Collector Contact Optimization in GaAs HBT Manufacturing

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Abstract

The split collector resistance is a specialized in line process control monitor (PCM) test used to determine device performance in GaAs HBT processing. It is the resistance measured between two adjacent collector structures using a two point probe technique. This paper is motivated by the investigation of intermittent high split collector resistance detected in GaAs HBT manufacturing. The root cause analysis was focused on the major contributors to the collector metal module. Specifically, the collector metallization and the post collector alloy processes were investigated and optimized. Progress was achieved in both reducing the split collector resistance and improving the overall reliability of the device. This paper explores the areas examined and describes the improvements made to tighten the split collector resistance distribution.

INTRODUCTION

In GaAs HBT manufacturing, the contact resistance of all three transistor contacts, the emitter, base and collector, must be minimized. The collector contacts are not as critical to high frequency performance as the base and emitter, but still must have low resistance for small features and must be reproducible. A high yielding, production worthy process requires optimization of the epitaxial layer, the collector metal deposition and the post deposition alloying process.

Contact resistance of the collector contact is monitored by measuring a standard TLM structure. However, this measurement is not sufficient to ensure a robust contact for the actual HBT circuits. Therefore, split collector contacts are also measured. With a width of 3um, these structures mimic the actual HBT circuits better than the larger TLM structure. The TLM and split collector structures are both used during the in-line parametric test to assess the functional quality of the collector in the HBT circuits. The split collector measurement is composed of two collector contacts on a sheet of collector epi. Metal interconnects connect each of the collector structures to bond pads for the electrical measurements. The split collector PCM measures the collector contact resistance and the epitaxial sheet resistance for these small collector structures (see FIGURE 1).

The total resistance $R = 2Rp + 2Rc + 2Rsp + Rs$. Assuming Rp (probe resistance) and Rsp (spreading resistance under each probe) are the same for each measurement, then $R' = 2Rc + Rs = 2Rc + Rsheet \times L/W$. The split collector resistance is defined as the sum of these resistances and is especially sensitive to variation in the collector because of its small dimensions.

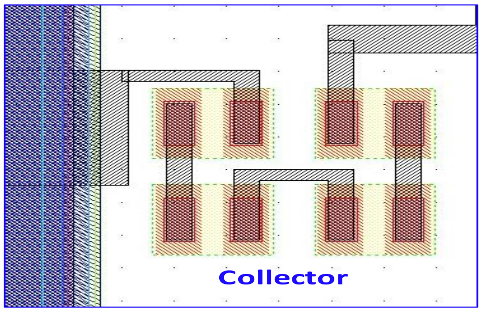
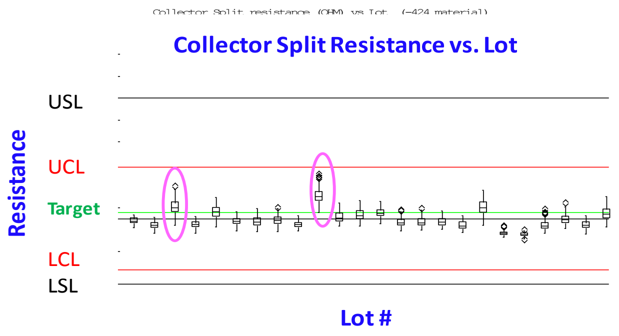


FIGURE 1. Split Collector Resistance PCM Layout

Historically, this parameter has maintained a well centered distribution. However, there were occasional outlier lots with uncommonly high resistance and generally wider distribution than the normal population (see FIGURE 2). During this same time period, the collector contact resistance measured using the TLM structure was averaging 0.04 ohm-mm, without outliers and having a tight distribution. The process engineers investigated, but could not identify any process or tool corresponding to the shift in the splitcollector resistance distribution.

Although this parameter remained in specification, to ensure that high quality products were being manufactured, the principal factors of the collector contact module were investigated. The factors included: incoming material used for the collector metal deposition, the AuGe:Ni ratio of the collector ohmic contact and the post metallization alloying temperature.



