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High Speed and Uniform Self-Aligned InGaAs/InP HBTs for 40 Gb/s Fiber Optic Communications Applications

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1. Introduction

To meet the rapidly growing demand for high speed and broadband fiber optic communications including OC-768, InP-based device technology has become indispensable. As InGaAs/InP heterojunction bipolar transistors (HBTs) have excellent properties, such as ultra high speed and low power consumption, the InGaAs/InP HBTs are the most promising candidate for the applications. We aimed to develop a fabrication process of the HBTs with high uniformity and high yield for use in 40 Gb/s fiber optic applications. Self-aligned fabrication processes, such as BMOSA [1] need many etching steps. To simplify the fabrication process, we have developed a simple self-aligned process utilizing an overhung mesa profile. This process enables us to form a narrow spacing between the emitter contact mesa and the base electrodes resulting in very high-speed operation and excellent uniformity.

2. HBT fabrication and measurement

Fabrication of self-aligned HBTs

The epitaxial layer structure of InGaAs/InP HBTs is tabulated in Table 1. The thickness of the InP emitter is 10 nm. The thin emitter layer acts as a passivation layer for the surface of the extrinsic base region [2]. The InGaAs base layer is a C-doped layer (4E19 cm^{-3}) with a thickness of 50 nm. The schematic cross-sectional view of the fabricated HBT is shown in Fig. 1. We have developed a simple self-aligned process using an overhung mesa profile. The first step of the fabrication process is the formation of emitter contact mesas using an SiN film as an etching mask, which is performed by only wet chemical etching. The etchants are H_3PO_4:H_2O_2:H_2O and HCl:H_2O systems for InGaAs and InP, respectively. The InGaAs overhung mesa profile is controlled by the composition of the etchant and etching time. Following the base mesa formation by wet chemical etching, ohmic electrodes of Pt/Ti/Pt/Au are evaporated over the base and emitter mesas. The electrodes are separated owing to the overhung emitter contact mesa. In this self-aligned process, the distance between the emitter contact mesa and the base metal is precisely determined by the thickness of the emitter contact layer. The cross-sectional SEM photograph of the emitter region is shown in Fig. 2. We achieved a narrow separation of 0.15 μm between the base electrode and the 250 nm thick emitter contact as shown in the figure.

Table 1. Layer structure of the HBTs.

Layer	Material	Thickness (nm)	Dopant	Carrier density (cm^{-3})
Emitter contact	n^+-InGaAs	200	Si	2.0E+19
Emitter cap	n^+-InGaAs	50	Si	4.0E+18
Emitter	n-InP	10	Si	4.0E+18
Base	p^+-InGaAs	50	C	4.0E+19
Collector	n^--InGaAs	400	Si	5.0E+16
Sub-collector	n^+-InGaAs	300	Si	1.0E+19

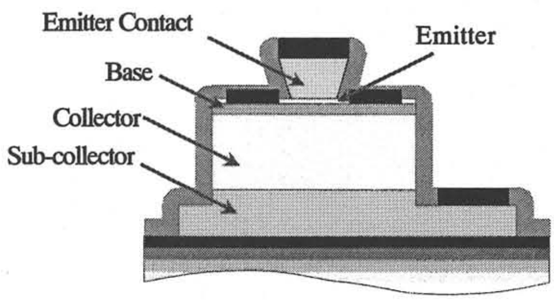

Fig. 1. Schematic cross-sectional view of the fabricated InP/InGaAs HBT.

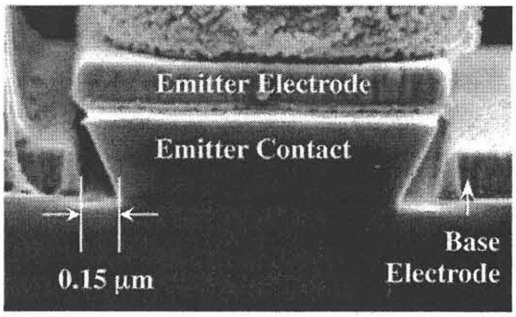

Fig. 2. SEM photograph showing a cross section of an emitter region.

DC characteristics

The fabricated HBTs, which have rectangular emitters of 0.7× 5.8 μm^2, showed an average current gain of 27.9 at a collector current density of 1×10^5 A/cm^2. The standard deviation is 4.0 over a 3-inch diameter wafer. We obtained very high uniformity of the emitter size even with wet chemical etching. The standard deviation is only 0.1 μm^2, which results in excellent uniformity of the characteristics. The uniformity of the current gain over a 2.4×4.8 mm^2 region, which was evaluated by measuring HBT array consisting of two dimensionally arranged 26×57 (1,482) HBTs with rectangular emitters of 1.3×5.8 μm^2 is shown in Fig. 3. The average current gain at J_c of 1×10^5 A/cm^2 is 39.9 and its standard deviation is only 0.5. This demonstrates that we can fabricate MUX/DEMUX-level ICs with high yield.

