W_e=100nm InP/InGaAs DHBT with Self-aligned MOCVD Regrown p-GaAs Extrinsic Base Exhibiting 1Ω-μm^2 Base Contact Resistivity

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We report DC results from a W_e=100nm InP/InGaAs DHBT technology with a self-aligned MOCVD regrown GaAs extrinsic base providing low base access resistance R_{bb} while maintaining acceptable DC current gain β. A 0.09×5μm^2 transistor exhibits a base contact resistivity ρ_c=1Ω-μm^2, and a peak β~15. The HBTs exhibit a common-emitter breakdown voltage BV_{CEO}=3.6V (J_C=10μA/μm^2). According to the general scaling law for InP HBTs in [1], the low ρ_c meets the requirement for f_{max}=2.8THz operation.

InP/InGaAs DHBTs with f_{max}>1THz have been reported. The InGaAs bases in [2-3] are thinned to <25nm with a high carbon doping (>5×10^{19}cm^{-3}) to achieve fast electron transport while supporting a low ρ_c. Further scaling to thinner base layer and higher doping concentration poses two major challenges: (1) the >4nm metal/semiconductor reaction depth of Pd- or Pt-based metal contacts diminishes transistor reliability [2], and (2) higher doping reduces the Auger-limited β, degrading the transistor noise figure NF. Therefore, self-aligned regrowth of a heavily doped extrinsic base on a moderately doped intrinsic base is studied as a path to higher f_{max} operation. A thick and heavily carbon doped regrown GaAs (4×10^{20}cm^{-3}) extrinsic base provides ample room for metal contact sinking and low ρ_c, while an InGaAs intrinsic base (7×10^{19}cm^{-3}) maintains moderate β for reasonable NF.

The intrinsic HBT epitaxy in this work is similar to that in [4]. A 520nm refractory Mo/Ti$_{4wt\%}$W emitter metal contact is co-sputtered and dry etched in SF_6/Ar to form <100nm W_e. A 15nm thick PECVD SiN sidewall is deposited. To reveal the intrinsic InGaAs base, the InP emitter is wet etched in 1:4 HCl:H_3PO_4. Samples are loaded immediately into a Thomas Swan horizontal flow MOCVD reactor. Surface oxide desorption is carried out at 540°C for 3min in H_2 with group-V overpressure provided by tertiarybutylphosphine (TBP) to protect the InP emitter sidewall surface. Trimethylgallium (TMGa), tertiarybutylarsine (TBAs), and carbon tetrabromide (CBr4) are employed to grow ~50nm heavily doped GaAs (4×10^{20}cm^{-3}). The samples are subject to an in-situ N_2 anneal at 475°C for 3min before cooldown to drive out hydrogen passivation of *p*-type dopants. Base contact metal, Pt/Ru/Pd/Au 5/11/16.5/100nm, is then deposited. Subsequent base/collector mesa isolation, collector metal contact, and device backend processes (**Fig. 1-2**) are similar to that in [4], except that the base/collector mesa includes a large base metal contact pad area (35×35μm^2) for direct DC probing. This enables fast DC device turnaround.

Fig. 3 shows measured HBT characteristics of RG67D. W_e=100nm devices exhibit a peak current gain β~15, and a common-emitter breakdown voltage BV_{CEO}=3.6V (J_C=10μA/μm^2). Measurement of the $1/\beta$ versus $1/W_e$ relationship indicates that periphery recombination limits device current gain. Base current ideality is ~4 for 0.4V<V_{BE}<1V, suggesting a large deep defect level recombination current [5]. Since base current does not have a strong dependency on V_{CB}, it is suspected that the recombination current originates at the *p*+-*p* extrinsic/intrinsic base interface. Collector current ideality ~1.3 is similar to that in [4] with similar intrinsic epi design. Total emitter access resistivity ρ_{ex}~4.5Ω-μm^2 is measured by the emitter flyback method. RG67A, a different sample, processed similarly but without the in-situ 475°C N_2 anneal in MOCVD shows ρ_{ex}~3.7Ω-μm^2. The discrepancy in ρ_{ex} suggests degradation of the Mo/Ti$_{4wt\%}$W emitter metal contact in N_2. On-wafer transmission line measurement (TLM) results in **Fig. 4** show a contact resistivity $\rho_{bc,ex}$=0.4Ω-μm^2 between the base metal contact and GaAs extrinsic base, and an overall contact resistivity $\rho_{bc,tot}$=1.0Ω-μm^2 between the GaAs/metal composite base contact and InGaAs intrinsic base. The sheet resistance of the intrinsic InGaAs base is larger for wider emitters than it is for narrow emitters, corresponding to hydrogen passivation below the InP emitter being harder to reverse [6]. For W_e<300nm, however, an intrinsic base sheet resistance $\rho_{b,sh}$=1940Ω/sq. appears constant.

In this work, we demonstrate an InP/InGaAs DHBT technology with a MOCVD regrown GaAs extrinsic base self-aligned to W_e=100nm InP emitter for low base resistance R_{bb}, and high DC current gain β. Low R_{bb} is necessary for >2THz f_{max} operation, while high β enhances device NF. DC device results show the survival of the refractory Mo/Ti$_{4wt\%}$W emitter metal contact, and low base contact resistivities with heavily *p*-doped GaAs (4×10^{20}cm^{-3}) and use of Pt/Ru/Pd/Au base contact metal. This work was supported by the Semiconductor Research Corporation (SRC) and DARPA under the JUMP ComSenTer program.

