EFFECT OF COLLECTOR DOPING ON INP BASED DOUBLE HETEROJUNCTION BIPOLAR TRANSISTOR

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ABSTRACT

In this study, high current effects on DHBT performance are investigated. Three samples with different collector doping are experimentally realized. DC and RF measurements have been done to see the influence of collector doping and related Kirk effect on HBT performance.

I. INTRODUCTION

Especially by the advances in optical communication systems, InP-based Heterojunction Bipolar Transistors (HBTs) were intensively investigated in recent years. One of the main advantages of this material is the compatibility with the optoelectronic devices, which operates at the 1.3µm and 1.55µm communication wavelengths, where the optical attenuation is at its minimum. Moreover, since HBTs have high transconductance, high current density and excellent RF behaviour, they are also attractive for high-speed electronic applications.

The figures of merit for high frequency performance are the cut-off frequency f_T and the maximum frequency of oscillation f_{max} [1].

$$\frac{1}{2\pi \cdot f_T} = \tau_{base} + \tau_{collector} + C_{je}\frac{kT}{qI_E} + C_{bc}\left(\frac{kT}{qI_E} + R_{ex} + R_{coll}\right) \quad (1)$$

$$f_{\max} \cong \sqrt{\frac{f_T}{8\pi \cdot R_{BB} C_{BC}}} \quad (2)$$

As it is depicted in equation (1), the cut-off frequency is limited by the transition times, which are mostly influenced by the vertical dimension of the HBT structure. In contrary to this, maximum oscillation frequency is mostly affected by the parasitic capacitances and resistances, which can be controlled by lateral scaling of the devices.

Briefly, f_T can be improved by epitaxy and processing and layout can improve fmax.

To achieve higher f_{max} values, several techniques have been introduced in the literature. These are base undercut, transferred substrate HBTs, buried collector HBTs, in which the parasitic base collector (C_{BC}) can be reduced [2-7].

By decreasing the base and collector thickness, the transit frequency f_T can be improved but at the same time f_{max} may be affected adversely.

In this work, we have investigated the effect of collector doping on improvement of f_T. When the collector current increases ($I_C > qN_{dC}v_{sat}$), the electron density entering the base collector depletion region exceeds the doping level and this changes the electric field profile in the junction. This will cause increase of hole injection from base to collector and so increasing the base width. Since there is a larger distance for carriers to penetrate, this will degrade the current gain and also increase the base transit time. Doping the collector can minimize this situation. The details about Kirk Effect have been explained in [8,9].

II. EXPERIMENTAL

The epitaxial layer structure used for the device fabrication is listed in Table 1.

Table 1. Layer structure of the processed DHBTs

n++ InGaAs	**E-Cap**	**50nm**
n+ InP	**E-contact**	**50nm**
n InP	**Emitter**	**50nm**
p InGaAs	**Base**	**50nm**
InGaAs	**Spacer**	**30nm**
InGaAsP	**Quaternary layer**	**10nm**
InGaAsP	**Quaternary layer**	**20nm**
InP	**Collector**	**100nm**
n+ InP	**Collector contact**	**100nm**
n++ InGaAs	**Sub-collector**	**200nm**
InP	**Buffer**	**50nm**
SI InP Substrate		

The structure was grown by LP-MOVPE (Low Pressure-Metal Organic Vapour Phase Epitaxy) (Aixtron 200) on (001) ± 0.5° oriented semi insulating (001) InP (Fe) substrate. Three samples were used for this investigation. Sample A, Sample B and Sample C have the same layer structure depicted in table 1, but the collector doping differs. The collector doping is nid (A) (non-intentionally doped), $5x10^{16}cm^{-3}$ (B), $5x10^{17}cm^{-3}$ (C), respectively. These samples are processed in parallel, to eliminate any deviation that may occur by environmental effect during processing.

Device fabrication is carried out by conventional wet chemical etching based on phosphoric acid (H_3PO_4) for InGaAs and InGaAsP layers, and hydrochloric acid for InP containing layers. The emitter, base and collector layers are defined by optical lithography. The Ti/Pt/Au contact metal system is used for emitter and collector contacts. The self-aligned base metallization is deposited as Pt/Ti/Pt/Au. Traditionally, air bridges are used for the connections to the measurement pads. SEM (Scanning Electron microscope) picture of one of the realized HBTs is shown in Figure 1.

