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Designing and Optimization of Hetrojunction Bipolar Transistor

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ABSTRACT - This paper deals with the simulation of Si-Ge HBT structures using SILVACO TCAD with various parameters. HBT structure has been generated through DevEdit and device simulation was carried out using Atlas. Base width and Ge profile are very important parameter for HBT. In view of this, the effect of variation of base width and Ge profile on the parameters like I_c, current gain (β), f_T and f_{max} has been studied. Our simulation results show that decreasing base width with graded Ge profile in the base region increases both f_T and f_{max} due to decrease in transit time. Effect of boron out diffusion from base is studied next. In this case, the base profile was considered to be Gaussian in nature. Effect on various parameters and parasitic barrier has been studied when the base dopant profile Δx is varied. The simulation shows that as Δx is increased f_T,f_{max} is decreased due to parasitic barrier formation on both the junction i.e. base collector and base emitter heterojunction.

Index terms- HBT,SILVACO,Bipolar Transistor

I. INTRODUCTION

In this paper chapter, optimization of Si-Ge HBT structures has been attempted by considering different device parameters for simulation. Base width is an important parameter for HBT structure. The effects of variation of base width on the different parameters have been studied. HBTs of three different base widths of 90nm, 70nm and 50nm have been simulated. The structures with the thinnest base have better control on cutoff frequency. Ge profile is also studied for all the above HBTs of different base widths i.e. uniform and graded Ge profile or box and trapezium Ge profile for each of the HBT. It shows that the graded Ge profile shows better results in context of f_T and f_{max}.

II. HBT WITH DIFFERENT BASE WIDTHS

Base width plays an important role in designing of Si-Ge HBT. Changing the base width of the structure affects the device current and other parameters.

HBT structures with different base widths were simulated. Three different base widths of 90nm, 70nm and 50nm were considered. Other than the base width remaining structural parameters were kept same. Doping in all the three structures was kept same. 70nm and 50nm base width structures are shown in fig. 1 and fig. 2 respectively.

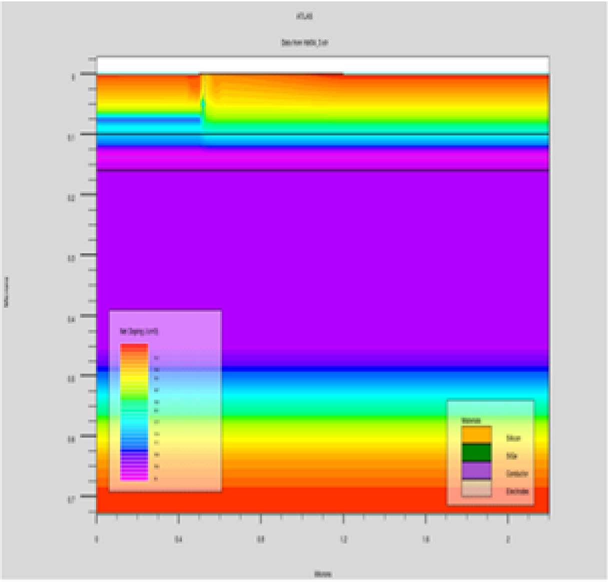

Figure 1:70nm base width HBT

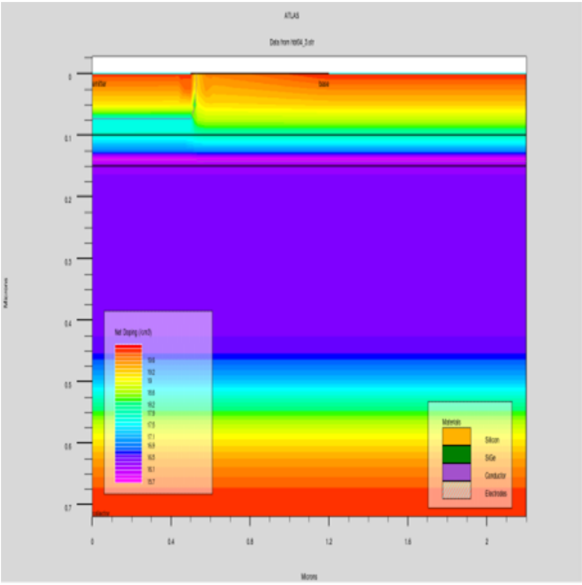

Figure 2:50nm base width HBT

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The structural parameters for the three structures are given below 1 :

