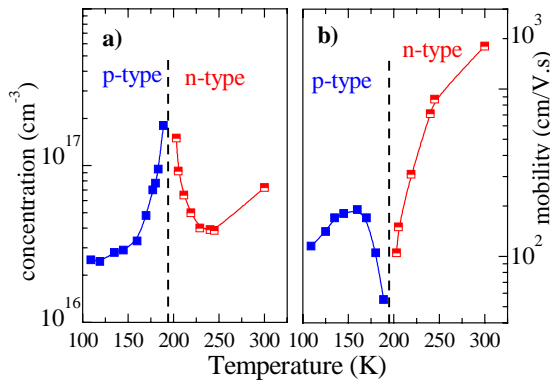


Fig.2: Measured carrier concentration (a) and Hall mobility (b) of the nid SL versus temperature. The Hall coefficient converts from p-type at low temperature to n-type at around 190 K.

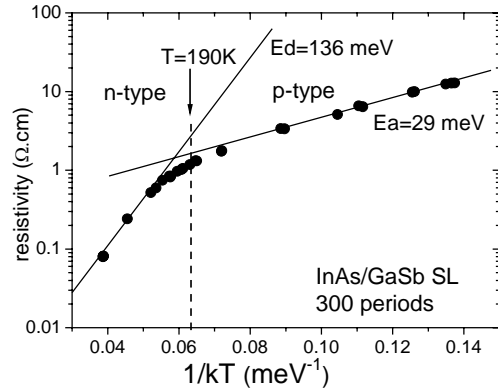


Fig.3: Resistivity versus inverse temperature showing two regimes with two activation energies at high and low temperatures.

In order to validate such previous observations, another kind of electrical investigations were planned. Mesa devices were prepared with the nid SL structure grown on n-type GaSb substrate ($1 \times 10^{18} \text{ cm}^{-3}$), by using standard photolithography and wet etching techniques. Au/Zn ohmic contacts have been realized on the cap layer structure made by the last GaSb layer of the nid SL. The diodes were not passivated.

Figure 4 presents the current-voltage (I-V) and capacitance-voltage (C-V) characteristics measured at several temperatures for a device of $350 \mu\text{m}$ diameter. The device shows rectifying characteristics in the whole temperature range 300K-80K (Fig. 4a). However, we can easily note the change in slope of forward bias characteristics below 190K. In the same way, the C-V curves begin to exhibit anomalous behavior around the same temperature (Fig. 4b). These observed uncharacteristic electrical properties are signatures of reverse polarity induces by change in type of conductivity of the SL structure. **A CHANGER**

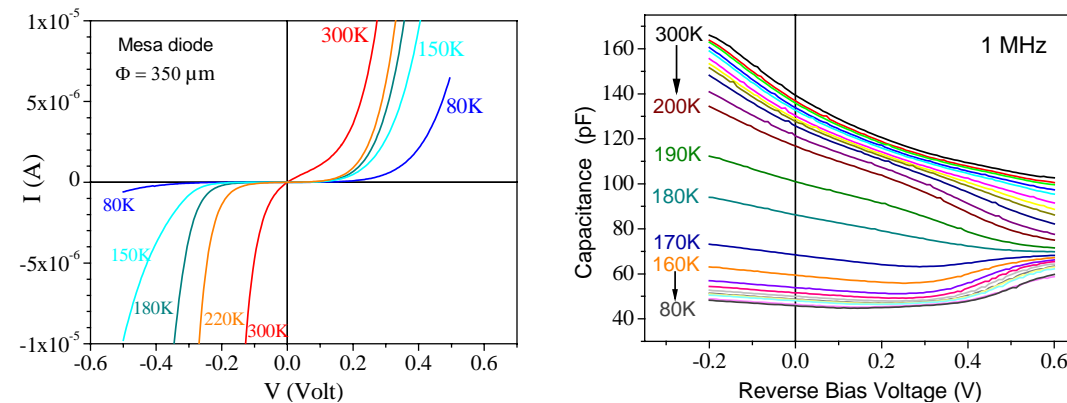


Fig.4: I-V characteristics in linear scale (a) and C-V characteristics performed at 1MHz (b) of nid-SL / n-GaSb heterojunction recorded at several temperatures

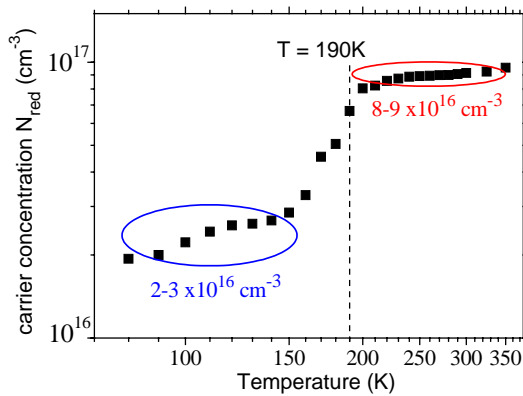


Fig.5 : Reduced carrier concentration N_{red} of the undoped SL versus temperature.

