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GaSb AND GaInAsSb PHOTODETECTORS FOR λ > 1.55 μm PREPARED BY METAL ORGANIC CHEMICAL VAPOR DEPOSITION

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Résumé - Des couches de GaSb de type p et n ont été élaborées par dépôt en phase vapeur à partir d'organométalliques (MOCVD) sur des substrats de GaSb et de GaAs semi-isolant ; les plus faibles niveaux de dopage obtenus sont, $p = 2 \times 10^{16} cm^{-3}$, $n = 8 \times 10^{15} cm^{-3}$. Des couches de $Ga_{1-x}In_xAs_ySb_{1-y}$ de type p ont aussi été fabriquées par cette méthode avec une composition assurant la photodétection à 2.5µm. Les propriétés des couches et des jonctions obtenues sont décrites.

Abstract - p and n GaSb layers have been grown on GaSb and semi-insulating GaAs substrates by Metal Organic Chemical Vapor Deposition (MOCVD) method ; the lowest doping levels obtained are : $p = 2 \times 10^{16} cm^{-3}$, $n = 8 \times 10^{15} cm^{-3}$. P type $Ga_{1-x}In_xAs_ySb_{1-y}$ layers have also been fabricated by MOCVD with a composition insuring the photodetection at a wavelength of 2.5µm. The properties of the layers and of the as grown junctions are described.

With the aim of realizing a Separated Absorption and Multiplication (SAM) photodetector, at a wavelength of 2.5µm preparation and characterization of GaSb and $Ga_{1-x}In_xAs_ySb_{1-y}$ layers and devices have been undertaken.

1 - FABRICATION /1/

The different layers are elaborated by Metal Organic Chemical Vapor Deposition (MOCVD) using trimethyl-gallium (TMG), trimethyl-indium (TMI) and trimethyl-antimony (TMSb) in a vertical reactor at atmospheric pressure. The n doping is obtained using dimethyl tellurium (DMTe) diluted in H_2. The results presented here are relative to :

- n and p type GaSb layers deposited on semi-insulating GaAs ; GaSb mesa diodes : p GaSb/n GaSb substrate.
- mesa diodes : p $Ga_{1-x}In_xAs_ySb_{1-y}$/n GaSb substrate, this device has allowed to test the infrared photodetection in the MOCVD ternary and quaternary alloys.

2 - LAYERS CHARACTERIZATIONS

p GaSb

The lowest p_H value (Hall p density) obtained in our native GaSb is $2 \times 10^{16} cm^{-3}$ at 300K with an associated mobility μ_{pH}= 900cm²/V.s. The variations of p_H and μ_{pH} with temperature ($77 < T < 300K$) are shown on figure 1a and b. A model involving two acceptor levels and a compensating donor level has been used to account for the p variation and leads to the determination of the energies E_{A_1} = 23meV, E_{A_2} = 76 meV with respective densities $N_{A_1} = 1.3 \times 10^{16} cm^{-3}$, $N_{A_2} = 1.03 \times 10^{16} cm^{-3}$. The donor density is negligible, the hole effective mass has been choosen equal to 0.23 m_o/2/, the spin degeneracy factor $g_{A_1} = 4$; the factor $g_{A_2} = 2$ has been derived from the calculation. This result indicates that this p layer is weakly doped and weakly compensated and that the involved elaboration technique does not introduce any new electrically active defect. The existence of two native acceptor levels has already been derived from optical and electrical measurements in various GaSb samples ; our N_{A_1} and N_{A_2} values are nearly equivalent indicating that E_{A_2} may correspond to the 2nd ionization of A_1. Our less doped sample is comparable to the best publicated results of H. Miki et al./3/ ; $p_H = 1.1 \times 10^{16} cm^{-3}$, μ_{pH}= 620cm²/V.s and M. Lee et al/4/ : $p_H = 7.8 \times 10^{15} cm^{-3}$, μ_{pH}= 950cm²/V.s.

n GaSb

The n doping level has been controlled by varying the DMTe pressure in the reactor /5/. The lowest n_H value has been obtained with the following growth parameters : T = 560°C, P(DMTe) = 1×10^{-6} Atm ; V/III ratio = 1 : $n_H = 8 \times 10^{15} cm^{-3}$, $\mu_{nH} = 5000 cm^2/V.s$ at 300K. The figures 2a and b show the variations of n_H and μ_{nH} as a function of T for three representative samples. The increase of n_H with decreasing temperature can be explained by the contribution of two types of carriers (Γ and L bands) coming from a degenerated Te donor level.

