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Evaluation of base-collector capacitance in submicron buried metal heterojunction bipolar transistors

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1. Introduction

Reduction of base-collector capacitance (C_{BC}) is essential for high-speed operation of heterojunction bipolar transistors. Usually reduction of C_{BC} is evaluated by increase of maximum oscillation frequency (f_{MAX}). Thus, decrease of intrinsic C_{BC} (C_{BCin}) becomes most important [1]. However, future scaling of HBT [2] requires reduction of total C_{BC} (C_{BCT}) for increase of cutoff frequency (f_T). Moreover, smaller C_{BCT} provides smaller feedback capacitance, results in larger maximum available gain [1].

In this report, we describe base-collector capacitance in submicron buried metal heterojunction bipolar transistors (BMHBT)[3], which is our proposed structure for reduction of C_{BCT}. When emitter width is 0.3 μm, C_{BCT} was less than 1fF. To our knowledge, this is smallest C_{BCT} in HBT.

2.Device and microwave performance

In a structure of BMHBT, metal wires buried in semiconductor extract electrons as shown in Fig. 1. Because buried metal wires replace conventional sub-collector layer and no conducting region exists under the extrinsic base region, extrinsic C_{BC} (C_{BCext}) can be eliminated, results in small C_{BCT}. We reported the fabrication process of submicron BMHBT previously [4].

Common emitter characteristics and microwave characteristics of BMHBT with emitter area of 0.3x1.5 μm^2 are shown in Fig. 2 and 3. The pad capacitances were extracted. As shown in Fig.3, estimated f_T and f_{MAX} are 82 GHz and 200 GHz, respectively.

C_{BCT} was estimated by imaginary part of Y_{12} parameter in a low frequency region as shown in open circles of Fig.4. Estimated C_{BCT} decreased with reduction of emitter area. When emitter width was 0.3μm, observed C_{BCT} was 0.95 fF.

3.Analysis by elements

In case of BMHBT, observed C_{BCT} should be equal to C_{BCin}. To confirm this expectation, Elements of equivalent circuit (Fig. 5) were estimated in the device with emitter area of 0.5x2.5 μm^2. Collector resistance R_{CC} and sum of emitter resistance were estimated from Z parameters [5]. Dynamic emitter resistance r_E and contact resistance R_{EE} were divided from sum of emitter resistance by collector current dependence of emitter resistance. Emitter charging time was estimated by collector current dependence of f_T. Base emitter capacitance C_{BE} was estimated from emitter charging time and r_E. Base resistance including contact resistance was estimated by sheet resistance and contact resistivity measured by the transmission line method. As base-collector capacitance, we assume C_{BCT} is equal to C_{BCin}. Estimated elements under I_c =3.5mA and V_{CE}=5V are shown in Table 1. Figure 6 shows simulated gains with measured data. From Fig.6, we could explain observed result without C_{BCext}.

4.Discussion

From Table 1, major reason of present poor f_T can be explained by high R_{CC}. We estimated that the high R_{CC} was due to poor contact between tungsten and metal for wiring because oxide on the tungsten surface was formed by ashing process. Toward next trials, we confirmed that oxide could be removed by BHF treatment. Estimated r_E is 10 times higher than emitter resistance calculated from collector current. This might be explained by space charge in the emitter because we used high current density (250 kA/cm^2).

Observed C_{BCT} was larger than estimation from emitter area as shown in the line of theory in Fig. 4. Because C_{BCT} consisted from C_{BCin} only, this could be explained by conductive region around metal wires. When we assume that conductive region has same width around metal wires, observed C_{BCT} can be explained by width of conductive region of 0.25 μm as shown in Fig. 4. The temperature of buried growth was 585 ^{0}C at present trial. When we used 600 ^{0}C as growth temperature [6], observed width of conductive region was estimated as 1 μm. In separate experiment using C-V measurement, we confirmed that present process did not make additional carrier around grown interface. Moreover, present resistivity of the tungsten was 10 times higher than that of bulk. Thus diffusion of impurity from tungsten wires is one of the possible reasons of the conductive region. Improvement of purity of tungsten might reduce the width of the conductive region.

