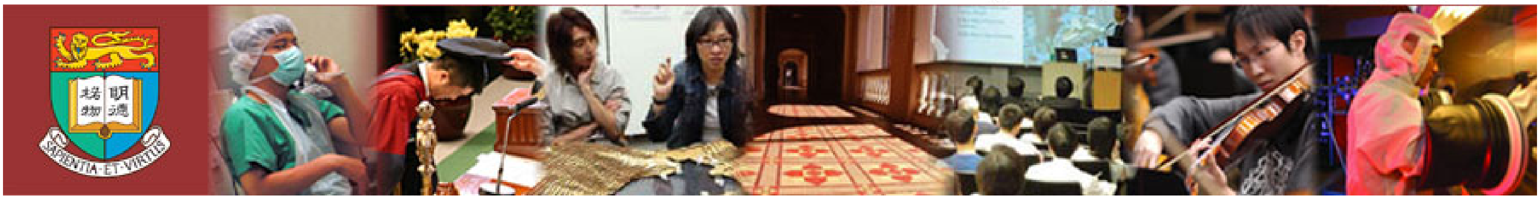

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A High-Frequency GaInP/GaAs Heterojunction Bipolar Transistor with Reduced Base–Collector Capacitance Using a Selective Buried Sub-Collector

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***Abstract*— A C-doped GaInP/GaAs HBT using a selective buried sub-collector has been fabricated by two growth steps. The device was fabricated with minimum overlap of the extrinsic base and the sub-collector region to reduce base-collector capacitance. The experiment shows that the base collector capacitance is reduced to about half of that of an HBT without selective buried sub-collector while the base resistance remains unchanged. A current gain of 35, f_T of 50 GHz and f_{max} of 140 GHz are obtained with this technology.**

I. Introduction

EXTRINSIC base-collector capacitance under the base ohmic contact region is often a large portion of the total collector capacitance (C_{BC}) which degrades RF performance for heterojunction bipolar transistors (HBT's). The conventional method of reducing the base-collector capacitance makes use of either H^+ or O^+ implantation into the extrinsic collector region [1], [2]. However, there still is a significant contribution from the capacitance between the extrinsic base and the sub-collector to C_{BC}. The deep H^+ implantation to sub-collector layer gives rise to significantly reduction in C_{BC} [3], but it also increases the base resistance.

This paper reports a GaInP/GaAs HBT with the reduced extrinsic base–collector capacitance using a selective buried sub-collector (SBSC) layer. The HBT is grown on the selective buried sub-collector mesa. The active HBT region is made on the sub-collector layer and the base contact region is formed on the lightly doped collector layer above the SI GaAs substrate. The collector layer under the base contact region is depleted under bias so that the extrinsic base–collector capacitance is substantially reduced and the maximum oscillation frequency is significantly increased.

II. Device Fabrication

The schematic cross section of the fabricated device is shown in Fig. 1. A 4000-Å sub-collector layer is first grown on an SI GaAs substrate followed by chemical etching to form a sub-collector mesa. By using sulfuric acid based etchant [4], the sub-collector mesa has the shape of a trapezoid. The HBT structure is then regrown starting from the lightly doped collector layer to the emitter cap layer after cleaning. Epitaxial growth was performed in a commercial (Aixtron) MOVPE reactor. The growth conditions were the same as those reported earlier [5]. The n-type and p-type dopants are Si and C, respectively. The regrown HBT structure consists of a 5000-Å GaAs collector layer ($n = 3 \times 10^{16}$ cm^{-3}), a 1000-Å GaAs base layer ($p = 6 \times 10^{19}$ cm^{-3}), a 500-Å GaInP emitter layer ($n = 3 \times 10^{17}$ cm^{-3}), a 1500-Å GaAs emitter cap layer ($n = 4 \times 10^{18}$ cm^{-3}) and a 600-Å graded $In_xGa_{1-x}As$ (x from 0 to 0.5) contact layer ($n = 5 \times 10^{18}$ cm^{-3}). A conventional GaInP/GaAs HBT without SBSC was also grown and fabricated as a control sample. The base sheet resistance of 200 Ω/□ was measured.

