

# GaAsSb/InP DHBT Extrinsic Base Regrowth Using In-situ Hydrogen Plasma Surface Treatment and Molecular Beam Epitaxy

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## Abstract

A low-temperature GaAsSb extrinsic base regrowth process using in-situ hydrogen plasma treatment and MBE regrowth of a highly doped p+ GaAs<sub>1-y</sub>Sb<sub>y</sub>:C layer is developed on Keysight's commercial GaAsSb/InP NpN DHBT technology platform. The SIMS data shows that the regrowth interface oxygen sheet concentration is effectively reduced by *in-situ* hydrogen plasma, and a 30% reduction of base resistance (R<sub>b</sub>) of a standard emitter width GaAsSb/InP DHBT is demonstrated.

## INTRODUCTION

In SiGe BiCMOS technologies, epitaxial regrowth of SiGe HBT base has been an important process to optimize the device high speed performances, such as current gain cut-off frequency f<sub>T</sub>, maximum oscillation frequency f<sub>MAX</sub>, and ring oscillator gate delay [1]. State of the art BiCMOS processes [2] utilize either selective or non-selective base epitaxial regrowth of highly doped extrinsic base to reduce the base contact resistances. This reduces base resistance R<sub>b</sub> and achieves improved high-speed performance for higher frequency applications or better design margin. In compound semiconductor HBT technologies, even though the superior intrinsic material parameters compared to Si/SiGe enable superior performance for SiGe counterparts at relaxed device dimensions, the efforts in improving R<sub>b</sub> utilizing extrinsic base regrowth processes have been lagging even though the regrowth process in compound semiconductors has been demonstrated in laser diodes, GaN HEMTs, and AlGaAs/GaAs HBTs [3-5].

The difficulty of extrinsic base regrowth in InP HBTs lies in the process integration requirement of lower overall process temperature than GaAs or GaN to protect the InP materials and the electrical contacts. This limits the regrowth technique selection and the effectiveness of thermal cleaning prior to the regrowth. In this paper, a low-temperature GaAsSb extrinsic base regrowth process using in-situ hydrogen plasma treatment and MBE non-selective regrowth of a highly doped ( $p > 3e20 \text{ cm}^{-3}$ ), high hole mobility GaAs<sub>1-y</sub>Sb<sub>y</sub>:C layer is developed to integrate into Keysight's commercial GaAsSb/InP NpN DHBT IC technology platform, and a 30% reduction of R<sub>b</sub> is demonstrated on standard 0.5 μm emitter width HBT devices.

## GAASSB/INP EXTRINSIC BASE REGROWTH PROCESS DEVELOPMENT

The growths of GaAsSb:C on 3" semi-insulating InP:Fe substrates were done in a Veeco Gen200 multi-wafer MBE system equipped with group III effusion cells and Arsenic and Antimony valved crackers. P-type carbon doping is achieved by injecting CBr<sub>4</sub> through a low temperature gas source injector. A Veeco UNI-Bulb hydrogen remote plasma source with RF generator and auto-tuning unit is installed in the preparation chamber of the Gen200 cluster module, to which the III-V growth chamber is also connected. The configuration ensures the wafers are transferred under ultra-high vacuum (UHV) between hydrogen plasma treatment and subsequent regrowth.

To test the effectiveness of hydrogen plasma surface treatment, epitaxial wafers with 250nm GaAs<sub>0.51</sub>Sb<sub>0.49</sub> on InP substrates underwent typical III-V semiconductor fabrication procedures such as ashing and wet de-oxidation before being loaded into the MBE system for hydrogen plasma treatment and regrowth of 50nm GaAsSb with C-doping of about 5e20 cm<sup>-3</sup>. The test wafers had the same plasma treatment parameters except for different plasma treatment duration. As control, three additional growths with the same layer structure stayed in UHV and underwent three plasma treatment durations without being exposed in atmosphere. Figure 1 shows the SIMS oxygen sheet concentration across the GaAsSb regrowth interface versus the plasma treatment time. With increasing hydrogen plasma treatment time, the oxygen concentration decreases by ~ 50X. Figure 2 shows the SIMS depth profile of various elements of the sample with 105 min treatment time. At the regrowth interface (50nm from top), oxygen concentration is significantly lower than at the epilayer-substrate interface (300nm from top) where the substrate is cleaned by thermal desorption of surface oxide. The regrown GaAsSb:C also shows ultra-high C-doping (> 1e21 cm<sup>-3</sup> in SIMS and > 5e20 cm<sup>-3</sup> in Hall measurement) and therefore is suitable for extrinsic base.

