Application of Electrical CD Measurement Methodology for InGaP/GaAs HBT Production

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Keywords: ELECTRICAL CRITICAL DIMENSION, INGAP/GAAS HBTS, SPC, PCM

Abstract

Applications of an electrical CD measurement methodology to monitor the CDs of emitter and base mesas in high-volume InGaP/GaAs HBT production are presented. A calibration method with the introduction of a calibration offset has been developed to provide an accurate CD measurement. The calibration offset was found to vary with photo resist adhesion and epi materials. We have incorporated these measurements into the regular PCM parameter test routines, which makes data collection and analysis much faster and easier than other regular CD measurement techniques.

INTRODUCTION

InGaP/GaAs HBTs are now widely used in high volume production for wireless communication systems. Because of its good wet etching selectivity between InGaP and GaAs, wet etch is commonly used in production. Monitoring of HBT device dimensions such as emitter mesa (EM) and base mesa (BM) widths is important to ensure consistency of products because these parameters determine HBT's base -emitter and base-collector capacitances and therefore the device's RF characteristics and circuit performance. The critical dimensions (CD) in HBT fabrication are usually measured with CD SEM or optical CD measurement tools, which are expensive and time consuming. Electrical CD measurement technique has been widely used in semiconductor industry to measure metal line width, semiconductor device CD because it is faster, more convenient, and more cost-effective [1-3].

In this paper, we will present applications of an electrical method to measure emitter and base mesa CDs for InGaP/GaAs HBT production. This method provides a fast and low-cost measurement, which can be incorporated into the regular PCM parameter tests.

DESCRIPTION OF MEASUREMENT METHODOLOGY

Fig. 1 shows the electrical CD measurement structure, which consists of a Van der Pauw (VDP) pattern for the sheet resistance measurement and a resistor bar for the line width measurement. Two separate structures were fabricated in the PCM area for emitter mesa and base mesa measurements. A 4-terminal (A, B, C, and D) resistor was used to test the resistance between B and C. The length (*L*) of the resistor was designed to be much longer than the width (*W*) with an *L* to *W* ratio of 10. A resistor bar with *W* of 10 μm and *L* of 100 μm was used in our test structure. As a result, a small variation of *L* in the fabrication process did not affect the resistance value. The contact widths of two sensor terminals (B and C) were made so small that no current flowed into the contact metals. Hence, the contact resistance of the sensor terminals could be ignored in the 4-terminal resistance measurement. The accuracy of the measurement was highly based on the quality of edge definition and the relative width of the resistor bar. For example, any micro defects in the resistor bar or roughness of edge would dramatically affect measurement accuracy if the resistor bar width were designed to be close to that of device's CD (about 2 μm). Therefore, a wider dimension of 10 μm for the resistor bar was used. However, the wider resistor bar resulted in a low resolution in SEM or optical CD measurement because the low magnification had to be used. Hence, a CD bar with width of about 2 μm was placed on the same location of the resistor bar for SEM or optical measurement for calibration use.

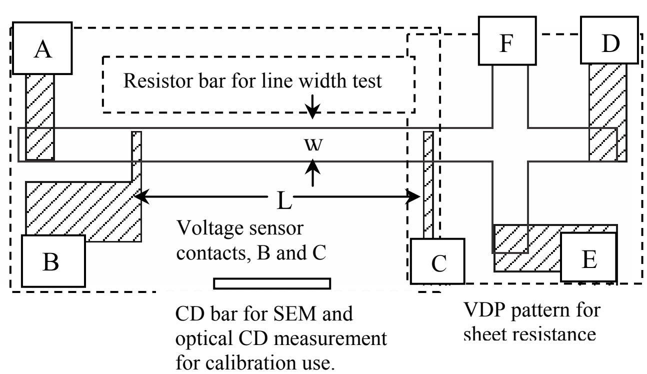

Fig. 1 Electrical CD Measurement Structure and a CD bar

The test procedure is as follows:

1. The sheet resistance (*Rsh*) of the emitter or base layer was first measured with a VDP pattern.
2. A constant current (*I*) was applied from A to D followed by a measure of voltage drop (*Vbc*) between B and C. Resistance between B and C is calculated by

$$Rbc=Vbc/I=Rsh*L/We+2Rc,$$

where *Rc* is the sensor's contact resistance, and *We* is the electrical line width. As mentioned earlier, *Rc* can be ignored.