Devices were fabricated using the mesa structure and self-aligned techniques as described in [6]. The key difference for making the HBT with SBSC is that the active HBT is on the sub-collector region and most of the base contact is formed outside of the sub-collector region. Fig. 1(b) shows the layout for the HBT with SBSC. The same layout is also employed for making the HBT without SBSC. In order to minimize the base resistance, the base contact is made surrounding the emitter mesa, but the overlap of the base contact and the sub-collector region is only along the half periphery of the emitter mesa with the width of 1 μm. HBT's have an emitter mesa area of 3.5×11.5 μm^2 and a base mesa size of 13×16 μm^2. The collector metal surrounds and self-aligns with the base mesa.

III. Results and Discussion

Fig. 2 shows the current–voltage curve for HBT's with and without SBSC. The two sets of IV characteristics are almost identical. A current gain of 35 and a BV_{ceo} of 10 V are obtained for both devices. The same values of gain and BV_{ceo} indicate that the regrown materials are of high quality and the regrown interface between the sub-collector and the collector does not degrade the device performance.

Microwave measurements were made with an HP8510B network analyzer and cascade microwave probes in the frequency range from 100 MHz to 20 GHz. The base–collector capacitance and parasitic resistance were extracted using the method of Pehlke [7]. The current gain ($|h21|$), maximum stable gain/maximum available gain, (MSG/MAG), and unilateral gain (U) as a function of frequency for the HBT with SBSC

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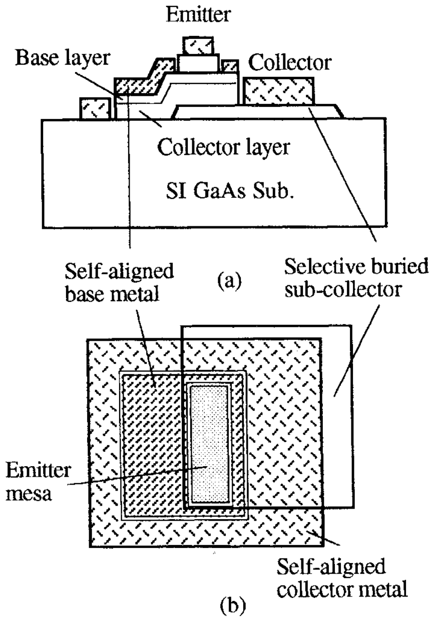

Fig. 1. (a) Cross section of the HBT with selective buried sub-collector and (b) schematic layout of the HBT.

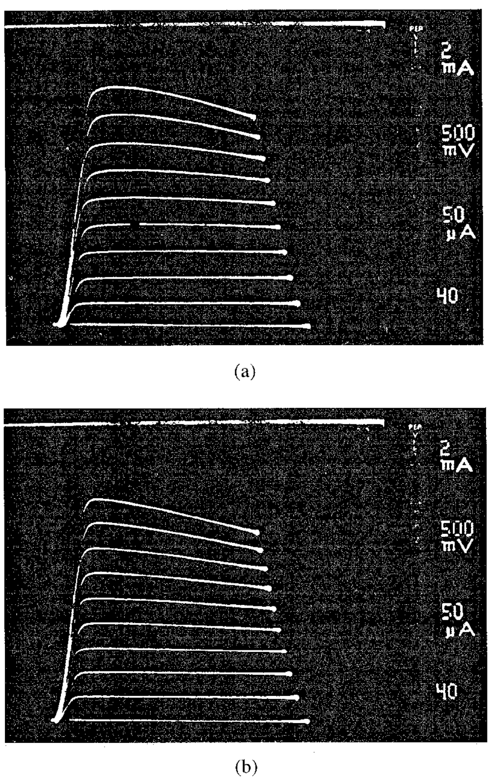

Fig. 2. Common-emitter IV curves for HBT's (a) with SBSC and (b) without SBSC.

