High-Volume Manufacturing of InGaP /GaAs HBT Wafers

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Abstract

An operational approach to manufacturing InGaP/GaAs HBT's by MOCVD is presented. By comparison to published data on MBE grown AlGaAs/GaAs HBT structures, tighter distribution of DC parameters such as gain and Vbe is reported. Details of the underlying calibration and control methodology are presented.

Introduction

InGaP/GaAs HBT's are emerging as a preferred technology choice for cell phone power amplifiers to meet requirements of W-CDMA and CDMA 2000. This is primarily because of improved reliability [1], improved temperature stability, and improved linearity [2]. Availability of selective etch-stop chemistry is also advantageous for ease of fabrication. We present production epitaxial data on several thousand wafers, indicating manufacturability of production InGaP HBT's. Emcore has shipped over 6800 InGaP HBT (4" and 6") wafers and has effectively completed the transition from R&D effort to production operations.

Large Area Device Measurement

Production HBT wafers were assessed using 70x70 µm emitter Large Area Quick Fab HBT's. All wafers were grown on an Emcore E400 reactor in either a 4"x12 or 6"x5 configuration. The epitaxial structure contained a standard power amplifier 4E19/cm^2 carbon doped base and InGaAs emitter contact layer. The distribution of DC gain at 1kA/cm^2 normalized with respect to the mean is shown in Figure 1 measured during consecutive production runs under a variable sampling plan. Each point is the average of 10 measurements distributed across a full 6" diameter wafer.

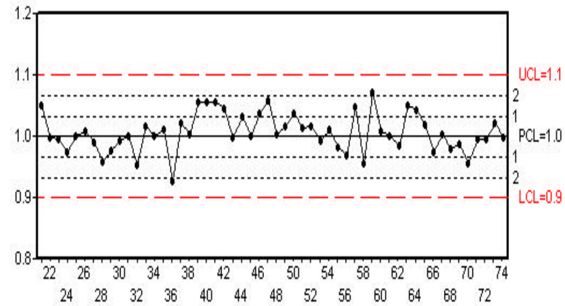

Fig 1: Large Area DC gain

The normalized base sheet resistance for the same set of production runs is shown in Figure 2. This, as with the data of Fig 1, meets or exceeds previously reported results. The population sigma is 3.2% for gain and 1.7% for base sheet resistivity. Both indicate capable processes.

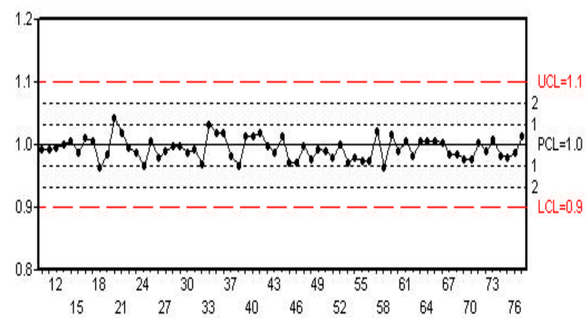

Fig 2: Base Sheet Resistivity from TLM

The Vbe distribution shown below has a population sigma less than 0.3% and is controlled to an overall range less than 10mV which is comparable or tighter than previously reported [3].

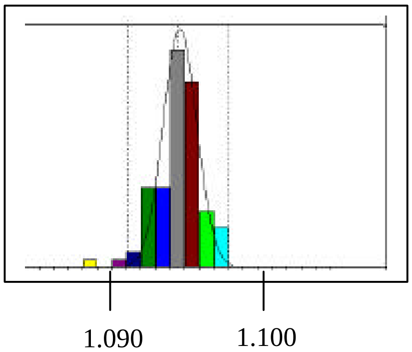

Fig 3: Distribution of Vbe

Along with run-to-run reproducibility, within wafer uniformity is monitored by a multipoint map measured in a cross pattern distributed across the wafer. (See Figure 4) Typical base sheet uniformity (σ / mean) for 6” wafers less than 3% can be routinely achieved. The overall uniformity of the product is then given by the square root of the sum of the squares of the run-to-run and within wafer distributions.

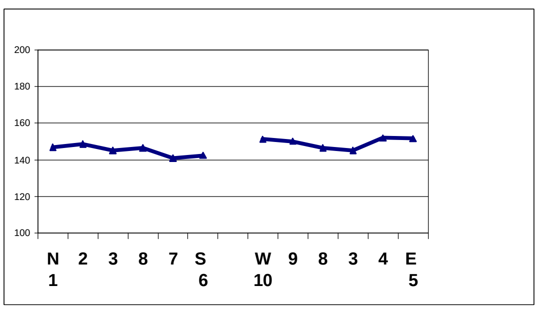

Fig 4: Base Sheet Resistance Across wafer (north to south, west to east)

Gain as a function of collector current can be tracked from the Large Area device Gummel measurements. One of the advantages that InGaP HBT’s have over AlGaAs is that the heterojunction formed by InGaP provides a barrier to hole current injection and reduces base current over a wider range of current density and temperature. This results in a more linear gain vs collector current characteristic as shown in Fig 5.

