Temperature dependence of built in potential and valence band offsets in the GaAlAsSb (n) /GaSb (p) heterojunction.

Bahaous MESSANI, Khaled MAHI and Hocine AÏT-KACI
Physics of Plasmas and Conductors Materials and their Applications Laboratory (P.P.C.M.A.L)
Department of Physics, B.P.1505 El M'Naouar, Oran, Algeria
e-mail: messanizn@yahoo fr

Abstract— **The $GaAlAs_ySb_{1-y}$ quaternary alloys are important materials covering the wavelengths between the visible and infrared region (0.57, 1.72 µm) suitable for device applications, such as injection lasers, photodiodes, and solar cells [1.2]. In this paper we present how to determine the build in voltage Vd and the intercept voltage Vint and also the net doping concentration Nd in the $Ga_{0.60}Al_{0.40}As_{0.034}Sb_{0.96}$ layer from capacitance-voltage measurements at different temperature (220, 240, 260 k), using the " intercept method". And Finally we report on the determination of the conduction and valance band-offsets ΔEc and ΔEv in a GaSb (p =2.1018) / $Ga_{0.60}Al_{0.40}As_{0.03}Sb_{0.96}$ (n).**

Keywords- capacitance-voltage characteristic; GaAlAsSb (n) /GaSb (p) heterojunction; temperature

I. INTRODUCTION

Heterostructures based on Sb- containing III–V semi conductors are particularly attractive for the fabrication of a wide variety of optoelectronic devices such as light emitting diodes, laser diodes and photodetectors and thermo photovoltaic devices operating in the mid-infrared range of wavelength Narrow-gap quaternary [3] $Ga_{1-x}In_xAs_ySb_{1-y}$ compounds serve as active layers in Emitters and detectors, whereas $Ga_{1-x}Al_xAs_ySb_{1-y}$ compounds are useful materials for low refractive index Cladding layers in DH GaSb/GaInAsSb/GaAlAsSb lasers and LEDs and for wide-gap window layers in photodetectors

II. COMPOSITION DEPENDENCE

The quaternary material $A_xB_{1-x}C_yD_{1-y}$ is constructed of four binary compounds : AC, AD, BC and BD, or else of four ternary compounds :$A_xB_{1-x}C$, $A_{1-x}B_{1-x}D$, AC_yD_{1-y}, and BC_yD_{y-1} in particular, for AlGaAsSb.

With form $A_xB_{1-x}C_yD_{1-y}$, its compounds are AC = AlAs, AD = AlSb, BC = GaAs, and BD = GaSb its ternary compounds Are ABC = AlGaAs, ABD = AlGaSb, ACD = AlAsSb, and BCD = GaAsSb.
The quaternary material parameters (from $A_xB_{1-x}C_yD_{1-y}$) may be obtained from the binary parameters using Vegard's rule[4.2]

$$Q_{ABCD}(x,y) = xy\,B_{AC} + x(1-y)B_{AD} + (1-x)yB_{BC} + (1-x)(1-y)B_{BD} + C_{A-B}.x(1-x) + C_{C-D}y(1-y)$$

For GaAlAsSb is characterized by the variations of the band of energy Γ, L and X in the range of the compositions 0 at 1 by the these equations [6.5]:

$$E_\Gamma(x) = 0{,}725(1-x) + 2{,}338x - 0{,}47x(1-x)$$

$$E_L(x) = 0{,}748(1-x) + 2{,}201x - 0{,}47x(1-x)$$

$$E_X(x) = 1{,}054(1-x) + 1{,}639x$$

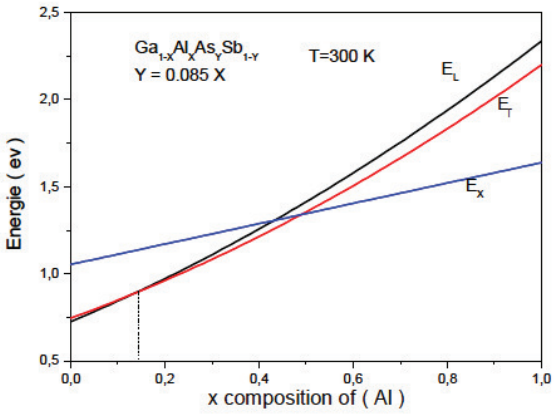

Figure 1. Variation of band gap as a function of x composition.