3. The electrical line width of the resistor is then simplified as

$$We=Rsh*L/Rbc.$$

In order to measure the difference between the electrical line width and the designed value, we define a ΔCD as

$$\Delta CD=We-W+\delta,$$

where *W* is the designed resistor bar width. δ is a calibration offset between the electrical line width (*We*) and the actual physical line width (*Wa*) of a CD bar.

We assume that amount of lateral etch is same for different line width. *We-W* should be linearly proportional to *Wa*.. The ΔCD is defined to be 0, when *Wa* is equal to the design value. So we can get

$$\delta=-(We-W)$$

when the width of the CD bar is at target value. In order to a get better estimation of the calibration offset, (*We-W*) as a function of *Wa* was plotted from some wafers with varying CD width. With that, δ is easy to find from the plot.

From our experiments, δ is a fixed value in the range of ±0.7 μm depending on the shape of the cross-section, process and doping profile as described in next section.

Both emitter and base mesa CD bars and electrical CD test structure were fabricated in the PCM area oriented perpendicular to the $(01\overline{1})$ plane in our baseline InGaP/GaAs HBT production. Design widths of CD bars were 2.1 μm for EM and 2.4 μm for BP, respectively. Width of CD bars were measured with an optical CD microscope which was well calibrated with SEM. EM CD was measured at bottom of the bar and BP CD on top of the bar. Electrical measurement was performed by Reedholm DC parameter test system.

RESULTS OF CALIBRATION OFFSET

Fig. 2 shows a plot of *We-W* versus the CD bar width for base mesa as an example of the estimation of δ. For base mesa, design width of CD bar was 2.4 μm. The calibration offset was found to be –0.65 μm for base mesa in our baseline process. Solid line in the chart was fitted from measurement data (dots in the chart) with a correlation factor of 0.96. The difference between dots and line in Fig. 2 is less than 0.05 μm, which indicated a good correlation between electrical and optical measurement. In addition, this also confirmed that amount of lateral etch was independent to line width as expected.

Calibration offset for BM was found to be same for different process and different Epi-material vender as it should be. However, calibration offset for EM was not same for wafers from different Epi vender. We found that EM ΔCD for the wafers from a new epi vender was significantly lower than that of wafers from our standard epi vender during new epi vender qualification. Fig. 3 shows the plot of *We-W* versus the CD bar width for emitter mesa with combination of epi vender and process. Table I summarizes the epi vender and emitter mesa process versus calibration offset and mesa profile angle. The mesa profile angle was

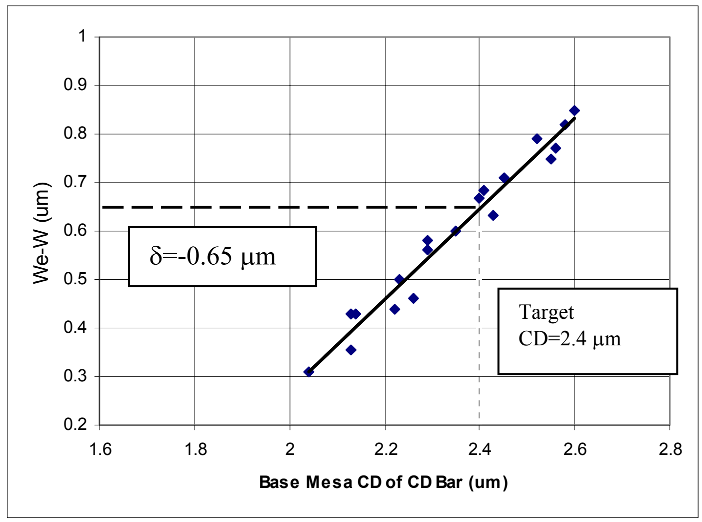

Fig. 2. Electrical line width versus optical measured CD of base mesa. Correlation factor is better than 0.97.