5.Conclusion

Base collector capacitances of submicron BMHBT were evaluated through microwave measurement. Smallest C_{BCT} was less than 1 fF when emitter width was 0.3 μm. From elemental analysis of BMHBT with emitter width of 0.5 μm, observed result could be explained when C_{BCin} is equal to C_{BCT}. Methods to improve the characteristics are also discussed.

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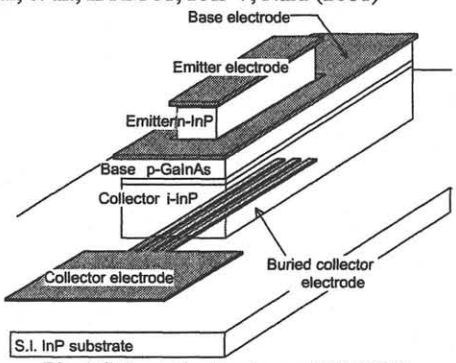

Fig.1 Schematic structure of BMHBT.

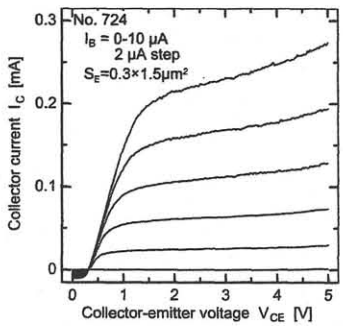

Fig.2 Common emitter characteristics of BMHBT with emitter width of 0.3 μm.

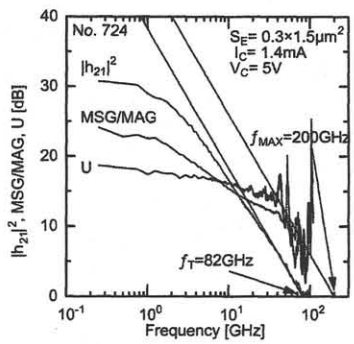

Fig.3 Microwave characteristics of BMHBT with emitter width of 0.3 μm.

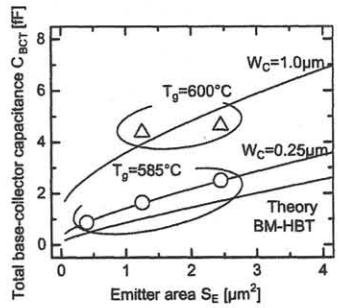

Fig.4 Estimated C_{BCT} from Y_{12} parameters. Open circles indicate present trials while open triangles indicate former trials by using higher growth temperature.

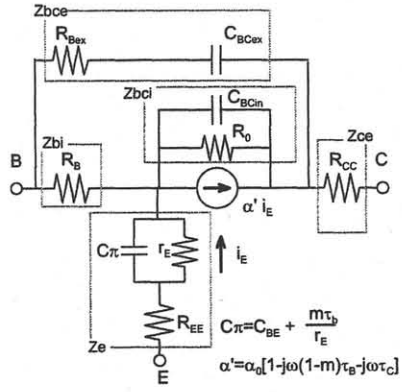

Fig.5 Using equivalent circuit.

Table 1 Estimated elements of Fig.5. Emitter area of the device is 0.5x2.5 μm². The bias conditions are I_C =3.5mA and V_{CE}=5 V.

C_{Bcin}	1.65 [fF]	R_0	60000 [Ω]
C_{BCext}	0 [fF]	R_{Bext}	9.1 [Ω]
C_{BE}	1.47 [fF]	α_0	0.992
r_E	121 [Ω]	m	0.33
R_{EE}	48 [Ω]	τ_B	0.31 [ps]
R_{CC}	540 [Ω]	τ_C	0.30 [ps]

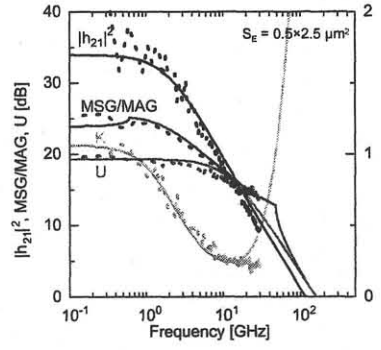

Fig.6 Simulated microwave characteristics. Measured results are shown as dots.