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AlGaAs/GaAs HBT Fabricated Using Selective MOCVD

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Selectively-grown AlGaAs/GaAs heterojunction bipolar transistor(HBT) with a reduced base-collector capacitance is proposed and fabricated using selective metalorganic chemical vapor deposition(SMOCVD) technique. The proposed device features a triangular void over SiO_2 stripe, 20° off from [T10] direction. The dc characteristics of the selectively-grown HBT are similar to those of the conventional one. However, the microwave performance is improved because the extrinsic base-collector capacitance is significantly reduced. For a transistor with two 3x10μm^2 emitter fingers, the selectively-grown HBT has a higher maximum oscillation frequency than the conventional one by factor of 1.4 at V_{CE}=2V.

1. Introduction

Heterojunction bipolar transistors(HBTs) have shown high speed performance but it is limited by the extrinsic base-collector capacitance of the extrinsic base regions used to form a contact to the base layer of the transistor.

Previously reported techniques for the reduction of the extrinsic base-collector capacitance by the use of buried oxygen-implanted isolation layer[1], buried SiO_2 and polycrystalline GaAs in the extrinsic base and collector[2], buried subcollector layer using selective epitaxy techniques[3], and collector-up structure[4] are less effective and complex processing steps are needed.

In this paper, a selectively-grown AlGaAs/GaAs HBT with a prominently reduced base-collector capacitance is proposed and fabricated in a simple manner using selective metalorganic chemical vapor deposition (SMOCVD) technique. It is experimentally confirmed that the geometrical shapes of the laterally grown facets during SMOCVD growth depend on the growth condition, the crystal orientation of the substrate, and the mask orientation[5][6]. The effective base-collector overlap area can be reduced in the proposed device because the collector layer under the base metal contact is isolated from the collector metal contact by a triangular void over SiO_2 stripe. Therefore, the base-collector capacitance of the selectively-grown HBT is substantially reduced compared to conventional HBTs and an improved high speed performance is expected.

2. Device Structure and Fabrication

The proposed HBT, schemetically illustrated in Fig.1, features a triangular void over SiO_2 stripe, 10°~40° off from [T10] direction. The n^+-GaAs subcollector and n-GaAs collector layer under the base metal contact are isolated from the collector metal contact when the distance between the top vertex of void and the p^+-GaAs base layer is smaller than a depletion width in collector layer. Thus, the extrinsic base-collector capacitance can be reduced. The device fabrication process is briefly described as follows.

After cleaning and etching an undoped semi-insulating GaAs(001) substrate with $H_2SO_4:H_2O_2:H_2O$ solution, the SiO_2 stripes, 20° off from [T10] direction, are formed on the substrate using e-beam evaporation and lift-off process. The width and the thickness of the SiO_2 stripes are 2.5µm and 0.1µm, respectively. The void height, H, can be experimentally expressed by :

$$H = L / 2(\alpha\tan\theta + 0.71) \qquad (1)$$

where L is the SiO_2 stripe width, α(1.25 for θ=20°) is empirical constant, which is called the lateral growth

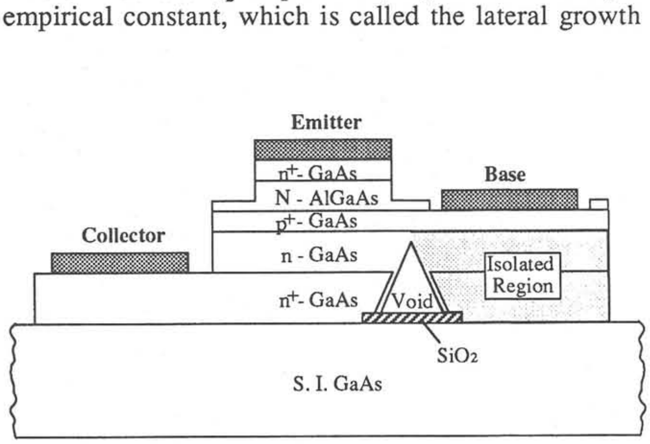

Fig. 1 Schematic structure of the proposed HBT.

parameter, and θ is the mask orientation angle. Expected void height from Eq.(1) is 1μm. The epitaxial layers of HBT, shown in Table 1, are grown by atmospheric pressure-MOCVD system. Trimethylgallium(TMG), Trimethylaluminum(TMA) and AsH_3 are used as source materials. N- and p-type dopant source materials are SiH_4 and CCl_4, respectively. The device has no spacer layer between the base and the emitter layer. During the growth, the void with height of 1μm is formed over the SiO_2 stripe. The distance between the top vertex and the base layer is 0.1μm and smaller than the collector depletion width. For the collector doping concentration of $1x10^{17}cm^{-3}$ and the collector-base voltage of zero, the depletion width is about 0.14μm. Thus, an isolation between the collector metal contact and the extrinsic collector layer is achieved.