is shown in Fig. 3(a). A cutoff frequency (f_T) of 50 GHz and a maximum oscillation frequency (f_{maxU}) of 140 GHz are obtained, respectively, at V_{ce} of 2.5 V and J_c of 2.2×10^4 A/cm^2. Fig. 3(b) shows f_{maxU}, f_T and extracted C_{BC} versus collector current density for HBT's with and without SBSC

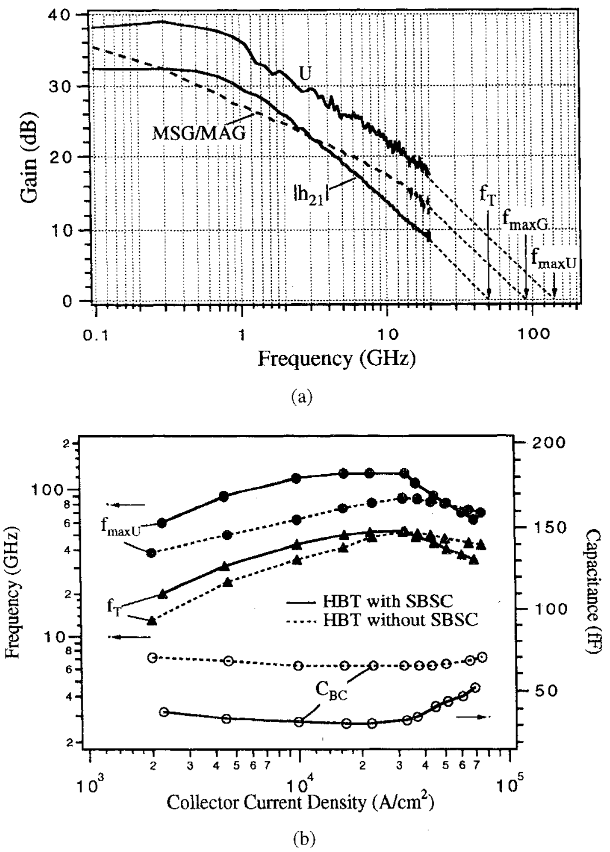

Fig. 3. (a) $|h21|$, MSG/MAG and U as a function of frequency for the HBT with SBSC at V_{cs} of 2.5 V and J_c of 2.2×10^4 A/cm^2; (b) f_{maxU}, f_T, and extracted C_{BC} versus J_c for HBT's with SBSC (solid lines with symbols) and without SBSC (dashed lines with symbols) at V_{ce} of 2.0 V.

at $V_{ce} = 2.0$ V. The typical values of C_{BC} are 31 and 65 fF for HBT's with and without SBSC, respectively, at V_{ce} of 2.0 V and J_c of 2.2×10^4 A/cm^2. The value of C_{BC} for the HBT with SBSC is reduced to more than half of the HBT without SBSC. About 40–50% increase in f_{maxU} and f_{maxG} [not shown in Fig. 3(b)] for the HBT with SBSC is observed at $J_c < 3 \times 10^4$ A/cm^2.

In order to check whether the capacitance under the base contact region makes large contribution to C_{BC} at low bias, we have measured C_{BC} versus V_{bc}. The results show that the value of C_{BC} for the HBT with SBSC is always about half of that of the HBT without SBSC even at zero bias. From simple calculations using depletion approximations, the collector depletion thickness is 2370 Å at V_{cb} of 0 V. We can assume a built-in potential of 0.64 eV at the interface between the semi-insulating GaAs substrate and n-GaAs collector, because the Fermi level of the semi-insulating GaAs substrate is at mid-gap [8], [9] and the Fermi level of the n^--GaAs collector is at 0.06 eV below the conduction band. The band bending of the interface creates a depletion layer of approximately 1600 Å in the collector. Hence, most of the collector layer is depleted and the capacitance under the base contact region makes negligible contribution to the total C_{BC} at zero bias.