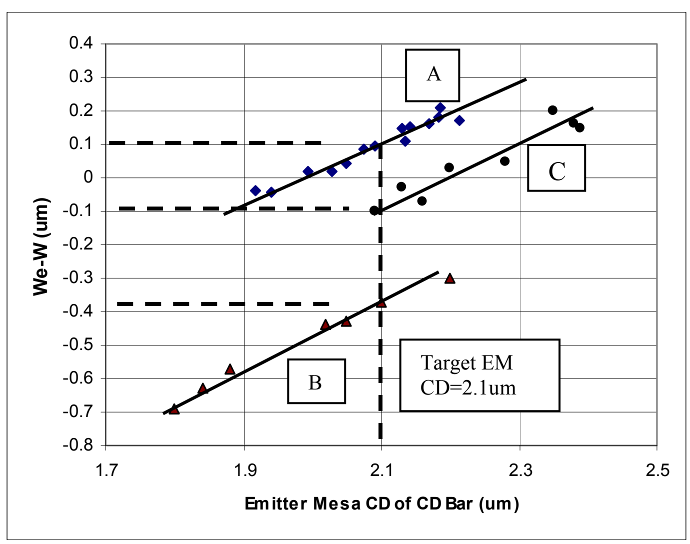

Fig. 3. Electrical line width versus optical measured CD of emitter mesa. for different epi venders and process as summarized in table I.

TABLE I

SUMMARY OF EPI VENDER AND PROCESS VERSUS CALIBTRATION OFFSET

Curve in Fig. 3	Epi Vender	Emitter Mesa Process	Calibration offset (μm)	Mesa profile angle*
A	Std Vender A	Std	-0.1	57
B	New Vender B	Std	0.38	40
C	New Vender B	Improved	0.1	55

*The mesa profile angle is measured from cross section

measured from cross section. It shows that for a same standard emitter mesa process, difference of calibration factor can be about 0.5 μm due to difference in mesa profile. Since emitter mesa width was measured at bottom of CD bar, only performing physical CD measurement might not catch profile difference in production line. The electrical CD measurement showed a big difference for new epi material, which prompted engineer to investigate the issue in detail. It was found out that the photo resist adhesion was not same for the epi wafers from different vendors in our base line process, which makes mesa profile different. As shown in table I, with improved emitter mesa process for vender B epi wafers, mesa profile was close to that of standard process of vender A epi wafers. However, there was still about 0.2 μm difference in the calibration offset. This offset was probably due to the deference in the doping profile in emitter cap layers.

Once calibration factors for both emitter and base mesas are defined for a certain process and particular epi wafers, testing and data analysis are easy and quick.

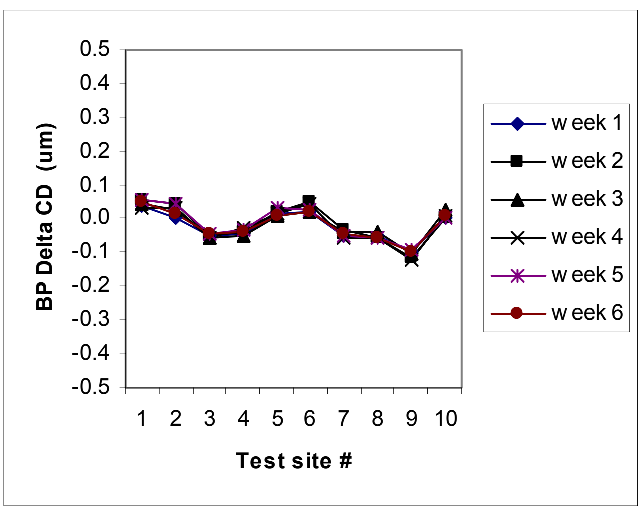

Fig. 4 Electrical ΔCD of base mesa on a wafer tested once a week for 6 weeks.

REPEATABILITY OF THE ELECTRICAL CD MEASUREMENT

Repeatability of this electrical ΔCD measurement was investigated by testing the same 10 sites across a wafer once a week for 6 weeks. The results are shown in Fig. 4. By analyzing the data using Gauge R&R method, a good repeatability with R&R% of 6% was obtained. In other words, range of measurement variations was less than 0.04 μm at each site.

RESULTS OF ΔCD FOR EM AND BM

A wafer map of EM ΔCD on a 4 inch wafer is shown in Fig. 5. Average ΔCD was 0.056 μm with a range of 0.161 μm and standard deviation of 0.040 μm. For a typical device with EM CD of 2 μm, 8% variation in CD on a 4 inch wafer was observed.

	0.079	0.070	0.060	
0.012	0.023	0.068	0.047	0.150
0.104	0.022	0.072	0.017	0.034
	-0.011	0.087	0.061	

Fig. 5 Wafer map of emitter mesa ΔCD for a 4 inch InGaP/GaAs HBT wafer. Average ΔCD =0.056 μm. Range = 0.161 μm.

