



AC Analysis of InP/GaAsSb DHBT Device

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Abstract: Tremendous increment in the high speed demands of data rate results in the continuous improvement in Indium Phosphide /Gallium Arsenide Antimonide / Indium Phosphide Dual Heterojunction Bipolar Transistor Device. In this paper frequency response of the InP/GaAsSb/InP DHBT has been reported. Physical based two dimensional device simulators, Atlas tool is used to study the Ac operation and performance of InP/GaAsSb Dual Heterojunction Bipolar Transistor Device approaching Giga Hertz frequency range. Gallium Arsenide Antimonide lattice matched to Indium Phosphide is the replacement of Indium Gallium Arsenide based DHBTs because of its non collector blocking effect. Simulated device has reported a peak Ac current gain of 29.63 dB, cutoff frequency of 310 GHz and maximum oscillation frequency of 190 GHz.

Keywords: Double Heterojunction Bipolar Transistor (DHBTs); InP; GaAsSb; InGaAs; HBTs; maximum oscillation frequency (f_{MAX}); cutoff frequency (f_T).

I. INTRODUCTION

In today's scenario, Double Heterojunction Bipolar Transistors (DHBTs) have niche market in wideband communication industry, RF amplification and space exploration [1]. DHBTs have shown unprecedented performance in term of high speed, higher current gain, lower operating voltage and lower noise [2]. Among the Indium Phosphide based heterojunction bipolar transistor, InP/InGaAs based (HBTs) have respond good figure of merits in term of cutoff frequency f_T & f_{MAX} but experience lower breakdown voltage due to thinner bandgap $Ga_{0.47}In_{0.53}As$ collector. Use of GaAsSb material as base in InP DHBTs results in higher Breakdown voltage by reducing impact ionization in the collector layer and results in higher cutoff frequency f_T & f_{MAX} and higher breakdown compare to InP/InGaAs DHBT and other InP HEMTs [3].

InP/GaAsSb DHBTs have shown outstanding results in Giga Hertz frequency ranges and approaching toward Tetra Hertz frequency range [4]. GaAsSb base layer have results in better solution compare to InGaAs based DHBT device because of type II band alignment of GaAsSb/InP heterojunction causes unhindered injection of electron from GaAsSb base in to InP collector [5]. The primary goal of this paper is to perform the Ac simulation of the device. Energy band diagram, carrier distribution & Ac characteristics of InP/DHBT is reported with uniform GaAsSb base and InP collector.

II. INP/GAASSB DHBT STRUCTURE

The InP/GaAsSb DHBTs consists of lattice matched $Ga_{0.51}Sb_{0.49}$ base ($E_G=0.72eV$) and InP based emitter and collector region ($E_G\approx 1.35eV$) [5]. Triple mesa DHBTs structure consists of semi - insulating InP substrate, 500 Å $N^+= 2.10^{19} cm^{-3}$ $In_{0.53}Ga_{0.47}As$ sub collector layer, 2000 Å $N^- = 2.10^{16} cm^{-3}$ InP collector layer, 150 Å $P^+= 7.10^{19} cm^{-3}$ $Ga_{0.51}As_{0.49}Sb$ base, 900 Å $N^- = 7.10^{17} cm^{-3}$ InP emitter layer, 500 Å $N^- = 3.10^{19} cm^{-3}$ InP emitter cap layer, 1000 Å $N^+= 1.10^{19} cm^{-3}$ $In_{0.53}Ga_{0.47}As$ emitter contact layer. Base, emitter & collector contacts have dimension of $0.5\mu m \times 0.2\mu m$ with gold metal of resistivity of $2.35\mu\Omega\cdot cm$. Physically-based two dimension simulation of semiconductor devices is performed using TCAD tool, SILVACO to study the energy band diagrams, current gain, Gummel characteristics and junction capacitance of the device [6]. Study considers the impact of Poisson equation, carrier continuity equation, Shockley Read Hall recombination (SRH), Auger recombination, and Boltzmann statistics on stable functioning of the device.

