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Highly Reproducible Fabrication Process for Passivated AlGaAs/GaAs HBT's with Pt/Ti/Pt/Au Base Electrodes

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A highly reproducible fabrication technology for passivated HBT's has been developed. A thermally stable Pt/Ti/Pt/Au base metal system which penetrates through the $Al_{0.3}Ga_{0.7}As$ emitter layer to contact the base layer forms the base passivation layer. A citric-acid-based selective etchant eliminates the ambiguity of etching and thus confirms the reproducibility of passivation layer thickness. An excess base leakage current density was reduced by the factor of 4.

1. Introduction

AlGaAs/GaAs heterojunction bipolar transistors (HBT's) are attractive for application in high-speed optical communications or microwave power transistors.^{1),2)} Scaling down the emitter size is an indispensable requirement for low-power and highspeed operation. However, the current gain degradation due to the relative increase of carrier recombination in the extrinsic base surface is a serious problem in scaling down the emitter size.3) Passivating this extrinsic base region by an AlGaAs layer is an effective way to suppress the surface recombination current, thereby ultimately increasing the current gain.4) We found that Pt can contact the p+-GaAs through n-AlGaAs. This feature enables formation of a base electrode without exposing the base layer. Therefore a passivation layer to an extrinsic base region is automatically formed.

The Pt/Ti/Pt/Au metal system used in this work is an excellent base metal system with respect to three factors. The first advantage is that the diffusion front of Pt after annealing is flat compared to gold-based metals, e.g. AuZn/Au, which are subject to the disadvantage of alloy spikes which may reach the collector layer, thereby increasing the leakage current of base-collector diodes. The second advantage is that extremely low contact resistivity to p⁺-GaAs is obtained by this metal system because Pt is a low potential barrier height metal to p-type semiconductor.⁵⁾ The third point is the system's superior thermal stability to alloy-type metal systems, e.g. AuZn/Au, because Pt forms a very stable

intermetallic compound with GaAs.

When a passivated HBT is fabricated, the passivation layer thickness strongly depends on the current gain.⁶) In order to achieve a high current gain, optimum passivation layer thickness must be obtained. A citricacid-based selective etchant was used to improve the reproducibility of passivation thickness.

This paper describes the fabrication process of the passivated HBT using a citric-acid-based etchant and a Pt/Ti/Pt/Au base metal system. This process successfully reduced the emitter size dependence of the current gain.

2. Device Fabrication

Figure 1 shows the schematic cross section of the passivated HBT. The epitaxial layer structure of HBT's



Fig. 1 Schematic cross section of the passivated HBT.

Layer	Material	Doping(cm ⁻³)	Thickness(nm)
Contact	n ⁺ InyGa1-yAs y=0→0.5	3×10 ¹⁹	110
Emitter	n Al _x Ga _{1-x} As x=0.3→0	5×10 ¹⁸	30
	n A10.3Gao.7As	9×10 ¹⁷	30
	n A1 _x Ga1-xAs x=0.1→0.3	9×10 ¹⁷	20
Base	p ⁺ Al _x Ga _{1-x} As x=0→0.1	5×10 ¹⁹	50
Collector	n GaAs	5×10 ¹⁶	600
	n ⁺ GaAs	5×10 ¹⁸	500

Table 1 Layer structure of the passivated HBT.

used in this study is shown in Table 1. All the wafers were grown by MBE. The base layer has a gradedbandgap base structure and the emitter-base junction is a graded junction. The emitter layer consists of an $Al_{0.3}Ga_{0.7}As$ layer. This $Al_{0.3}Ga_{0.7}As$ layer serves not only as a wide bandgap emitter layer but as an etch stop layer as will be mentioned below. An InGaAs layer was deposited on top as an emitter contact layer in order to reduce the emitter contact resistance.

electrode fabrication The characteristic base procedure was achieved by a citric-acid-based selective etchant and a Pt/Ti/Pt/Au metal system. A 100:1 (by volume) mixture of the 1 wt% water solution of citric acid monohydrate and hydrogen peroxide was utilized as the etchant. In addition, ammonia water was added to the etchant so as to make the etchant be pH=7.0.7) The etching rate of GaAs is about 50 nm/min at 15 °C and the etching selectivity to Al0.3Ga0.7As of more than 40 was obtained. As a selective etchant which has an etching selectivity between GaAs and AlGaAs, this the is superior to citric-acid-based etchant conventionally used NH4OH-H2O2 based etchant. In NH4OH-H2O2 based etchant, etching rate of GaAs is much faster than the citric-acid-based etchant even though both have a high etching selectivity between GaAs and Al_{0.3}Ga_{0.7}As. It is a critical point because if an etching rate of GaAs is very fast, a side-etch width in



Fig. 2 Etching trace by a nonselective etchant (N) and a citricacid-based selective etchant (S).

a GaAs layer becomes uncontrollably large. It seriously degrades scale precision in fabrication.