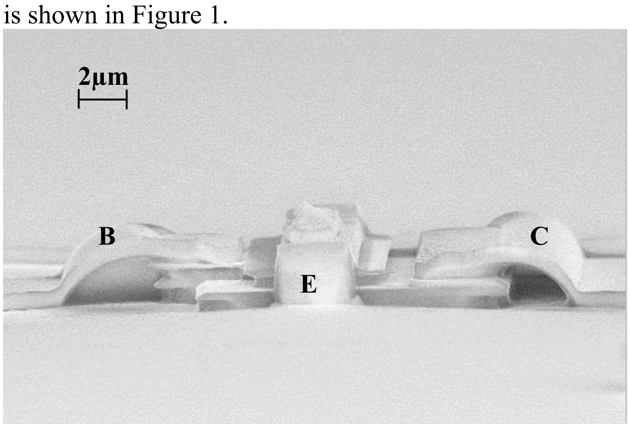

Figure 1. SEM picture of HBT with nominal A_E=2x10μm²

III. RESULTS and DISCUSSION

The DC characteristics of the DHBTs were measured by an HP4515B parameter analyzer.

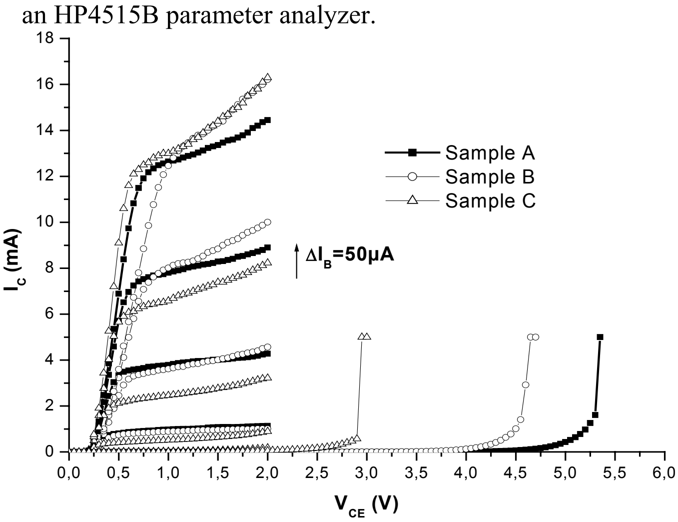

Figure 2. Common Emitter Output Characteristics for Sample A, B and C

In figure 2 common emitter output characteristic for sample A, B and C are shown. The DC current gain is ~70 for all three samples at I_B=200μA.

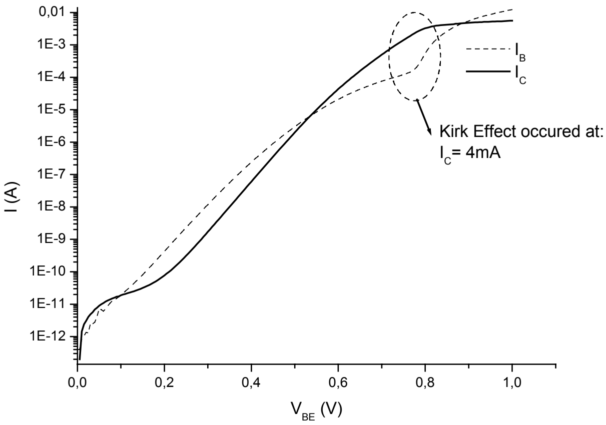

Figure 3. Gummel Plot for Sample A

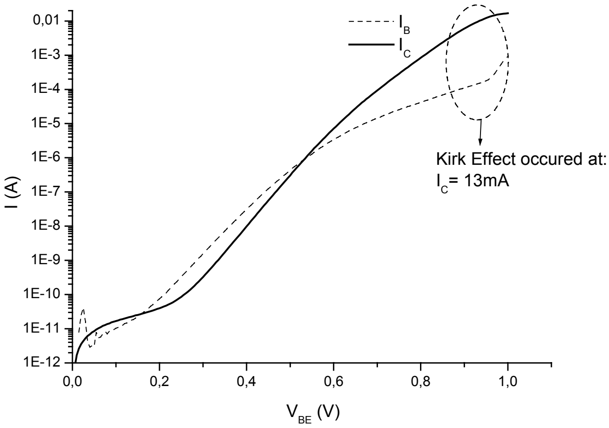

Figure 4. Gummel Plot for Sample B

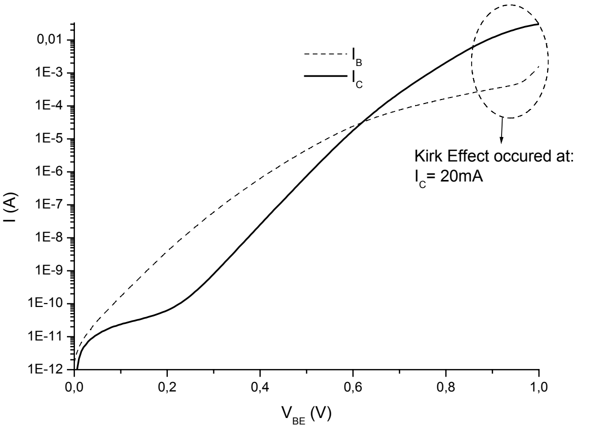

Figure 5. Gummel Plot for Sample C

In Figure 3,4 and 5, high current regions are marked with dashed circle. In these circles, Kirk effect, the sudden