Our device was design with an emitter up triple mesa structure. Emitter area of $0.5 \times 1 \mu m^2$ is considered for simulation. The junction area between base-collector and base-emitter result in the reduction of charge storage in respective junction, which finally result in increasing the maximum oscillation frequency of the device. Figure 1(a) shows the schematic cross section of the InP/GaAsSb DHBT device where as figure 1(b) represents the schematics view of the device with meshing in simulation environment.

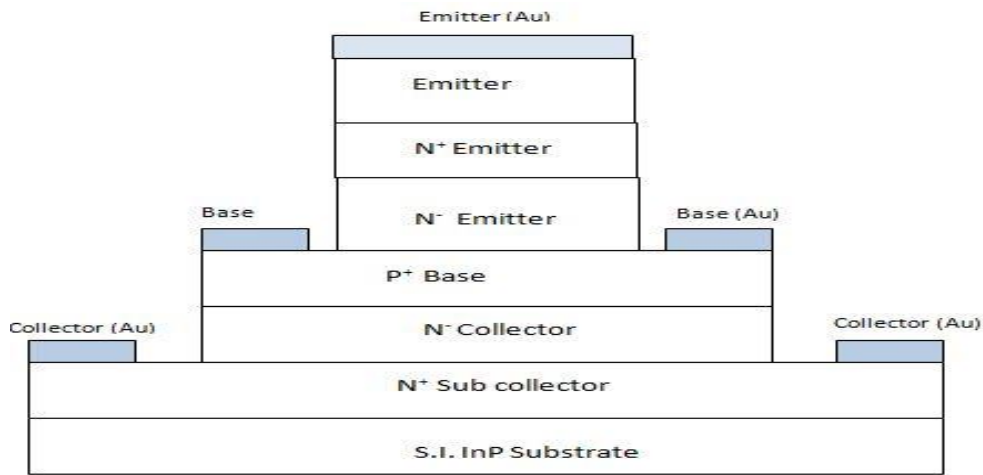


Fig.1 (a) Schematic view of InP/GaAsSb DHBT

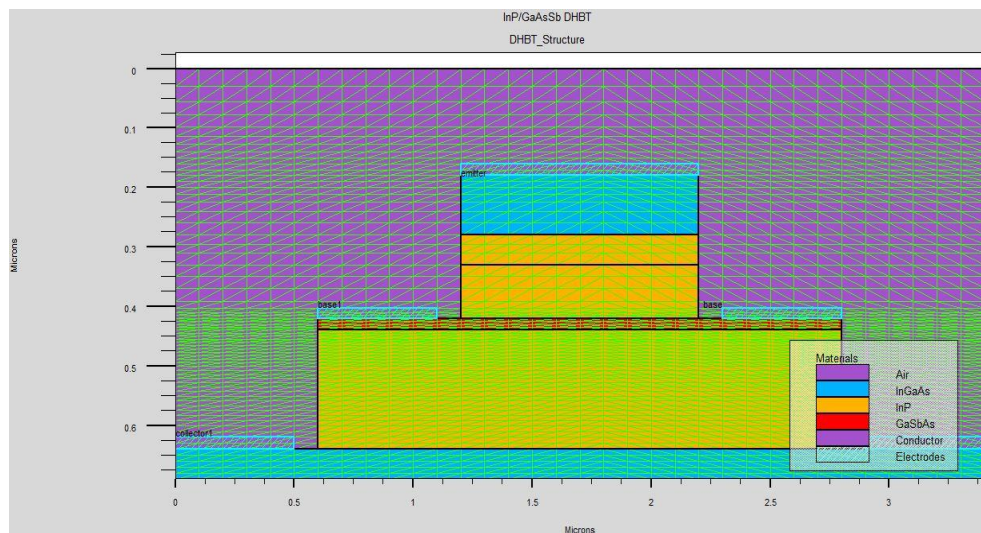


Fig.1 (b) Schematic view of InP/GaAsSb DHBT with meshing in Atlas tool

III. SIMULATION SETUP

The Simulation has done by activating the following Shockley-Read hall recombination model, concentration dependent mobility model, parallel electric field dependence mobility model, Hot electron model in Atlas simulation tool. Activation of these model results in efficient simulation of the device. Newton numerical algorithm used to solve equations. For thin base, transport process is not diffusive as carriers meet lesser collision in crossing the base. Electron enters into base, overcome conduction band spike with higher energy and velocity. Activating the Hot electron model reduces the transit time of carrier through base by replacing slow diffusive motion by fast ballistic propagation [7].

