Riding the Wireless Wave With 150mm GaAs Manufacturing

M.R. Wilson, K. Adams, and E. Huang

Motorola Semiconductor Products Sector - CS1 Manufacturing Facility
2100 East Elliot Road, MD EL-609, Tempe AZ 85284
Phone: 480-413-6046, Email: Mark.Wilson@motorola.com

Abstract

The explosion in wireless handheld communications devices evidenced by a nearly 50% compounded growth rate of GaAs RF semiconductor component demand has placed a severe strain on wafer manufacturing capacity worldwide for MESFET, pHEMT, and HBT technologies. At the same time, participation in consumer markets results in extreme pressure from handset equipment manufacturers for continual cost reduction of these semiconductor components. As a result of these two factors, the need for high volume 150mm GaAs manufacturing lines has become acutely evident. To fulfill this need, Motorola has begun conversion of its GaAs facility, CS1, to 150mm wafer size. This paper will describe the conversion strategy, GaAs substrate evaluation, process characterization methodology, and 150mm product results during the conversion.

INTRODUCTION

The never ending, worldwide thirst for wireless handheld communications devices has resulted in an exponentially increasing demand for RF semiconductors. Moreover, the desire for increasing handset performance in terms of standby time and talk time have exploded the demand for GaAs RF semiconductors which offer a superior cost-performance tradeoff to Si RF semiconductors, particularly in the transmit chain of the radio. This increasing demand is clearly demonstrated in Figure 1, which shows the increasing TAM for GaAs integrated circuits over the past several years.

This increased demand for GaAs IC's has resulted in a worldwide scramble to install capacity in the form of factory expansions, and new green field sites. However, at the same time that demand has increased, handset manufacturer's RF component cost expectations continue to drop. This combination of events makes it necessary to add factory capacity in the most cost effective means possible in order to allow the most aggressive die cost reductions possible. After consideration of the factors of time, capital expense, final die cost, and risk, Motorola embarked on an aggressive plan to convert CS1 from 100mm substrates to 150mm substrates on all of its manufacturing technologies including ion implanted MESFET, pHEMT, and HBT. Since all of the equipment in CS1 was 150mm capable, capital cost consideration was a major factor in the decision to convert rather than add 100mm capacity or build a new facility. The conversion cost for a roughly 2000 wafer/week facility going from 100mm to 150mm is less than $15M, and provides a capacity increase greater than 2X. A corresponding capacity increase realized through a doubling of 100mm capacity could not be achieved for less than $75M. This cost differential makes wafer size conversion extremely attractive if the risks of size conversion can be

