Thermally optimized and electrically isolated buffer layer study in high volume HBT manufacturing

A. Zaman, M. Sun, W. Sun, J. Hu, N. Ebrahimi, V. Ramanathan, P. Zampardi and A. Popalzai
Skyworks Solutions, Inc, 2427 W. Hillcrest Drive, Newbury Park, CA91320
Email: arif.zaman@Skyworksinc.com, Phone: 805-480-4145

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Abstract

An experimental study has been performed to investigate and to optimize the HBT buffer layer for higher collector isolation resistance in a high volume HBT manufacturing environment. The device characterization results indicate that the interface states at the substrate-epi interface play a critical role in the degradation of collector isolation resistance and were found to be dependant on the substrate type and the growth condition. With the introduction of thermally optimized and electrically isolated AlGaAs buffer, no difference was observed in the electrical and thermal performance of the Power Amplifier Modules (PAM).

INTRODUCTION

Sporadic incidents of abnormal decrease in collector isolation resistance, as depicted in Fig. 1 (region A), were observed in the high volume HBT production line.

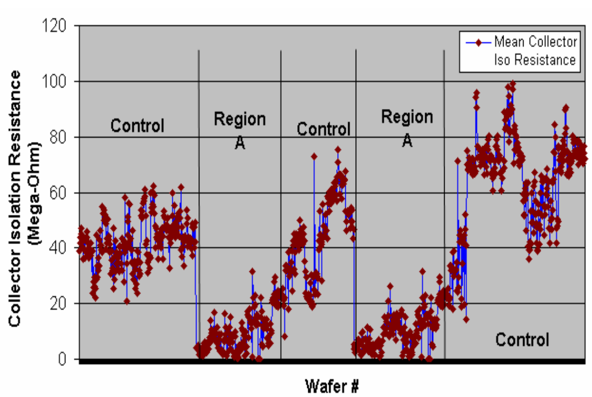

Figure 1: Collector Isolation Resistance Trend

The low resistance wafers were identified by measuring the leakage current between an interdigitated collector comb structure.

In order to minimize factory yield loss, extensive experiments were conducted to identify the sources of leakage current. Based on the studies, the interface between epi and substrate was found to be responsible for higher leakage currents (and lower isolation resistance). Without affecting the power amplifier module (PAM) performance and without adding complexities to the existing Fab processes, a carefully designed buffer layer was added to effectively eliminate the low resistance issue.

The device isolation, in the fabrication of HBT, is achieved by the combination of wet chemical etch and high energy helium ion implant. After examining the etch depth and the record of implant doses and energies, the fab processes were found to be stable during the time of incidents and should not be the root cause for the low isolation resistance. In addition, the sensitivity of the helium implant process has been evaluated by varying the HBT sub-collector thickness. The results indicate that the projected range of implant (Rp) is well beyond the normal variability in collector thickness. Additional characterization results indicate that the interface states at the substrate-epi interface play a critical role in the degradation of collector isolation resistance and were found to be dependant on the substrate type and the growth condition.

EXPERIMENTAL

The InGaP/GaAs HBT epitaxial wafers were grown by MOCVD technique. Several experiments were conducted to optimize the HBT buffer layer for the application of Power Amplifier Module. The electrical characteristics were also evaluated to determine the effectiveness of collector isolation resistance.

In order to avoid dealing with multiple sources of variations in substrate types and growth runs/reactors, an AlGaAs buffer layer was introduced between the epi and the substrate, which has shown to improve the isolation resistance. However, the addition of thick AlGaAs buffer was found to degrade the thermal resistance of the HBT, due to lower thermal conductance of AlGaAs compared to that of GaAs. To optimize the buffer layer for robust high volume production process, a design of experiments was conducted with different buffer material type, buffer thickness, GaAs substrate suppliers, substrate resistivity, and GaAs-epi interface growth conditions.

The Matrix for the Design of Experiments (DOE) is provided in Table 1.