LOT	836	044	045	046	047	048	050	051	052	053	183	184	185	186	187	188	798	784	796	798	799	801	803	804
# Pts	45	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Mean	68	64	80	64	76	67	67	68	65	90	71	73	75	66	66	66	63	80	57	55	63	69	64	74
IQR	4	4	8	4	8	4	6	6	4	8	7	7	5	5	5	6	6	9	2	2	5	6	5	8

FIGURE 2. Split Collector Resistance Trend Chart at PCM test

For the collector metal deposition, the incoming AuGe material was examined and found to have a high level of carbon impurities. The AuGe melt occasionally showed a dark smudge when wiped with a text wipe immediately after the melt was made from smaller AuGe pellets. The dark contamination was attributed to a high content of carbon (see FIGURE 3a). Extensive effort was invested in working with the material supplier and the source of the carbon contamination was identified and removed. The subsequent material produced a much cleaner AuGe melt (see FIGURE 3b).

FIGURE 3

(a) AuGe Melt with Carbon (b) Clean AuGe Melt

Several qualification lots were split using the old and new AuGe material. The resulting data showed the lots using the new, cleaner material had a statistically lower split collector resistance (see FIGURE 4).

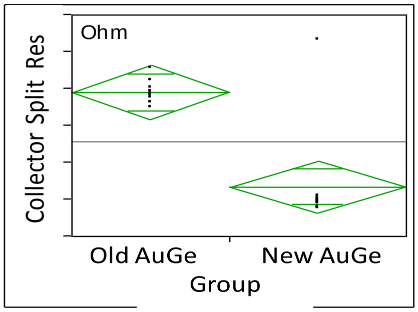


FIGURE 4. Split Collector Resistance vs. AuGe Material

However, even with better quality material, periodic high resistance was not completely eliminated. For this reason, the next step in the investigation was directed towards the post metallization alloy process. In particular, the alloy temperature was optimized to further the diffusion process of the AuGe/Ni/Au into the GaAs substrate. It is critical to achieve an alloying temperature as close to the eutectic point as possible. However, the temperature must be adjusted high enough to achieve a favorable diffusion process without damaging the device. A thorough study was conducted at various alloying temperatures to evaluate the impact on the electrical performance and surface morphology. This resulted in the enhancement of the overall ohmic contact and reduced the resistance of the split collector (see FIGURE 5 and FIGURE 6).

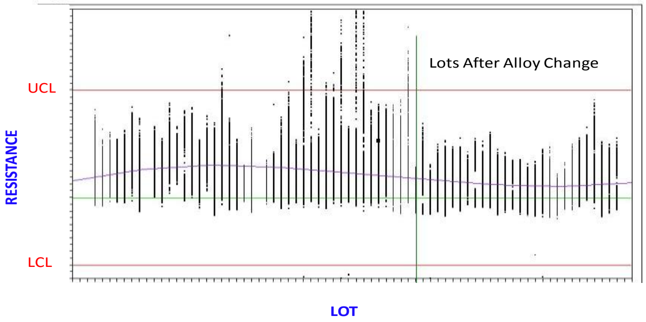


FIGURE 5. Split collector resistance vs. lot showing the effect of the optimized alloy