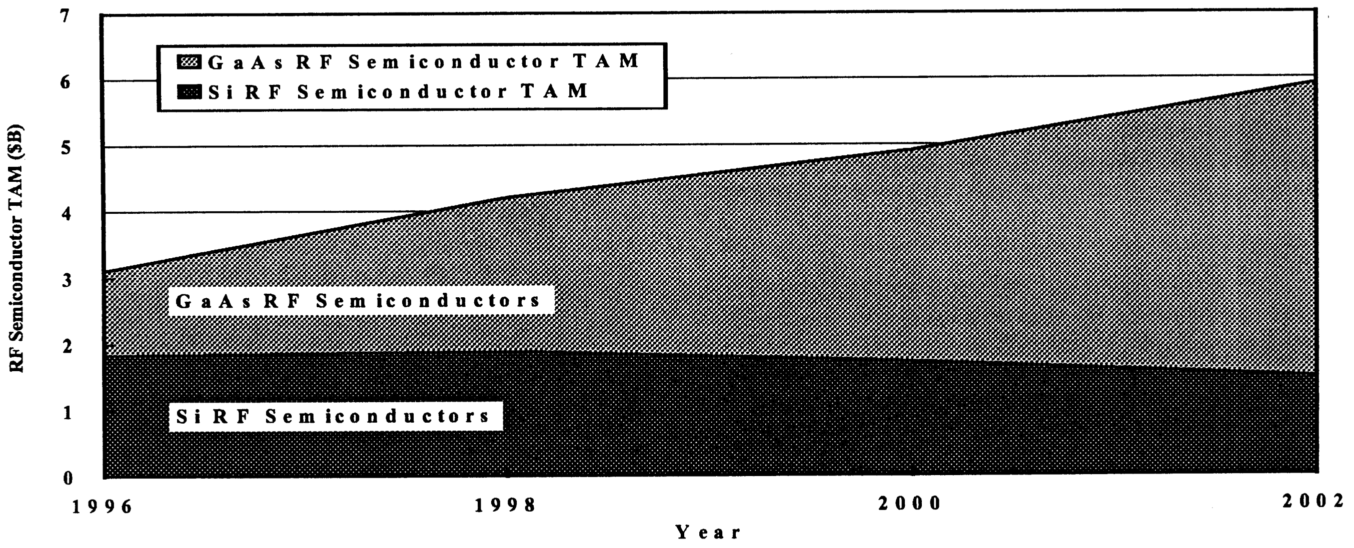


Figure 1. Worldwide TAM for RF semiconductors showing the rising demand for GaAs components resulting from the growth in Cellular/PCS, automotive, and high frequency applications [1].

managed properly. This paper will describe Motorola's conversion strategy, GaAs substrate evaluations, process characterization methodology, and 150mm product results during the conversion.

SUBSTRATE EVALUATION

Obviously one of the most basic requirements prior to initiating a wafer size conversion is to ensure the availability of adequate quantities and quality of 150mm substrates. To evaluate substrate quality prior to having a qualified 150mm process line Motorola purchased several 150mm ingots with the wafers cored down to 100mm diameter. To ensure that we adequately sampled across wafer uniformity to the edge of 150mm boules, some of the ingots were cored off the central axis so that the edge of the 100mm wafer corresponded to the edge of the original 150mm boule. These ingots were purchased from each of our major suppliers, and combined with standard 100mm ingots for full device processing in CS1. The results of these process runs clearly demonstrated that 150mm substrates were of identical electrical quality to 100mm substrates as shown in Table 1.

The fabricated devices from the standard 100mm substrates, and the cored substrates were sent on to final assembly and test. The RF test results and yields were identical between the 100mm and 150mm boules. These results gave us full confidence that 150mm ion implanted substrates were a reality.

Unfortunately, the same methodology of coring down the 150mm substrate to 100mm could not be applied to epitaxial substrates. In this case, we depended on layer thickness uniformity, and doping concentration mapping of the 150mm epitaxial substrates. Characterization data obtained on 150mm epitaxial wafers showed similar results to those obtained on 100mm wafers. While full device data would have been more reassuring, we were confident that substrates would not stand in the way of 150mm manufacturing for epitaxial or ion implanted technologies.

PROCESS CHARACTERIZATION

CS1's equipment set consists primarily of single wafer process tools designed for high volume 150mm manufacturing. The recipes currently being used for 100mm production actually originated in many cases from 150mm silicon factories running similar processes. So, it was our fundamental goal to keep the same process recipes for 150mm GaAs production as we were using for 100mm GaAs production. Moreover, we felt that if we could establish 150mm recipes that were fundamentally unchanged for their 100mm counterparts, we could greatly simplify the qualification phase of the conversion.

The first phase of the characterization was to convert a set of equipment to 150mm. This required careful coordination with production and maintenance to understand capacity constraints, equipment redundancy, and equipment conversion times. Equipment with adequate redundancy and long conversion times were permanently converted to 150mm. This included a photo stepper, metal deposition, and metal etch tools. The metal etch tools had a significant conversion time because we elected to change from having the wafer physically clamped to the lower electrode, to using electrostatic clamping for reduced breakage. Electrostatic clamping was selected for ion implantation, dielectric etch, and metal etch tools where available.