**Table 1: Mobility model parameter (a) Electron (b) Hole
(a) Electron**

Parameter	Units	InP	InGaAs	GaAsSb
$\mu_{\min}$	$\text{cm}^2/\text{V-s}$	300	3372	574
$\mu_{\max}$	$\text{cm}^2/\text{V-s}$	4917	11599	750
N_c	cm^{-3}	6.4×10^{17}	8.9×10^{16}	1.82×10^{17}
A	-----	0.46	0.76	1.057

(b) Hole

Parameter	Units	InP	InGaAs	GaAsSb
$\mu_{\min}$	$\text{cm}^2/\text{V-s}$	20	75	20
$\mu_{\max}$	$\text{cm}^2/\text{V-s}$	151	331	60
N_c	cm^{-3}	7.4×10^{17}	1.0×10^{18}	7.93×10^{18}
A	-----	0.96	1.37	0.452

All the important mobility parameter of InP, InGaAs, GaAsSb material extracted from literature are reported in Table 1. Accuracy of these parameter values play important role in successful simulation of the device. Carrier's mobility is a dominating function of doping. All the mobility parameters are put into Caughey Thomas mobility model for stable simulation of the device [6]. From Table 2, we can analyze that electron effective mass is much smaller compare to hole effective mass. Hence hole mobility is smaller than electron mobility.

Table 2: Material parameter for InP, InGaAs, GaAsSb.

Parameter	Symbol	InP	InGaAs	GaAsSb
Permittivity	ϵ_r/ϵ_0	12.35	13.88	14.27
Electron Affinity	$\chi(\text{eV})$	4.37	4.58	4.07
Electron Effective Mass	m_n^*/m_0	0.077	0.041	0.0449
Light Hole Effective Mass	m_{lh}^*/m_0	0.12	0.05	0.0663
Heavy Hole Effective Mass	m_{hh}^*/m_0	0.56	0.46	0.4561
Valance Band density of states	cm^{-3}	1.1×10^{19}	7.7×10^{18}	2.38×10^{17}
Conduction Band Density of States	cm^{-3}	5.7×10^{17}	2.1×10^{13}	4.64×10^{17}

IV. DEVICE CHARACTERISTICS & RESULTS

Energy band diagram of the proposed InP/GaAs_{0.51}Sb_{0.49}/InP DHBTs with eliminating current blocking effect at base-collector junction is shown in figure 2. Band gap of conduction band in InP/GaAsSb DHBT device is shown in figure 3.

