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Thermal Runaway Tolerance in Double Heterojunction Bipolar Transistors

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On the double heterojunction bipolar transistor (DHBT) with narrow bandgap base, collector current is strongly impeded at high current level where the Kirk effect occurs. This phenomenon was studied in conjunction with thermal stability of transistor. The experimental comparison of Si/SiGe/Si-DHBT with Si bipolar junction transistor (Si-BJT) confirmed that SiGe-DHBTs are more stable with regard to thermal runaway than Si-BJTs.

1. Background

Because of the positive feedback relation between emitter-base junction temperature and collector current, suppressing thermal runaway has been a critical issue for high power bipolar transistors. The emitter ballast resistance compensating this positive feedback relation has been an indispensable means to handle high power. On the other hand, the emitter ballast resistance reduces transconductance and degrades high frequency performance. Thus, this trade off between high frequency performance and thermal stability has made the implementation of high frequency power bipolar transistors difficult.

In this paper, we propose the use of double heterojunction bipolar transistor (DHBT) as a ballast-less high power microwave transistor.

Double heterojunction bipolar transistor with narrow bandgap base and wide bandgap emitter has intrinsically a superior potential with large injection efficiency and low base resistance. In DHBTs which have narrow bandgap base and wide bandgap collector, collector current flow is strongly impeded when base pushout occurs[1,2]. Referring to Schröter *et.al.*[3], the collector current is expressed as

$$I_C \propto \frac{qV_T}{\int \frac{p}{\mu_n n_i^2} dx}$$

where

$$\int \frac{p}{\mu_n n_i^2} dx = \int_E \frac{p}{\mu_n n_{iE}^2} dx + \int_B \frac{p}{\mu_n n_{iB}^2} dx + \int_C \frac{p}{\mu_n n_{iC}^2} dx$$

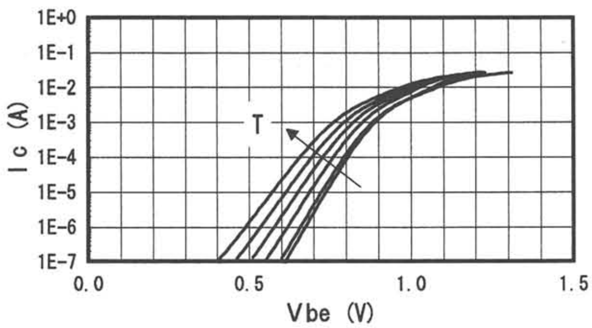
Before occurrence of base pushout, the first and third terms are negligible. Once base pushes out to the collector region, the third term remarkably increased because n_{iC} is much smaller than n_{iB}. Thus the collector current is strongly impeded. This phenomenon could cancel the positive feedback between collector current and junction temperature. In this case, the ballast resistance could be omitted without thermal runaway Before base pushout occurs, no ballast-resistance scheme maintains a superior high frequency performance. Therefore the DHBTs would be suitable for high-power high-frequency applications.

2. Sample Preparations

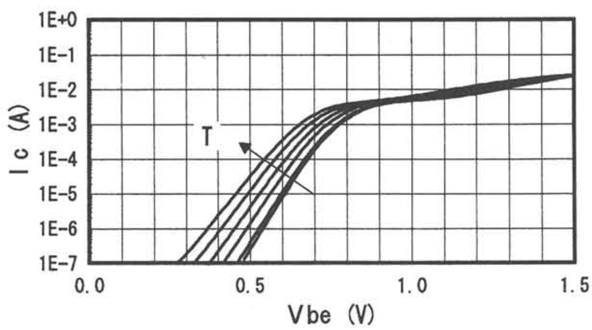
To confirm the effect of the expected thermal stability of DHBTs, experimental studies were carried out on a Si/SiGe/Si-DHBT and the results were compared with those for a Si bipolar transistor. Both BJTs have epicollectors whose donor concentration and thickness are $3\text{x}10^{16}$ cm^{-3} and 0.9 μm respectively The base layers of SiGe and Si were grown with UHV/CVD[4]. The SiGe base which is composed of $Si_{0.8}Ge_{0.2}$ has 20nm thickness and $5\text{x}10^{18}$ cm^{-3} acceptor concentration. The Si base has 50 nm thickness and the same acceptor concentration. The polysiliconemitter was re-grown from amorphous silicon doped with $5\text{x}10^{20}$ cm^{-3} phosphorous. Low temperature process of 750 °C RTA was used after growth of epitaxial base. Phosphorous in amorphous silicon was completely activated at this relatively low temperature, which is appropriate for SiGe-HBT. The processing was completed by Al-metalization without passivation. All experiments were carried out on non-selfalignment transistors with 1x5 μm emitter.

3. Results and Discussions

I-V characteristics of a SiGe-DHBT and a Si transistor at from 30 °C to 120 °C were measured (Fig.1). In comparison with Si-BJT, collector current of SiGe-DHBT increased with Vbe offset to reflect a smaller bandgap base, while the slope was same in both cases each other. When the collector current reached the Kirk effect level, that of the SiGe-DHBT was much more impeded than that of the Si-BJT.