150mm process characterizations were conducted in every major process area including photo, chemical vapor deposition (CVD), metals, etch, ion implantation, rapid thermal anneal (RTA), wafer thinning, and wet processing. The starting point was always the existing 100mm process. That process was then optimized to match existing 100mm critical SPC parameters and uniformities. In virtually every process module only minor adjustments were required to achieve similar or better process characteristics to standard 100mm production. An example of an SPC chart comparing silicon nitride ion implantation screen layer thickness control for 100mm and 150mm wafers is shown in Figure 2. In general, it was possible to optimize across wafer uniformity

Table 1

Electrical Comparison of Standard 100mm GaAs Boules to Twelve Cored 150mm GaAs Boules From Four Manufacturers on Motorola's Triple Vth, Mixed-Mode RF IC Process

Electrical Parameter	Standard 100mm Boules	Cored 100mm Boules
Power Threshold Voltage (v)	-2.514 ± 0.056	-2.495 ± 0.043
Power Drain Saturation Current (mA/mm)	252.9 ± 5.25	250.6 ± 4.39
Power Drain-Gate Breakdown Voltage (v)	20.9 ± 2.1	21.2 ± 1.7
Depletion Threshold Voltage (v)	-0.504 ± 0.028	-0.508 ± 0.028
Depletion Drain Saturation Current (mA/mm)	57.3 ± 4.2	57.2 ± 4.6
Depletion Drain-Gate Breakdown Voltage (v)	10.1 ± 0.8	9.9 ± 0.6
Enhancement Threshold Voltage (v)	+0.241 ± 0.013	+0.235 ± 0.018
Enhancement Drain Saturation Current (mA/mm)	68.9 ± 3.1	68.4 ± 3.6
Enhancement Drain-Gate Breakdown Voltage (v)	12.2 ± 0.6	12.1 ± 0.5
N+ Sheet Resistance (Ω/Sq.)	233 ± 8.0	229 ± 9.0
Ohmic Contact Resistance (Ω-mm)	0.130 ± 0.007	0.130 ± 0.008

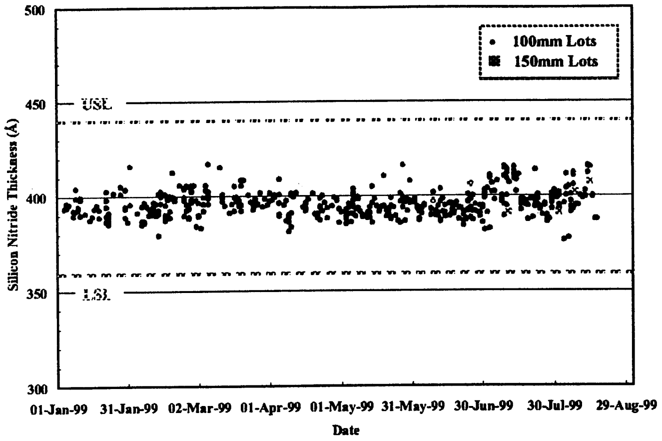
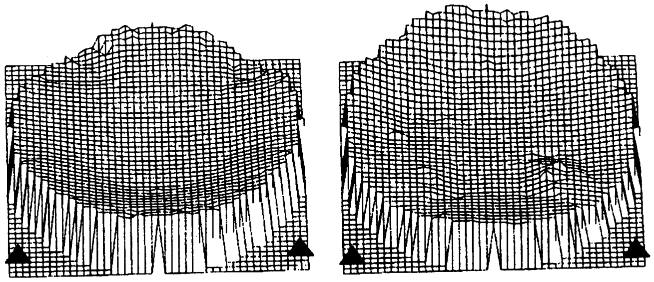


Figure 2. Control chart illustrating similar levels of CVD control on 100mm and 150mm substrates for a critical 400Å silicon nitride ion implant screen dielectric.



100mm GaAs Results
Thickness = 403 ± 3.5Å (0.85%)
Range = 11Å

150mm GaAs Results
Thickness = 390 ± 3.0Å (0.79%)
Range = 12Å

Figure 3. Across wafer maps showing similar uniformity's on 150mm wafers as 100mm production for a critical 400Å silicon nitride ion implant screen dielectric.

equal to or better than that routinely obtained on 100mm wafers as shown in the example in Figure 3.