In conclusion, despite of the huge lattice mismatch ($\Delta a/a = 7.8.10^{-2}$) the electrical properties of these p and n layers are very similar to those of single crystal materials.

3 - OPTOELECTRONIC PROPERTIES OF THE DEVICES

GaSb diodes

They are made of natural p MOCVD GaSb layer on n GaSb substrate. The mesa diode diameter is 190µm.

- Capacitance - Voltage (C-V) characteristics.

Some devices exhibit a linear $1/C^2 = f(V)$ variation, however, generally such a variation is not observed and two limiting effective doping levels N_{B_1} at low voltage and $N_{B_2} > N_{B_1}$ at high voltage can be deduced. This fact could be related to an interaction layer - substrate during the growth which needs further investigations. The experimental N_B values does not exactly coïncide with the calculated ones deduced from the hole density in the layer and the electron density in the substrate ; M. Yano et al /6/ have already observed such a discrepancy and attributed it to interface defects.

- Current voltage I-V characteristics.

A typical example of room temperature I-V characteristic is shown on figure 3. A generation-recombination current I_{G-R} is dominant in the low voltage range with a τ value of 10^{-10}s. For higher polarization values an excedentary current is present greater than the expected current. This current can be due to the extension of the space charge in a perturbed region with lower values, this region could be the metallographic interface ; this current may also be due to surface leakages in these unpassivated devices. For V > 7V a more or less soft breakdown occurs which can be attributed to multiplication. The multiplication is confirmed by the variation of the I-V characteristic with temperature which exhibits a shift of the breakdown to lower V values and a more abrupt avalanche ; it is also confirmed by the observed photocurrent multiplication measured at 1.3µm (figure 4).

- Spectral responses

The figure 5a represents a typical spectral response of a GaSb diode with a junction depth of 4 µm. The external quantum efficiency at 1.55µm is equal to 0.22. Based on a single model of homojunction, the diffusion length in the MOCVD GaSb layer can be estimated : Ln $\simeq$ 4µm.

$Ga_{1-x}In_xAs_ySb_{1-y}$ diodes

In this first step of investigation, the non optimized, and generally mismatched heterojunctions made of a p $Ga_{1-x}In_xAs_ySb_{1-y}$ deposited on n GaSb substrate have been elaborated in order to determine the growth parameters corresponding to x and y values allowing the photodetection at a wavelength of 2.5µm.

The spectral response of figure 5b is relative to the diode P20 in which the quaternary layer was $Ga_{0.8}In_{0.2}As_{0.18}Sb_{0.82}$ is matched to GaSb, the figure 5c is relative to the diode I9 on which the ternary layer was $Ga_{0.63}In_{0.37}Sb$. A backward illumination (through the substrate) has been used to do the measurement.

For the matched heterojunction, the spectral response is classical, the cut-off wavelength in the near infrared range is about 2.3µm. For the mismatched heterojunction, the cut-off appears beyond 2.5µm (the evaluated gap for x = 0.37 is 430 meV) but the photoresponse cannot be explained by the presence of only two materials : GaSb (Eg = 730 mev), $Ga_{0.63}In_{0.37}Sb$ (Eg = 430 meV), the increase of the response at about 1.9µm is probably due to a material of intermediate composition.

4 - CONCLUSION

MOCVD method has allowed to elaborate p and n type GaSb layers with electrical properties very similar to the best ones measured on material grown by other techniques.

The growth method has also allowed to deposite $Ga_{1-x}In_xAs_ySb_{1-y}$ layers with a gap value adapted to the photodetection at λ = 2.5µm.

This work must be extended with three main purposes : the decrease of the doping level in GaSb, the control of the growth conditions in order to fabricate $Ga_{0.74}In_{0.26}As_{0.24}Sb_{0.76}$ layers matched to GaSb with Eg = 490 meV and the evaluation of the phototransport parameters in this absorbing layer.

REFERENCES

/1/ Bougnot, G., Foucaran, A.F., Marjan, M., Etienne, D., Bougnot, J., Delannoy, F.M.H., Roumanille, F.M., J. of Crystal Growth 77-400 (1986).

/2/ Nakashima, K., Jap. J. of Appl. Phys. 20-1085 (1981).

/3/ Miki, H., Segawa, K., Fujibayashi, K., Jap. J. of Appl. Phys. 13-203 (1974).

/4/ Lee, M., Nicholas, D.J., Singer, K.E., Hamilton, B., J. of Appl. Phys. 59-2895 (1986).