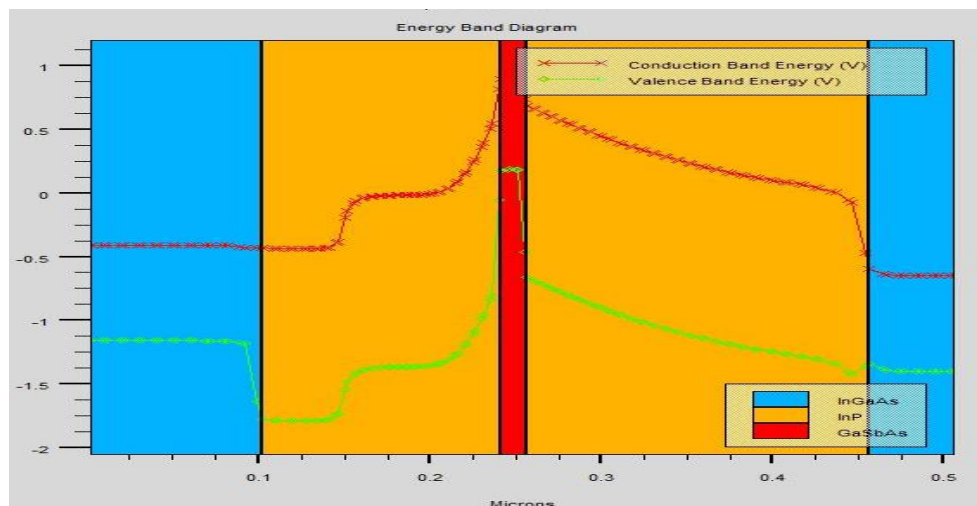


Fig.2. Energy band diagram of simulated InP/GaAsSb DHBT

Energy band gap of GaAsSb base is smaller than the energy band gap of InP emitter. For our InP/GaAsSb DHBT, however, the hot-electron effect will modify the transit time across the base-collector space charge region, since the conduction band edge for the base is above that of the collector layer as seen in Figure 2. We can conclude hot electron model is dominant transport mechanism through the base of the InP/GaAsSb DHBT and the reason for impressive f_T and f_{MAX} performance in spite of the low carrier mobility in the GaAsSb base

[7]. Band offset between base-emitter conduction bands is 0.18 eV where as band offset between base-collector junctions is found to be 0.78 eV as shown in figure 3.

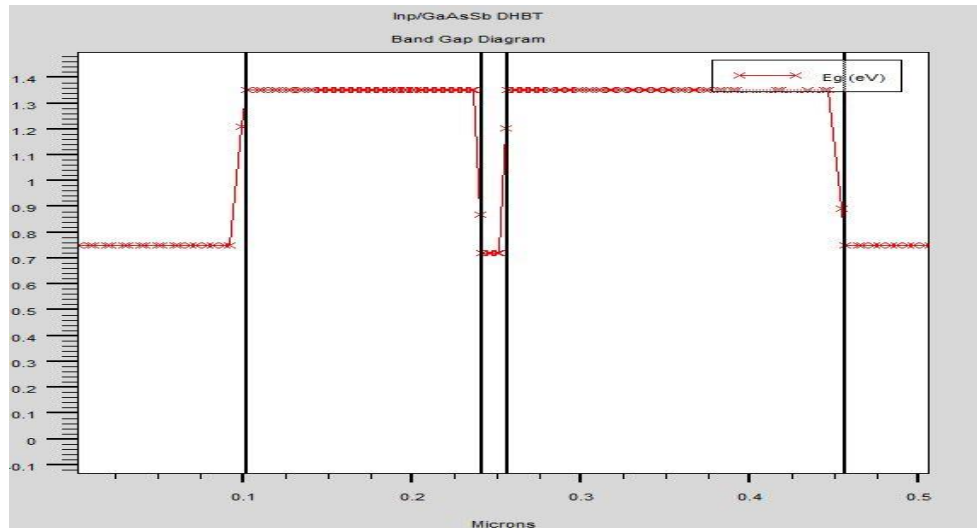


Fig.3. Band offset of proposed DHBT Device.

Dc analysis of the device is reported in another paper. Here Ac analysis of the device is the core objective. For ac analysis, initial solution is obtained by applying dc voltage to find out the operating point i.e. $V_{CE}=1.8$ V & $I_C=3.21$ mA in our simulated device structure. After that ac signal is applied, simultaneously frequency of analysis can be swept. DHBT device performance can be measure as a function of the frequency. Cutoff frequency f_T & maximum oscillation frequency, f_{MAX} plays important role in stable functioning of the DHBT device. Cutoff frequency, f_T is define as the frequency at which current gain in unity. Maximum oscillation frequency, f_{MAX} is define as the frequency at which unilateral power gain reduced to one. Finally, Cutoff frequency f_T and the maximum frequency of oscillation f_{MAX} , current Gain is extracted after simulation.

Simulated Common emitter InP/GaAsSb DHBTs device has maximum f_T of 310 GHz and the peak current gain was 28.9 dB, as shown in Figure 4. Maximum oscillation frequency of 190GHz is obtained from unilateral power gain Vs frequency plot at power gain of zero decibels as shown in Figure 5.