Base Width	90 nm	70 nm	50 nm
Device Height	760nm	760nm	760nm
Emitter Doping	1 X 10^{20} cm^{-3}	1 X 10^{20} cm^{-3}	1 X 10^{20} cm^{-3}
Base Doping	8 X 10^{19} cm^{-3}	8 X 10^{19} cm^{-3}	8 X 10^{19} cm^{-3}
Collector Doping	8 X 10^{19} cm^{-3}	8 X 10^{19} cm^{-3}	8 X 10^{19} cm^{-3}
Ge Concentration in base region	20%	20%	20%

Table 1: 90, 70, 50nm base width HBT structure parameters

A. HBT WITH 50nm BASE WIDTH

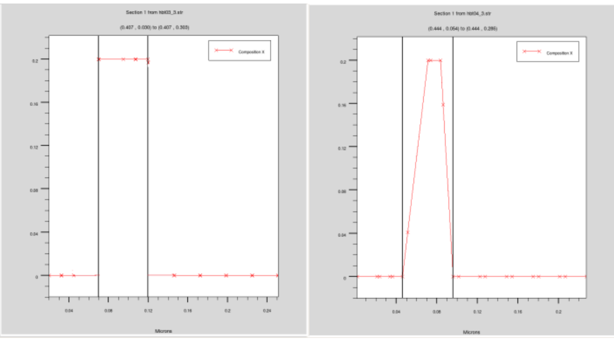

Figure 3:50nm HBT with box and graded Ge profile

Fig. 3 show two different Ge profile in the base region with base width of 50 nm. It shows amount of x composition for Si-Ge HBT. Figure 3 shows the box profile of Ge i.e. amount of Ge placed in the base region is 20% and is constant throughout the base region. Figure 4 shows the box profile of Ge i.e. amount of Ge placed in the base region is 20% and it is graded across the base region from 0 to 20%.

This grading in the base region forms a trapezium of Ge concentration.

B. Characteristics curve

Figure 5 and Figure 6 shows the graph of IC vs VCE plot for 50nm base width HBT. It is very clear from the graphs that the collector current decreased when we moved on from box to graded profile of Ge.

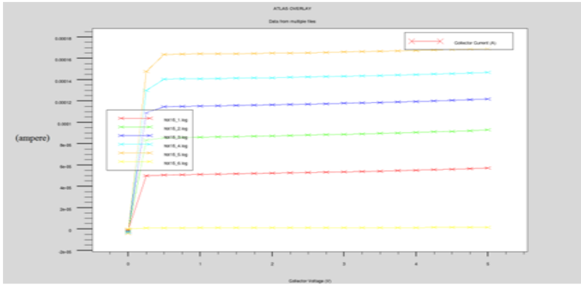

Figure 5: collector current vs collector voltage plot 50nmHBTwith box Ge profile

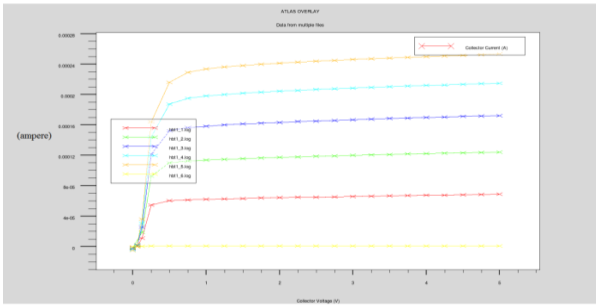

Figure 6: collector current vs collector voltage plot 50nm HBT with trapezium Ge profile

C. Collector current

Figure 7 shows the comparison of 50 nm HBT collector current of two different Ge profiles i.e. box and trapezium and there is decrease in collector current due to grading in base region.