Some process modules required reduction of thermal ramp rates to prevent increased breakage or wafer distortion. For example RTA ramp rates had to be reduced from 10°C/sec to 7°C/sec on high temperature anneals to prevent wafer slip which will result in photo alignment errors. In some cases wafer handling wait times were extended to give the larger wafers more time to thermally equilibrate to their surroundings to prevent increased breakage due to thermal shock.

After characterizing and optimizing all of the 150mm process modules individually we started to couple them together in much the same way as they are integrated to build live products. An example would be the formation of electrically active ion implanted layers that depend on wet cleans, CVD films, ion implantation, and RTA all working together. These short flows of process steps worked flawlessly when they were combined as illustrated in Figure 4 which shows 150mm active layer sheet resistance control compared to 100mm SPC data.

PRODUCT FABRICATION PHASE

Following the characterization phase, which lasted about 3 months, we began full flow lot processing. This phase started with ion implanted products, and subsequently moved on to epitaxial products. The design of this phase of the conversion project involved considerable interaction with internal and external customers. By sharing the wealth of characterization and SPC data obtained during the previous phase, we were able to establish a simplified qualification plan that required the fabrication and sampling of six products. These products were spread across three unique Motorola GaAs technologies, and internal and external end users. With the appropriate products identified, we started our first 150mm full flow product lots.

There were no significant issues observed during the fabrication of the first product lots. Layer champions were identified for each photo layer of the process to observe processing of the first lots, and to identify problem areas that required further engineering effort. It was clear when the first product lots reached test that the extensive characterization effort had paid off. Electrical PCM results showed that all of the standard parameters were sitting near the center of the 100mm distributions. Even more gratifying, the circuit probe yields for the very first lot of 3V integrated power amplifiers were in excess of 95% as shown in Figure 5. Moreover, the first four lots of this product exhibited yields very similar to standard 100mm production as shown in Figure 6.

Following thinning and die separation, both 100mm and 150mm die of the same product line were sent for packaging and RF test. The die from the center and edge of the 150mm

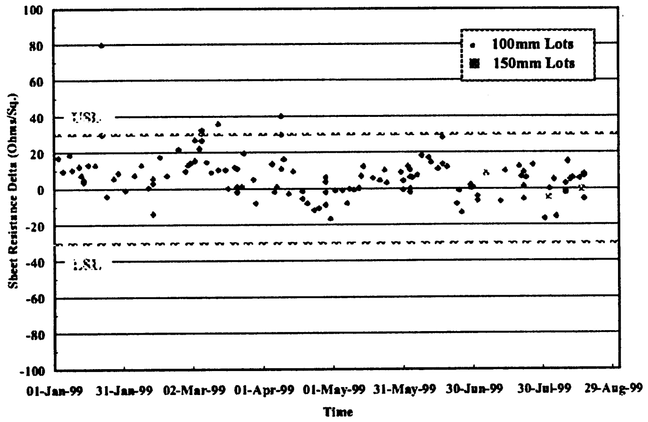


Figure 4. Control chart illustrating that the ion implanted active layer control for 150mm wafers is similar to 100mm wafers.