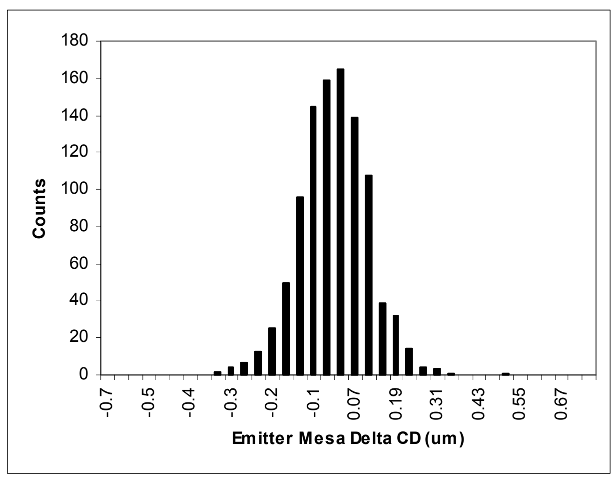

Fig. 6 Histogram of emitter mesa ΔCD for a base line power InGaP/GaAs HBT process from more than 70 wafers.

Fig. 6 shows a histogram of EM ΔCD for our base line power InGaP/GaAs HBT process from more than 70 wafers. A Cpk of the EM ΔCDs was >1.0 with spec limits of ±0.3 μm, which indicates emitter mesa CD variation in our InGaP/GaAs HBT process is better than ±0.3 μm from wafer to wafer and lot to lot.

Fig. 7 shows an SPC chart of BM ΔCD from same wafers as shown in Fig. 6. Cpk of the BP ΔCDs was >1.0 with spec limits of ±0.35 μm. For a typical minimum BM width of 5 μm, a less than 15% variation in BM CD was obtained from wafer to wafer and lot to lot. This indicates both wet etch process are under good controls.

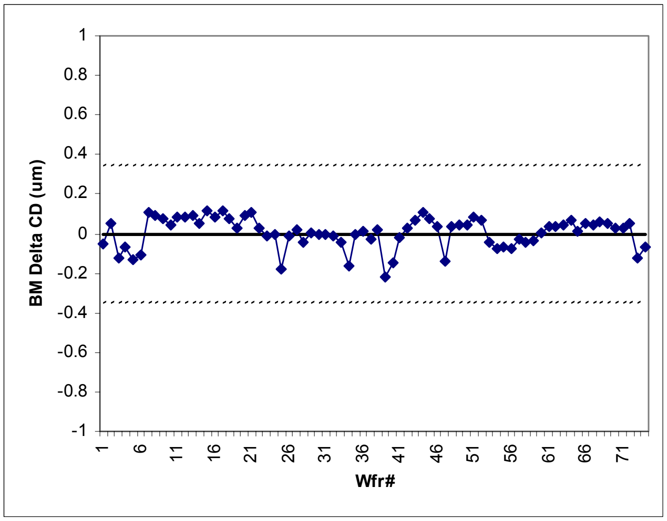

Fig. 7 SPC Chart of base mesa ΔCD for a base line power InGaP HBT process from more than 70 wafers.

CONCLUSIONS

We presented applications of an electrical CD measurement methodology to monitor the CDs of emitter and base mesas in high-volume InGaP/GaAs HBT production. A calibration method with the introduction of a calibration offset was developed to provide more accurate CD measurements. The calibration offset was found to vary with photo resist adhesion and epi materials. A parameter ΔCD was introduced to check CD variations across wafer, wafer to wafer and lot to lot. We have incorporated this measurement into our regular PCM parameter test routines, which provides a fast, low-cost measurement, and easy data collection and analysis. In addition, we also demonstrated this measurement provides early warning for potential process or material issues.

ACKNOWLEDGEMENTS

The authors would like to thank the people from GCS engineering and manufacture groups for the wafer processing and testing.

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ACRONYMS

HBT: Hetero-junction Bipolar Transistor
EM: Emitter Mesa
BM: Base Mesa
CD: Critical Dimension
SEM: Scan Electron Microscope
VDP: Van der Pau
PCM: Process Control Module
R&R: Repeatability and Reproducibility
SPC: Statistical Process Control
Cpk : Process Capability