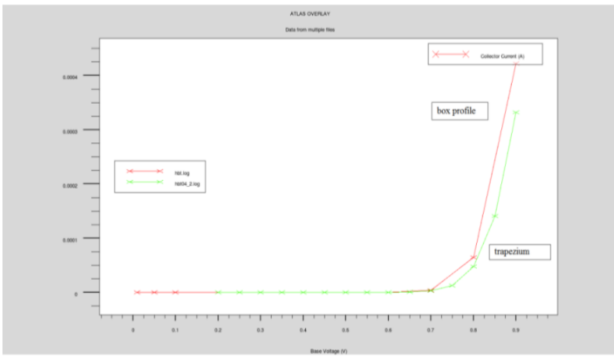

Figure 7: Comparison of 90nm HBT collector current with box and trapezium Ge profile

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D. Current gain Vs frequency plot

Current gain for 50nm HBT with box and trapezium profiles of Ge has been compared in fig. 8. From graph we can get value of cutoff frequency for 50 nm HBT structure with two different Ge profiles. The graph shows that the graded structure has more cutoff frequency than the box profile because grading induces electric field reducing transit time, thus increase in cutoff frequency.

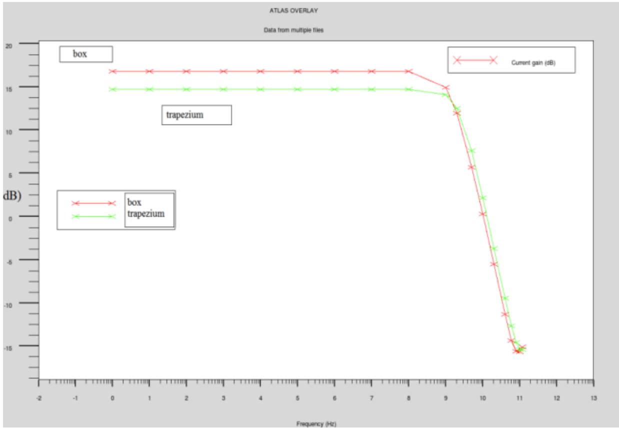

Figure 8: Comparison of 50nm HBT current gain with box and trapezium Ge profile

E. Power gain Vs frequency plot

50nm HBT structure for power gain with box and trapezium Ge profiles is compared in fig. 9. Maximum oscillation frequency of 50 nm HBT structure for two different Ge profiles can be calculated from graph. It shows that the graded structures have more maximum oscillation frequency than the box profile because fmax is directly proportional to the fT and as the fT is decreased maximum oscillation frequency is also decreased.

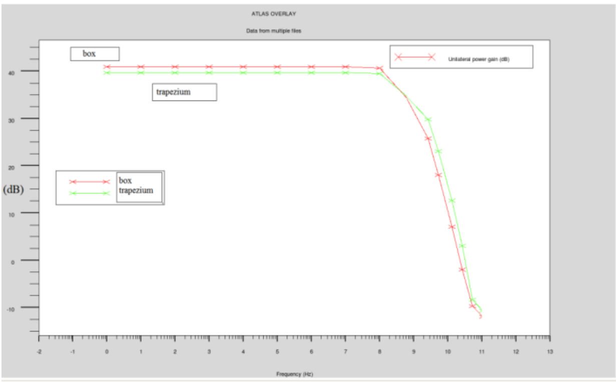

Figure 9: Comparison of 50nm HBT power gain with box and trapezium Ge profile

III. RESULTS

A. Collector current

Figure 10 shows the comparison of the box profile 90, 70 and 50nm collector current. Values obtained by the simulation shows that the collector currents for 90, 70 and 50 nm are 0.60mA, 0.56mA and 0.51mA respectively for box profile. The graph clearly shows the collector current goes on decreasing as we decrease base width of device. This is because reduction in device dimension leads to reduction in emitter base junction area and consequently reduction in collector current.

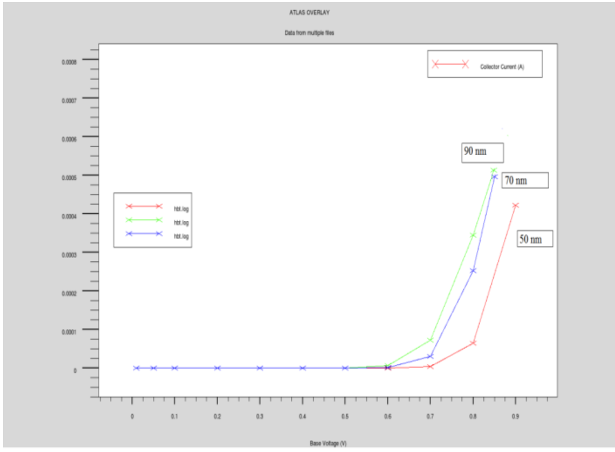

Figure 10: Comparison of 90, 70 and 50nm HBT collector current with box Ge profile

Fig. 11 shows the comparison of trapezium profile for 90, 70 and 50nm base width Si-Ge HBT collector current. The graph shows that collector current goes on decreasing by the values of 0.40mA, 0.36mA and 0.33mA for the above mentioned base widths respectively.

