

# **Cover Sheet**

**Paper title :**  
**Performance of New Self-Aligned InP HBT's Using  
Crystallographically Defined Emitter Contact Technology**

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# Performance of New Self-Aligned InP HBT's Using Crystallographically Defined Emitter Contact Technology

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InP-based heterojunction bipolar transistors(HBT's) have demonstrated impressive high-speed performance due to their superior carrier transport properties and high frequency characteristics[1]. Recently various process methods have been reported for fabrication of self-aligned HBT's using techniques such as the conventional wet chemical etching using an emitter electrode mask, a WSi/Ti base electrode and buried SiO<sub>2</sub> sidewall formation around the emitter electrode[2], and T-shaped emitter electrode[3]. However, the previously reported methods rely on unreliable wet-etching or reactive ion etching, resulting in problems such as plasma damage of etched surface. In this work, a novel self-aligned processing technique for InP/InGaAs HBT's is reported, which uses damage-free all wet chemical etching, while producing precisely controlled undercut profiles. The performance of fabricated HBT's using the proposed self-align technology is also presented.

The epitaxial layer structure of the InP/InGaAs HBT used in this work is shown in Table 1. The proposed new self-aligned process utilizes the consistent crystallo-graphic etching characteristics of the InP dummy emitter layer, which provides highly uniform undercut profiles. A brief fabrication sequence of the proposed process is shown in Fig. 1. The detailed fabrication will be discussed later in the full paper.

The common-emitter DC characteristics of the fabricated  $1 \times 20 \mu\text{m}^2$  emitter device are shown in Fig. 2. The offset voltage  $V_{CE,offset}$  was 65mV and collector-emitter breakdown voltage  $BV_{CEO}$  was 5.8V. The DC current gain  $h_{FE}$  of 56 was obtained from the fabricated HBT with the ideality factors of  $n_C = 1.06$  and  $n_B = 1.2$ . The emitter-size effect of the fabricated HBT's on current gain was also investigated using the widely used characterization method based on  $1/h_{FE}$  versus the perimeter to area ratio of emitters. The peripheral component of the base current was estimated to be  $0.74 \times 10^{-6} \text{ A}/\mu\text{m}$  at  $J_C = 4 \times 10^4 \text{ A}/\text{cm}^2$ . It is found that the damage-free self-aligned process based on the proposed all wet-etching technique as well as the inherent low surface recombination characteristics of InP-based materials substantially suppress the degradation of current gain for small size area devices[4]. The proposed self-align process is expected to be very effective in preserving high current gain of the device even down to sub-micron emitter dimension without considerable gain degradation. Fig. 3 shows the frequency dependence of current gain  $h_{21}$  and unilateral power gain  $U$  for the fabricated  $1 \times 20 \mu\text{m}^2$  emitter device. The maximum  $f_T$  and  $f_{max}$ , estimated from -20dB/decade extrapolation, were found to be 96 and 106 GHz, respectively. Further optimization of the fabrication process, such as reduction of the base-collector junction area, is in progress to improve the frequency characteristics of the device. Fig. 4 shows the dependence of  $f_T$  and  $f_{max}$  of the fabricated HBT with  $1 \times 20 \mu\text{m}^2$  emitter size on collector current density. The peak  $f_T$  and  $f_{max}$  were obtained at about  $J_C = 2 \times 10^5 \text{ A}/\text{cm}^2$ . The power characteristics of the fabricated HBT's were measured on-wafer using a source- and load-pull system at 1.8 GHz after the substrate was thinned down to 100 $\mu\text{m}$  and back-side electro-plated. The input-output and gain curves when tuned for maximum output power are shown in Fig. 5. The fabricated HBT with  $1 \times 20 \mu\text{m}^2$  emitter size produced maximum output power of 12.0dBm, resulting in output power density of  $0.796 \text{ mW}/\mu\text{m}^2$  at  $I_C = 10 \text{ mA}$  and  $V_{CE} = 2.0 \text{ V}$ . The power density can be increased by optimizing bias conditions. The peak gain and  $P_{O-1dB}$  were measured to be 20.8dB and 11.5dBm respectively. From the measured power gain at 1.8GHz, 10dB gain is expected at 20 GHz from the fabricated device.

In summary, a new self-aligned process for fabricating InP-based HBT's using a crystallographically defined emitter contact technology was proposed, and the performance characteristics of fabricated HBT's were presented. The proposed process technology is believed to be very useful for fabrication of future sub-micron emitter HBT's.

## References

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- [2] T. Oka et al., IEEE Trans. Electron Devices, Vol. 45, No. 11, pp. 2276-2282, 1998
- [3] H. Masuda et al., Proc. InP and Related Materials, pp. 644-647, 1995
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Layer	Material	Doping (cm <sup>-3</sup> )	Thickness (nm)
Dummy	InP	undoped	250
Emitter	InGaAs	n <sup>+</sup> = 1 × 10 <sup>19</sup>	100
	InP	n <sup>+</sup> = 4.2 × 10 <sup>19</sup>	50
	InP	n = 3 × 10 <sup>17</sup>	100
Spacer	InGaAs	undoped	5
Base	InGaAs	p <sup>+</sup> = 4 × 10 <sup>19</sup>	55
Collector	InGaAs	n <sup>-</sup> = 4 × 10 <sup>16</sup>	600
Etch-stop	InP	n <sup>-</sup> = 4 × 10 <sup>16</sup>	10
Subcollector	InGaAs	n <sup>+</sup> = 1 × 10 <sup>19</sup>	500
Buffer	InP	undoped	
Substrate	InP	S.I.	

