DC 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 development in Type II InP/GaAsSb/InP Dual Heterojunction Bipolar Transistor Device. Physical based two dimensional device simulators, Atlas tool is used to study the DC 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 shown a dc peak current gain of 70-80 dB, turn on voltage of 0.1V for* 0.5 x 1 μm^2 *emitter device having 15nm thick uniform GaAsSb base.*
Keywords - *Double Heterojunction Bipolar Transistor (DHBTs), Indium phosphide (InP),Gallium Arsenide Antimonide (GaAsSb) ,Indium Gallium Arsenide (InGaAs), Heterojunction Bipolar Transistor (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]. In this paper DC simulation of the device is reported. Energy band diagram, carrier distribution & Dc 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 $GaAs_{0.51}Sb_{0.49}$ base (E_G=0.72eV) and InP based emitter and collector region (Eg≃1.35eV) [5]. Triple mesa DHBTs structure consists of semi - insulating InP substrate, 500 Å thickness & doping of N^+= 2.10^{19} cm^{-3} $In_{0.53}Ga_{0.47}As$ sub collector layer, 2000 Å thickness & doping of N^- = 2.10^{16} cm^{-3} InP collector layer, 150 Å thickness & doping of P^+= 7.10^{19} cm^{-3} $Ga_{0.51}As_{0.49}Sb$ base, 900 Å thickness & doping of N^- = 7.10^{17} cm^{-3} InP emitter layer, 500 Å thickness & doping of N^- = 3.10^{19} cm^{-3} InP emitter cap layer, 1000 Å thickness & doping of N^+= 1.10^{19} cm^{-3} $In_{0.53}Ga_{0.47}As$ emitter contact layer. Base, emitter & collector contacts have dimension of 0.5μm x 0.2μm with gold metal of resistivity of 2.35μΩ-cm. Physically-based two dimension simulation of semiconductor devices is performed using TCAD tool, SILVACO for analyze the deep study of the energy band diagrams, Dc current gain, Gummel characteristics and junction capacitance of the device [6]. Simulation is performed, 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 x 1 μm^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 shows the schematic cross section of the InP/GaAsSb DHBT device.

III. Simulation Details

The Simulation 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 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].
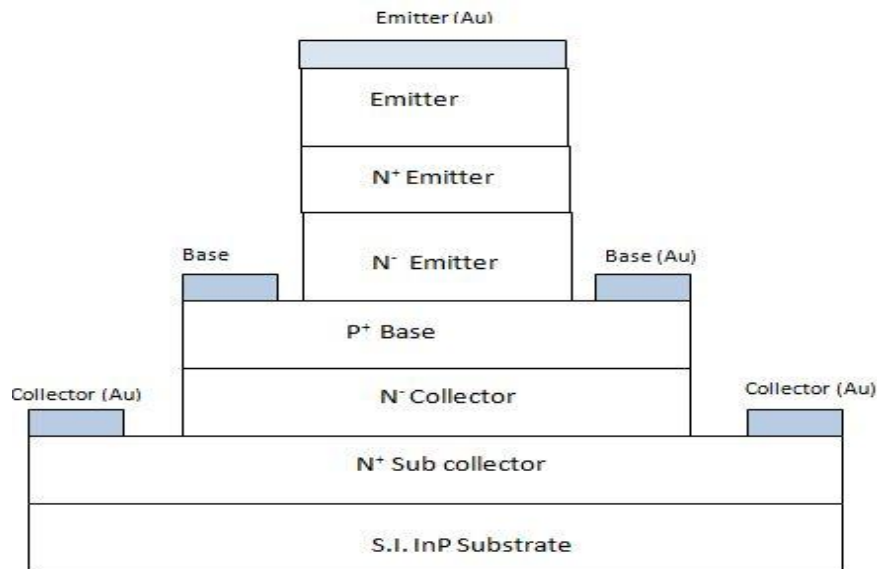