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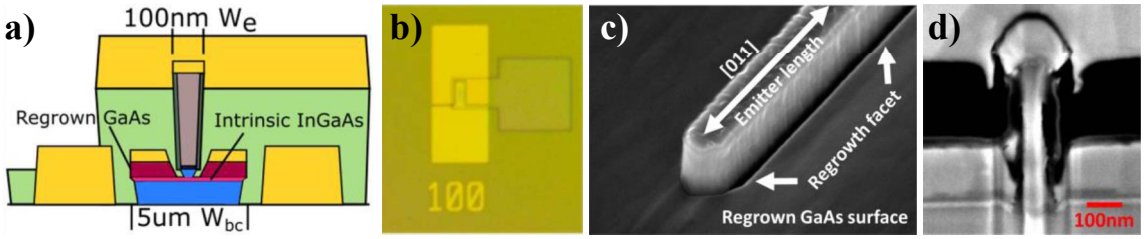

Fig. 1. DC device cross-sectional schematic of an 100nm W_e device with large base/collector mesa for fast turnaround (a); Top view of a W_e=100nm device before M1 deposition (b); Tilted SEM view of the regrown GaAs surface (c); SEM of 100nm W_e device (d)

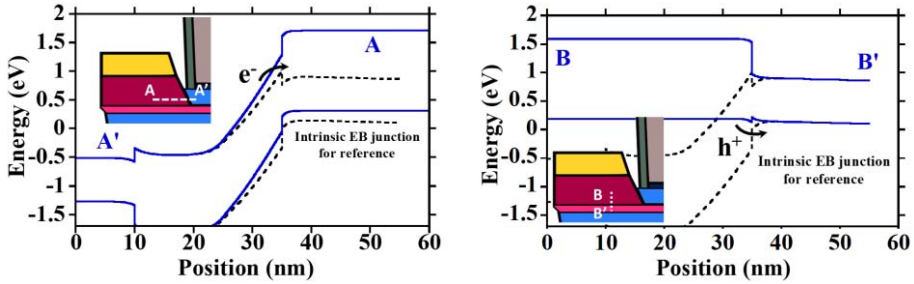

Fig. 2. The larger bandgap of regrown GaAs vs. InGaAs prevents electron injection from the emitter to the extrinsic base (left); heavy GaAs doping (4×10^{20}cm^{-3}) minimizes the InGaAs/GaAs valence-band barrier.

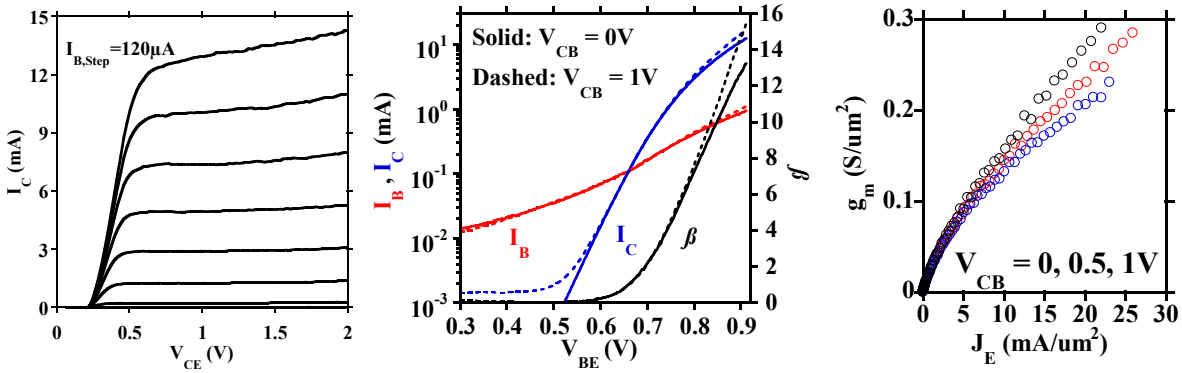

Fig. 3. Output, Gummel, and transconductance characteristics of a 0.09×5μm^2 device; the positive output conductance is due to the large base/collector mesa dimensions (35×35μm^2)

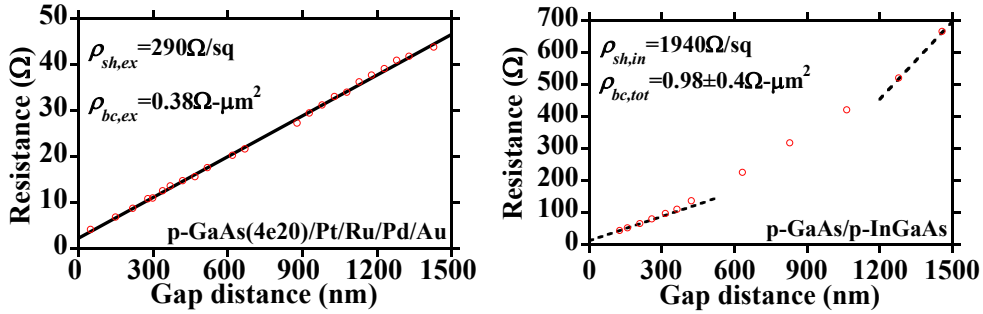

Fig. 4. On wafer TLM results showing $\rho_{sh,ex}$ of regrown extrinsic GaAs, and metal/GaAs contact resistance $\rho_{bc,ex}$ (left); $\rho_{sh,in}$ of intrinsic InGaAs, and metal/GaAs/InGaAs contact resistance $\rho_{bc,tot}$ (right);