Improvement of RF Performance of Carbon-doped Base InP/InGaAs HBTs by Carbon-dehydrogenation through Thermal Annealing

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Abstract

The effects of thermal annealing on the performance of InP/InGaAs heterojunction bipolar transistors with a carbon-doped base have been studied. After emitter etching, a 5minute annealing at 500°C under N_2–ambient was performed to eliminate hydrogen from p-type dopant (carbon) in the base. The results show that the base sheet resistance decreases from about 2500Ω/□ to 800Ω/□ and the dc current gain from 20 to 5. The reduced base resistance enhanced the maximum oscillation frequency from 37GHz to 100GHz.

1. Introduction

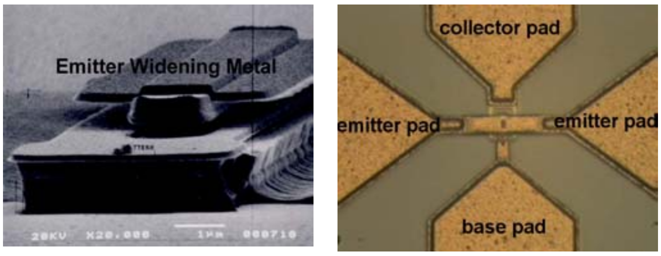
InP-based heterojunction bipolar transistors (HBT's) have shown a great potential for high-speed digital, microwave, and optoelectronic applications because of their intrinsic advantages over GaAs-based HBT's[1]. For high $f_{max} \cong (f_T/8\pi R_B C_{BC})^{1/2}$, it is required to have low B/C capacitance, high f_T, and low base resistance. These transistors feature a very thin highly-doped base layer in order to reduce the base transit time and the base resistance simultaneously for good RF performances [2],[3]. In the case of p-type InGaAs base, the base resistance is strongly dependent on the dopant. Carbon is a primary p-type dopant for high performance and reliable GaAs-based HBT's because of its low diffusivity. However, Zn is the most commonly used p-type dopant, in spite of its high diffusivity, MOCVD grown InGaAs base. Carbon has been known to be amphoteric in InGaAs, resulting in heavily compensated n-type [4]. Several publications report on the carbon hydrogen passivation and suggest treatments of the wafer such as post-growth annealing or ex-situ annealing process for carbon-dehydrogenation [1],[5].

In this paper, we report the first successful demonstration of reduction of base resistance during device processing by carbon-dehydrogenation through thermal annealing after emitter layer etch. Base sheet resistance reduced from 2500Ω/□ to 800Ω/□, and the maximum oscillation frequency increases from 37GHz to 100GHz, due to the reduced of base sheet resistance. The results clearly demonstrate that with proper treatment, the heavily carbon doped p-type InGaAs is usable for InP/InGaAs HBTs.

2. Device Fabrication

The epitaxial layer of the fabricated HBTs is grown by MOCVD on a Fe-doped semi-insulating (100) InP substrate, starting with a 5000Å InGaAs subcollector layer and 6000Å thick, 2.0×10^{19} cm^{-3} Si-doped collector layer. The 600Å InGaAs base is C-doped at 5.0×10^{19} cm^{-3} with 70Å spacer. The emitter layer is 1000Å InP with Si-doped to 4.0×10^{17} cm^{-3}.

The fabrication starts with the evaporation of Ti/Pt/Au emitter contacts. Two step selective wet etch was used to etch down to the base layer and was undercut. After emitter layer etching, a 5minute annealing was performed at 500°C under N_2–ambient in order to activate the p-type dopant carbon in the base layer. Next, Self-aligned Pt/Ti/Pt/Au base metal is evaporated. The emitter was protected and the base layer was then etched using base contact mask. Next, Polyimide was coated, and was etched without mask using O_2 RIE until the emitter metal was exposed. Next, a Ti/Au emitter widening metal was evaporated, and residual polyimide was removed using RIE and ashering. The collector was etched and the subcollector was etched for isolation (Fig.1.(a)), and AuGe/Ni/Au collector metal and pad metal were evaporated and alloyed. Au air-bridge formation was followed. (Fig.1.(b))



(a)

(b)

Fig. 1. (a) SEM picture of HBT with emitter widening metal, (b) Photograph of completed HBT with 1×10 μm^2 emitter area.

3. Results and Discussion

The common emitter dc current gains were about 20 and 5 for normal and annealed HBTs at collector current density of about 1×10^5 A/cm^2, repectively. Base sheet resistances of 2500Ω/□ and 800Ω/□ for normal and annealed devices were measured using transmission line measurement (TLM) pattern. These results mean that a significant hydrogen passivation was incorporated in our material.