Fig.1. Schematic view of InP/GaAsSb DHBT

IV. Device Characteristics & Results

Energy band diagram of the proposed DHBT structure is shown in figure 2. Band offset of conduction band in InP/GaAsSb DHBT device is shown in figure 3. 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.
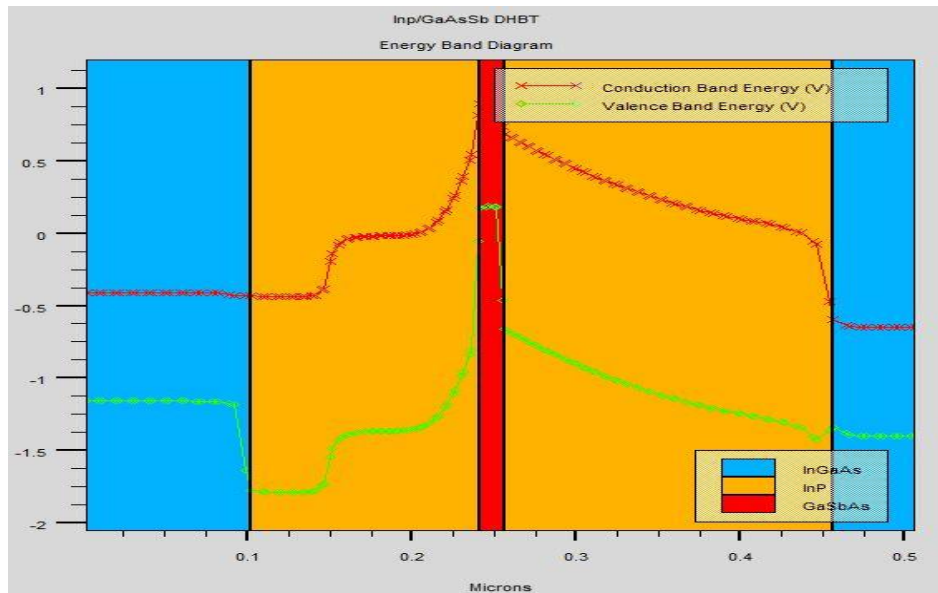

Fig.2. Energy band diagram of simulated InP/GaAsSb DHBT.

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 fT and fmax performance in spite of the low carrier mobility in the GaAsSb base [7]. Energy band gap of the different layers conduction band and valence band are shown in figure 3. With increment of the base supply voltage results in increment in Junction capacitance of the base-collector junction as well as base-emitter junction as shown in figure 4 (a) & 4(b).

The Common emitter InP/GaAsSb DHBTs device have shown the turn on voltage of 0.1 V as shown in figure 5. Base current saturates to 10mA at base voltage of 0.9 V. The Gap between base current and collector current in figure 5 represents the dc gain of transistor. Simulate InP/GaAsSb device have reported dc gain of 80-70 dB as shown in figure 6. The output characteristics of simulated InP/GaAsSb DHBTs device is shown in figure 7. Device has shown saturation current of 180 mA at collector emitter voltage difference of 1.4V at base current 100μA.
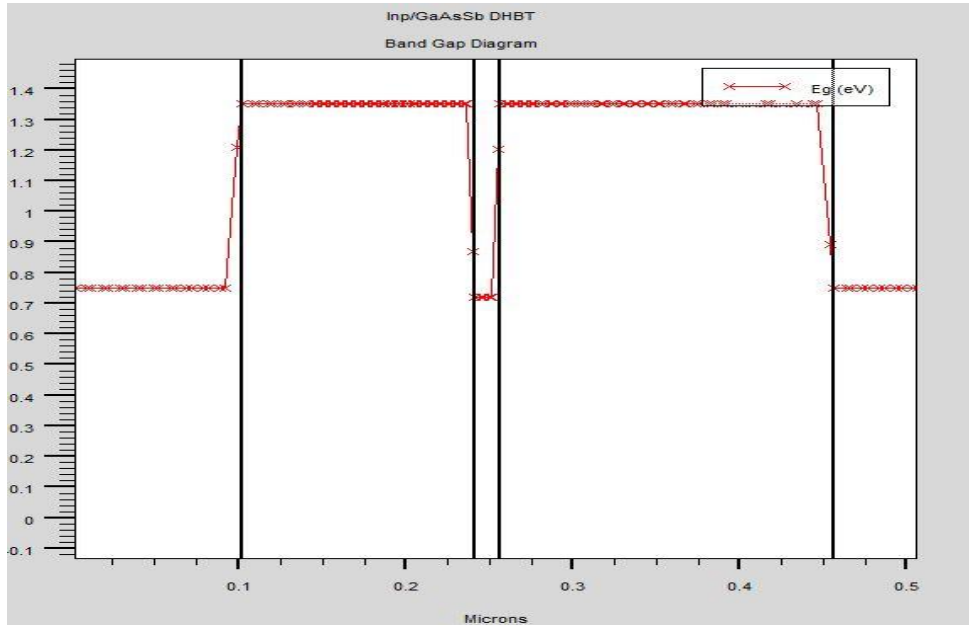
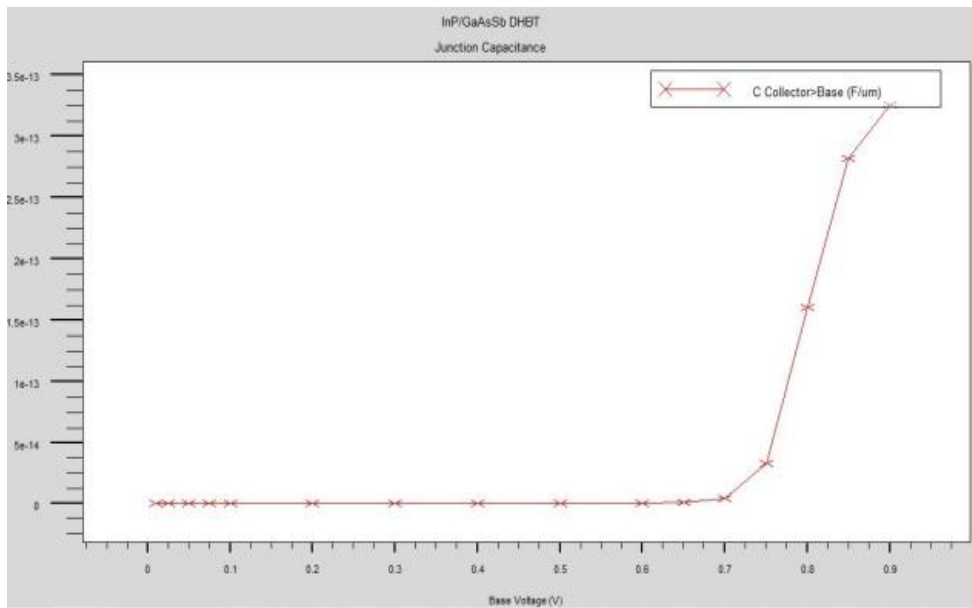**Fig.3.** Band offset of proposed DHBT Device.