## GAASSB EXTRINSIC BASE REGROWTH ON GAASSB/INP HBT

The *in-situ* hydrogen plasma cleaning process and the extremely high doping GaAsSb:C regrowth were integrated

into Keysight's commercial 3" GaAsSb/InP HBT technology platform with 0.5  $\mu\text{m}$  emitter width. Minimum number of process parameters were adjusted to implement the extrinsic base regrowth and Figure 3 top shows the transmission electron microscope (TEM) image of a standard HBT transistor after 50nm extrinsic base regrowth before base metal deposition. And Figure 3 bottom shows the enlarged regions of emitter ledge and extrinsic base regrowth. Due to the emitter post shadowing effect, the regrowth thickness beside the emitter is about half (25.7nm) of the regrowth thickness in the field (50nm). And the non-selective MBE regrowth results in metallic Ga/As/Sb deposition on the emitter post. Figure 4 shows the extracted base resistance R<sub>b</sub> comparison of the wafer with extrinsic GaAsSb base regrowth and a representative production wafer without base regrowth. A 30% R<sub>b</sub> reduction is demonstrated using this process and the R<sub>b</sub> distribution across the wafer is as tight as the one without base regrowth. Furthermore, reliability investigation reveals that the device reliability is on par, if not better, than the current production process.

## CONCLUSIONS

The process integration of extrinsic base regrowth using *in-situ* hydrogen plasma treatment and MBE regrowth is demonstrated on Keysight's commercial 3" GaAsSb/InP HBT technology platform with 0.5  $\mu\text{m}$  emitter width. A 30% R<sub>b</sub> reduction is demonstrated, and this shows the potential for further device performance improvements with additional scaling of the device dimensions.

## ACKNOWLEDGEMENTS

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## References

- [1] B. Heinemann, H. Rücker, R. Barth, J. Drews, O. Fursenko, T. Grabolla, R. Kurps, S. Marschmeyer, A. Scheit, D. Schmidt, A. Trusch, D. Wolansky, and Y. Yamamoto, IEEE Electron Dev Lett, 35, 814 (2014).
- [2] P. Chevalier, G. Avenier, G. Ribes, A. Montagné, E. Canderle, D. Céli, N. Derrier, C. Deglise, C. Durand, T. Quémérais, M. Buczko, D. Gloria, O. Robin, S. Petididier, Y. Campidelli, F. Abbate, M. Gros-Jean, L. Berthier, J.D. Chapon, F. Leverd, C. Jenny, C. Richard, O. Gourhant, C. De-Buttet, R. Beneyton, P. Maury, S. Joblot, L. Favennec, M. Guillermet, P. Brun, K. Courouble, K. Haxaire, G. Imbert, E. Gourvest, J. Cossalter, O. Saxod, C. Tavernier, F. Foussadier, B. Ramadout, R. Bianchini, C. Julien, D. Ney, J. Rosa, S. Haendler, Y. Carminati, B. Boro, IEDM Conference Digest, 77, (2014).

- [3] K. J. Reilly, A. Kalapala, S. Yeom, S. J. Addamane, E. Renteria, W. Zhou, and G. Balakrishnan, J Crystal Growth, 535, 125531 (2020).
- [4] K. Shinohara, A. Corrion, D. Regan, I. Milosavljevic, D. Brown, S. Burnham, P. J. Willadsen, C. Butler, A. Schmitz, D. Wheeler, A. Fung, and M. Micovic, IEDM Conference Digest, 672, (2010).
- [5] H. Dodo, Y. Amamiya, T. Niwa, M. Mamada, N. Goto, and H. Shimawaki, IEEE Electron Dev Lett, 19, 121 (1998).

## ACRONYMS

DHBT: DOUBLE HETEROJUNCTION BIPOLAR TRANSISTOR

MBE: MOLECULAR BEAM EPITAXY

SIMS: SECONDARY ION MASS SPECTROSCOPY

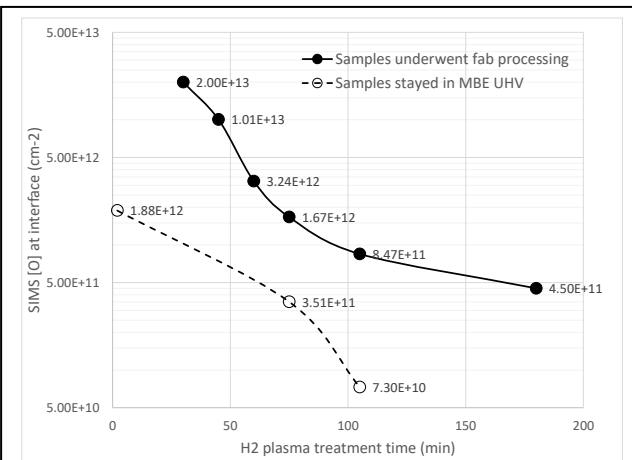


Fig. 1. SIMS oxygen sheet concentration vs hydrogen plasma treatment time for samples underwent standard fab processing before loading into MBE (solid curve) and for control samples which stayed in UHV without seeing atmosphere (dashed curve).