Microwave S-parameters were measured on wafer over the frequency range of 0.1 to 40GHz using an HP8510C network analyzer. Measured S-parameters for each devices are shown in Fig. 2. A small-signal equivalent circuit was extracted using the measured S-parameters, and its element values and some measured data are shown in Fig. 3. Remarkable reduction of base resistance (R_B) for annealed device was observed from 100.3Ω to 17.5Ω. Fig. 4. shows the comparision of gain-frequency characteristics of the normal and annealed HBTs with 1×20 μm^2 emitter. The f_T and f_{max} are 61GHz and 37GHz repectively at I_C=15mA and V_{CE}=2V for normal HBTs, and 56GHz and 100GHz at the same bias point for annealed HBTs. f_{max} is increasesed by more than two times because of the remarkable reduction of base resistance by carbon-dehydrogenation through thermal annealing. f_T was around 60GHz and was not changed much.

4. Conclusions

After emitter etch, a thermal annealing of HBTs at 500°C under N_2–ambient during 5minute was performed to eliminate hydrogen from the base of carbon-doped InP/InGaAs HBTs to reduce base resistance. The base sheet resistance decreases from about 2500Ω/□ to 800Ω/□ and the dc current gain from 20 to 5. The reduction of base resistance enhanced maximum oscillation frequency from 37GHz to 100GHz.

5. Acknoledgements

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6. References

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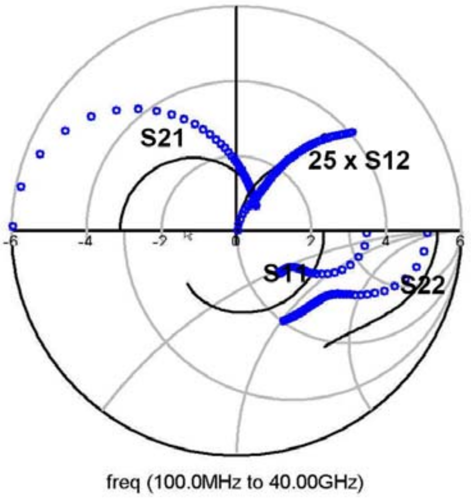
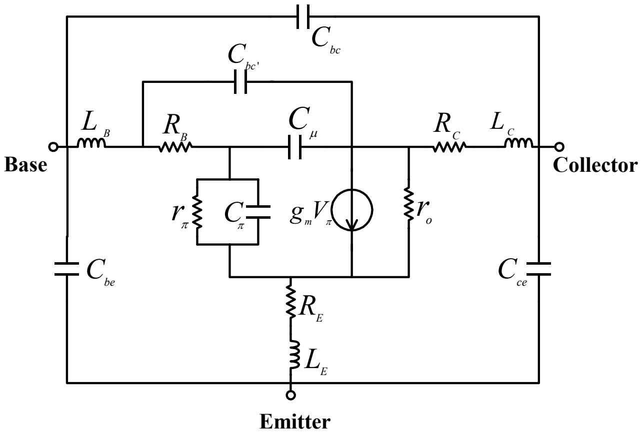


Fig 2. Comparision of s-parameters from the measurement of normal and annealed HBTs. The circles are normal HBT data and lines are annealed HBT data.



	normal	annealed		normal	annealed
f_T	61	56	$f_{max,G}$	37	75
			$f_{max,U}$	37	100
g_m	286	79	r_o	530	810
R_E	2.2	2.8	C_π	730	170
R_B	**100.3**	**17.5**	C_μ	10.9	8.01
R_C	0.53	0.82	$C_{bc'}$	13.2	9.9
r_π	54.7	79.2			

Fig. 3. Small-signal equivalent circuit and their element values for the normal and annealed HBTs with 1 × 20 μm^2 emitter area. The units of conductance, resistance, capacitance, and frequency are mS, Ω, fF, and GHz, respectively.

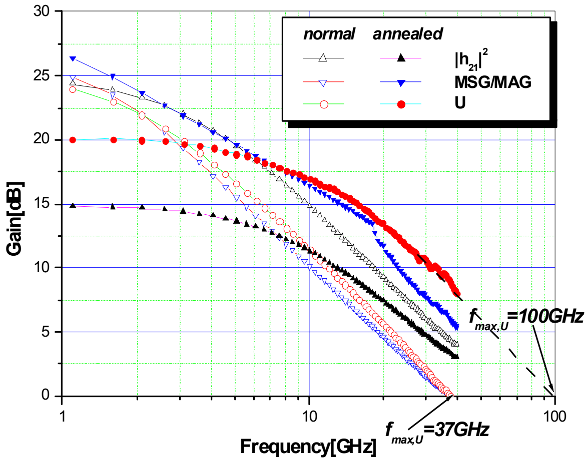


Fig. 4. RF performances of the normal and annealed HBTs with 1 × 20 μm^2 emitter area.