Wafer #	Substrate-Epi Interface	Substrate Type	Substrate Resistivity	Buffer Type
1	A_Epi	E_Sub	High	With Buffer
2	A_Epi	E_Sub	High	No Buffer
3	A_Epi	F_Sub	Low	No Buffer
4	B_Epi	D_Sub	Low	No Buffer
5	A_Epi	E_Sub	Low	No Buffer
6	B_Epi	C_Sub	Low	No Buffer
7	B_Epi	E_Sub	High	No Buffer
8	B_Epi	F_Sub	Low	No Buffer
9	A_Epi	D_Sub	Low	With Buffer
10	B_Epi	E_Sub	Low	No Buffer
11	B_Epi	E_Sub	Low	No Buffer
12	A_Epi	C_Sub	Low	No Buffer
13	A_Epi	C_Sub	Low	With Buffer
14	A_Epi	F_Sub	Low	With Buffer
15	A_Epi	D_Sub	Low	With Buffer
16	A_Epi	E_Sub	Low	With Buffer

Table 1: Matrix for Design of Experiments

In these experiments, five different types of the substrates were used with two substrate-epi growth processes. Two types of substrate resistivity, high and low, were also chosen for this experiment. Since the epi buffer layer is critical for the growth of HBT epi materials, GaAs and AlGaAs were considered as the buffer layers for these experiments.

The collector isolation resistance was measured for these experiments using the inter-digitated collector comb structure. The separation between the active areas is 2 μm, both horizontally and vertically. The typical PCM structure used is shown in Figure 2. The FIB cross section is depicted in Figure 3.

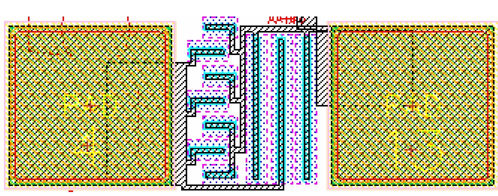

Figure 2: Interdigitated collector comb structure

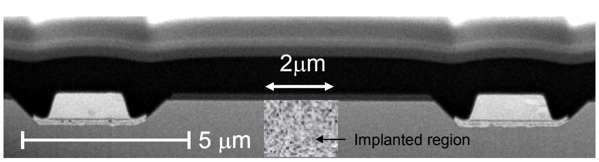

Figure 3: SEM cross-section of the collector isolation structure with the shaded implanted

In addition, the complete Power Amplifier Module (PAM) was fabricated using the epi variants, given in Table 1, and tested to evaluate the PA performance.

Results and Discussions

The InGaP/GaAs HBT epitaxial wafers with various DOE conditions, as depicted in Table 1, were investigated to evaluate the performance of power amplifier module for thermal & electrical properties. The collector isolation resistance with optimized AlGaAs buffer layer is much more robust with different epi-substrate interface growth condition. The composition and the thickness of the AlGaAs buffer are optimized based on the collector isolation resistance data as well as on the power amplifier module data. The collector isolation resistance for the experiments, Table 1, is shown in Figure 4.

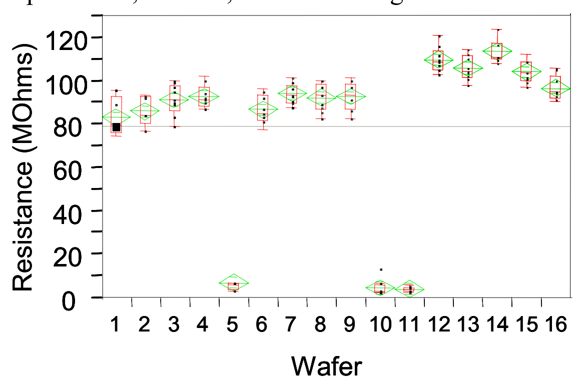

Figure 4: Collector isolation resistance as a function of experimental conditions given in Table 1.

The thermal profiles for open cavity module thermal scans were compared to evaluate the thermal impact on the power amplifier module for various experimental conditions. The optimized AlGaAs buffer indicates no noticeable differences in both thermally and electrically. The scans with AlGaAs and with no buffer are shown in Figure 5 and 6.