increase in the base current (I_B) and a slight decrease in the collector current (I_C) can be seen.
From the Gummel plots, it can be seen that by the increased doping of collector, the current density (J_{Kirk}) where the high current effects appear, has increased, too [10].
On the other hand, the breakdown voltage has decreased by increasing collector doping. ($BV_{CEsampleA}$= 5.5V, $BV_{CEsampleB}$ = 4.5V, $BV_{CEsampleC}$ = 3V)
After having these results from DC measurements, high frequency measurements using an HP8510C network analyser, have been done. For these measurements, again the same devices (A_E=2x10µm^2) are used. Here, Sample A, B and C have shown transit frequency (f_T) of 100GHz, 120GHz and 165GHz, respectively.

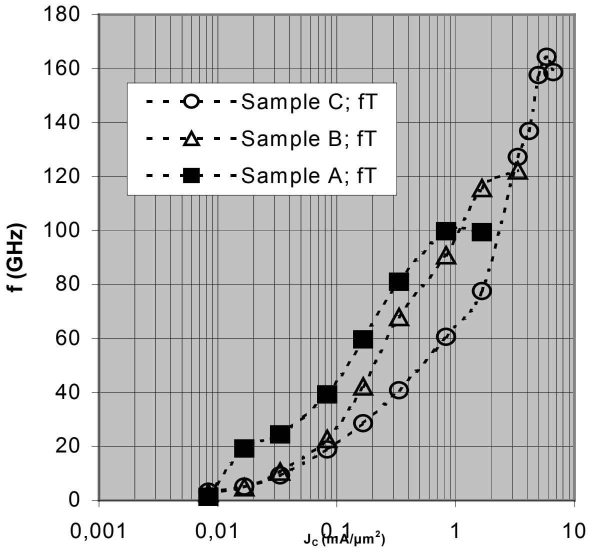

Figure 6. f_T vs. Current density

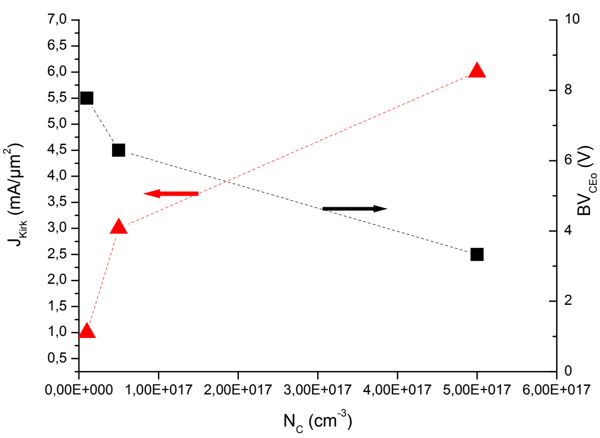

Figure 7. Compromise for collector doping to J_{Kirk} and breakdown voltage

The effect of collector doping on the J_{Kirk} and collector emitter breakdown voltage can be seen at the same time. These results are also crosschecked with some calculation using the equation (3).

$$J_{Kirk} = (1 + \frac{V_{CB} + \phi_{CB}}{V_2 + \phi_{CB}}) q N_C v_{sat} \qquad (3)$$

where;

ϕ_{CB} : Base collector junction potential

V_2 : applied base-collector bias that totally depletes collector layer when J_C=0

N_C : Collector doping

v_{sat} : Saturation velocity

Calculated Kirk current densities (J_{Kirk}) are as follows; $J_{Kirk,A}$=0.9mA/µm^2,$J_{Kirk,B}$=2.5mA/µm^2, $J_{Kirk,C}$=6.5mA/µm^2. These values fit really nice with the values measured.

IV. CONCLUSION

Kirk effect has been experimentally observed on DHBT performance. To see the effect, DC measurements have been done and by the help of Gummel Plot the point where the Kirk effect occurs, J_{Kirk}, (the point where sudden increase in base current occurs) has been identified. It has been concluded that doping the collector can reduce this effect. This will lead to better RF performance, but a compromise is necessary, because when the collector is doped, breakdown voltage decreases. All these experimental results are compared with the theoretical calculations and good fitting has been achieved.

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