Since InGaAs is not etched by the citric-acid-based etchant, a nonselective etchant is utilized to etch off the InGaAs emitter cap layer. Figure 2 shows the trace of etching in a time domain which reveals the etching characteristics of the nonselective etchant (N) and the citric-acid-based selective etchant (S). The thickness of the layer structure shown on the right side corresponds to the vertical axis. The etchant is switched from the nonselective etchant to the citric-acid-based selective etchant after the InGaAs emitter cap layer is etched off The etching is automatically stopped at the surface of the Al_{0.3}Ga_{0.7}As layer by the citric-acid-based etchant even with one minute over-etching.

A Pt/Ti/Pt/Au base metal system is evaporated successively on top of the $Al_{0.3}Ga_{0.7}As$ emitter layer after the etching is automatically stopped. The thickness of each layer is Pt(40 nm), Ti(40 nm), Pt(50 nm) and Au(100 nm). An ohmic contact to the base layer is obtained by annealing at 350 °C for 40 min in a nitrogen atmosphere. This procedure lets the firstly deposited Pt penetrate through the passivation layer to form an intermetallic compound with AlGaAs. The intermetallic compound layer thickness is easily controlled by the amount of the firstly evaporated Pt thickness according to the passivation layer thickness.

The emitter electrode metal and the collector electrode metal are Ti/Pt/Au and AuGe/Ni//Ti/Au respectively.

In order to investigate the effect of the passivation, five different dimensional HBT's with emitter-base junction areas of $3 \times 10 \mu m$, $4 \times 10 \mu m$, $6 \times 10 \mu m$ and $10 \times$ $10 \mu m$ were fabricated on the same HBT wafer and the emitter size dependence of the performance was measured.

For the RF performance measurement, smaller emitter size HBT's were fabricated on a different wafer. A self-alignment technology using polyimide for the separation of emitter electrodes and base electrodes was utilized in this case. The smallest emitter size is 1.5×1.5 µm.

3. Device Performances

Figure 3 shows typical I-V characteristics of the passivated HBT with an emitter size of $3 \times 10 \mu m$. Fairly good DC performance is obtained without incrementing a base resistance even though the base electrode metal contacts the base layer through the passivation layer. A base resistivity of $1 \times 10^{-6} \Omega cm^2$ was obtained.

Figure 4 shows the current gain dependence on the emitter size of devices with and without a passivation layer measured at a collector current density $J_C=5\times10^4$ A/cm². The HBT with a passivation layer shows less



Fig. 3 Typical I-V characteristics of the passivated HBT.



Fig. 4 Current gain dependence on the emitter size.

dependence on the emitter size. Supposing that the base current is divided into two major components for simplicity. One is assigned to the recombination current on the periphery of the emitter mesa, and the other is assigned to the recombination in the intrinsic region. The total base current I_B is written as:

$$I_{B} = J_{BL} \cdot L + J_{BS} \cdot S,$$

where L is emitter periphery length, S is emitter area, J_{BL} is base leakage current around the emitter periphery and J_{BS} is recombination current in the intrinsic region. The inverse of current gain β is then written as:

$$\begin{split} \beta^{-1} &= I_B / I_C \\ &= (J_{BL} \cdot L + J_{BS} \cdot S) / (J_C \cdot S) \\ &= (J_{BL} / J_C) \cdot L / S + J_{BS} / J_C, \end{split}$$

where I_c is collector current. From the slope of the dependence of β^{-1} on L/S, the base leakage current on the emitter mesa periphery is estimated to be 6.5 μ A/ μ m for the passivated HBT. It is 1/4 of the base leakage current of the unpassivated HBT.



Fig. 5 Maximum oscillation frequency $f_{max}\ vs.$ collector current $I_C.$

Figure 5 shows the RF performance of a passivated HBT fabricated by a self-alignment technology with a small $1.5 \times 1.5 \mu m$ emitter. Thanks to the effect of the Pt-buried metal, fairly high maximum oscillation frequency, f_{max} , of 136 GHz was obtained.

4. Conclusion

A highly reproducible fabrication technology for an AlGaAs/GaAs HBT was developed. The citric-acidbased etchant eliminates the ambiguity of passivation layer thickness in etching and a Pt/Ti/Pt/Au base metal system assures low base contact resistance and high reliability of base metal. The maximum oscillation frequency of 136 GHz was obtained for a $1.5 \times 1.5 \mu m$ passivated HBT.

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