RF characteristics

On-wafer S-parameter measurements were performed by using a 110-GHz network analyzer. The dependence of the current gain cutoff frequency f_t and maximum oscillation frequency f_{max} on the collector current density J_c at a fixed emitter to collector bias of 1.5 V for a HBT with a rectangular emitter of 0.7×5.8 μm^2 is plotted in Fig.4. The maximum value of f_t and f_{max} are 231 and 280 GHz at J_c of 4.3×10^5 A/cm^2, respectively. The uniformity of f_t and f_{max} over a 3-inch wafer is excellent. The number of the tested HBT is 110 and the standard deviations are only 6.7 GHz and 6.9 GHz, respectively. From the S-parameter measurements, we extracted R_b, C_{bc}, and C_{be}, as 12.0 Ω, 12.5 fF and 35.0 fF, respectively. The total delay time τ_{ec} as a function of inverse collector current $1/I_c$, which is given by eq. (1), is shown in Fig.5.

$$\tau_{ec} = 1/2\pi f_t = \frac{kT}{qI_c}(C_{be} + C_{bc}) + \tau_b + \tau_c + C_{bc}(R_e + R_c) \quad (1)$$

By extrapolating the linear relationship between τ_{ec} and $1/I_c$, we obtained the total transit time, $\tau_b + \tau_c$, as 0.41 ps.

3. Conclusion

We have developed a simple self-aligned process utilizing an overhung emitter contact mesa profile. With this process, we achieved a narrow separation of 0.15 μm between the emitter contact mesa and base electrodes, as well as a high f_t and f_{max} of 231 GHz and 280 GHz, respectively. We also obtained a very high uniformity of f_t and f_{max} over a 3-inch diameter wafer. The results promise a high yield of 40 Gb/s optical communications ICs.

References

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[2] H. Yano, S. Sawada, K. Doguchi, K. Kato and G. Sasaki, *IEICE Trans. Electron.*, E80-C, pp. 689 -694(1997).

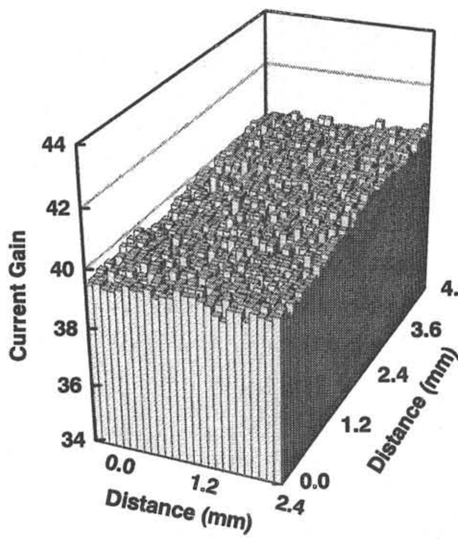

Fig. 3. Current gain distribution at J_c of 1.0×10^5 A/cm^2 over a 2.4×4.8 mm^2 region.

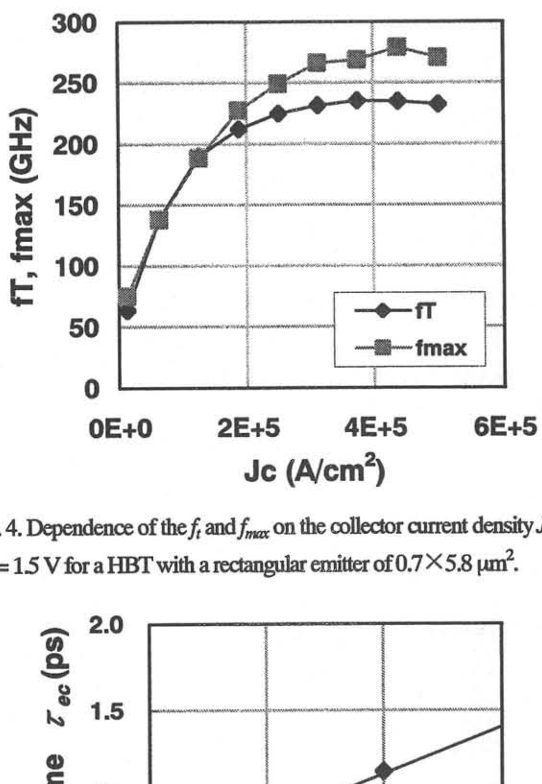

Fig. 4. Dependence of the f_t and f_{max} on the collector current density J_c at V_{ce} = 1.5 V for a HBT with a rectangular emitter of 0.7×5.8 μm^2.

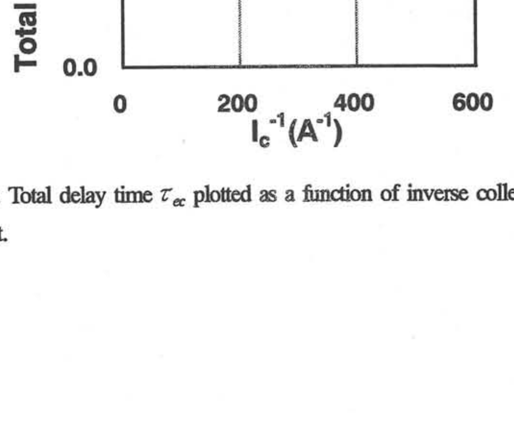

Fig. 5. Total delay time τ_{ec} plotted as a function of inverse collector current.