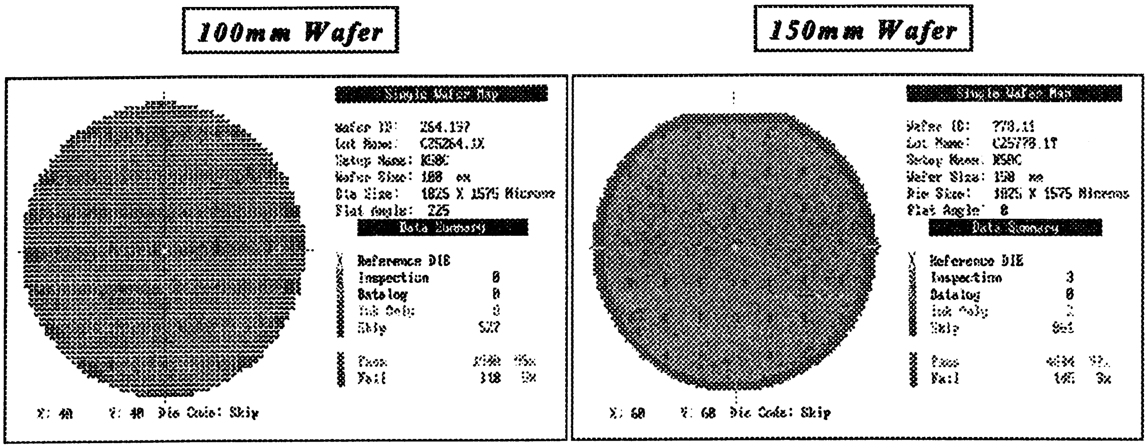


Figure 5. Unit probe yield maps comparing the yield of a 3V integrated power amplifier (IPA) on 100mm standard production and a wafer from the first 150mm lot.

wafers were picked and assembled separately to ensure there was no observable difference in RF characteristics over the 150mm wafer surface. The final test yields, and RF test results were nearly identical for the center and edge 150mm die, and the 100mm control die. Assembled parts from each of the fabricated product lines were sampled to customers for radio evaluation. No differences were observed in any radio evaluations, thus clearing the way to begin production ramp-up of 150mm wafers.

PRODUCTION RAMP-UP

Following the successful fabrication, and customer sampling of 150mm GaAs product we started the production ramp-up phase of the conversion. This phase started with production volumes of 300 wafers/week, and has currently progressed to 450 wafers/week. We expect to complete the conversion of CS1 by the summer of 2000. The successes, difficulties, and experiences during this ramp-up phase will be presented in detail at the conference. This will include ramp-up of ion implanted as well as epitaxial products.

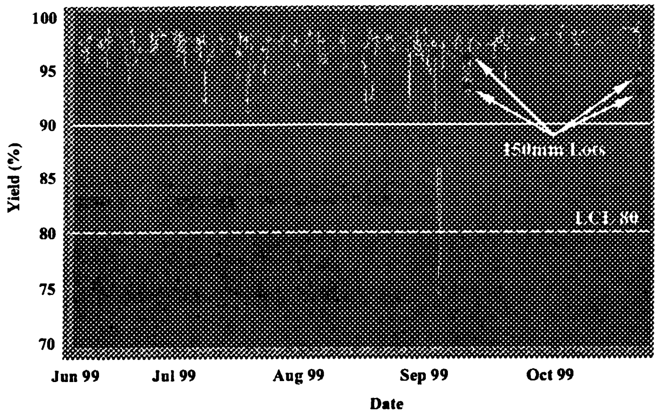


Figure 6. Unit probe control chart showing similar yield trends for the first four 150mm product lots as compared to standard 100mm production for a 3V IPA.

SUMMARY AND CONCLUSIONS

This paper has described Motorola's strategy and specific results of converting CS1 from 100mm to 150mm GaAs production substrates. This conversion includes all process technologies for ion implanted as well as epitaxial products.

The conversion has been implemented in three major phases. The first phase verified the availability and quality of GaAs substrates by coring 150mm ingots to 100mm. These tests conclusively showed that 150mm substrates for ion implantation were ready for manufacturing. Epitaxial substrates had to be evaluated by layer thickness and doping characterization methods, but were found to be suitable for device manufacturing.

The second phase entailed process characterization of every module for 150mm wafers. The standard 100mm process module was used as a starting point, and the process was optimized for acceptable 150mm uniformity. No major issues were observed during this phase of the conversion project.

The third phase consisted of full flow lots processed on 150mm wafers using six identified products that covered all manufacturing technologies. The very first lots exhibited electrical results and yields similar to their 100mm counterparts. Final assembly test and customer sampling revealed identical RF performance to 100mm production, thus opening the way for volume manufacturing with 150mm substrates.

REFERENCES

[1] Worldwide GaAs TAM data obtained from Dataquest Web Site.