Transport measurements on InAs/GaSb superlattice structures for mid-infrared photodiode

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Abstract. In this communication, we report on electrical transport measurements of non-intentionally doped InAs/GaSb Superlattice structures grown by Molecular Beam Epitaxy. Resistivity and Hall Effect measurements were performed on two samples, corresponding to the same SL structure that has been grown on two different substrates: one on semi-insulating GaAs substrate, another on n-type GaSb substrate. To carry out the electrical measurements, the conducting GaSb substrate of the second sample has been removed. The study were performed in the temperature range 77-300K, for magnetic fields of 0.38 T. The both samples exhibited a change in type of conductivity from p-type at low temperature to n-type near room temperature.

1. Introduction
Thanks to recent results obtained in the mid-infrared domain (MWIR 3-5µm), InAs/GaSb superlattice (SL) is now considered as a new material system\(^1\) for the fabrication of high performance infrared (IR) p-i-n photodiodes suitable for thermal imaging camera\(^2\). To enhance performances and/or temperature operation, improvements of device technology as well as a better knowledge on fundamental properties of the SL photodiodes are still necessary. In particular, one needs to have a better understanding of carrier transport in this material where a reproducible change in type of conductivity as a function of temperature has been observed by different groups\(^3, 4\).

Hall Effect measurement is an efficient way to determine the effective carrier concentration in quantum structure. For the practical applications the InAs/GaSb SL photodiode structures are grown on lattice matched GaSb substrate and in this case there is no insulating substrate allowing accurate Hall measurements. The structures can be grown on semi-insulating GaAs substrates\(^5\), but it is well-known that the important density of defects inducing by the lattice mismatch between the SL structure and the GaAs substrate can lead to the experimental conclusions which cannot be directly applied into the lattice matched structures grown on GaSb substrate. Consequently, it is necessary to develop an experimental procedure to measure transport properties of high quality SL structure without influence of the substrate.

In this paper, we report Hall Effect measurements on a MWIR SL sample after the GaSb substrate has been mechanically and chemically removed. In this case, only the carriers from the SL materials...
take part in electrical conduction process and we compare results with those obtained for the same SL structure grown on semi-insulating GaAs substrate.

## 2. Experimental

The non-intentionally-doped (nid) InAs/GaSb SL structures were grown by molecular beam epitaxy (MBE) on n-type (001) GaSb substrate (called: GaSb-based sample) and on semi-insulating (001) GaAs substrate (called: GaAs-based sample), mounted on In-free molybdenum holders. The both structures are identical and composed of 600 periods of 8 monolayers (MLs) InAs / 8 MLs GaSb for a total thickness of about 3 µm. In the case of SL structure grown on GaSb substrate, an InAsSb layer was inserted between the SL and the substrate as a stop-layer to allow removing the conducting GaSb substrate by an appropriate technological process.

5x5 mm² piece of epilayers of GaSb-based sample was first cleaved and front-side-bonded on an Al₂O₃ host substrate using liquid epoxy adhesive. The GaSb substrate was then mechanically thinned up to 80/100 µm in a polishing machine utilizing various roughness abrasive pads. The last GaSb substrate micrometers were selectively wet etched by using a diluted CrO₃/HF based solution with an etch rate of about 5-6 µm/min. Next, to remove the InAsSb stop-layer, a standard citric acid (C₆H₈O₇) based solution with a 100:1 InAsSb:GaSb selectivity was used. Further details on the technological procedure will be the subject of a forthcoming paper.

Concerning GaAs-based sample (semi-insulating substrate), the measurements have been done on two type of samples: with and without the GaAs substrate. To remove the GaAs substrate, the same technological procedure was employed with a chemical wet etching using a C₆H₈O₇/H₂O/H₂O₂ based solution. To perform transport measurements, the prepared samples (5x5 mm²) were placed inside the cryostat installed between the electromagnet pole pieces. The contacts were made of indium. The Hall coefficient and the resistivity were measured in Van der Pauw configuration by a standard DC method. For Hall Effect measurement the magnetic field of 0.38 T was applied. The temperature inside the cell was measured using Pt100 resistor and stabilized within 0.1 K accuracy.