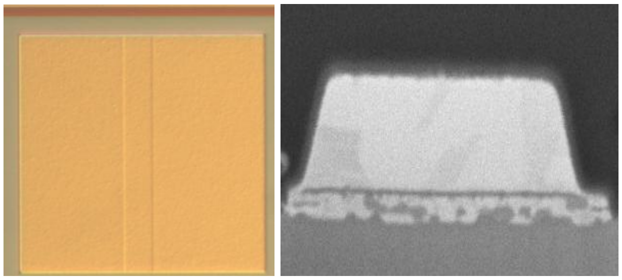
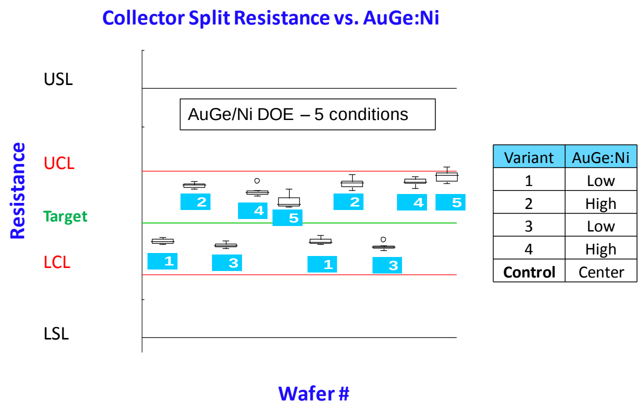


FIGURE 6. Post optimized alloy optical and FIB images

In parallel to the alloy modification, additional effort was placed on further developing the ohmic contact of the collector metal. DOEs were run to dial in the AuGe:Ni ratio, which is crucial in achieving the optimal contact. Although this ratio had been previously optimized, further adjustments were needed after the material and alloy temperature optimizations were completed. Several DOEs were run with variants for the ratio of AuGe to Ni. The AuGe:Ni ratio was varied higher and lower than the control in four conditions. For the variants with lower AuGe:Ni ratio, the split collector resistance was consistently lower. For example, DOE conditions #1 and #3 repeatedly resulted in a lower split collector resistance. Conversely, the conditions #2 and #4 with higher AuGe:Ni ratio yielded high split collector resistance. The control conditions #5 has one sample with on target split collector resistance and one with high resistance (see FIGURE 7).



Variant	AuGe:Ni
1	Low
2	High
3	Low
4	High
Control	Center

FIGURE 7. Split Collector Resistance vs. AuGe:Ni Ratio

This AuGe:Ni change was also carefully monitored for any interaction with the optimized alloy temperature for both contact resistance and post alloy surface morphology. For the same DOE variants, there were no statistical differences observed for the collector TLM Rc and morphology (see FIGURE 8).

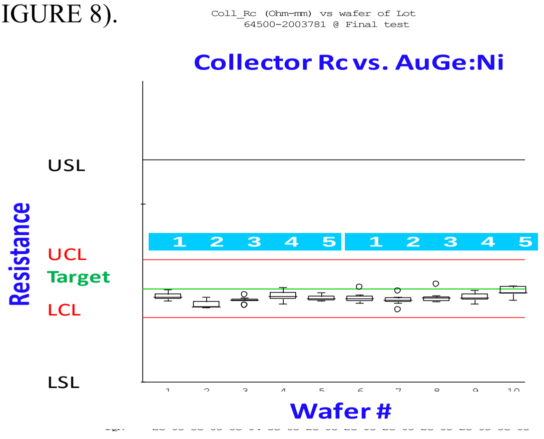


FIGURE 8. Collector Rc vs. AuGe:Ni Ratio

Samples from both good and high split collector groups were sent for Auger analysis to determine if any composition variation could be correlated to the electrical result. The analytical data shown in FIGURE 9 indicates a higher concentration of Germanium for the high split collector sample. With the Nickel concentration being comparable between the two groups, this would imply that the AuGe:Ni ratio is higher for the high split collector sample. This also supports the correlation found from the DOE that the higher AuGe:Ni ratio, the higher the split collector resistance. All data validates the direct correlation between the AuGe:Ni ratio and the final split collector resistance.