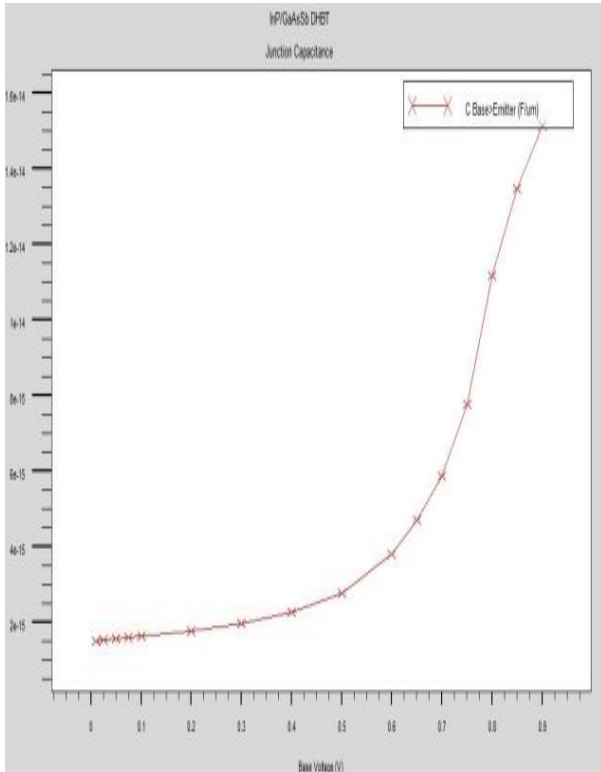**Fig.4.a** Capacitance of the collector-base junction.