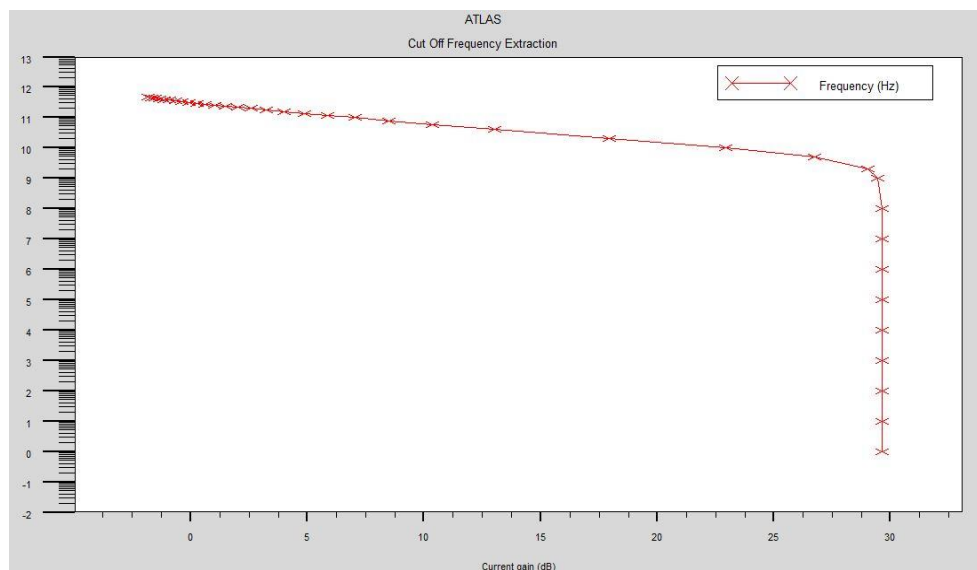


Fig.4. Current gain of the device as the function of frequency

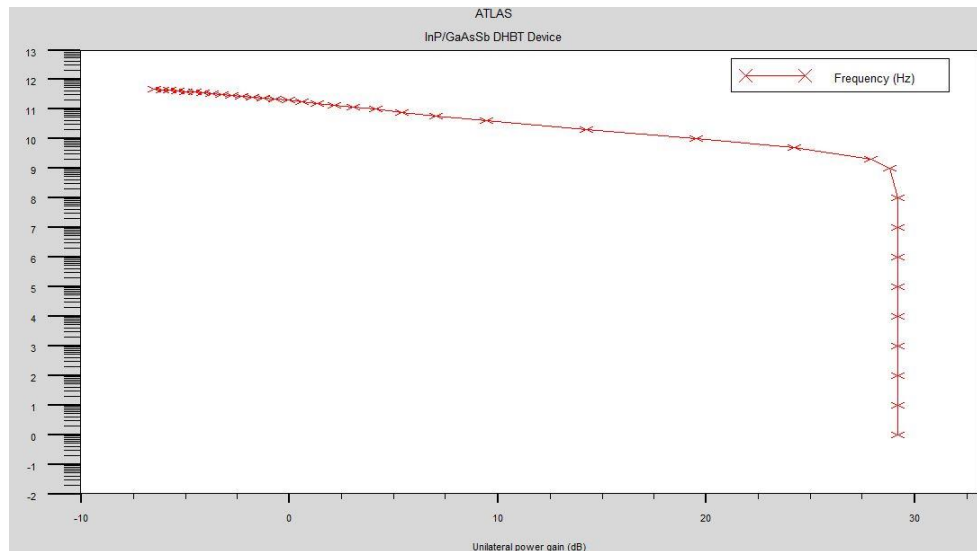


Fig 5. Unilateral power gain of simulated InP/GaAsSb DHBTs

V. CONCLUSION

Two dimensional device modeling, using Atlas simulation tool from SILVACO Inc. for the InP/GaAsSb DHBT has been reported in this paper. Vertical, horizontal and power scaling of the InP/GaAsSb/InP DHBT device has performed for stable functioning of the device. We have achieved the $f_T = 310\text{GHz}$ & $f_{MAX} = 190\text{GHz}$ with current gain of 29.63 for $150\text{ \AA}$ $\text{Ga}_{0.51}\text{As}_{0.49}\text{Sb}$ base layer.

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