## 3. Results

First of all, we wanted to verify the influence of the substrate on Hall measurements. The Figure 1 shows the results obtained from measurements on two pieces of the sample grown on GaAs substrate: first one with the substrate and second one with substrate removed.

![Figure 1. Hall carrier concentration and Hall mobility versus temperature measured on the nid SL GaAs-based sample. The carrier type switches from p-type (open symbol) to n-type (full symbol) at 235°C.](image-url)
As it can be seen from this figure an overall good agreement was obtained between the two measurements, confirming that the method used to remove the substrate didn’t modify the carrier transport properties. The carrier density variation \( n_H \) with the temperature shows values in the range of \( 1.8 \times 10^{16} \text{ cm}^{-3} – 3.5 \times 10^{16} \text{ cm}^{-3} \) between 77 and 300 K. One can notice the carrier-type switch from p-type to n-type occurring at 235°C, that reveals the compensated nature of the SL.

Mobility in the range of 48 cm²/V.s at 77 K (p-type material), and 1720 cm²/V.s at 300 K (n-type material) was measured. Those fairly low values can be attributed to the high density of threading dislocations due to the large lattice-mismatch existing between the SL structure and the GaAs substrate.

Similar measurements were made on GaSb-based sample without substrate. Temperature dependence of the effective carrier concentration \( n_H \) and Hall coefficient \( R_H \) are presented in Figure 2. A reproducible change of sign of Hall coefficient \( R_H \) is observed. It means that the change of type of conductivity of the nid SL occurs around \( T_{\text{crit}} \sim 120 \text{ K} \). At low temperature the sample is p-type with carrier density \( p_H (100K) = 2.8 \times 10^{15} \text{ cm}^{-3} \). At room temperature, the SL is n-type with \( n_H (300K) = 1.5 \times 10^{16} \text{ cm}^{-3} \). We can remark that at low temperature, the carrier density value is one order of magnitude lower than the value measured on the sample grown on GaAs (Figure 1).

![Figure 2. Measured apparent Hall carrier concentration \( n_H \) and Hall mobility versus temperature, results for the nid SL grown on GaSb substrate. The carrier type switches from p-type (open symbol) to n-type (full symbol) at 120°C.](image)

Mobilities measured on GaSb-based sample were also notably higher compared to the GaAs-based sample. The values measured reached respectively: 270 cm²/V at 77K (p-type material) and 3850 cm²/V.s at 300 K (n-type material).

Comparison between GaAs-based and GaSb-based samples with substrates removed is presented on Figure 3. It can be seen that the character of temperature variation of apparent Hall concentration for the both samples is very similar. At low temperature range (p-type conduction) they are characterised by the same thermally activated process. The analogue situation takes place at room temperatures, in n-type conduction regime. Of course, due to the lower hole concentration the switch
from p-type to n-type conduction in GaSb-based sample occurs in lower temperature than in GaAs-based one. This difference in hole concentration manifests itself in mobility vs temperature variation. In case of GaSb-based sample the low temperature mobility (p-type conduction) is much higher and decreases with increasing temperature. In GaAs-based sample the increase of hole mobility with temperature indicate that the ionized impurity scattering mode is predominant in this material.

Figure 3a. Apparent Hall carrier concentration $n_H$ versus temperature, results for the nid SL grown on GaSb and GaAs substrate respectively.

Figure 3b. Hall mobility versus temperature, results for the nid SL grown on GaSb and GaAs based samples respectively, without substrates (log to log).

4. Conclusion

Up till now the only way to study the electrical transport in InAs/GaSb SL for MWIR photodiodes applications was to grown the structures on semi-insulating GaAs substrates. However the results of such a study could be deform by important density of defects inducing by the lattice mismatch between the SL structure and the GaAs substrate. In the presented paper, we have demonstrated that the resistivity and Hall Effect can be measured on a structure in which the substrate has been mechanically and chemically removed. It allows studying electrical properties of InAs/GaSb SL grown on a lattice-matched GaSb substrate. From the Hall data, a change of conductance from p-type below 120 K to n-type for higher temperatures was observed. A hole concentration and a mobility of $2.8 \times 10^{15}$ cm$^{-3}$ and 270 cm$^2$/Vs were measured at 77 K.

This reliable method for Hall measurements of SL carrier transport properties could prove very helpful for the sake of material improvement, photodiode design and simulation.

References

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