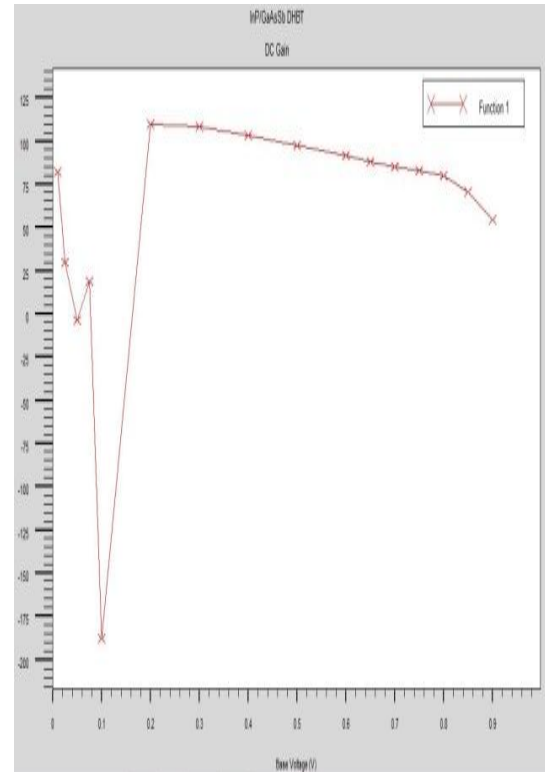**Fig.4.b** Capacitance of the base-emitter junction.

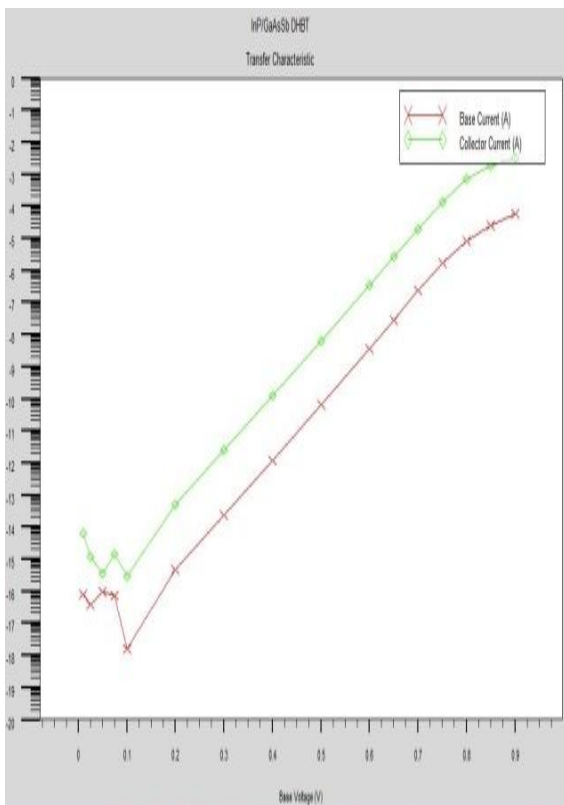**Fig 6.** Dc gain of simulated InP/GaAsSb DHBTs

Fig 5. CE Transfer characteristic of proposed InP/GaAsSb DHBTs at room temperature.
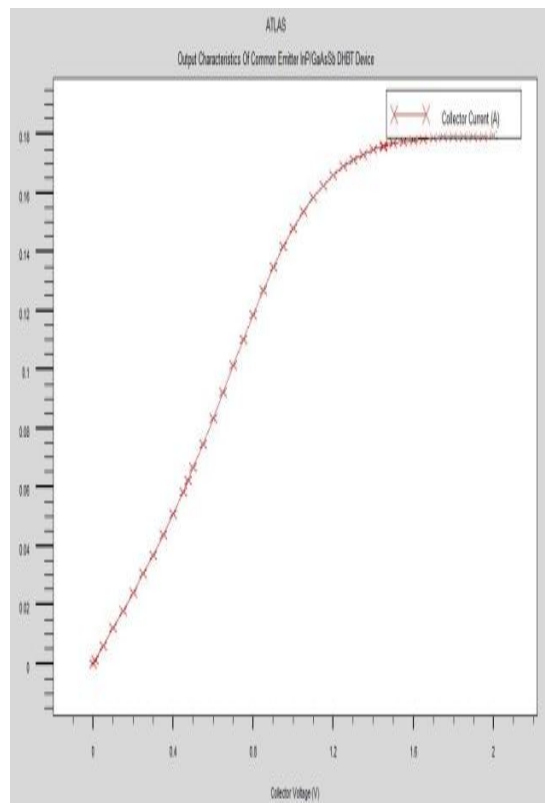

Fig 6. Output characteristics of Common Emitter InP/GaAsSb device with base step size of 100 μA.

V. Conclusion

A Two dimensional device modeling, using Atlas tool for the InP/GaAsSb DHBT results in turn on voltage of 0.1V. Device have reported a peak dc gain of 70-80 dB with emitter area of 0.5 x $1\mu m^2$.

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