Using wet chemical etching with H_2SO_4:H_2O_2:H_2O solution and lift-off process, the selectively-grown and the conventional HBTs are fabricated as mesa-type with thin AlGaAs ledge. AuGe/Ni/Au and Au/AuZn/Au are used as n- and p-type ohmic metals, respectively, and alloyed at 430°C using rapid thermal annealing(RTA) system. The base sheet resistance otained from TLM measurement is 500Ω/square. Fig.2 shows the cross sectional SEM photograph of the fabricated device with a $4x10\mu m^2$ emitter finger.

Table 1 Epitaxial layer structure of AlGaAs/GaAs HBT.

Layer	Material	Thickness	Doping		Temp.
Emitter cap	n^+-GaAs	0.05μm	Si	$5x10^{18}$	700°C
Emitter	N-$Al_{0.3}Ga_{0.7}As$	0.15μm	Si	$1x10^{18}$	700°C
Base	p^+-GaAs	0.1μm	C	$2x10^{19}$	650°C
Collector	n-GaAs	0.5μm	Si	$1x10^{17}$	650°C
Subcollector	n^+-GaAs	0.7μm	Si	$5x10^{18}$	650°C

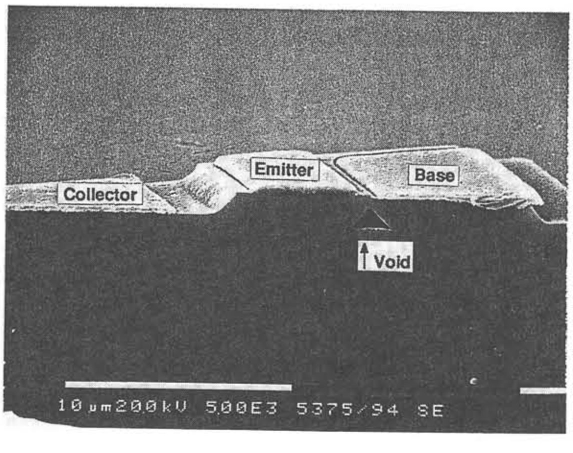

Fig. 2 SEM photograph of the selectively-grown HBT with a $4x10\mu m^2$ emitter finger.

3. Results and Discussion

Common emitter I-V characteristics of the selectively-grown HBT with two $3x10\mu m^2$ emitter fingers is shown in Fig.3. The I-V characteristics is the same as that of the conventional one. The dc current gain h_{FE} of 14 at J_C=60kA/cm^2 and a base current ideality factor η_B of 1.5 are obtained. Fig.4 shows the base-collector capacitance as a function of collector-base voltage for two kinds of device with the same emitter size of $50x100\mu m^2$. The selectively-grown HBT has about half of the base-collector capacitance of the conventional one because the capacitance of the extrinsic base region is almost eliminated for the selectively-grown device. Therefore, the effective base-collector overlap area is $100x100\mu m^2$ for the conventional device while it is $50x100\mu m^2$ for the selectively-grown device.

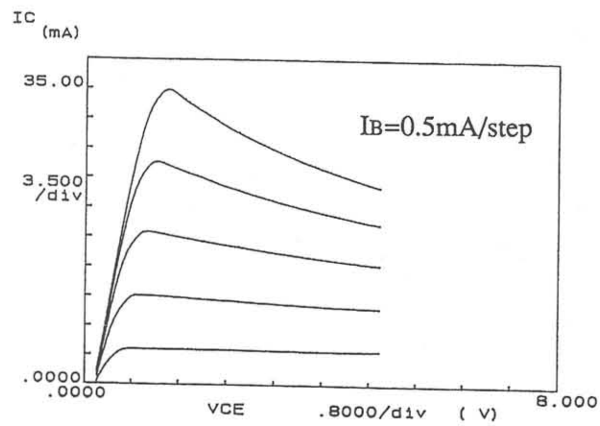

Fig. 3 Common emitter I-V characteristics of the selectively-grown HBT with two $3x10\mu m^2$ emitter fingers.