Table 1. Epitaxial layer structure of the fabricated HBT

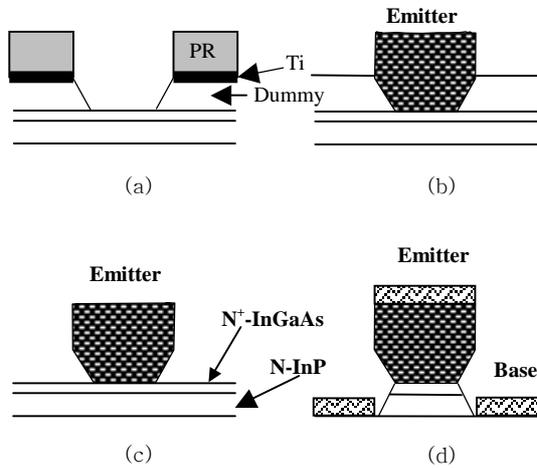


Fig. 1. A brief fabrication sequence of the proposed process; (a) wet-etching of dummy emitter, (b) emitter metallization, (c) wet-etching of remained dummy emitter, and (d) emitter mesa etching & base metallization.

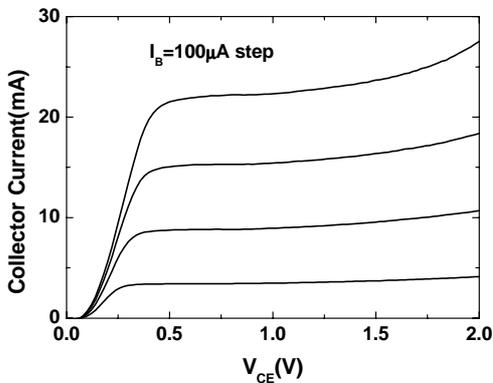


Fig. 2. Common-emitter characteristics of the fabricated HBT with an emitter area of 1 × 20 μm<sup>2</sup>

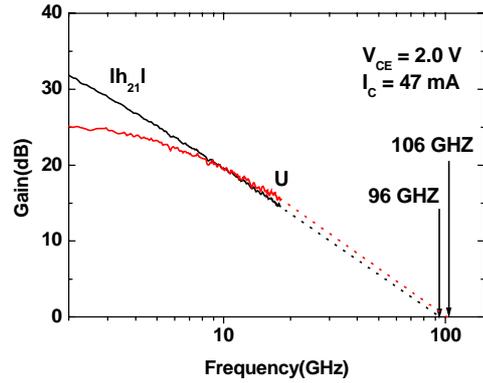


Fig. 3. Frequency dependence of current gain  $h_{21}$  and unilateral power gain U. The dashed lines are extrapolated from  $h_{21}$  and U with a -20dB/decade slope.

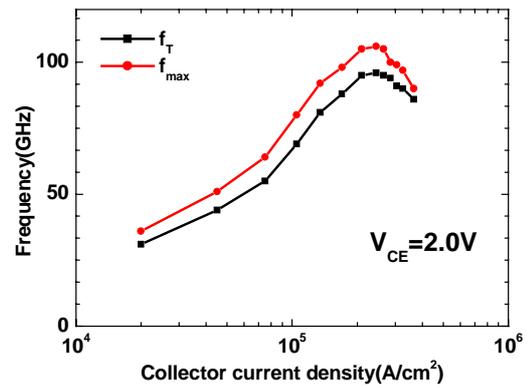


Fig. 4. Dependence of  $f_T$  and  $f_{max}$  of the fabricated HBT with an emitter area of 1 × 20 μm<sup>2</sup> on collector current density.

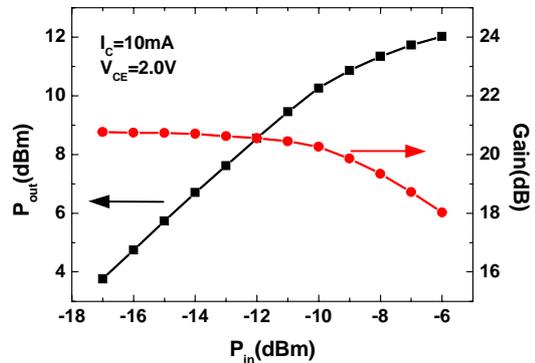


Fig. 5. Power characteristics of the fabricated HBT with 1 × 20 μm<sup>2</sup> emitter size measured at 1.8 GHz. (I<sub>C</sub>=10mA, V<sub>CE</sub>=2.0V)