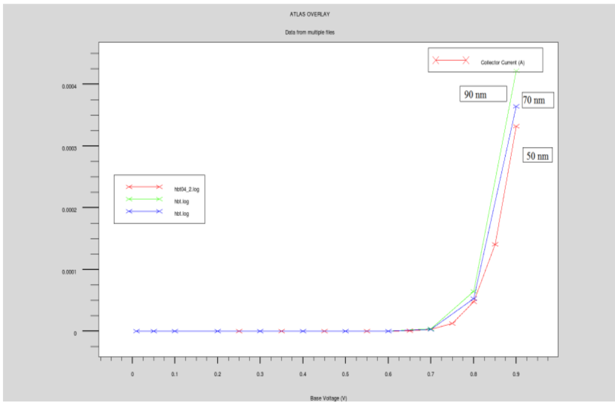

Figure 11: Comparison of 90, 70 and 50nm HBT collector current with trapezium Ge profile

Hence the two graphs conclude that the collector current for box profile is higher than graded Ge profile. In graded base Si-Ge HBT the current gain is lower because the average bandgap in the graded base is higher and the holes do not encounter an abrupt barrier [20].

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B. Current gain Vs frequency plot

Figure 12 and Figure 13 shows the current gain comparison of all the 3 base widths for 90, 70 and 50nm of both Ge profiles i.e. box and grading. The simulation results shows that decrement in base width results in increment in current gain and also cutoff frequency because as the base width is decreased τ is increased and so cutoff frequency. There is always an invertible tradeoff between current gain and cutoff frequency and this trade off depend on amount of Ge concentration placed in base as shown in fig. 8. So to achieve high cutoff frequency, Si-Ge HBT with grading is preferred over the box profile.

The fT is calculated by this graph and for 90nm, 70nm and 50nm Si-Ge HBT with Ge box profile its value is 36.6, 42.3 and 50.0 GHz respectively. Hence, this shows increase in cutoff frequency as the base width is decreased. The cutoff frequency obtained for 50nm base width is highest amongst all the three structures.

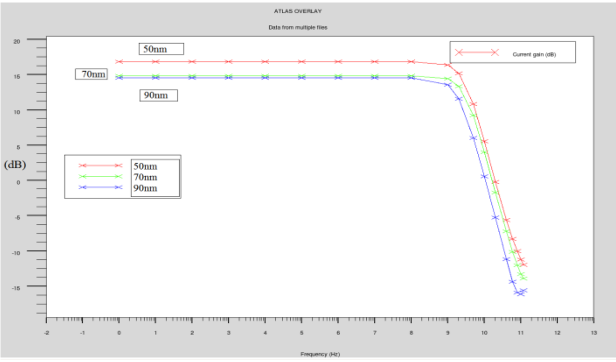

Figure 12: Comparison of 90, 70 and 50nm HBT current gain with box Ge profile

The cutoff frequency is calculated from figure 13 for the graded Ge profile. The cutoff frequency for 90nm, 70nm and 50nm base width with Ge graded profile is 38.6, 46.3 and 54.0 GHz respectively which shows significant increase in cutoff frequency as the base width is decreased. Hence from the graphs it is well shown that grading of Ge profile shows better performance to box profile.

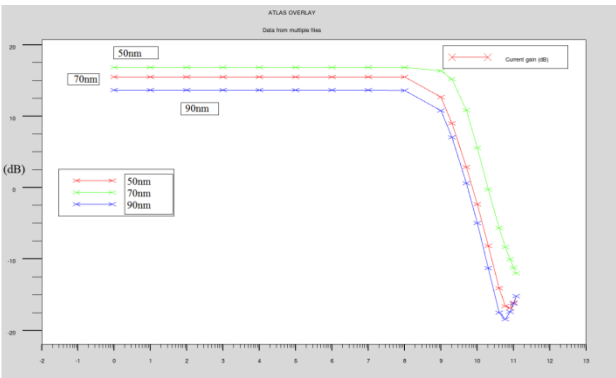

Figure 13: Comparison of 90, 70 and 50nm HBT current gain with trapezium Ge profile

C. Power gain Vs frequency plot

Figure 14 and Figure 15 shows the power gain comparison of the entire 3 base widths of 90, 70 and 50nm for both profiles i.e. box and grading. The simulation results show that decrement in base width results in increment of power gain and fmax. The reason behind is that fmax is directly proportional to fT and as cutoff frequency is decreased, decrement in maximum oscillation frequency takes place.