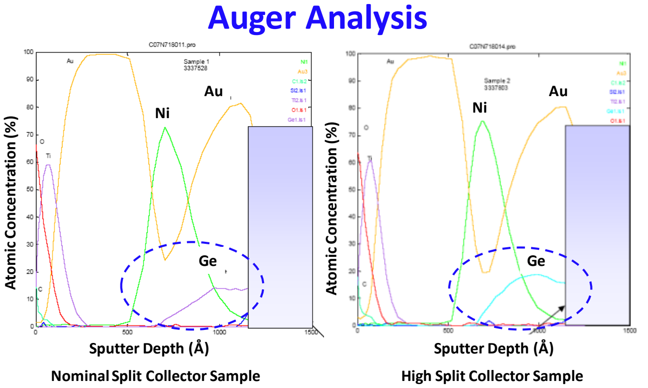


FIGURE 9. Auger analysis of good vs. high split collector contact

As an added benefit, a reliability study showed the optimized AuGe:Ni ratio device was statistically more stable and robust over life time (see FIGURE 10). This was the ultimate confirmation that the changes made were in the proper direction.

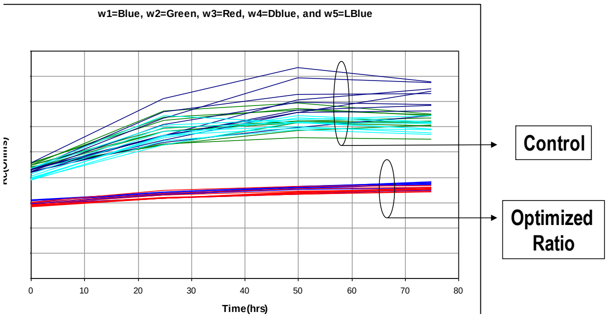
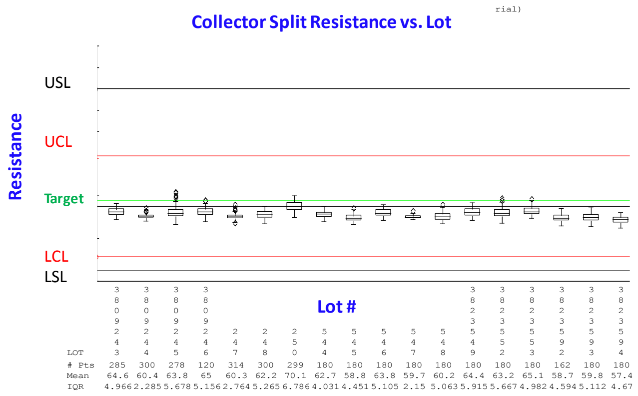


FIGURE 10. HTOL data for control and optimized collector contact

CONCLUSIONS

High volume GaAs HBT manufacturing provides an environment with continuous challenges. This particular case of intermittent high split collector resistance was a rewarding experience that required extensive investigation and took a collaboration of engineering work to arrive at a solution. By optimizing multiple factors affecting the HBT collector contact module, the occasional high split collector resistance was eliminated. Due to the continual focus placed on all facets of the collector processes, improvements were

made in the material quality, the metal stack composition, and the subsequent alloying process all contributed to this achievement. This process optimization continues to yield stable and highly uniform split collector resistance
(see FIGURE 11).



LOT	3809243	3809244	3809245	3809246	247	248	250	544	545	546	547	548	3823549	3823552	3823553	3823592	3823593	3823594
# Pts	285	300	278	120	314	300	299	180	180	180	180	180	180	180	180	162	180	180
Mean	64.6	60.4	63.8	65	60.3	62.2	70.1	62.7	58.8	63.8	59.7	60.2	64.4	63.2	65.1	58.7	59.8	57.4
IQR	4.966	2.285	5.678	5.156	2.764	5.265	6.786	4.031	4.451	5.105	2.15	5.063	5.915	5.667	4.982	4.594	5.112	4.67

FIGURE 11. Post Collector Contact Optimization Split Collector Resistance Trend Chart at PCM test

ACRONYMS

HBT: Heterojunction Bipolar Transistor
GaAs: Gallium Arsenide
Rc: Contact Resistance
AuGe: Gold Germanium alloy
Ni: Nickel
DOE: Design of Experiments
PCM: Process Control Monitor
HTOL: High Temperature Operating Life
FIB: Focused Ion Beam