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High Current Gain Carbon-Doped-Base AlGaAs/GaAs HBTs Grown by Gas-Source MBE Using TMAAl as the Al Source

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This paper reports the highest current gain of 160 reported to date for carbon-doped-base AlGaAs/GaAs heterojunction bipolar transistors (HBTs) grown by gas-source molecular beam epitaxy (GSMBE) using trimethylamine alane (TMAAl) as the Al source.

We previously reported DC characteristics of carbon-doped-base AlGaAs/GaAs HBTs grown by GSMBE and the electrically stable operation under current stress1). However, the current gain of the HBTs was small in comparison with that of Be-doped-base AlGaAs/GaAs HBTs grown by MBE. We attributed this to the quality of n-AlGaAs emitter layer. In order to improve the emitter quality, we used TMAAl as the Al source instead of using triethylaluminium (TEAl).

The HBT structure grown by GSMBE is shown in Figure 1. The base layer is doped with carbon to a concentration of 3.4×10^{19} cm^{-3}. The AlAs composition (x-value) of the emitter layer is 0.25. Two types of HBTs, one with an abrupt emitter and the other one with a graded emitter, are prepared. The Al, Ga, and As sources used were TMAAl, triethylgallium (TEGa), and arsine (AsH_3). The n-type dopant (silicon) source was 10% disilane (Si_2H_6) diluted with H_2. Trimethylgallium (TMGa) was used as both the p-type dopant (carbon) source and the Ga source. During growth, the substrate temperature for each layer was kept at 515°C. A conventional wet chemical etching technique was used to fabricate the HBTs.

We used secondary ion mass spectroscopy (SIMS) to determine carbon and oxygen concentration in the HBTs' emitter layer. Since carbon was not detected, the carbon concentration in the emitter layer was lower than the SIMS detection limit ($<1\times10^{16}$ cm^{-3}). The oxygen concentration was 7×10^{16} cm^{-3}. These are the lowest values reported to date for GSMBE grown AlGaAs2,3), indicating that excellent emitter quality was achieved.

Figure 2 shows common emitter I-V characteristics of an abrupt HBT grown by GSMBE. The emitter size was 4x5 μm^2. We observed a current gain of more than 150 at a collector current of 8 mA. Figure 3 shows the Gummel plots of the abrupt and graded HBTs grown by GSMBE using TMAAl as the Al source. The collector currents (Ic) of both HBT types are almost same, but the base current for the abrupt junction is about one order of magnitude smaller than the current in the graded one. This means the abrupt junction is more effective for preventing recombination at the heterojunction. Figure 4 shows current gain dependence on collector current density for the abrupt and graded HBTs. In the graded HBT, a maximum current gain of 100 was obtained for a collector current density of 6×10^4 A/cm^2. On the other hand, a maximum current gain of 160 was obtained for a collector current density of 3×10^4 A/cm^2 in the abrupt HBT. This improved current gain, which is the highest ever reported for GSMBE grown AlGaAs/GaAs HBTs1,2,4), is due to the excellent quality of AlGaAs emitter using TMAAl.

These electrical characteristics indicate that C-doped-base AlGaAs/GaAs HBTs grown by GSMBE could be ideal for practical applications.

References

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Layer	Carrier (cm^{-3})	Thickness (nm)
n^+-GaAs	2E18	300
Graded	1E18	30
n-AlGaAs	5E17	150
(Graded)	(5E17)	(30)
p^+-GaAs	3.4E19	70
n-GaAs	1E17	400
n^+-GaAs	2E18	600
SI GaAs	——	——

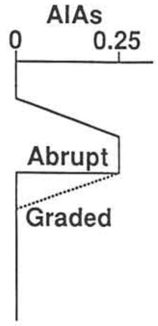

Figure 1 HBT structure grown by gas-source MBE.

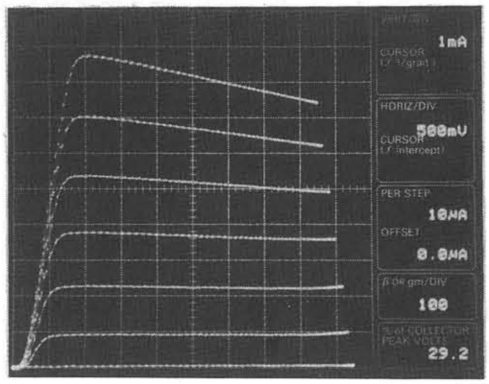

Figure 2 Common emitter I-V characteristics of an HBT grown by gas-source MBE.

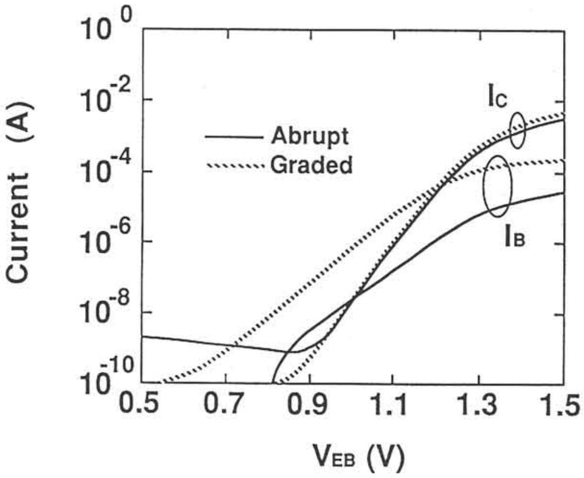

Figure 3 Gummel plots of abrupt and graded HBTs.

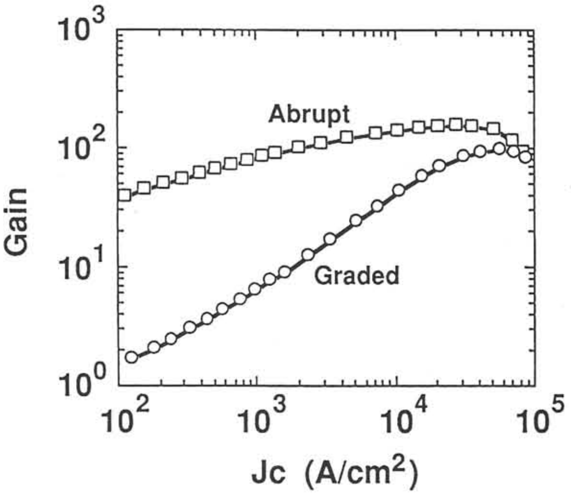

Figure 4 Current gain dependence on the collector current density for of abrupt and graded HBTs.