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Carbon-Doped-Base AlGaAs/GaAs HBTs Grown by Gas-Source MBE Using Only Gaseous Sources

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We report the fabrication and electrical characteristics of carbon-doped-base AlGaAs/GaAs heterojunction bipolar transistors (HBTs) grown by gas-source MBE using only gaseous sources. The HBTs had an abrupt emitter-base junction, and the base layer was doped with carbon to a carrier concentration of $4x10^{19}$ cm^{-3}. A current gain of 45 was obtained at a collector current density of $4x10^{4}$ A/cm^{2}. The HBTs were electrically stable under current stress, as confirmed by current gain and Gummel plots. We regard the improved GSMBE as an attractive growth technique method for growing C-doped-base AlGaAs/GaAs HBTs.

1. Introduction

In MBE-grown AlGaAs/GaAs heterojunction bipolar transistors (HBTs), beryllium is widely used as the p-type base dopant. Recently, however, there have been several reports on the electrical degradation of Be-doped-base HBTs due to Be diffusion[1,2]. Such degradation could be suppressed by substituting carbon for beryllium because carbon has a very small diffusion coefficient in GaAs. We tried gas-source MBE (GSMBE) using only gaseous sources to fabricate C-doped-base AlGaAs/GaAs HBTs.

It is possible to get carbon doping levels of 10^{20} cm^{-3} using GSMBE[3]. We have developed an improved GSMBE growth method, in which all sources, including dopant sources, are in the form of gases[4,5]. Since conventional GSMBE uses both gaseous and solid sources during growth, the doping efficiency is severely degraded due to the reaction between hot solid sources and gaseous metalorganic by-products[6]. The use of only gaseous sources enables the reproducible, controllable growth and doping of (Al,Ga)As[7]. This paper reports the electrical stability of C-doped-base AlGaAs/GaAs HBTs grown by GSMBE using only gaseous sources.

2.Epitaxial Growth and Device Fabrication

The Al, Ga, and As sources used to grow C-doped-base AlGaAs/GaAs HBTs were triethylaluminum (TEAl), triethylgallium (TEGa), and arsine (AsH_3) cracked at 1100°C. No carrier gas was used to transfer these sources into the growth chamber. We used cold gaseous dopant sources, which require no cracking, instead of conventional hot solid sources contained in Knudsen cells. The n-type dopant (silicon) source was 10% disilane (Si_2H_6) diluted with H_2. Trimethylgallium (TMGa) was used both as the p-type dopant (carbon) and Ga source of the base layer.

The HBT structure grown is shown in Figure 1. The structure was grown on (100)-oriented semi-

Epitaxial layer	Carrier (cm^{-3})	Thickness (nm)
n+-GaAs	$5x10^{18}$	50
n - GaAs	$2x10^{18}$	230
N-$Al_{0.2}Ga_{0.8}As$	$9x10^{17}$	150
i - GaAs	—	7.5
p+ - GaAs	$4x10^{19}$	92.5
n - GaAs	$1x10^{17}$	400
n+-GaAs	$3x10^{18}$	500
SI GaAs substrate		

Figure 1 HBT structure grown by gas source MBE using only gaseous sources.

insulating GaAs. The carrier concentrations of the subcollector (500 nm) and collector (400 nm) layers were $3x10^{18}$ cm^{-3} and $1x10^{17}$ cm^{-3}. The base layer (92.5 nm) was doped with carbon to a carrier concentration of $4x10^{19}$ cm^{-3} and had a uniform composition. The 150-nm-thick $Al_{0.2}Ga_{0.8}As$ emitter layer had an abrupt junction with a carrier concentration of $9x10^{17}$ cm^{-3}. A 7.5-nm undoped GaAs spacer layer was grown between the emitter and base layers. The emitter contact layer ($2x10^{18}$ cm^{-3}, 150 nm) and a cap layer ($5x10^{18}$ cm^{-3}, 50 nm) were grown on the $Al_{0.2}Ga_{0.8}As$ emitter layer. During growth, the temperature of each layer was kept at 580°C. Conventional wet chemical etching and lift-off were used. CVD-SiO_2 was deposited for the surface passivation film. The emitter and collector ohmic contact metals were AuGe (20 nm)/Au (330 nm), alloyed at 400°C in N_2 gas. The base ohmic contact metal was nonalloyed Cr (10 nm)/Au (300 nm).

3. Results and Discussion

Figure 2 shows the common-emitter I-V characteristics of HBTs grown by GSMBE using only gaseous sources and having an emitter size of 4x5 μm^2. A current gain of about 50 was obtained at an emitter-corrector voltage of 1.0 V. The transistor had a turn-on voltage of about 0.2 V.

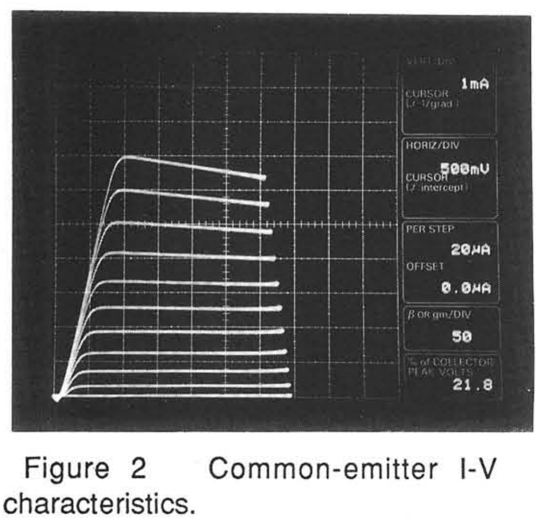

Figure 2 Common-emitter I-V characteristics.