/5/ Bougnot, G., Pascal, F., Roumanille, F., Grosse, P., Bougnot, J., Gouskov, L., Foucaran, A.,2nd Eur. Workshop on MOVPE - Fife (Scotland) 19-22 june 1988.

/6/ Yano, M., Suzuki, Y., Ishii, T., Matsushima, Y., Kimata, M., Jap. J. of Appl. Phys. 17-2091 (1978).

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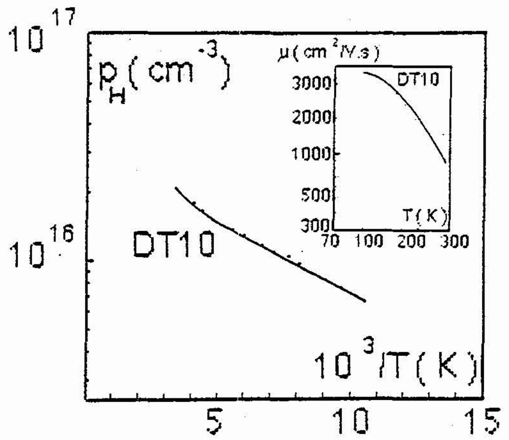

Fig.1 - Hole density and mobility in p type MOCVD GaSb layer as a function of temperature

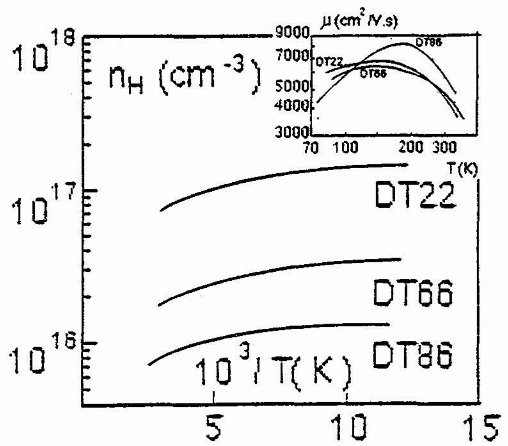

Fig.2 - Electron density and mobility in n type MOCVD Te doped layers as a function of temperature

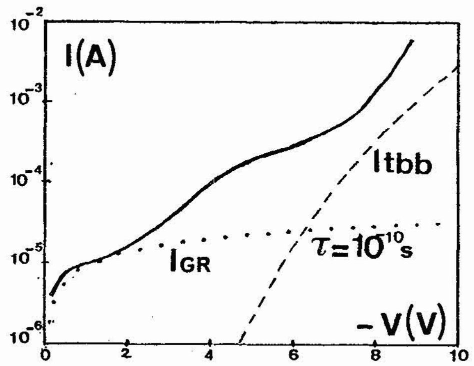

Fig.3 - Reverse dark I-V characteristic at 300K for a typical GaSb diode.
...Calculated generation-recombination I_{GR} and band to band tunnel I_{tbb} currents

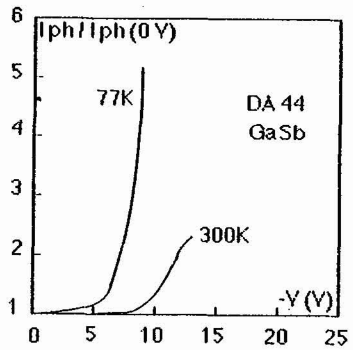

Fig.4 - Photocurrent multiplication at 300 and 77K measured on a GaSb diode (λ = 1.3µm)

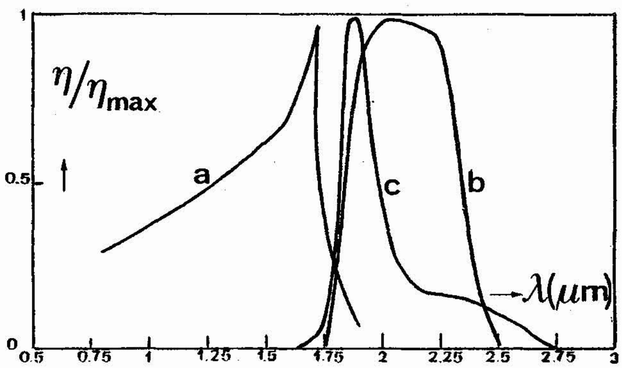

Fig. 5 - Spectral responses measured on :
a) GaSb photodiode DT29 $\eta_{max} = 0.32$
b) matched $Ga_{0.2}In_{0.8}As_{0.18}Sb_{0.82}$/GaSb heterojunction P20
c) mismatched $Ga_{0.63}In_{0.37}Sb$/GaSb heterojunction I9