Despite of the reduction of $C_{\rm BC}$, the vales of $f_{\rm T}$ for the HBT with SBSC are only 10–20% higher than that of the HBT without SBSC at $J_c < 2$ A/cm^2 as seen from Fig. 3(b). This is because the cutoff frequency of an HBT is not only dependent on the emitter and collector RC charging times but also dominated by base and collector transit times. In addition, the collector resistance of 10 Ω for the HBT with SBSC is about twice that of 5 Ω for the HBT without SBSC, because the collector contact area for the HBT with SBSC is only half of that of the HBT without SBSC [Fig. 1(b)]. The base resistances are similar for both devices with values of 6 and 6.5 Ω for HBT's with and without SBSC, respectively. From the relation of $f_{\max}$ and $C_{\rm BC}$, if $f_{\rm T}$ and $R_{\rm b}$ are fixed, a 50% reduction in $C_{\rm BC}$ results in a 41% increase in $f_{\max}$. Our results show a 40–50% increase in $f_{\max}$. Considering the slightly higher $f_{\rm T}$ and lower $R_{\rm b}$ of the HBT with SBSC, a 50% increase in $f_{\max}$ is reasonable. It is also noted from Fig. 3(b) that $f_{\max}$ and $f_{\rm T}$ decrease for HBT's at high current region due to Kirk effect. However, $C_{\rm BC}$ for the HBT with SBSC increase faster causing a rapid decrease of $f_{\max}$ and $f_{\rm T}$ after the onset of Kirk effect. The reason for the more pronounced Kirk effect is not understood at present.

IV. Conclusion

The selective buried sub-collector provides an effective technique for reducing the extrinsic base-collector capacitance while keeping the base resistance uncharged for a GaInP/GaAs HBT. A 50% reduction in $C_{\rm BC}$ and a 40–50% increase in $f_{\max}$ are observed with this technology. A maximum oscillation frequency of 140 GHz and a cutoff frequency of 50 GHz have been obtained.

References

[1] O. Nakajima, K. Nagata, Y. Yamauchi, H. Ito, and T. Ishibashi, "Improvement in AlGaAs/GaAs HBT power gains with buried proton-implanted layer," *Electron Lett.*, vol. 22, pp. 1317–1318, 1986.

[2] P. M. Asbeck, D. L. Miller, R. J. Anderson, and F. H. Eisen, "GaAs/AlGaAs heterojunction bipolar transistors with buried oxygen-implanted isolation layers," *IEEE Electron Device Lett.*, vol. 5, pp. 310–312, 1984.

[3] M. C. Ho, R. A. Johnson, W. J. Ho, M. F. Chang, and P. M. Asbeck, "High-performance low-base collector capacitance AlGaAs/GaAs heterojunction bipolar transistors fabricated by deep ion implantation," *IEEE Electron Device Lett.*, vol. 16, pp. 51–513, 1995.

[4] D. W. Shaw, "Localized GaAs etching with acidic hydrogen peroxide solutions," *J. Electrochem. Soc.*, vol. 128, p. 874–880, 1981.

[5] Y. F. Yang, C. C. Hsu, E. S. Yang, and Y. K. Chen, "Comparison of GaInP/GaAs heterostructure-emitter bipolar transistors and heterojunction bipolar transistors," *IEEE Trans. Electron Devices*, vol. 42, pp. 1210–1215, 1995.

[6] Y. F. Yang, C. C. Hsu, and E. S. Yang, "A high frequency and low noise C-doped GaInP/GaAs heterojunction bipolar transistor grown by MOCVD using TBA and TBP," *Electron. Lett.*, vol. 32, pp. 689–691, 1996.

[7] D. Pehkle and D. Pavlidis, "Evaluation of the factors determining HBT high-frequency performance by direct analysis of s-parameter data," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 2367–2373, 1992.

[8] P. F. Lindquist and W. M. Ford, "Semi-insulating GaAs substrates," in *GaAs FET Principles and Technology*, J. V. DiLorenzo and D. D. Khandelwal, Eds. Norwood, MA: Artech House, 1982, ch. 1.

[9] R. J. Krantz, D. C. Mayer and W. L. Bloss, "The influence of Fermi-level pinning at the GaAs substrate on HEMT threshold voltage," *Solid-State Electron.*, vol. 33, pp. 1189–1195, 1990.