DC characteristics of as-grown AlGaAs/GaAs HBTs and AlGaAs/GaAs/GaN HBTs by direct wafer fusion

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AlGaAs/GaAs/GaN HBTs have been proposed and demonstrated recently, by direct wafer fusion, to harvest the high quality p-type GaAs and the large bandgap properties of GaN for high speed high power devices. [1,2] Employing a lower fusion temperature of 600 °C and inserting an UID setback layer, a current gain of ~ 2 was obtained. [3] In this paper, we show fused HBTs with current gain of up to 10 as a result of improved fusion process and device structure. We also compare the IV characteristics of the as-grown AlGaAs/GaAs HBTs with similar layer structures and the fused HBTs.

All AlGaAs/GaAs samples were grown by MBE while GaN samples were grown by MOCVD on c-plane sapphire, and the detailed device layer structures are shown in Fig. 1. Before joining the AlGaAs/GaAs emitter/base wafer and the GaN collector wafer, both wafers underwent solvent clean and oxide removal using NH_4OH. After the wafers were joined in methanol, a uniaxial pressure of 5 MPa was applied, followed by one hour heat treatment in quartz furnace in N_2 atmosphere at ~ 500 mTorr and 550-650 °C. Replacing the previous AlAs etch stop layer by $Al_{0.9}GaAs$, a smoother film with an rms of ~ 1 nm was obtained after the GaAs substrate removal. As a comparison, the GaAs film fused onto GaN (as-grown rms ~ 0.6 nm) generally had an rms of > 10 nm when AlAs etch stop was used. The as-grown HBTs have alloyed AuGe/Ni/Au for emitter and collector contacts and alloyed Ti/Au for base contacts; the fused HBTs have alloyed AuGe/Ni/Au for emitter contacts and non-alloyed Ti/Au and Al/Au as base and collector contacts, respectively.

Fig. 2 shows the common emitter I-Vs and the Gummel plot of as-grown and fused HBTs at various temperatures. The as-grown HBTs are well behaved: exhibiting β of ~ 170 and ideality factor of I_C of 1.0 as expected while that of I_B was 1.5; the large knee voltage is owing to the high collector resistance since the collector contacts are placed > 2 μm on the low-doping GaAs as shown in Fig. 1. The HBTs fused at 550 °C show a current gain of ~ 5-10 and those fused at 600 °C and 650 °C exhibit similar gains ~ 2-3, which is consistent with our previous observation that lower fusion temperature tends to render better electronic operations. Assuming a unity emitter injection coefficient, the minority carrier diffusion length degraded ~ 3-4 times in the fused HBTs compared to the as-grown ones. Shown in the Gummel plot, the kink of currents at V_{BE} ~ 1 V was found to be due to the non-ohmic base contacts (non-alloyed). Though it complicates the analysis, the ideality factor of both I_B and I_C falls between 1 and 2, which indicates normal bipolar transistor actions in the fused HBTs. The increasing collector current with increasing V_{CE} also indicate likely existence of a small barrier for electron transport between the GaAs base and GaN collector if the Gummel number in the base has not changed. The device breakdown voltages are also measured with the base floating: the as-grown HBT shows a sharp current increase at ~ 10 V while the fused HBT shows soft increase in current reaching ~ 10 A/cm^2 at 15 V.

[1] Estrada et al., APL 83(3): P. 560-562, 2003

[2] Estrada et al., Int. J. of High Speed Electronics and Systems 14(1): P. 265-284, 2004

[3] Estrada et al., MRS Proc. 798, Y10-20-1, 2004

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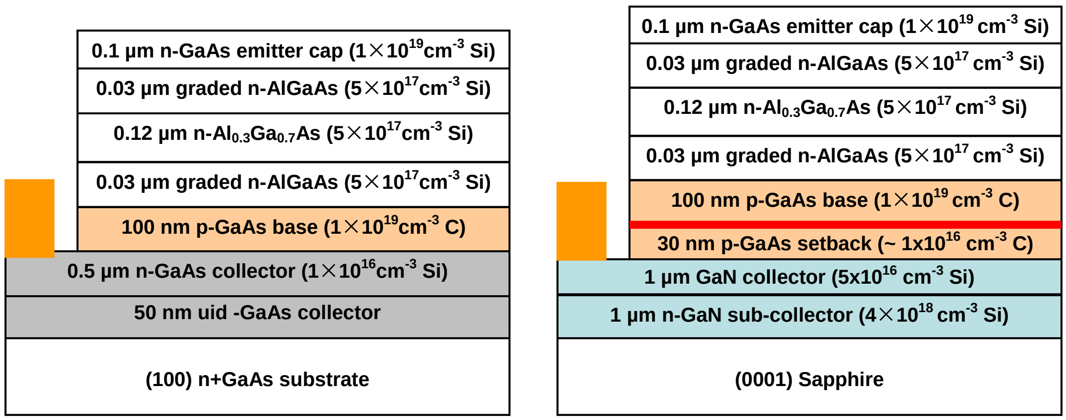

Fig.1 Device layer structures of (left) as-grown AlGaAs/GaAs HBT and (right) fused AlGaAs/GaAs/GaN HBT, with collector contacts shown as well.