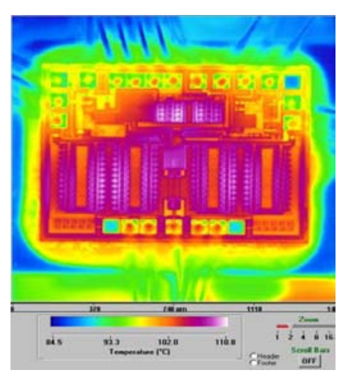

Figure 5: Thermal profile of open cavity PAM with no buffer

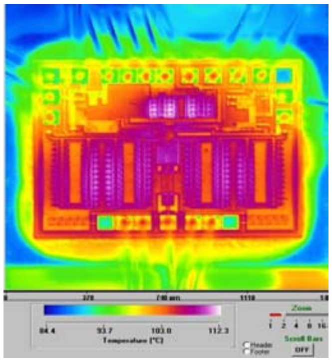

Figure 6: Thermal profile of open cavity PAM with AlGaAs buffer

Both the substrate resistivity and the epi-substrate interface are found to influence the FET matching and FET isolation leakage. Hence the optimized AlGaAs buffer is tested in the epi MESFET fabrication flow as well. Figure 7 depicts the collector isolation from the MESFET epi with and with no buffer layer. As shown, the isolation resistance is lower on epi wafers with the buffer layer. No differences are observed in the electrical tests of the depletion mode FET due to the buffer layer, as shown in Figures 8 and 9.

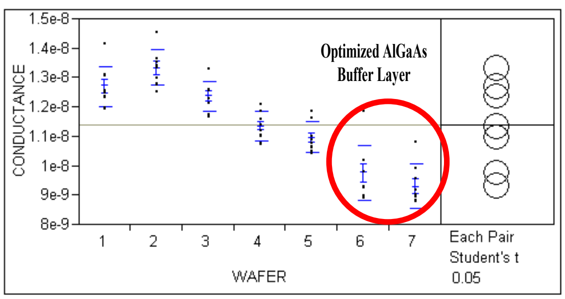

Figure 7: Conductance (1/Resistance) of the collector isolation structure from MESFET epi. Wafers with the optimized AlGaAs buffer layer are highlighted in circle.

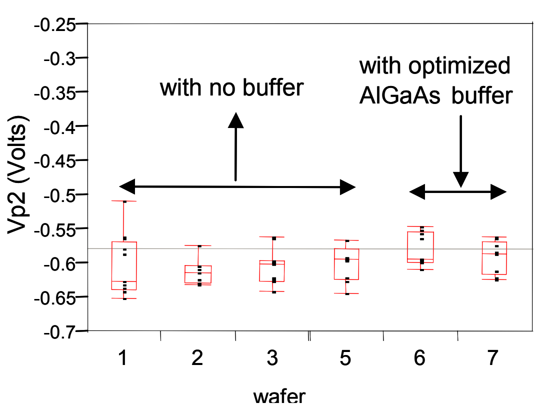

Figure 8: Pinch off voltage of 1x100 μm epi MESFET device. There is no influence of AlGaAs buffer on the FET parameters.

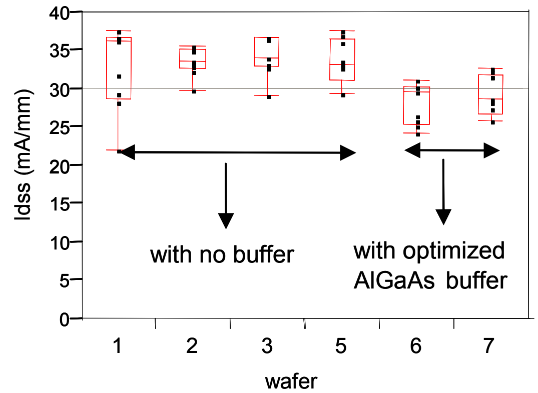

Figure 9: Saturation current (Idss) in mA/mm of the 1x100 μm epi MESFET device. No statistical difference is observed between the epi wafers with or with no buffer layer.

CONCLUSION

The epi-substrate interface plays an important role for collector isolation. The optimized AlGaAs buffer layer eliminates the variability on the impact on substrate resistivity as well as the epi-substrate interface process. The optimized buffer exhibits no impact on device and PAM performance, and serves as thermally optimized and electrically isolated buffer.

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ACRONYMS

HBT: Heterojunction Bipolar Transistor
PAM: Power Amplifier Module
MESFET: Metal Semiconductor Field Effect-Transistor