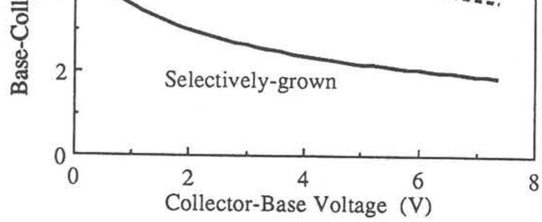

Fig. 4 Measured base-collector capacitance as a function of the collector-base voltage for the devices with $50x100\mu m^2$ emitter finger.

A microwave performance of the devices is characterized with a Cascade Microtech on-wafer prober using Wiltron 360B network analyzer. Fig.5 shows measured current gain cutoff frequency f_T and maximum oscillation frequency f_{max} as a function of collector current at V_{CE}=2V. The selectively-grown HBT has superior microwave performance compared to the conventional one due to a reduced base-collector capacitance. In particular, the selectively-grown device has higher maximum oscillation frequency than the conventional one by a factor of 1.4. For the selectively-grown HBT, f_T of 43GHz and f_{max} of 20.5GHz at V_{CE}=3V are obtained. Fig.6 shows a small-signal lumped-element equivalent circuit of HBT and Table 2 lists several values, extracted using Libra software, of the circuit elements in the model. The extrinsic base-collector capacitance(C_{BCX}) of the selectively-grown HBT is remarkably reduced while other elements are almost the same as those of the conventional one.

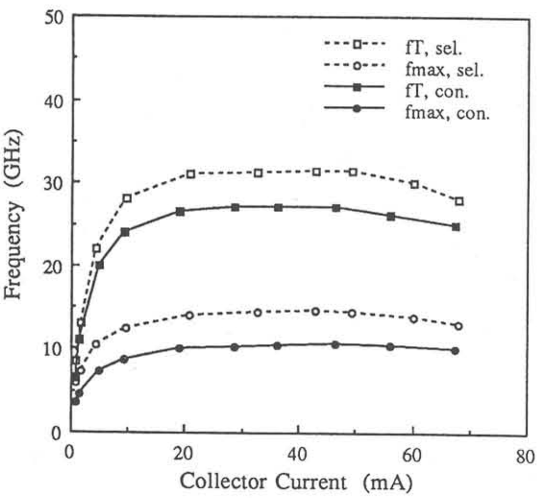

Fig. 5 Dependence of the f_T and f_{max} for the HBTs with two 3x10μm² emitter fingers on the collector current at V_{CE}=2V.

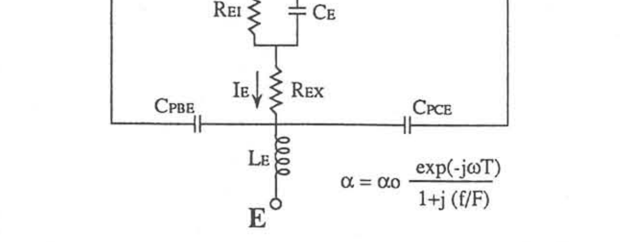

Fig. 6 Small-signal lumped-element equivalent circuit of the HBT with two 3x10μm² emitter fingers.

Table 2 Parameter values of equivalent circuit for HBTs with two 3x10μm² emitter fingers.

Parameter	Selectively-grown	Conventional
α_o	0.93	0.94
C_{BCI}	60.3fF	60.4fF
C_{BCX}	3.9fF	70.4fF
C_E	1.3pF	1.5pF
$R_C(R_{CI}+R_{CX})$	2.0Ω	3.1Ω
$R_B(R_{BI}+R_{BX})$	61.3Ω	70.8Ω
$R_E(R_{EI}+R_{EX})$	2.8Ω	3.4Ω

4. Conclusions

We have proposed and fabricated a selectively-grown HBT with a triangular void over SiO_2 stripe, using SMOCVD technique. The dc characteristics of the selectively-grown HBT are similar to those of the conventional one. However, the selectively-grown HBT has an improved microwave performance due to a significantly reduced extrinsic base-collector capacitance. For maximum oscillation frequency, it is higher by a factor of 1.4 than in the conventioal HBT. The proposed HBT has strong potentials for high speed and power applications due to the reduced base-collector capacitance.

5. References

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