Figure 3 shows how the current gain varied with collector current density, measured at an emitter-collector voltage of 2.5 V. The emitter size was 4x5 μm^2. At a collector current density of $4x10^4$ A/cm^2, we obtained a current gain of 45, suitable

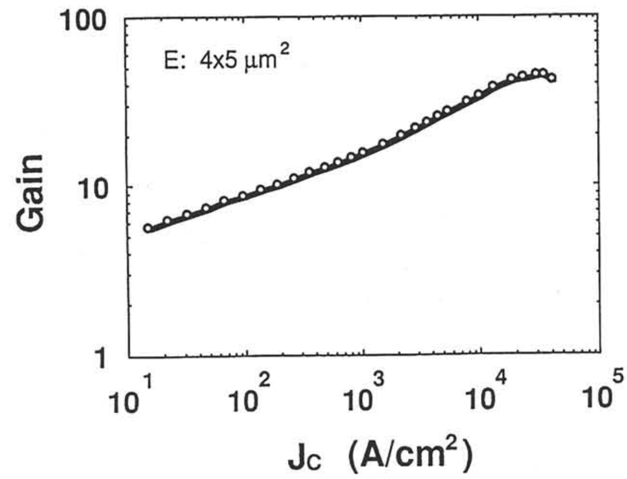

Figure 3 Dependence of current gain on the collector current density of HBTs with an emitter 4x5 μm^2.

for practical use in IC fabrication. Ideality factors of 1.12 and 1.43 were measured for the emitter-base junction and base-collector junction, indicating a good emitter-base junction quality.

We also studied the electrical stability of a C-doped-base HBT having an emitter size of 5x5 μm^2 under current stress. Current stability was measured at room temperature under the common-base configuration in order to keep the emitter current constant by controlling the emitter-base voltage. The collector current (I_c) was measured as a function of stress time with the emitter current kept constant at 10 mA. Figure 4 shows the variation in I_c/I_b for a constant emitter current (10 mA) maintained for 10 hours. The

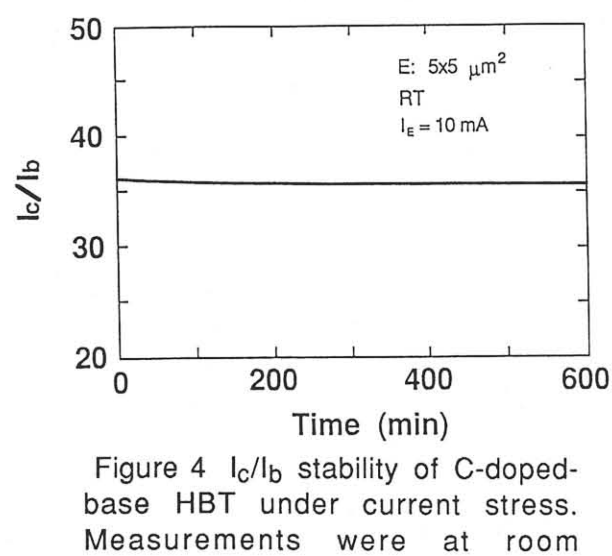

Figure 4 I_c/I_b stability of C-doped-base HBT under current stress. Measurements were at room temperature.

gain, I_c/I_b, was almost constant under current stress over this period. However, I_c/I_b was significantly degraded for Be-doped-base HBTs under similar conditions[2]. In the case of Be-doped-base HBTs, the origin of current gain degradation is assumed to be the current-induced diffusion of Be from the base to the emitter[8].

An increase in the turn-on voltage (V_{eb}) can be attributed to the diffusion of the base dopant into the wide bandgap emitter. The diffusion also is seen by shifts in Gummel plots characteristics. Figure 5 shows the Gummel plot for C-doped-base HBTs before and after current stress. The shift in Gummel plot attributed to the beryllium diffusion reported for Be-doped-base HBTs after current stress[2] was not observed in the Gummel plot for current-stressed C-doped-base HBTs even after 10 hours. No change in V_{eb} observed in C-doped-base HBTs under the above conditions implies that carbon is less mobile both thermally and electrically in (Al,Ga)As. This stability shows that C-doped-base AlGaAs/GaAs HBTs grown by an improved GSMBE method are potentially ideal for practical use.

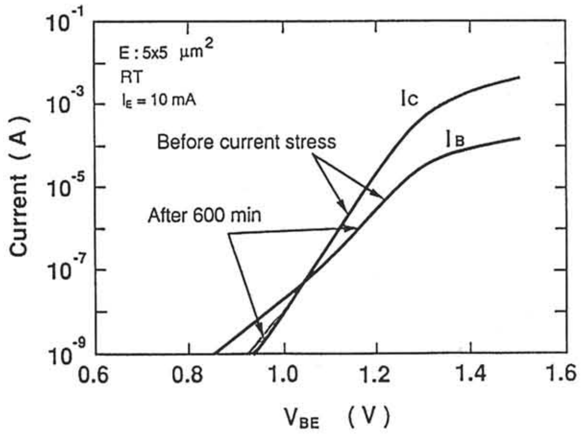

Figure 5 Gummel plots for C-doped-base HBTs before and after current stress.

4. Conclusion

We applied gas-source MBE using only gaseous sources to grow C-doped-base AlGaAs/GaAs HBTs. We obtained a current gain of 45 at a collector current density of 4×10^4 A/cm^2. The electrical stability of C-doped-base HBTs under current stress shows the good reliability of these HBTs. We regard the improved GSMBE as attractive for growing C-doped-base AlGaAs/GaAs HBTs.

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