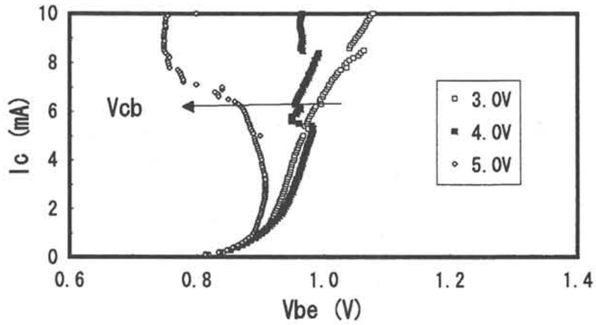
(a) Si - BJT



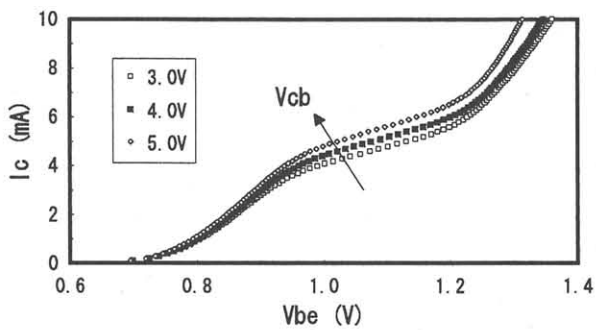
(b) SiGe - DHBT

Fig.1 *Dependence of I-V characteristics on temperature (at 30,40,60,80,100 and 120°c).*

Above a certain power dissipation level, the positive feedback between collector current and junction temperature results in a negative resistance feature in Ic-Vbe curves. In this study, this phenomenon was observed on the Si-BJT, but not on the SiGe-DHBT (Fig.2). This difference confirmed that the positive feedback was suppressed in SiGe-DHBT.



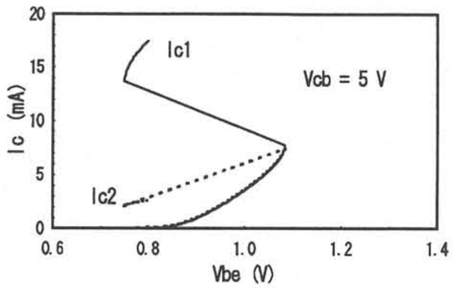
(a) Si - BJT



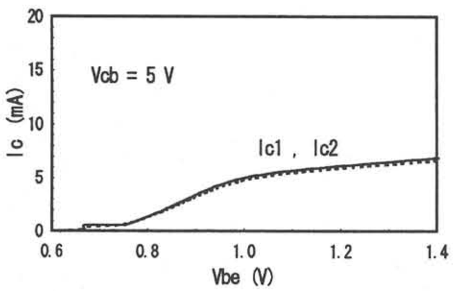
(b) SiGe - DHBT

Fig.2 *I-V characteristics at high power dissipation level (Vcb=3,4 and 5 V).*

Multiemitter finger structure is used in microwave power transistors. In this structure, once the negative resistance appears, current flow at each emitter finger cannot be equalized. At the emitter finger where the current is localized, the positive feedback mechanism strongly operates and the current density easily reaches a destructive level[5-7]. This problem was examined in a pair of parallel connected transistors. As shown in Fig.3, an asymmetrical current flow occurred on a pair of parallel connected Si transistors at high power dissipation level, but not on a pair of SiGe-DHBTs. As a result of this current hogging suppression the safety operating area (SOA) of a hundred parallel connected SiGe-DHBTs was wider than that of Si transistors (Fig.4). These experimental results confirmed that SiGe-DHBT is more thermally stable than Si-BJT.



(a) Si - BJTs



(b) SiGe - DHBTs

Fig.3 *Current flows of a pair of parallel connected transistors.*

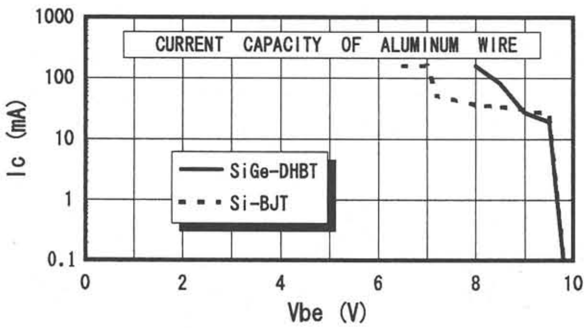


Fig.4 *Safety operating areas of a hundred parallel connected Si-BJTs and SiGe-DHBTs.*

Fig.5 shows ft-Ic relation. Thick collector epilayer gives a large collector transit time. As a result, almost the same cutoff frequency (ft) was obtained for the Si-BJT and the SiGe-DHBT. When the Ic exceeded the Kirk effect level, the ft of SiGe-DHBT decreased rapidly because of a larger carrier storage in base region. The collector current bias level is designed to be below the Kirk effect level and it was verified that thermal stability and high frequency performance coexist in DHBTs.

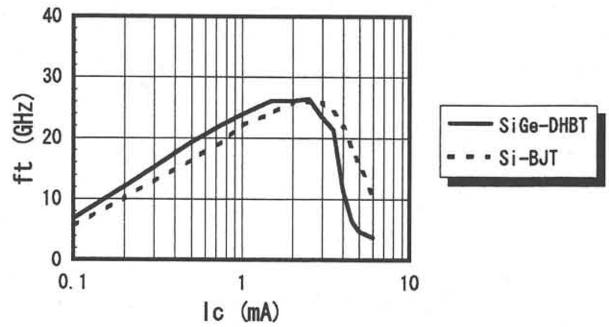


Fig.5 *Cutoff frequency of Si-BJT and SiGe-DHBT.*

4. Conclusion

Collector current of double heterojunction bipolar transistor is effectively impeded at high bias. In contrast with the ballast resistance methods, this unique feature of DHBT achieves thermal stability without sacrificing high frequency performance. Experimental studies verified this new effect on a Si/SiGe/Si-DHBT and the results were compared with those for a Si bipolar transistor. The negative value resistances and asymmetrical current flow associated with thermal instability vanished on SiGe-DHBTs at high power dissipation level. Wider safety operating area was also confirmed. The results of these experiments suggest that SiGe-DHBT is suitable for high-power microwave applications.

5. Acknowledgment

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