From linear C-V data and the theory of abrupt heterojunction, we can extract the reduced carrier concentration $1/N_{\text{red}}=1/N_A+1/N_D$ by using [16, 20] :

$$\left(\frac{A}{C(V)}\right)^2 = \frac{2V_d}{q\epsilon_r\epsilon_0 N_{\text{red}}} - \frac{2}{q\epsilon_r\epsilon_0 N_{\text{red}}} V$$

where A is the area and V_d is the built-in potential of the diode ; ϵ_r is the relative effective dielectric constant value of the multiplayer SL taken equal to 15.4. Figure 5 shows the temperature dependence of N_{red} . In the case of depletion at an np or pn junction, N_{red} represents the lower carrier concentration without precisions concerning the polarity of the carrier background of the mid SL region. However, these measurements confirm previous Hall results with a carrier concentration at around $2\text{-}3 \times 10^{16} \text{cm}^{-3}$ at low temperature and around $8\text{-}9 \times 10^{16} \text{cm}^{-3}$ above 200K.

In summary, we report electrical measurements performed on short-period InAs/GaSb SL in the temperature range between 80K and 300K. Whatever the electrical experiments (conventional hall effect, I-V and C-V), the mid InAs/GaSb SL reveals an unsettling change in type of conductivity. The SL is p-type at low temperature below 190K while is n-type at higher temperature. The accurate understanding of this versatile p or n-type behaviour of the SL active region is a key point on the way to improve InAs/GaSb system for mid-infrared detection.

References

- [1] D.L. Smith and C. Mailhot, J. Appl. Phys. **62**, 2545 (1987).
- [2] M. Razeghi and H. Mohseni, Handbook of Infrared Detection Technologies, M. Henini and M. Razeghi editors, (Elsevier Sciences Ltd, Oxford, 2002) p. 191.
- [3] H. Mohseni H, V.I. Litvinov V I and M. Razeghi M, Phys. Rev. B **58**, 15378 (1998).
- [4] C.M. Ciesla, B.N. Murdin, C.R. Pigeon, R.A. Stradling, C.C. Philips, M. Livingston, I. Galbraith, D.A. Jaroszynski, C.J.G.M. Langerak, P.J.P. Tang and M.J. Pullin, J. Appl. Phys. **80**, 2994 (1996).
- [5] M.J. Yang and B.R. Bennett Electron. Lett. **30**, 1710 (1994).
- [6] H. Mohseni, E. Michel, J. Sandoen, M. Razeghi, W. Mitchel and G. Brown, Appl. Phys. Lett. **71**, 1403 (1997).
- [7] H. Mohseni and M. Razeghi, IEEE Photon. Technol. Lett. **13**, 517 (2001).
- [8] Y. Wei, A. Hood, H. Yau, V. Yazdanpanah, M. Razeghi, M.Z. Tidrow, V. Nathan, Appl. Phys. Lett. **86**, 091109 (2005).
- [9] J.B. Rodriguez, P. Christol, A. Ouvrard, F. Chevrier, P. Grech and A. Joullié, Electron. Lett. **41**, 362 (2005).
- [10] Y. Wei, A. Hood, H. Yau, A. Gin and M. Razeghi, Appl. Phys. Lett. **86**, 233106 (2005).
- [11] M. Walther, J. Schmitz, R. Rehm, S. Kopta, F. Fuchs, J. Fleissner, W. Cabanski and J. Ziegler, J. Crystal Growth **278**, 156 (2005)-161
- [12] A. Gin, Y. Wei, A. Hood, A. Bajowala, V. Yazdanpanah, M. Razeghi, M. Tidrow, Appl. Phys. Lett. **84**, 2037 (2004).
- [13] R. Rehm, M. Walther, F. Fuchs, J. Schmitz and J. Fleissner, Appl. Phys. Lett. **86**, 173501 (2005).
- [14] D. Hoffman, A. Hood, E. Michel, F. Fuchs and M. Razeghi, IEEE J. Quantum Electron. **42**, 126 (2006).
- [15] D. Hoffman, A. Hood, F. Fuchs and M. Razeghi, J. Appl. Phys. **99**, 043503 (2006).
- [16] A. Hood, D. Hoffman, Y. Wei, F. Fuchs and M. Razeghi, Appl. Phys. Lett. **88**, 052112 (2006).
- [17] A. Rogalski A and P. Martyniuk, Infrared Phys. Technol. **48**, 39 (2006).
- [18] J.B. Rodriguez, P. Christol, L. Cerutti, F. Chevrier and A. Joullié, J. Crystal Growth **274**, 6 (2005).
- [19] X.B. Zhang, J.H. Ryou, R.D. Dupuis, A. Petschke, S. Mou, S.L. Chuang and K.C. Hsieh, Appl. Phys. Lett. **88**, 072104 (2006).
- [20] H. Ait-Kaci, D. Boukredimi and M. Mebarki, Phys. Stat. Sol (a), **163**, 101 (1997).