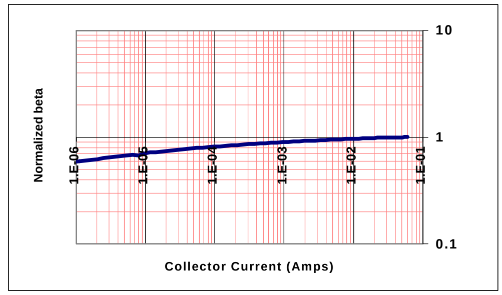

Fig 5: Gain Linearity-beta vs collector current

InGaP also enables a flatter gain response over a range of temperatures. Gummel plots were generated on wafers measured at 25 and 100^{o}C. (See Figure 6) There is only a 14% change in beta at 1kA/cm2 over that temperature range which is typical of an InGaP HBT and significantly less than a comparable AlGaAs/GaAs structure.

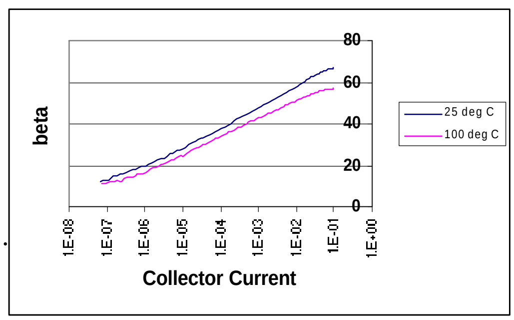

Fig 6. Gain linearity at 25 and 100 deg C.

Large area DC parameters serve as a useful acceptance criteria for HBT wafer quality. Direct correlations with customer TLM measurements for base sheet resistivity or emitter sheet resistivity are established. Since the Large Area die is tested at a different current density and has different geometry than the PCM (Process Control Monitor), a reasonable offset is typically established between the two measurements as shown in Fig 7 for a particular structure.

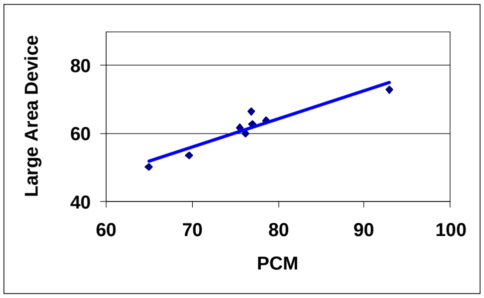

Figure 7: PCM, LA device Gain correlation

DC gain for a variety of typical HBT structures is shown to be a linear function of base sheet resistance in Figure 8. This means that once other layers of the structure are calibrated, the gain can be adjusted by controlling the base sheet resistance. This also suggests that establishing uniformity in the base sheet resistance leads to control of gain uniformity.

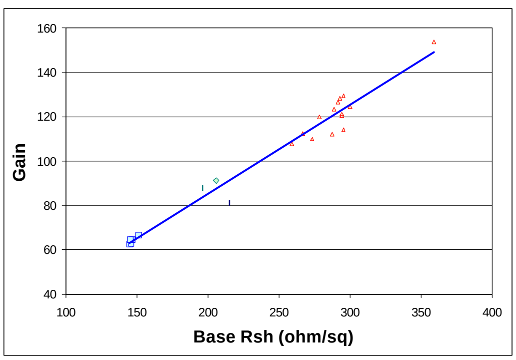

Figure 8: Gain vs Base Sheet Resistance

Calibration of p-Doped Base Layer

Use of correct calibration structures and test methodologies are essential to achieving stable and consistent growth. One of the most critical parameters is the doping and thickness of the carbon-doped base layer. X-ray reflection on bulk calibration layers is routinely used to measure the amount of carbon incorporation employing a technique similar to that described in [4]. Figure 9 shows a single-point x-ray scan.