III. INTERCEPT METHOD

A. Results and discussion

The capacitance–voltage characteristic (C-V) can be given by this relation

$$C = S\sqrt{\frac{q}{2}\times\frac{\varepsilon_1\varepsilon_2 N_{d_1} N_{a_2}}{\varepsilon_1 N_{d_1}+\varepsilon_2 N_{a_2}}}\left(V_d - V_{app}\right)^{-\frac{1}{2}} \quad (1)$$

The characteristic $1/C^2 = f(V)$ is linear in the reverse bias range 0 at 0.15V for different temperature shown in fig.3. consequently it can be perfectly interpreted by the law

$$\frac{1}{C^2} = \frac{1}{S^2}\left[\frac{2(\varepsilon_1 N_{d1}+\varepsilon_2 N_{a2}}{q\varepsilon_1 N_{d1}\varepsilon_2 N_{a2}}\right](V_{\text{int}} - V) \quad (2)$$

Where S is the heterojunction plane surface (S = 225 µm), $\varepsilon_1.\varepsilon_2$ are the dielectric constants of GaSb and $Ga_{0.60}Al_{0.40}As_{0.034}Sb_{0.96}$, N_{d1}, N_{a2} being their net doping concentration.

$1/C^2 = f(V)$ curve was assumed giving the real carrier concentration N_d the intercept voltage V_{int} is related to the diffusion voltage V_d in n-region by the following expression [6]

$$V_{\text{int}} = V_d + \frac{2kT}{q} - V_{SS} \quad (3)$$

Where V_{ss} is the potential resulting of the influence of the interface state densite, this density N_{ss} at the heterojunction plane can be roughly evaluated from the Kressel formula [7]

$$N_{SS} = \frac{8\Delta a}{a^3} \quad (4)$$

B. Experimental Results

The capacitance-voltage (C-V), measurements for our hétérojunction GaSb (p =2.1018) / $Ga_{0.60}Al_{0.40}As_{0.034}Sb_{0.96}$ (n) at different temperature is given by Fig. 2 and Fig. 3

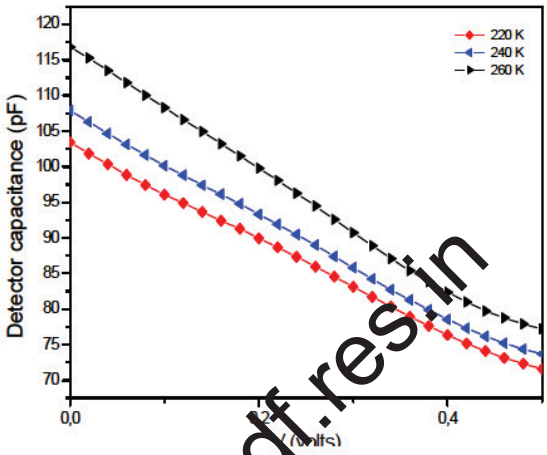

Figure 2. C=f(V) characteristic of $Ga_{0.60}Al_{0.40}As_{0.034}Sb_{0.96}$ / GaSb heterojunction at different temperature.

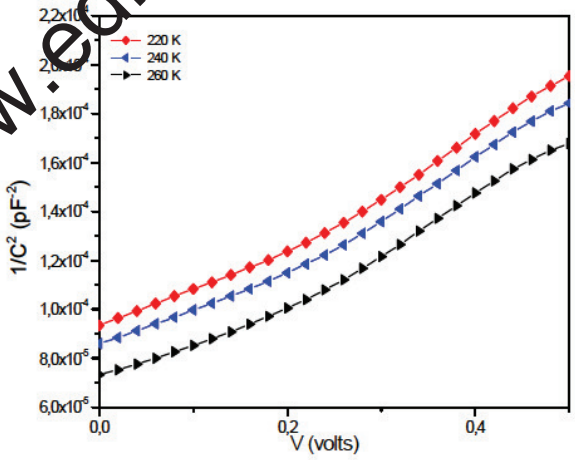

Figure 3. $1/C^2$=f(V) characteristic of $Ga_{0.60}Al_{0.40}As_{0.034}Sb_{0.96}$ / GaSb heterojunction at different temperature.

From capacitance-voltage (C-V) measurements, using the "intercept method" we can deduced the variation of built in voltage V_d and intercept voltage Vint with temperature Fig. 4 and also the carrier of concentration Nd Fig. 5 in quaternary GaAlAsSb.

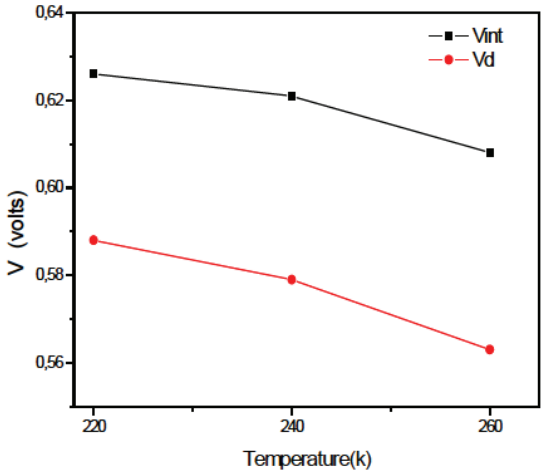

Figure 4. Variation of Vd and Vint as a function of temperature.