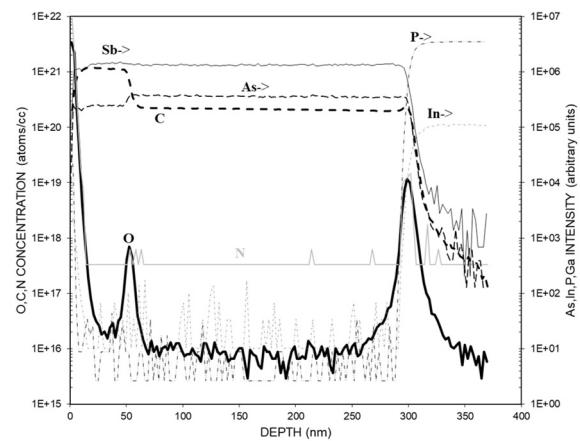


Fig. 2. SIMS depth profiles of various elements for the sample underwent standard fab processing before being loaded into MBE and 105 min hydrogen plasma treatment time.

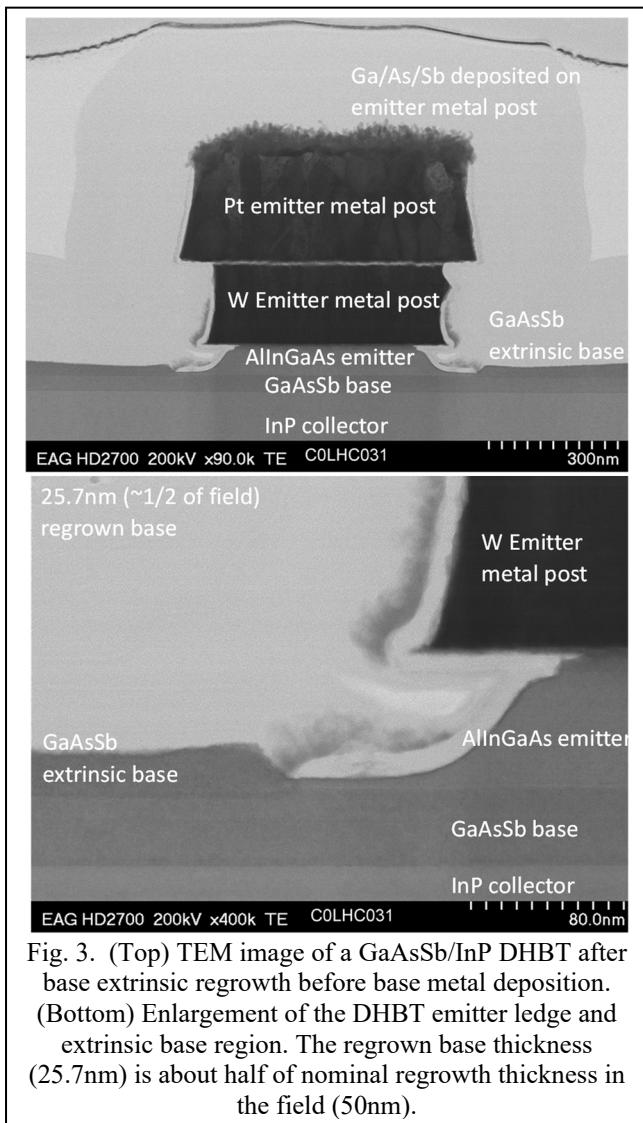


Fig. 3. (Top) TEM image of a GaAsSb/InP DHBT after base extrinsic regrowth before base metal deposition. (Bottom) Enlargement of the DHBT emitter ledge and extrinsic base region. The regrown base thickness (25.7nm) is about half of nominal regrowth thickness in the field (50nm).

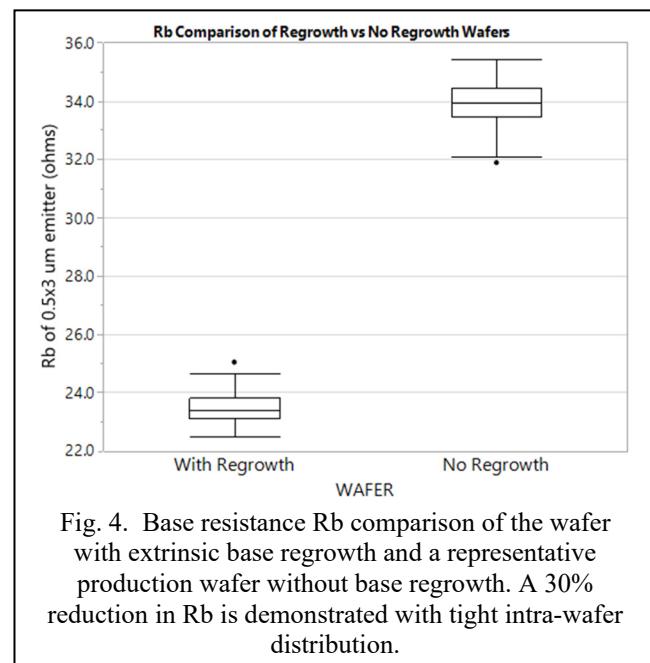


Fig. 4. Base resistance Rb comparison of the wafer with extrinsic base regrowth and a representative production wafer without base regrowth. A 30% reduction in Rb is demonstrated with tight intra-wafer distribution.