It is concluded from the graphs that grading leads to degrade the power gain but most effective part is, its leads to increment in maximum oscillation frequency which is more dominating for high speed devices.

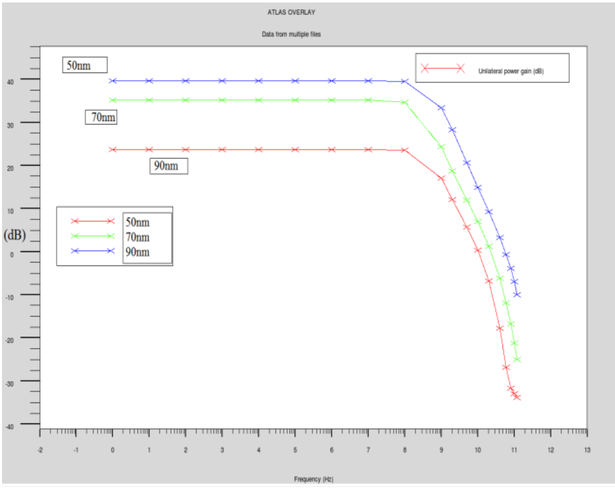

Figure 14: Comparison of 90, 70 and 50nm HBT power gain with box Ge profile

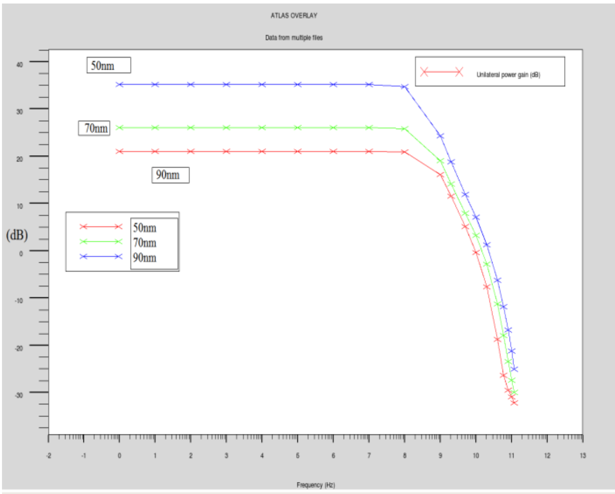

Figure 15: Comparison of 90, 70 and 50nm HBT power gain with trapezium Ge profile

Hence for all 3 devices parameters have been shown in table 3 with different base widths and the results has been compared.

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Parameters	**90nm**		**70nm**		**50nm**	
	Box	**Grading**	**Box**	**Grading**	**Box**	**Grading**
I_C (mA)	0.60	0.40	0.56	0.36	0.51	0.33
Current Gain (β)	554	406	665	555	725	625
Cutoff frequency (f_T in GHz**)**	36.6	38.6	42.3	46.3	50.0	54.0
Max. Oscillation Freq (f_{max} in GHz)	40.2	44.6	48.0	53.6	57.0	62.6
Transit Time (τ in psec)	4.35	4.12	3.76	3.43	3.18	2.94

Table 3: comparison of 90, 70, 50nm base width HBT structure parameters with different Ge profile

IV. CONCLUSION

It is concluded that after optimization the HBT parameters shown less base width and low base dopant profile increase cutoff frequency and current gain of device. Optimization of device shows that grading of the Ge profile leads to increase in fmax and fT. Overall it is concluded less base width; graded Ge profile and low base dopant profile are prime factors while optimizing device parameters. Among all the 4 structures designed in this thesis, the structure with thinnest base width i.e. 30nm having graded Ge profile and low base dopant profile shows highest cutoff frequency. So among the purposed structure this is the best one. HBT devices offer better working performance as compared to homojunction BJT structure. They have been shown to work till base width of 30nm.

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