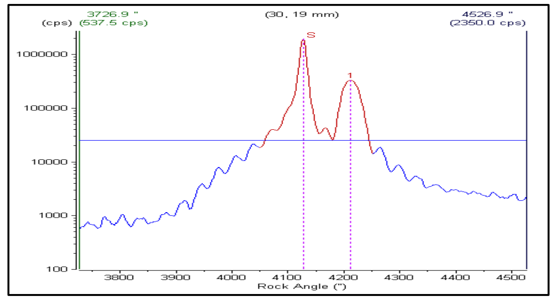

Figure 9: x-ray diffraction scan

Figure 10 shows a typical map of the peak separation distribution along the radius of rotation in the growth chamber where worst-case variation often occurs. This is used to control the doping level relative to specifications and to minimize variation across the wafer. The thickness of the base is also measured and mapped.

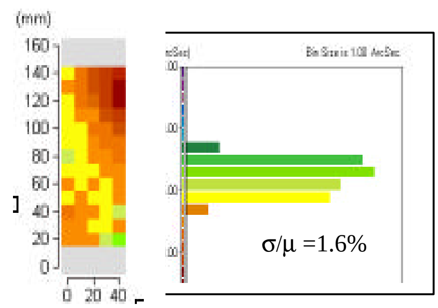

Figure 10: Peak separation map and distribution

The residual hydrogen level is initially determined by SIMS and maintained within target limits by monitoring the burn-in ratio (beta1/beta10 or the first relative to tenth measurement after successive sweeps of the Gummel plot) for a given structure. This has been shown to vary predictably with the hydrogen/carbon ratio

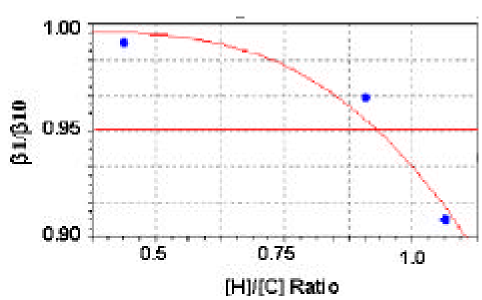

Figure 11: Burn-in ration vs base hydrogen concentration

Calibration of Other Layers

Use of a calibration structure incorporating a quarter-wave Bragg reflector provides an effective way to measure thickness of GaAs layers such as those used for the collector and subcollector. Typical uniformities of better than 1% are achieved on both 4 and 6" wafers as shown in Figure 11. This is significant because collector thickness is one of the important factors in determining BV_{cbo} and f_{max}.

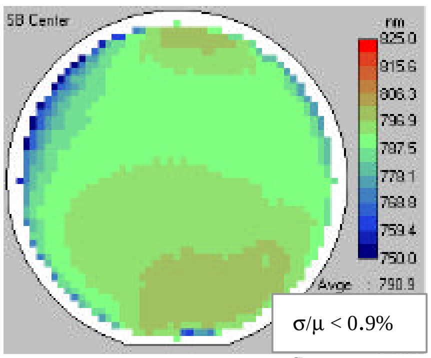

Figure 11: Bragg reflectance map

As another example, InGaP compositional uniformity can be verified by use of photoluminescence mapping and making use of the dependance of bandgap on wavelength.

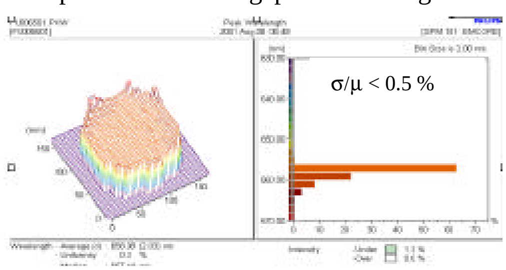

Figure 12: Photoluminescence map of InGaP

Process Capability

Process capability indices have been evaluated from consecutive production data using nominal specification limits as shown in the Table below. Cpk of 1.3 or greater is considered production-capable. [Note Cpk=(spec range) / (6 sigma) for centered distribution]:

Parameter	Cpk	spec
Beta	1.3	12%
base Rsh	1.8	10%
Bvebo	1.7	10%
Bvcbo	2.3	10%
Vbe	5.2	2%

Conclusion:

Growth of InGaP by MOCVD is anticipated to be far less sensitive to residual contamination and unwanted impurity levels than MBE [1]. With the correct control of the carbon doping level and InGaP growth parameters, more stability and greater reproducibility would be predicted than with MBE AlGaAs/GaAs. The estimated Cpk numbers validate this expected improvement and facilitate the implementation of the design of InGaP/GaAs for power amplifiers. Reliable devices with MTTF (mean-time-to-failure) greater than 10^8 hours at Tj = 125^oC and activation energy > 1.5eV have been demonstrated. [5]. Production of InGaP/GaAs HBT's has been shown to be a manufacturable and sustainable process capable of excellent uniformity and reproducibility.

Acknowledgments:

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