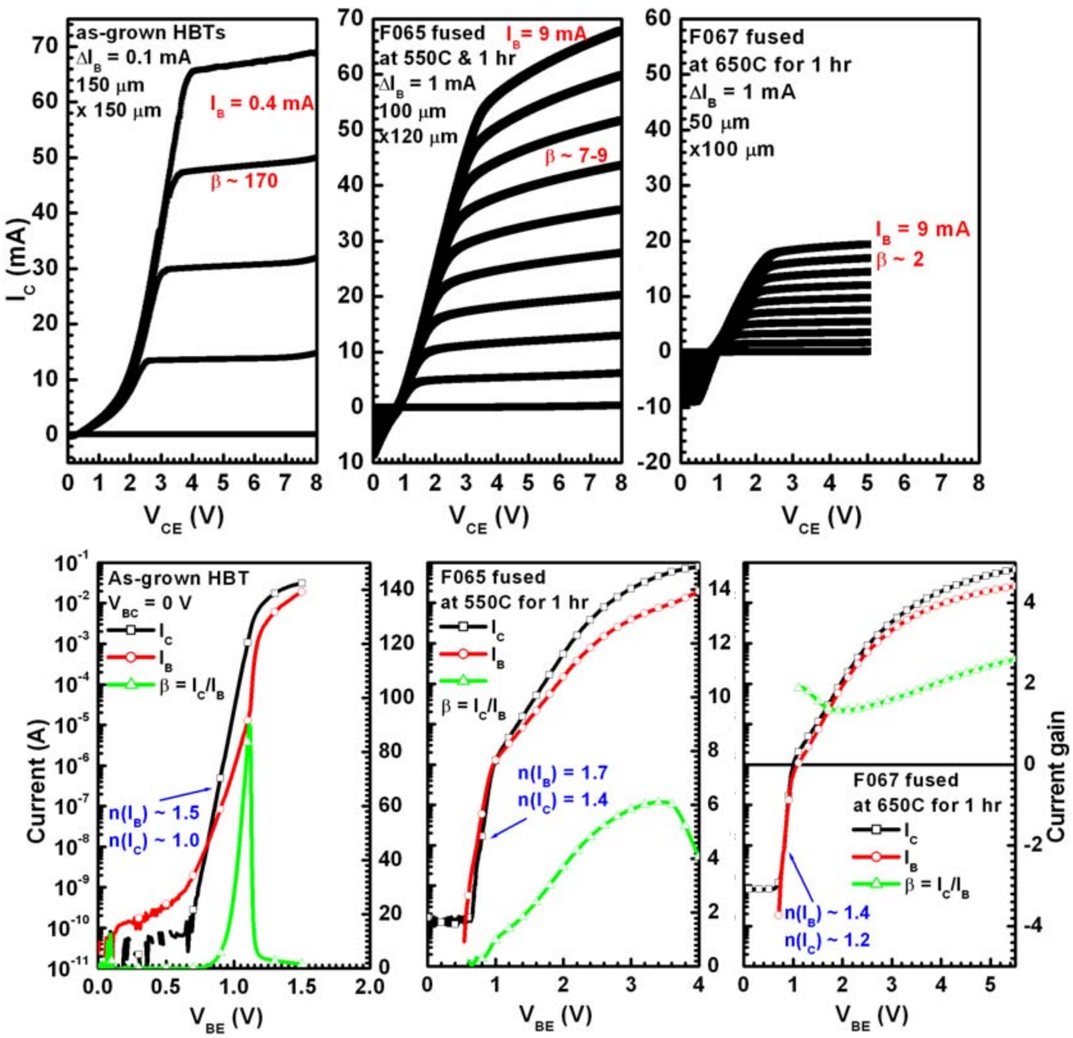

Fig.2 Comparison of common emitter characteristics (upper) and Gummel plot (lower) between as-grown and fused HBTs.