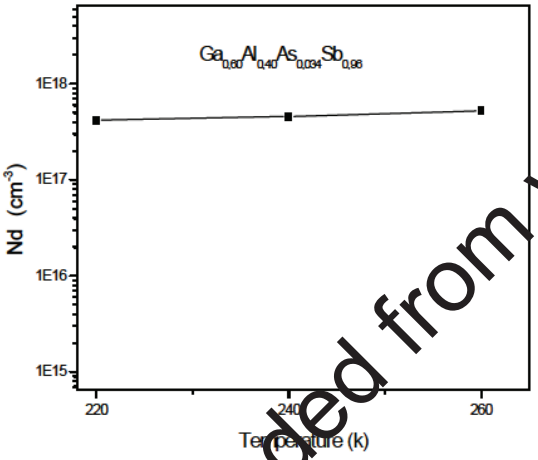

Figure 5. Variation of carrier concentration with temperature.

IV. EFFECT OF TEMPERATURE ON THE BAND GAP ENERGY OF GAALASSB

Traditionally, temperature variation of the band-gap energy Eg is expressed in terms of the Varshni formula [6.7]

$$E_g(T) = E_g(0) - \frac{\alpha . T^2}{B + T} \qquad (5)$$

where Eg (0) is the band-gap energy at T = 0 K, α is in electron volts per Kelvin and β is closely related to the Debye temperature of the material (in Kelvin).when we use the varshni parameters of binary compounds GaAs, GaSb, AlAs, AlSb of GaAlAsSb we can give the interpolation of the energy band gap for Γ, L, X transition of this quaternary with temperature.

The band discontinuity is a fundamental parameter needed for both understanding of heterojunction and designing of practical devices. The sheme in Fig. 3 presente the variation of band discontinuity as a function of temperature using theorical model of Anderson and we deduced that there is not a great variation of conduction and valance band-offsets ΔEc and ΔEv.

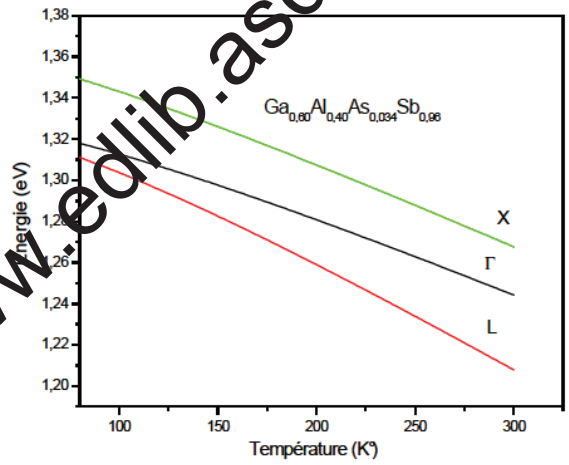

Figure 6. Band gap energy of Ga0 $Ga_{0.60}Al_{0.40}As_{0.034}Sb_{0.96}$ as a function of temperature.

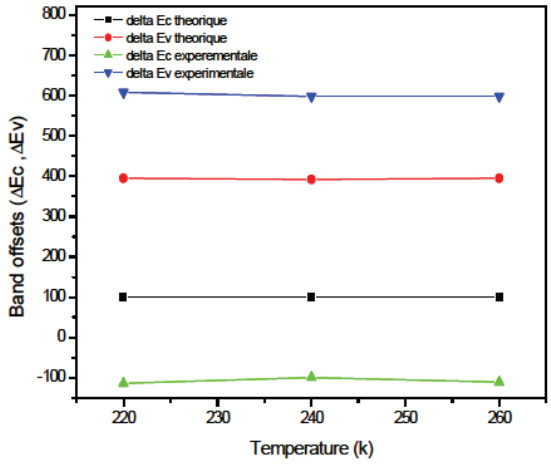

Figure 7. Variation of band offsets as a function of temperature.

V. CONCLUSION

We have reported in this work, the electrical characterisation of the interface GaSb/$Ga_{0\ 60}Al_{0\ 40}As_{0\ 034}Sb_{0\ 96}$ to get the Vint ,Vd at different temperature(220, 240, 260 k) and finally we give the band offsets ΔEc and ΔEv at different temperature using the theorical model of Anderson and results by capacitance –voltage measurements.

REFERENCES

[1] M. Piskorski, A. Piotrowska, T. T. Piotrowski, K.Golaszewska LPE growth an characterisation of GaInAsSb and GaAlAsSb quaternary layers on (100) GaSb substrates.

[2] Sadao adachi Band gaps and refractive indices of AlGaAsSb GaInAsSb and InPAsSb: key properties for a variety of the 2-4μm optoel -ectronic device application jannuary 1987.

[3] Gonzalez-cuevas et al J.Appl.Phys, 2007, p 102.

[4] L.Vegard.Z.Phys, 1921, p 175.

[5] Lazari these de doctorat, 1993.

[6] H. Ait-kaci, D. Boukredimi and M. .Mebarki, phis. Status. Solid, 1997, p 163.

[7] H. Kressel, J. Electronic Master, 1975, p, 108